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DOPAS

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D7.11.3 Dissemination activities, papers, presentations and posters (0-18 M)

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Project co-funded by the European Commission under the Euratom Research and Training Programme on Nuclear Energy within the Seventh Framework Programme		
Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the partners of the DOPAS project	
CO	Confidential, only for partners of the DOPAS project	

EURATOM

Scope	Deliverable n°7.11.3 (WP7)	Version:	1.0
Type/No.	Report	Total pages	3+136
		Appendixes	14
Title	D7.11.3 Dissemination activities, papers, presentations and posters (0-18 M)	Articles:	

ABSTRACT:

Compilation of papers, presentations and posters published during the first 18 months of the DOPAS project. Most of the papers, presentations are available via organisers internet pages and the source are referred also in the DOPAS public web page. In some cases also the papers, presentations and posters are available at DOPAS public web page. Type of audience, size of audience and countries addresses are listed in EC database SESAM Dissemination activities list. The presentations held in internal IGD-TP events (like EG meetings and Exchange forums) are not attached in this Deliverable while they are published within SecIGD2 Deliverables.

Appendix 1 Poster DOPAS general at Euradwaste 2013 (whole consortium presented by Posiva)
Appendix 2 Poster EPSP at Euradwaste 2013 (Surao)
Appendix 3 Poster POPLU at Euradwaste 2013 (Posiva)
Appendix 4 Poster FSS at Euradwaste 2013 (Andra)
Appendix 5 Poster FSS / Andra at Montpellier Clay Conference (Andra)
Appendix 6 Poster DOPAS general at Montpellier Clay Conference (whole consortium presented by Posiva)
Appendix 7 Paper FSS at Montpellier Clay Conference (Andra)
Appendix 8 Paper FSS in WM2013 Conference (Andra)
Appendix 9 Paper POPLU and DOMPLU at WM2014 Conference (the paper is done in February 2014) (SKB, Posiva and VTT presented by VTT)
Appendix 10 Oral presentation ELSA Workshop, September 2012 (GRS)
Appendix 11 Oral presentation Regional seminar 2013, Senec (UJV)
Appendix 12 Oral presentation Euradwaste 13 (whole consortium presented by Posiva)
Appendix 13 Oral presentation WM2013 Conference (Andra)
Appendix 14 Oral presentation DOPAS One year achievements at BEBS Conference, February 2014 (whole consortium presented by Posiva)

RESPONSIBLE:

Posiva Oy, Johanna Hansen

REVIEW/OTHER COMMENTS:

Before publishing dissemination items they have been reviewed by DOPAS consortium. Experiment related Dissemination items are reviewed by Partner responsible for Experiment.

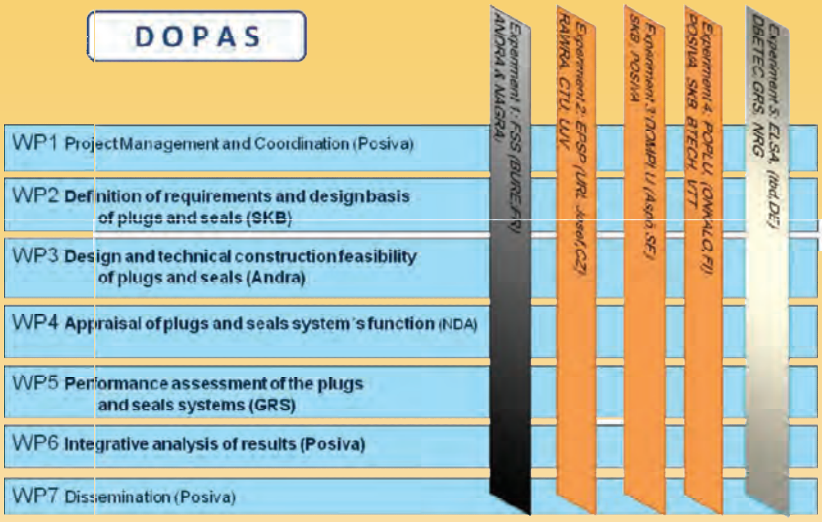
APPROVED FOR SUBMISSION:

by Johanna Hansen 17.7.2014

Appendix 1

FULL-SCALE DEMONSTRATION OF PLUGS AND SEALS

DOPAS



DOPAS will run in the period September 2012 – August 2016.

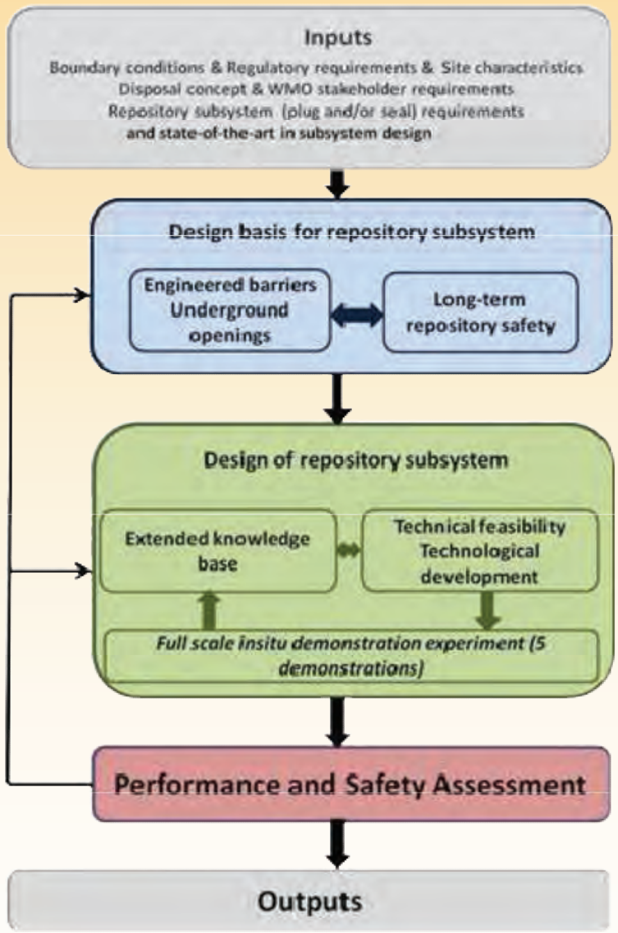
An International seminar will be organized together with IGD-TP in the last year of the project.

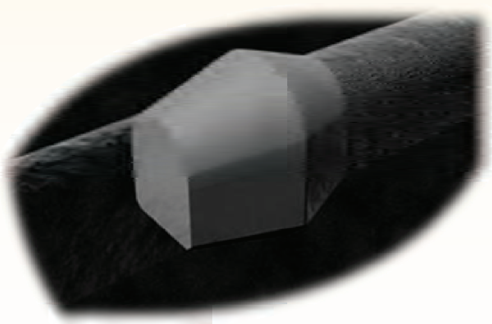
The DOPAS project is being carried out by a consortium of 14 partners representing waste management organizations, research institutes, academia & consulting companies.

DOPAS aims to improve the knowledge regarding the industrial feasibility of plugs and seals, the measurement of their characteristics, the monitoring of their hydraulic and mechanical behavior under repository conditions, and their performance with respect to a range of safety objectives.

DOPAS will identify the design basis of plugs and seals in geological disposal facilities, reference designs, and strategies to demonstrate the compliance of the reference designs to the design basis and to implement them into the experiments.

DOPAS is focusing on tunnel plugs for clay host rock (French and Swiss disposal concepts), tunnel plugs for crystalline rock (Czech, Finnish and Swedish disposal concepts), and shaft seals for salt host rock (German disposal concept).





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NDA nagra ČVUT FSv DBETEC B+TECH SÚRAO Správa úložišť radioaktivních odpadů Radioactive Waste Repository Authority ANDRA SKB ÚJV NRG VTT GRS IGD-TP EURATOM Galson Sciences Ltd POSIVA

Project Coordinator
johanna.hansen@posiva.fi

www.posiva.fi/dopas

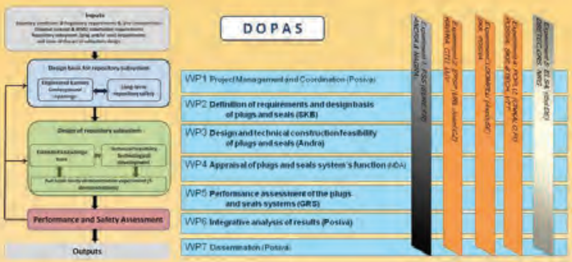
POSIVA nagra. ČVUT FSv NRG ÚJV igd·tp safe solutions for radioactive waste SÚRAO Správa úložišť radioaktivních odpadů Radioactive Waste Repository Authority B+TECH SKB Svensk Kärnbränslehantering AB

NDA Nuclear Decommissioning Authority DOPAS VTT GRS EURATOM Galson Sciences Ltd DBE TEC DBE TECHNOLOGY GmbH ANDRA

DOPAS Demonstration of Plugs and Seals Posiva Plug Experiment POPLU at URCF ONKALO

Petri Koho & Johanna Hansen, Posiva Oy, Erika Holt, VTT

Fourteen nuclear waste management organisations and research institutes from eight European countries are participating in a technology development project for testing plugging and sealing systems for geological disposal facilities for radioactive waste - the DOPAS project ("Full-Scale Demonstration Of Plugs And Seals"). The 4-year (2012-16) project is built around a set of full-scale underground demonstrations, laboratory experiments, and performance assessment studies. POPLU is one of five experiments evaluated in the DOPAS project. The Finnish partners in the DOPAS project participating to the POPLU experiment are Posiva Oy (coordinator), VTT Technical Research Centre of Finland and B+Tech Oy.



POPLU Objectives and Schedule

The objective of the POPLU experiments is to demonstrate that a full-scale deposition tunnel end plug can be implemented on an industrial scale and that it fulfils the specified requirements. The reference plug has been described within the Backfill Production Line reports by Posiva (2012) and a modified design will be evaluated in comparison with SKB's DOMPLU plug constructed in spring 2013.

The POPLU experiment includes the development of the detailed design for the deposition tunnel end plug and the methods necessary for the construction and follow-up of the plug's performance. This includes:

- selection and excavation of plug slot location
- modelling the expected performance evolution over the 100 year service life of the plug
- implementation of construction methods with qualified working methods and quality assurance, specific to ONKALO with actual repository conditions and material safety requirements
- development of the detailed plug structural design and low-pH concrete recipe
- evaluation of the water tightness and mechanical strength properties of the plug
- monitoring of the concrete plug behaviour and potential backfill layers behind the plug, both during and after casting, as well as during accelerated pressurization tests
- evaluating the watertightness of the plug during accelerated pressurization testing.

The schedule for the POPLU experiment is:

- 2012-2013 Plug demonstration planning, structural design and plug site selection, with RSC methodology
- 2013-2014 Test tunnel and plug area excavation, preparations for construction and construction and instrumentation of plug structures
- 2014-2015 Implementation with testing, monitoring and modelling the plug performance
- 2015-2016 Reporting period and dismantling planning

POPLU Facts

The POPLU experimental design includes a concrete wedge plug, 6 metres in length and 5.5 metres wide. The plug is constructed in two parts, using low-pH concrete around stainless steel reinforcement.

Injection grouting and bentonite sealing will be used around the circumference of the plug to improve watertightness. A short section of modified tunnel backfill and filter layers may be located behind the plug for experimental purposes.

The plug is pressurized over a one year period, simulating 100 years of service life while the central tunnels remain open during facility operation.

Plug and backfill performance is monitored using approximately 100 sensors, assessing pressure, temperature, humidity, strains and displacement. The sensors are lead to the neighbouring tunnel and out the front face of the plug. Leakage amounts and composition will be monitored from the front face.

The instrumentation plan of the experiment was subjected to EE (Expert Elicitation) process to developed it further.

POPLU Current Status

The excavation of the two POPLU demonstration tunnels is on-going, to be completed in Oct. 2013.

The Rock Suitability Classification to determine the plug location has been done based on pilot hole and tunnelling information. The plug location is confirmed, slot excavation should start in 2013.

Plug mechanical and hydraulic modelling is completed, which has influenced the monitoring plan and structural designs. Models will be verified based on data obtained after placement.

The detailed structural design for the concrete plug is completed. The design of the possible backfill layers behind the plug is on-going.

Recipe development and performance testing of the low-pH concrete is completed for decision making in POPLU, though long-term performance testing will be continue. Foreign material acceptance procedure is ongoing.

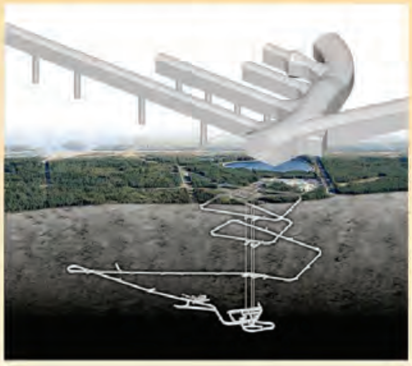
The instrumentation, pressurization and monitoring plan for the plug has been developed.

POPLU Location

The POPLU deposition tunnel end plug experiment will be implemented in the demonstration area at ONKALO, located in Olkiluoto, Finland. The demonstration area is at the depth of 420 metres below ground. The experiments will be conducted near the planned disposal depth for future actual operation of the spent fuel repository.

Two parallel tunnels of diameter 3.5 metres and lengths of approximately 25 meters are excavated for the purposes of the experiment. The tunnels are adjacent to the existing demonstration Tunnels 1 and 2, that have been excavated earlier and are used for the experimental evaluation of other EBS components.

One of the two new tunnels excavated for the POPLU experiment shall host the plug location. The plug location shall be evaluated after the Rock Suitability Classification work has determined an area in the tunnel that fulfils the requirements set for the plug location. The other tunnel shall serve as the pressurization area and instrumentation and monitoring tunnel for the experiment.



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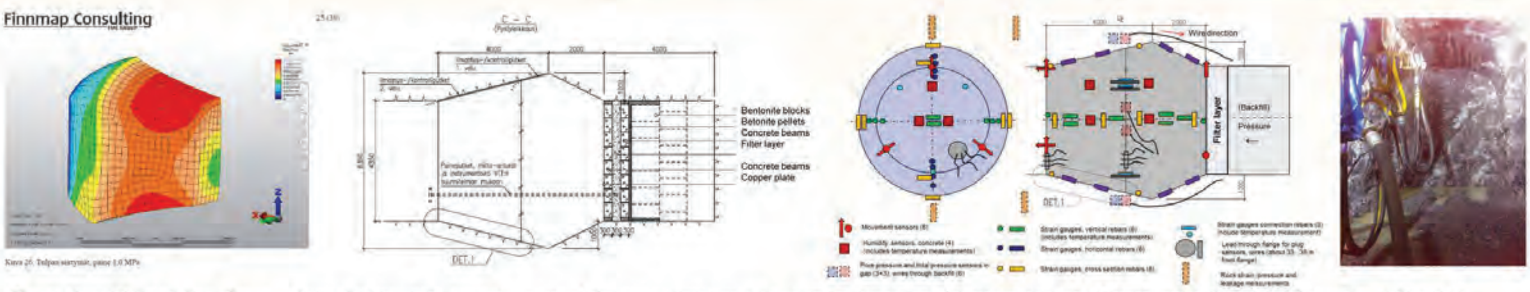

Figures (from left): modelling of expected plug displacements, concrete structural dimensions, instrumentation planning, tunnelling of demonstration area (Demonstration Tunnel 4, at future plug slot location).

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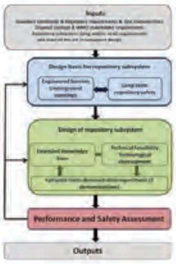
More about the DOPAS Project and POPLU:
www.posiva.fi/dopas

Appendix 4

DOPAS Project: Demonstration of Plugs and Seals
The FSS Experiment (Full Scale Seal)

J.M. Bosgiraud, F. Plas, R. Foin, G. Armand, J. Morel

DOPAS is a four year (2012-2016) cooperative project, financially supported by the **European Union** (**EC**) within the frame of the 7th Framework Program for Nuclear Research and Training (**EURATOM**). Its coordinator is **POSIVA** (Finland) :

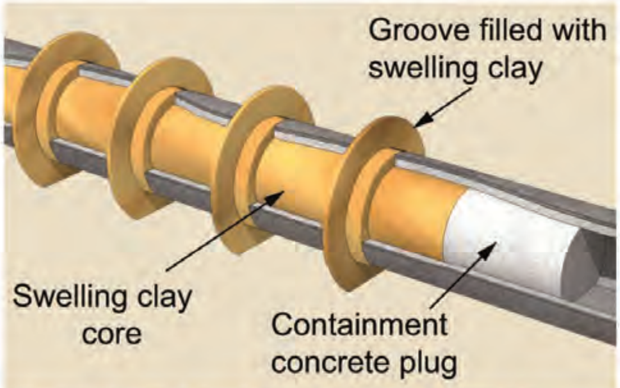


It involves **14** Partners coming from organizations responsible for implementing radioactive waste management in the EC & Switzerland, as well as from private companies or research institutes and universities with extensive experience in clayish / bentonitic & cementitious materials, modelling, instrumentations & risk analysis, monitoring, and stakeholder engagement. FSS is one of the **4** Full Scale Experiments carried out within DOPAS and is of concern for the French Deep Geological Repository (**DGR**) concept.

The successful implementation of a deep geological repository program for radioactive waste relies on a **sound long term safety strategy** and on a solid scientific and engineering basis as well as on social aspects such as stakeholders' acceptance.

The repository **closure** (by backfilling and **sealing**) policy is considered as instrumental in serving both technical and social objectives. It is not only essential to underpin the **long term safety strategy** and the quality of the associated engineering, but it is also an important tool of communication, contributing to the public confidence building in the repository long term behaviour.

Drift Sealing Concepts in the French DGR

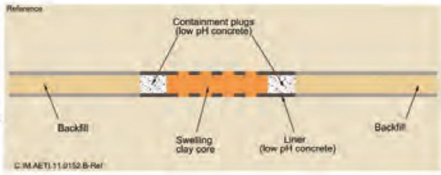


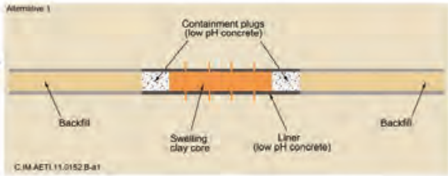
At time of DGR progressive closure, the sealing of horizontal drifts and disposal caverns must be assured by the construction of a specific barrier .

This seal is composed of a swelling clay core (bentonite) with 2 low pH concrete containment plugs, one at each end. The remaining part of the drift is backfilled with the original excavated material.

In the **reference** design, the seal is installed in a section of the drift where the concrete liner will have been partly dismantled, allowing a direct contact between the argillite formation and the bentonite core, whose swelling pressure should be as close as possible to 7 MPa.

In the **alternative** design, a thin groove is excavated at the extrados of the drift liner and filled with bentonite at direct contact with the argillites , providing an EDZ cut-off. The bentonite swelling pressure in the groove should be around 3 to 5 MPa.





The FSS Experiment Objectives & Schedule

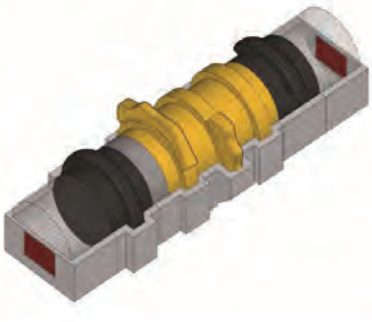
The FSS experiment conducted at Saint-Dizier, near the Bure Laboratory (URL) is a full scale construction test of the reference concept. It aims at:

1) **Demonstrating the industrial capacity to satisfactorily emplace large volumes of low pH concrete (shotcrete & cast concrete). Low pH value is equal or less than 11.**
2) **Demonstrating the industrial capacity to satisfactorily emplace large volumes of swelling clay (bentonitic material) at a satisfactory specific gravity value.**
3) **Defining the operational constraints linked to emplacement activities and compatible with the mechanical or hydraulic properties allocated to the seal components.**
4) **Defining and operating the commissioning means necessary to check the compatibility of the work during emplacement operations.**
5) **Defining and operating the commissioning means necessary to check the compatibility of the work after emplacement operations.**

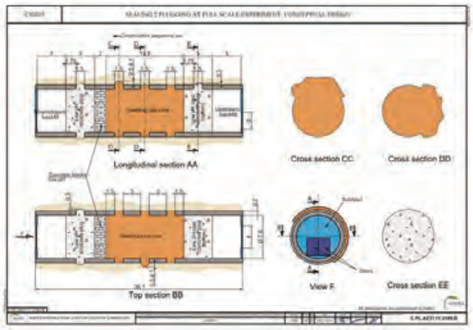
The FSS experiment is completed by a forced saturation test, which is conducted with the same swelling clay material at a lower scale (REM experiment, also carried out within the DOPAS Project). The main milestones are:

1) **Studies, formulations & characterization of materials : end 2012-mid 2013.**
2) **Construction of seal components: mid 2013 – end 2013.**
3) **Commissioning : end 2013 – beginning 2014.**
4) **Dismantling – Report & communication: end 2015.**

3D view of the FSS experiment in its box (drift model) with the breakouts (recesses) in the argillite formation



Longitudinal section view of the FSS experiment



The bentonite swelling core construction challenge:

- **Some 750 m^3 of pellets/powder admixture to be prepared, conveyed in DGR environmental conditions and emplaced so as to reach an effective density value as high as possible, with almost no residual vacuum in *summital* recesses. No segregation of pellets and powder is allowed. Height of core is up to 10 m with a natural slope of some 25-30 %.**
- **Observation windows will be positioned at relevant places on the test box frame, to check segregation, residual vacuum, subsidence, stability of slope.**

The low pH concrete containment plug construction challenge: some 250 m^3 for each plug (cast concrete and shotcrete), minimum cracking and shrinkage, limited curing temperature, minimum residual vacuum in summital recesses.

The beginning of low pH concrete formulation conception:

- Extraction of the solution to be measured
- Continuous agitation of the solution
- Measure of pH value

The FSS test box (DGR drift model at scale 1)

The beginning of bentonite admixture & filling conception:

In a first time the best possible arrangement of the pellets dropped in the box is looked after, and for that purpose the effective bentonite density in the cylinder box is measured with a scale.

Andra acknowledges the scientific support of NAGRA and the technical contribution of the consortium of companies in charge of implementing FSS : Eiffage TP, CEA-LECBA, Laviosa-MPC, SOLEXPERTS

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

More about the DOPAS Project and FSS: www.posiva.fi/dopas

www.andra.fr

Appendix 5

DOPAS Full Scale Demonstration of Plugs and Seals Dome Plug (DOMPLU) experiment at Äspö HRL

Pär Grahm
Experiment leader
Manager Engineered barriers, Repository Technology
SKB (Swedish Nuclear Fuel and Waste Management)

Johanna Hansen
Coordinator of the DOPAS project
Posiva Oy

Why?

The Dome Plug (DOMPLU) is a full-scale demonstration of the KBS-3V reference method to seal a deposition tunnel in the Spent Fuel Repository. In particular, we study the water leak through the plug in the interface between rock and concrete. It is important to know how tight the plug really is. Eroding water flow must be kept at an acceptable level so it can be proven that the backfilled bentonite clay is held in place in the tunnel.

How?

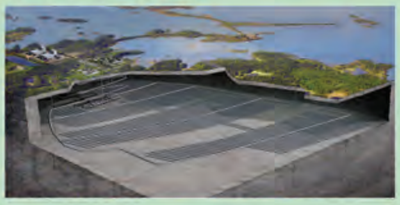
The experiment is pressurized partly with the help of the prevailing groundwater pressure at 450 meters depth and partly by water pumped into the backfill and filter behind the plug. The seal-test is conducted at 7 MPa, which is the design pressure of the plugs in the repository. In addition, a short-term strength test of the concrete dome is performed at very high load, corresponding to 1000 meters of water pressure (10 MPa). More than 100 sensors continuously monitor total pressure, water pressure, temperatures, stresses and displacements in different parts of the plug. By collecting water in a tight weir downstream the concrete dome leakage can be determined by drainage to a scale that records the flow on-line.

Results?

The project is monitored and reported within the EU-project DOPAS (Full Scale Demonstration of Plugs and Seals) in 2014 and 2015. Measurements in DOMPLU continue in 2016 and then the experiment is interrupted. The results will be used to define detailed requirements and for future safety analysis.

The Spent Fuel Repository in Forsmark (- 470m)

(licensing ongoing)



Each deposition tunnel will be sealed by an end plug that will limit axial groundwater flows to ensure that backfill and buffer materials remain in place and do not erode.

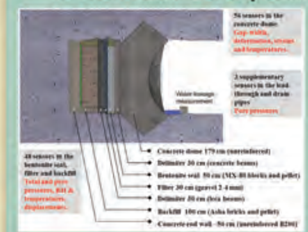
The plug is an important barrier until the outside main tunnel has been backfilled and thereafter become water saturated (up to 100 years).

Äspö Hard Rock Laboratory in Oskarshamn

The DOMPLU experimental site at level -450 m

The DOMPLU test is carried out at Äspö Hard Rock Laboratory, where conditions are similar to what will be the case in the Spent Fuel Repository in Forsmark.

1. The DOMPLU experimental set-up



In total more than 100 sensors record data.

Leakage past the plug is measured during pressurization up to 7 MPa.

A strength test of the concrete dome will be performed at 10 MPa.

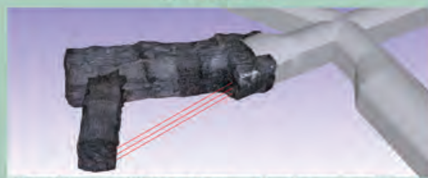
2. Plug location

A suitable plug location was determined by core drilling and high pressure water injection tests (10 MPa) in the pilot hole.

The test-tunnel was excavated by careful blasting, in two steps, to minimize the excavation damaged zone (EDZ). The contour boreholes were blasted in a separate round.

The test tunnel correspond to the reference design of SKB:s deposition tunnels in crystalline rock 4,8 x 4,2 m (KBS-3V).

3. Test site



Three 21 m long Ø200 mm bore-holes for lead-through pipes to the monitoring niche:

- Two for sensor cabling (out)
- One for water pressurization pipes (in)

4. Wire sawing of the octagonal slot

Careful rock excavation of the concrete dome abutment by the use of wire-sawing method

5. Preparation of sensor cable packages

6. Installation of sensors, gravel-filter, bentonite seal and concrete delimiter

7. Injection grouting tubes

8. Cooling system and sensors in the dome

9. Casting of the unreinforced concrete dome

- Ø 8,8 m
- 94 m^3 low-pH SCC "B200"

10. The Concrete Dome Plug

Weir for leakage measurement

DOMPLU is part of the Euratom FP7 DOPAS project

Fourteen nuclear waste management organisations and research institutes from eight European countries are participating in a technology development project for assessing tunnel plugging and sealing systems in geological disposal facilities for radioactive waste - the DOPAS project ("Full-Scale Demonstration Of Plugs And Seals"). The project is built around a set of full-scale demonstrations, laboratory experiments, and performance assessment studies and is jointly funded by the Euratom's Seventh Framework Programme and European nuclear waste management organisations.

The DOMPLU installation at Äspö HRL has been carried out during 2012 -2013 as a joint project by SKB and Posiva Oy.

Monitoring and evaluation of DOMPLU are tasks included in the DOPAS project. The project is running from September 2012 to August 2016. 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. 323272, the DOPAS project.

Appendix 6

DOPAS Project: Demonstration of Plugs and Seals
The FSS Experiment (Full Scale Seal)

J.M. Bosgiraud, P. Lebon, R. Foin, G. Armand

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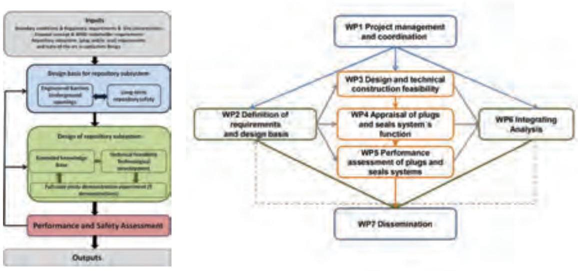

It involves **14** Partners coming from organizations responsible for implementing radioactive waste management in the EC & Switzerland, as well as from private companies or research institutes and universities with extensive experience in clayish / bentonitic & cementitious materials, modelling, instrumentations & risk analysis, monitoring, and stakeholder engagement. FSS is one of the **4** Full Scale Experiments carried out within DOPAS and is of concern for the French Deep Geological Repository (**DGR**) concept.

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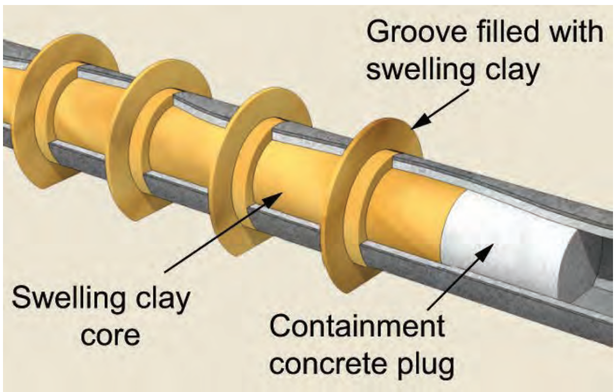
The Repository **closure (**by backfilling and **sealing)** policy is considered as instrumental in serving both technical and social objectives. It is not only essential to underpin the **long term safety strategy** and quality of the associated engineering, but it is also an important tool for public communication, contributing to public understanding / confidence building in the repository behaviour.

Drift Sealing Concepts in the French DGR

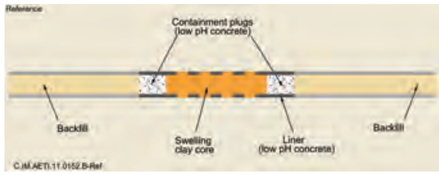


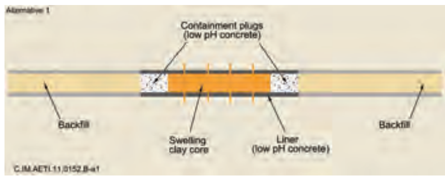
At time of DGR progressive closure, the sealing of horizontal drifts and disposal caverns must be assured by the construction of a specific barrier .

This seal is composed of a swelling clay core (bentonite) with 2 low pH concrete containment plugs, one at each end. The remaining part of the drift is backfilled with the original excavated material.

In the **reference** design, the seal is installed in a section of the drift where the concrete liner will have been partly dismantled, allowing a direct contact between the argillite formation and the bentonite core, whose swelling pressure should be close to 7MPa.

In the **alternative** design, a thin groove is excavated at the extrados of the drift liner and filled with bentonite at direct contact with the argillites , providing an EDZ cut-off. The bentonite swelling pressure in the groove should be around 3-5 MPa.





The FSS Experiment Objectives & Schedule

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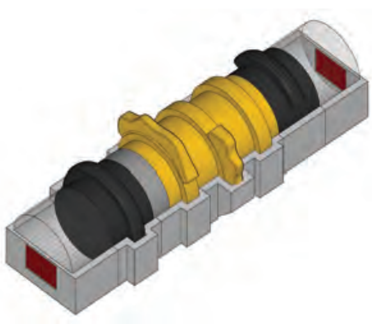
1) **Demonstrating the industrial capacity to satisfactorily emplace large volumes of low pH concrete (shotcrete & cast concrete). Low pH value is equal or less than 11,**
2) **Defining the operational constraints linked to emplacement activities and compatible with the mechanical or hydraulic properties allocated to the seal components,**
3) **Defining and operating the commissioning means necessary to check the compatibility of the work during emplacement operations,**
4) **Defining and operating the commissioning means necessary to check the compatibility of the work after emplacement operations,**

The FSS experiment does not include a saturation test, which is conducted with the same swelling clay material at a lower scale (REM experiment).

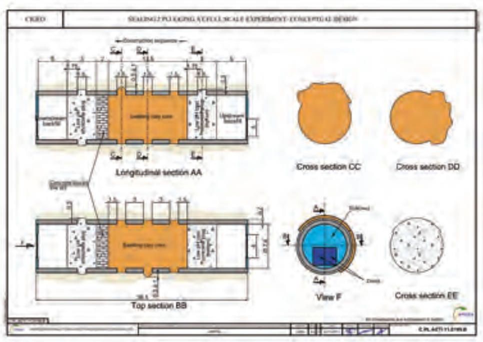
Main milestones:

1) **Studies, formulations & characterization : end 2012-mid 2013,**
2) **Construction of seal components: mid 2013 – end 2013,**
3) **Commissioning : end 2013 – beginning 2014,**
4) **Dismantling – Report & communication: end 2015.**

3D view of the FSS experiment in its box (drift model) with the breakouts (recesses) in the argillite formation



Longitudinal section view of the FSS experiment



The bentonite swelling core construction challenge:

- **Some 750 m³ of pellets/powder admixture to be prepared, conveyed in DGR environmental conditions and emplaced so as to reach an effective density of 1,62 with almost no residual vacuum in *summital* recesses. No segregation of pellets and powder is allowed. Height of core is up to 10 m with a natural slope of some 30 %.**
- **Observation windows will be positioned at relevant places on the test box frame, to check segregation, residual vacuum, subsidence, stability of slope.**

The low pH concrete containment plug construction challenge: some 250 m³ for each plug (cast concrete and shotcrete), minimum cracking and shrinkage, limited curing temperature, minimum residual vacuum in summital recesses.

The beginning of low pH concrete formulation conception:

- **Extraction of the solution to be measured**
- **Continuous agitation of the solution**
- **Measure of pH value**

The future FSS experiment box (DGR drift model at scale 1)

The beginning of bentonite admixture & filling conception:

In a first time the best possible arrangement of the pellets dropped in the box is looked after, and for that purpose the effective bentonite density in the box is measured.

Andra acknowledges the scientific support of NAGRA and the technical contribution of the following consortium of companies in charge of implementing the experiment : Eiffage TP, CEA-LECBA, Laviosa-MPC, SOLEXPERTS
Andra acknowledges the financial support of the European Commission within the frame of the cooperative project DOPAS (FP7 - Grant agreement 323273)

The DOPAS project is being carried out by a consortium of 14 partners representing waste management organizations, research institutes, academia & consulting companies.

DOPAS aims to improve the knowledge regarding the industrial feasibility of plugs and seals, the measurement of their characteristics, the monitoring of their hydraulic and mechanical behavior under repository conditions, and their performance with respect to a range of safety objectives.

Under negotiation

FULL-SCALE DEMONSTRATION OF PLUGS AND SEALS

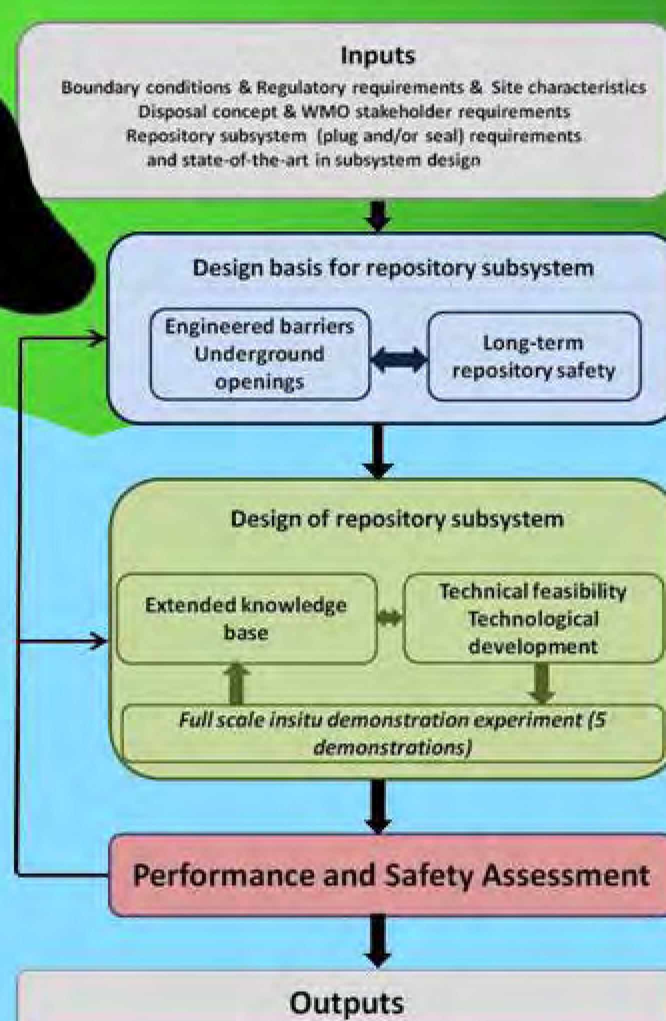
DOPAS

- WP1 Project Management and Coordination (Posiva)
- WP2 Definition of requirements and design basis of plugs and seals (SKB)
- WP3 Design and technical construction feasibility of plugs and seals (Andra)
- WP4 Appraisal of plugs and seals system´s function (NDA)
- WP5 Performance assessment of the plugs and seals systems (GRS)
- WP6 Integrative analysis of results (Posiva)
- WP7 Dissemination (Posiva)

- Experiment 1: FSS (BURE,FR) ANDRA & NAGRA
- Experiment 2: EPSP (URC Josef,CZ) RAWRA, CTU
- Experiment 3:DOMPLU (Äspö,SE) SKB , POSIVA
- Experiment 4: POPLU, (ONKALO,FI) POSIVA, SKB, BTECH
- Experiment 5: ELSA, (tbd,DE) DBETEC,GRS, NRG

DOPAS will run in the period September 2012 – August 2016.

An International seminar will be organized together with IGD-TP in the last year of the project.



DOPAS will identify the design basis of plugs and seals in geological disposal facilities, reference designs, and strategies to demonstrate the compliance of the reference designs to the design basis and to implement them into the experiments.

The identified plugging and sealing concepts will be demonstrated and evaluated in five thematic scientific / technological work packages, each of which will integrate the results of a set of five planned *in situ* experiments.

DOPAS is focusing on tunnel plugs for clay host rock (French and Swiss disposal concepts), tunnel plugs for crystalline rock (Czech, Finnish and Swedish disposal concepts), and shaft seals for salt host rock (German disposal concept).

The Full Scale Seal Experiment - A Seal Industrial Prototype for *Cigéo* – 13106

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ABSTRACT

The Full Scale Seal (FSS) Experiment is one of various experiments implemented by Andra, within the frame of the *Cigéo* (the French Deep Geological Repository) Project development, to demonstrate the technical construction feasibility and performance of seals to be constructed, at time of Repository components (shafts, ramps, drifts, disposal vaults) progressive closure.

FSS is built inside a drift model fabricated on surface for the purpose. Prior to the scale 1:1 seal construction test, various design tasks are scheduled. They include the engineering work on the drift model to make it fit with the experimental needs, on the various work sequences anticipated for the swelling clay core emplacement and the concrete containment plugs construction, on the specialized handling tools (and installation equipment) manufactured and delivered for the purpose, and of course on the various swelling clay materials and low pH (below 11) concrete formulations developed for the application. The engineering of the “seal-as-built” commissioning means (tools and methodology) must also be dealt with.

The FSS construction experiment is a technological demonstrator, thus it is not focused on the phenomenological survey (and by consequence, on the performance and behaviour forecast). As such, no hydration (forced or natural) is planned. However, the FSS implementation (in particular via the construction and commissioning activities carried out) is a key milestone in view of comforting phenomenological extrapolation in time and scale. The FSS experiment also allows for qualifying the commissioning methods of a real sealing system in the Repository, as built, at time of industrial operations.

INTRODUCTION

Andra’s successful implementation of a deep geological repository program for radioactive waste relies on a sound long term safety strategy and on its scientific and engineering basis as well as on social aspects such as stakeholders’ acceptance and confidence.[1]

The Repository progressive closure (by backfilling and sealing) policy is considered as instrumental in serving both the above technical and social objectives. It is not only essential to underpin the long term safety strategy and the quality of the associated engineering, but it is also an important tool for public communication, contributing to general understanding and confidence building in the repository behaviour.

The FSS experiment aims to raise the implementer’s industrial know-how and the acceptance of the sealing strategy by the long term safety evaluators and the stakeholders. Presented below is its rationale and planning.

THE DOPAS PROJECT

DOPAS (Demonstration of Plugs and Seals) is a four year (2012-2016) cooperative Project, financially supported by the European Community (EC) within the frame of the 7th Framework Program for Nuclear Research and Training (EURATOM). Its coordinator is POSIVA (Finland).

It involves 8 countries and 14 partners coming from organizations responsible for implementing radioactive waste management in the EC & Switzerland, as well as from private companies or research institutes and universities with extensive experience in bentonitic and cementitious materials, modelling, instrumentations, risk analysis, monitoring, and stakeholder engagement.

FSS is one of the 4 Full Scale Experiments carried out within DOPAS and is of concern for the French Deep Geological Repository (Cigéo) concept for sealing activities in a clayish formation. Full scale seals in crystalline formations will be implemented by SKB (Sweden) and POSIVA (Finland), within the frame of this European Project.

THE FSS RATIONALE

Drift Sealing Concepts in the French Deep Geological Repository

At time of Repository progressive closure, the sealing of shafts, ramps, horizontal drifts and disposal caverns must be assured by the construction of a specific barrier. The seal is composed of a swelling clay core (bentonite) with 2 low pH concrete containment plugs, one at each end. The remaining part of the drift/shaft is backfilled with the original excavated material (argillites).

In the reference design, the seal is installed in a section of the drift where the concrete liner will have been partly dismantled; allowing a direct contact between the argillite formation and the bentonite core, the swelling pressure of which should be close to 7MPa. This design is illustrated in Figure 1.

In the alternative design (presented in Figure 2), a thin groove is excavated at the extrados of the drift liner and filled with bentonite at direct contact with the argillites, providing an EDZ (Excavation Damaged Zone) cut-off. The bentonite swelling pressure inside the groove should be around 3 to 5 MPa.

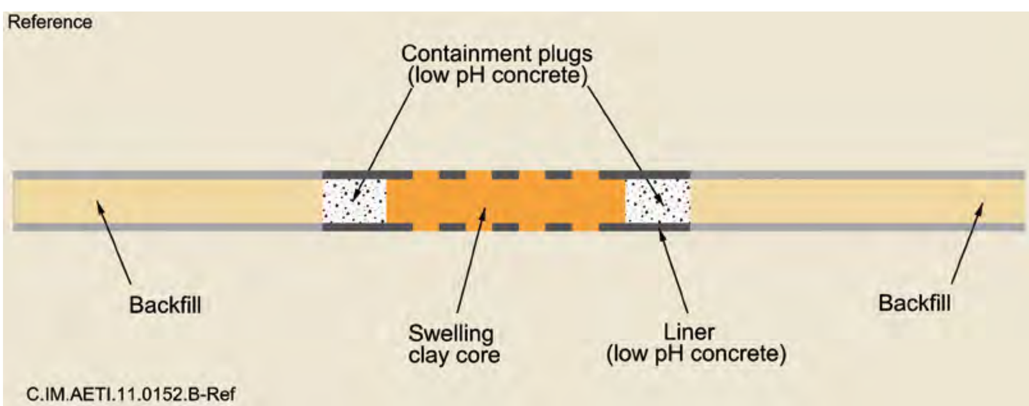

Fig. 1. Reference drift sealing and backfilling concept.

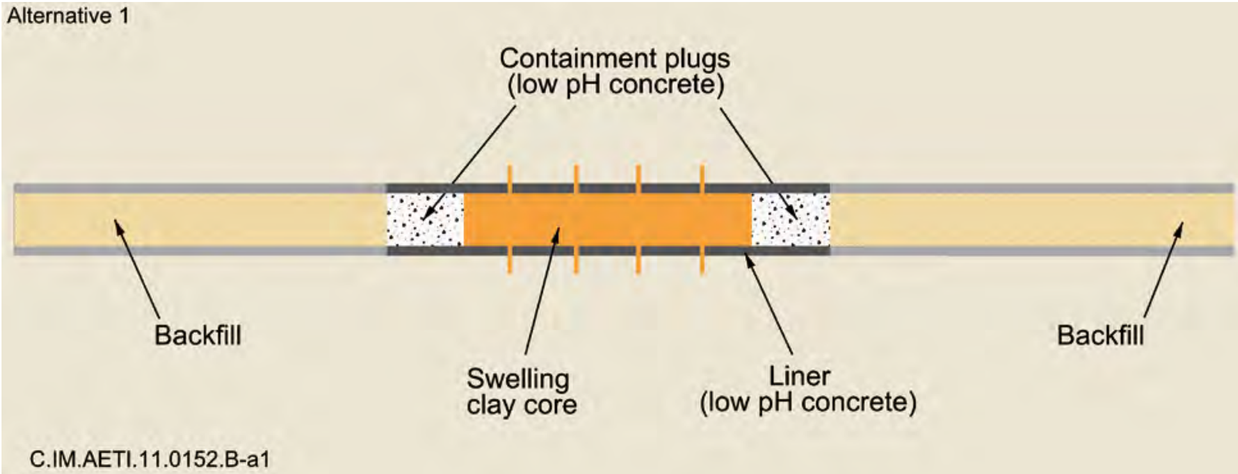

Fig. 2. Alternative drift sealing and backfilling concept.

The Various Seal Related Experiments and Tests Planned by ANDRA

In order to satisfy both the knowledge and demonstration needs in terms of phenomenology, safety assessment and engineering, a total of 4 experiments are planned by Andra: three (3) scientific experiments and a technical one. All these experiments are supposed to be completed (or to provide significant data) before the *Cigéo* license application filing milestone (mid-2015). The data availability is a challenge of its own, considering the time devoted to the resaturation of bentonite admixtures. By combining the results obtained from the 3 phenomenological experiments and the construction test, carried out at various scales and different experimental sites (on surface and in situ), and on various materials, Andra expects to cover all the aspects of the seal performance demonstration and provide some confidence to the national evaluators. This approach was presented to them and accepted.

A first scientific experiment is planned in the Bure Underground Laboratory, at scale 1:2 (the size of a laboratory drift is somehow half the size of a *Cigéo* drift). Its main objective consists in assessing the equivalent hydraulic performance of the swelling clay core and of the near field at core contact. After the excavation and preparation work scheduled in 2012, the construction and instrumentation will take place in 2013, followed by a speeded-up hydration with hydro-mechanical behaviour monitoring over the period 2013-2017. A measurement of equivalent permeability under pressure gradient is expected with the first results available for mid-2015. Figure 3 illustrates the experiment set-up principle.

A second scientific experiment is focused on the EDZ (Excavation Damaged Zone) cut-off. The main objectives are to excavate a circular and deep (2.5m) groove at the periphery of one of the Bure Laboratory drifts, assess its geometry, monitor its behavior with time, then backfill the groove with a self-supporting swelling clay material, using industrial means (representative here also of the future *Cigéo* operations), and finally proceed with an hydration test of the backfilled groove, in order to assess the hydraulic conductivity and demonstrate the efficiency of EDZ cut-off so created. Figure 4 shows the groove created underground for the purpose in the Bure clay formation. This EDZ cut-off experiment will be implemented by the end 2013, following a blank bentonite bricks emplacement test (to check the bentonite self-supportability), carried out on surface, on a groove gauge, in the early weeks of 2013.

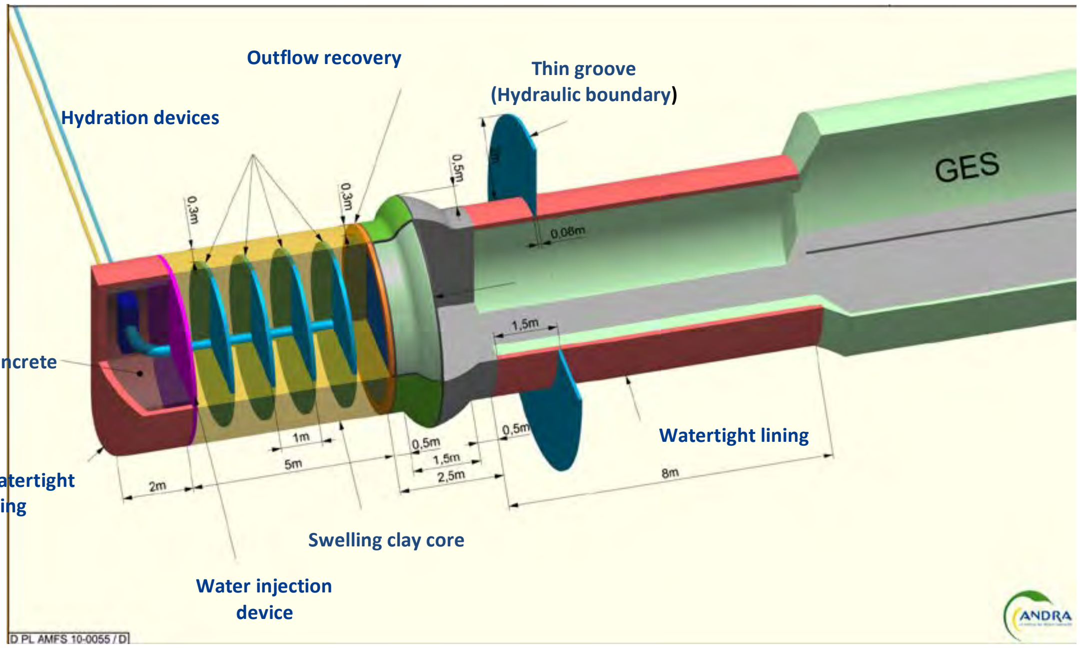

Fig. 3. Scientific seal hydration experiment at Bure underground laboratory.

Fig. 4. The EDZ cut-off: groove sawing prior to backfilling with bentonite blocks.

A third scientific experiment is a forced hydration test, carried out at a metric scale, with the same bentonite admixture (pellets and bentonite powder) as that used for the construction of the FSS swelling core. The same dry density (1.62) as that predetermined for FSS will also be looked for, as well as the same emplacement technology will be used. This metric scale test will confirm the relevancy of the bentonite admixture selected for FSS (which will have been checked only at decimetric scale during the performance characterization phase of the swelling clay material). It is the only saturation test coherent with FSS as far as the bentonite material (pellets and powder admixture) is concerned (since the 2 other scientific are implemented with compacted bricks), and the only one likely to provide performance data on time for the mid-2015 license application milestone. Hydrating the FSS swelling core would require a time allocation (and a box structure) not commensurate with the general *Cigéo* schedule.

FFS is the full scale technical construction challenge test described in detail in the next chapter.

THE FSS CONSTRUCTION

The FSS Significant Size

FSS will be built inside a drift model (also called the test box) fabricated for the purpose. The drift will be some 7.6m ID and 36m long. The drift concrete liner (70cm thick) and the formation break outs (recesses) likely to be generated by the drift lining deposition (up to 1m depth at the liner extrados) will be simulated. Representative underground ambient conditions (temperature around 18-30 °C, hygrometry between 50% and 75%), will be maintained within the drift. Low pH cast-concrete/shotcrete 5m long containment plugs will close the volume of the swelling core, on both sides. The bentonite swelling core will be some 14m long.

Figures 5 and 6 respectively show the FSS seal as constructed (at the end of the test) in its test box (the drift model) and the simulated recesses which must be thoroughly backfilled.

The construction methodologies selected for the construction of the various seal components are not frozen yet, but most likely the low pH cast concrete containment plug will be poured (if possible) in one continuous pass (to avoid discontinuities), while the low pH shotcrete containment plug will be applied in multiple layers, with minimum curing time between two layers. The swelling clay core will be made of a bentonite pellets admixture, and emplaced most likely by using two (or more) augers working at a time, in a continuous mode, while residual summital voids should be backfilled with dry pulverulent clay. The objective is to obtain a core as compact as possible, in order to reach the desired emplaced specific gravity (1.62), hence the swelling pressure performance required (7 MPa).

On the drift model periphery, polycarbonate windows will be provided for observation needs while reservations will be integrated to the drift model structure for monitoring and sample coring needs. All the work sequences will be video-taken and a chronogram of operations established to assess the overall time needed for building a complete seal in a real DGR drift.

The seal construction will have been preceded by some laboratory work tasks including mainly material characterization, in order to check that the measured performances are in line with the allocated performances. This will be true for the clay material admixture constituting the swelling core (bentonite pellets and granular/pulverulent bentonite) as well as for the low pH shotcrete and the cast concrete formulations.

Finally, a “confirmation campaign” of intermediate scale test tasks is forecast, before adopting the final industrial solutions. Metric tests of concrete formulations (cubic boxes for cast concrete, test panels for shotcrete) will be carried out, curing parameters will be evaluated and mechanical performances (including shrinkage values) will be measured and verified. As for the bentonite pellets and other granular materials, the granulometry spectrum and dry-density values will be optimized and validated in terms of swelling pressure performances.

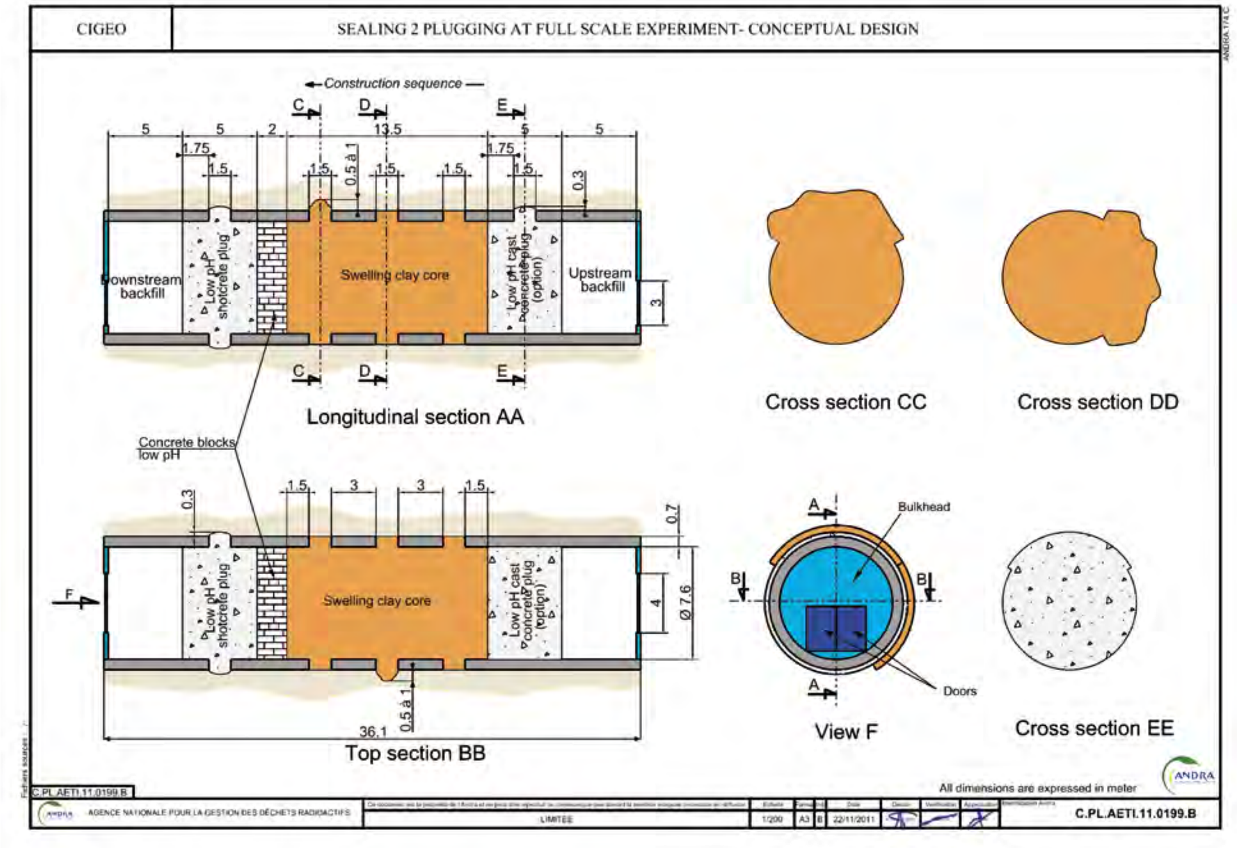

Fig. 5. Longitudinal view of the FSS experiment as built in its box.

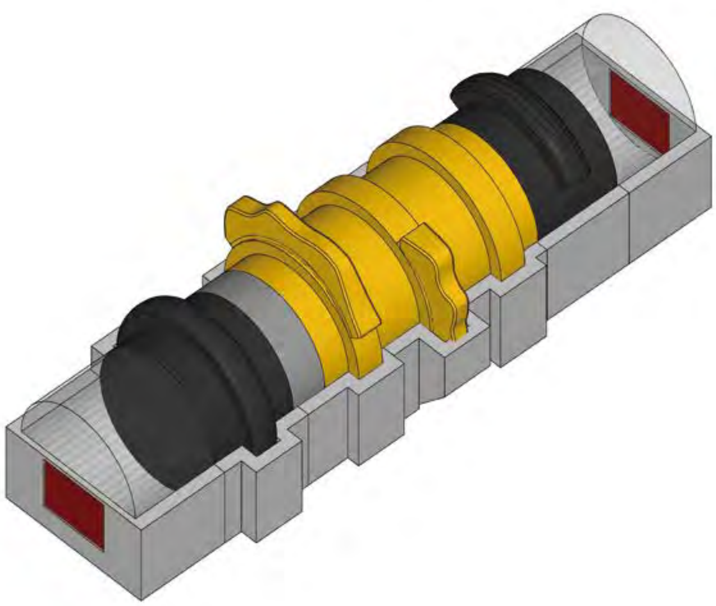

Fig. 6. 3D view of the FSS experiment as built in its box with the breakouts (recesses) in the argillite formation.

The Bentonite Swelling Core and Concrete Plugs Construction Challenge:

Some 750 m^3 of pellets/powder admixture will be prepared, conveyed in DGR environmental conditions and emplaced so as to reach an effective density of 1.62 with almost no residual vacuum in summital recesses. No segregation between pellets and powder is allowed. The maximum height of the core (when including the recesses) is up to 10 m with a natural slope of some 30 % (observation windows will be positioned at relevant places on the test box frame, to check segregation, residual vacuum, subsidence, stability of slope).

The low pH concrete containment plug construction challenge: is also significant: some 250 m^3 are needed for each type of plug (cast concrete and shotcrete), while one expects minimum cracking and shrinkage, limited curing temperature, and minimum residual vacuum in summital recesses.

The quality approach anticipated for commissioning the constructed seal components consists in measuring the average dry density of emplaced material by pellet weighing and “volume 3D scanning”; and in video supervising the backfilling operation with a focus on the contact quality at the rock/core interface, to assess the residual summital voids.

Main Milestones and Present Status

The contemplated work schedule of the FSS experiment is as follows:

- the general studies and the material formulations started in July 2012 and should be completed by mid-2013,
- the site preparation work is already on going and the test box is planned to be commissioned by mid-2013,
- the construction of the seal components (swelling core and containment plugs) should take place between mid-2013 and the end of 2013, followed by commissioning activities,
- and the experiment dismantling and the subsequent evaluation report are expected in late 2014.

CONCLUSION

The successful achievement of the FSS experiment is deemed critical by Andra’s national evaluators in order to demonstrate the effective full scale seal constructability and is also the only repetition of the in situ full scale seal test which is planned in the Cigéo access ramp in the early years of the repository construction (2022-2024).

Its successful completion will be instrumental in Andra’s overall demonstration on sealing issues and a convenient tool for confidence building with all the stakeholders concerned. The FSS experiment results are anticipated for publication by 2014.

Fig. 7. The future FSS experiment box (at scale 1).

REFERENCES

1. http://www.andra.fr/

ACKNOWLEDGEMENTS

Andra acknowledges the financial support of the EC (Grant agreement 323273) within the frame of the European cooperative Project DOPAS and the scientific expert contribution of NAGRA (Switzerland) in this technical challenge.

WM2014 Conference, March 2 – 6, 2014, Phoenix, Arizona, USA.

Nordic Full-Scale Demonstrations of Tunnel Plugging Technologies for Repository Conditions – 14282

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ABSTRACT

Two HLW deposition tunnel end plugs are being constructed in crystalline-rock in Finland and Sweden for deep geological repositories. These full-scale underground demonstrations are part of a Euratom demonstration project called DOPAS, which is running from 2012-2016 and involves 14 waste management and research organizations from 8 countries. The project goal is to improve the adequacy and consistency regarding industrial feasibility of plugs and seals to be used in different geological environments. The plug in Äspö, Sweden was constructed in early 2013 and the plug in ONKALO, Finland is scheduled for placement during the first half of 2014, with design, modeling and excavation now completed. New low-pH concrete plug materials have been developed and demonstrated for workability and durability properties. Elaborate monitoring systems have been designed using over 100 sensors to monitor each plug's performance during two accelerated pressurization tests. The expected mechanical and hydraulic performances of the plugs have been modeled during the design stage, and it is expected that the models will be updated based on the experimental results and reports generated in 2015-2016. The results will also be used to update reference designs and influence the plug requirements. All of these actions support long-term safety requirements, the future operation licensing process, and improving stakeholder confidence in repository operation. The published project outcomes can be used by the international community to enhance the siting, design, construction and quality management practices for future tunnel plugs and shaft seals used in various types of repository configurations and geological conditions.

INTRODUCTION

One major need identified by European nuclear waste management organizations prior to operation of HLW disposal facilities is the demonstration of tunnel sealing feasibility. In the year 2012 a project began, with joint funding from the Euratom's Seventh Framework Programme together with 14 European nuclear waste management and research organizations from eight countries. This four-year project, called DOPAS ("Full-Scale Demonstration Of Plugs And Seals") [1], is developing technologies for assessing tunnel plugging and sealing systems in varying geological disposal facilities for SNF and HLW. The project is built around a set of five full-scale plug demonstrations, together with laboratory experiments, modelling and performance assessment studies. The project is coordinated by Posiva Oy in Finland, who is host to one of the five experiments. The DOPAS requirements and design basis of plugs are managed by SKB in Sweden who also hosts one full-scale plug experiment.

BACKGROUND

Different types of plugs and other sealing structures are needed in HLW repositories worldwide, depending on the prevailing geological conditions. Part of these plugs serve to hydromechanically isolating different parts of the repository from each other, like deposition tunnel end plugs in the KBS-3 concept adopted for crystalline rock. The functional requirements of these plugs are mainly related to the buffer barrier and the risk for piping and erosion of its bentonite clay. Thus the plug system has to be watertight to stop or reduce the axial groundwater flow through a deposition tunnel and also be able to keep the backfill in its intended place. Furthermore, some plugs will have the role as a hydraulic seal to prevent the groundwater flow through the excavated access routes like tunnels and shafts in crystalline host rock. The controlling design parameters for the plugs are often related to the watertightness and durability over the plug's intended service life. Depending on the host rock geology, the purpose of the plug, and the long term safety functions of the plug, there are then different requirements and reference designs that are site specific. The plugs and seals will be used in a nuclear facility that set common challenges for developing the design basis, creating the designs, showing their compliance with the requirements and assessing the long term behavior and interactions with other barrier components and with the host rock.

European waste management organizations are at different stages of maturity in their repository development and in related licensing procedures for implementing geological disposal facilities. Construction license applications for SNF disposal facilities have been submitted in Finland and in Sweden, and construction of the facilities is foreseen to commence during this decade. In Sweden, the Äspö hard rock laboratory (HRL) has been operating since 1995 in the foreseen host rock environment of a future repository. In Olkiluoto, Finland, the ONKALO underground rock characterization facility (URCF), whose construction started in 2004, is foreseen to be licensed as part of Posiva's geological disposal facility for SNF.

The SKB dome plug experiment (DOMPLU) in the Äspö HRL and Posiva's wedge plug experiment (POPLU) in the ONKALO URCF are demonstrating two types of deposition tunnel end plugs that could be utilized in crystalline-rock. Both plug types are intended to isolate the emplaced tunnel backfill, bentonite clay buffer and SNF canister from the central tunnels during the operation phase. These structural plugs are typically made of low-pH concrete and possibly reinforcing steel bars, with a design life in the range of 100 years. The development of construction materials for the plugs and seals meeting the repository requirements is included in the DOPAS experiments' work. Both demonstrations have the goal of constructing full-scale plugs and monitoring their performance when pressurizing them to the full dimensioning loads over a short (1-2 year) time scale to simulate 100 years of service life.

The difference in the Swedish and Finnish plug demonstrations is related to the amount and size of the filter and seal layers in the interface between the backfill clay and the concrete plug. The DOMPLU dome-plug design is intended for deposition tunnels where there may be higher levels of water inflow, while the POPLU design is intended as a concrete-alone test, without backfill sealing behind the plug.

METHODS

Defining Requirements

Both of these plug demonstrations aim, within the Euratom DOPAS project, to improve the knowledge about construction feasibility of the large sealing structures and given confidence in the industrial scale construction of such plug and seals to be used in different geological environments. The main project challenges are related to: 1) location selection and construction technologies underground, 2) new material development, 3) in-situ instrumentation and performance assessment, and 4) quality and safety assurance procedure development and implementation. Posiva's experimental site will host the future disposal facility for SNF, thus setting stricter requirements on documentation, quality management procedures and selection of materials compared to other on-going experimental plugs. SKB's DOMPLU experiment strives, to the extent possible, to represent the future licensed design.

The deposition tunnel end plugs are a separate system part of the backfill design within the KBS-3V concept. The plugs have design requirements that are based on long-term performance and safety functions, as described within Posiva's Design Basis and Backfill Production Line 2012 reports [2, 3]. Examples of the most detailed design specific requirements for Posiva's future operational tunnel end plugs are:

- The plug shall maintain its hydraulic isolation capacity for at least 100 years.
- The mechanical strength of the plugs shall correspond to a pressure load of at least 7.5 MPa, including the ambient hydrostatic pressure.
- The main material component in the plug shall be quartz sand or crushed rock.
- The concrete shall be water tight after installation. The hydraulic conductivity of the concrete mass shall be <1x10-11 m/s.
- The cementitious materials that are used in plugs shall have a calcium to silica mass ratio less than 1:6.
- The organics and sulphur content in the plug shall be lower than 1 wt-%.

DOMPLU plug requirements in Sweden are similar, though some differences do exist such as material properties of the self-compacting concrete.

Due to the role of ONKALO in Posiva's future disposal facility, the POPLU experiment needs to comply with some oversight requirements of and reporting of the work to STUK, Finland's Radiation and Nuclear Safety Authority. The POPLU practices for information exchange procedures with the authorities and the procedures for various long-term safety and quality assurance approval (i.e. of stray materials and the requirements related to the classified nuclear safety related components) are important issues in addition to the construction and monitoring of the experiment.

Location Selection and Excavations

Location selection for the exact plug spot underground and the specific excavation methods of the plug location, have a limited record of previous full-scale testing, but they will be a part of the standard operations in future HLW disposal facilities. During the planning stage for excavation and location selection, the POPLU and DOMPLU projects have worked to develop practices related to occupational safety, selection of excavation methods such as wire sawing, and modified designs of tunnel supporting and rock support material use to preserve the geological conditions.

In Finland, the POPLU experiment is done in the demonstration area of ONKALO 420 meters below surface. Two plug demonstration tunnels were excavated in 2013, with tunnel lengths of approximately 26 meters and cross sectional area of 14.46 m^2 (4.35 meters high by 3.5 meters wide). Posiva's methodology of Rock Suitability Classification [4] was applied to characterize the fracture patterns, leakage and rock quality, prior to selecting the plug tunnel and the plug slot location within the tunnel. The final location and the minor fracture patterns are shown in Figure 1, where the yellow and red pattern represent a brittle deformation zone based on the detailed-scale model, dark grey lines show Tachymeter-measured traces of the largest fractures observed in the tunnel, and blue numbers indicate the length in meters from the central tunnel midpoint.

The POPLU plug slot excavation method will be decided upon based on discussions with contractors, cost, quality of excavation and safety. The plug construction is expected to take place during April to June 2014.

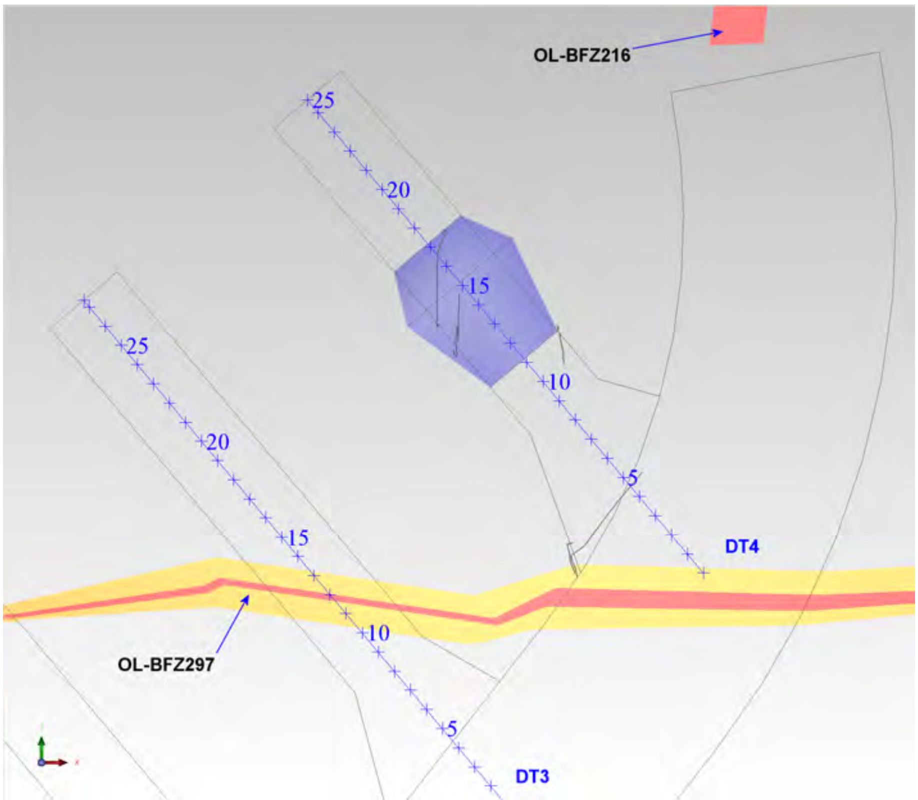

Fig. 1. Significant bedrock structures in ONKALO, in the vicinity of POPLU.

In Sweden, the DOMPLU experiment is carried out at 450 meters below surface in Äspö HRL, where conditions are similar to what will be the case in the SNF Repository in Forsmark. A suitable plug location was determined by core drilling and high pressure water injection tests (10 MPa) in a 30 meter long pilot hole. The test-tunnel was then excavated to 14 meters length by using drill and blast methods, with a modified blast sequence to ensure a minimal Excavation Damage Zone (EDZ). The contour boreholes were blasted in a separate round.

The tunnel dimensions correspond to the reference design of SKB`s deposition tunnels, which are 4,8 meters high by 4,2 meters wide, for a cross sectional area of 18,9 m^2.

The plug slot area was excavated to obtain smooth surfaces using the wire sawing technique in an octagonal shape (Figures 2-3).

The wire-sawing took longer than initially scheduled due to complications from rock stresses. As a consequence the originally planned pulling cuts were changed to blind cuts and accordingly a new drilling campaign was needed.

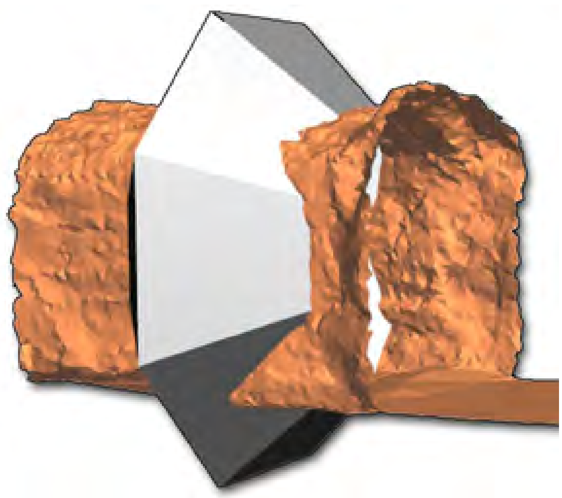

Fig 2. Model of the theoretical slot layout

Fig 3. The excavated slot for DOMPLU

RESULTS

Structural Designs

The POPLU plug will to be Posiva's first full-scale engineered barrier system (EBS) component constructed and demonstrated at the Olkiluoto disposal site. The original structural designs and calculations for Posiva's wedge plug were described by Haaramo et al [5] but were revised to the dome-shaped reference design within Posiva's Backfill Production Line report [2] to reflect experience gained in Sweden's earlier plug demonstrations [6, 7].

The POPLU wedge-shaped plug has dimensions of 6 meters in length and 5.5 meters diameter (Figure 4). The plug contains approximately 20 tons of steel reinforcement and the concrete will be cast in two sections, at approximately a two week interval. The rock grouting of the near-field will be done in three circumferential paths around the concrete, approximately three months after the concrete casting. Bentonite sealing tape will also be used in two bands between the plug and rock surface. A permeable filter layer is placed behind the plug to handle water during construction and operation, also during the accelerated pressurization test.

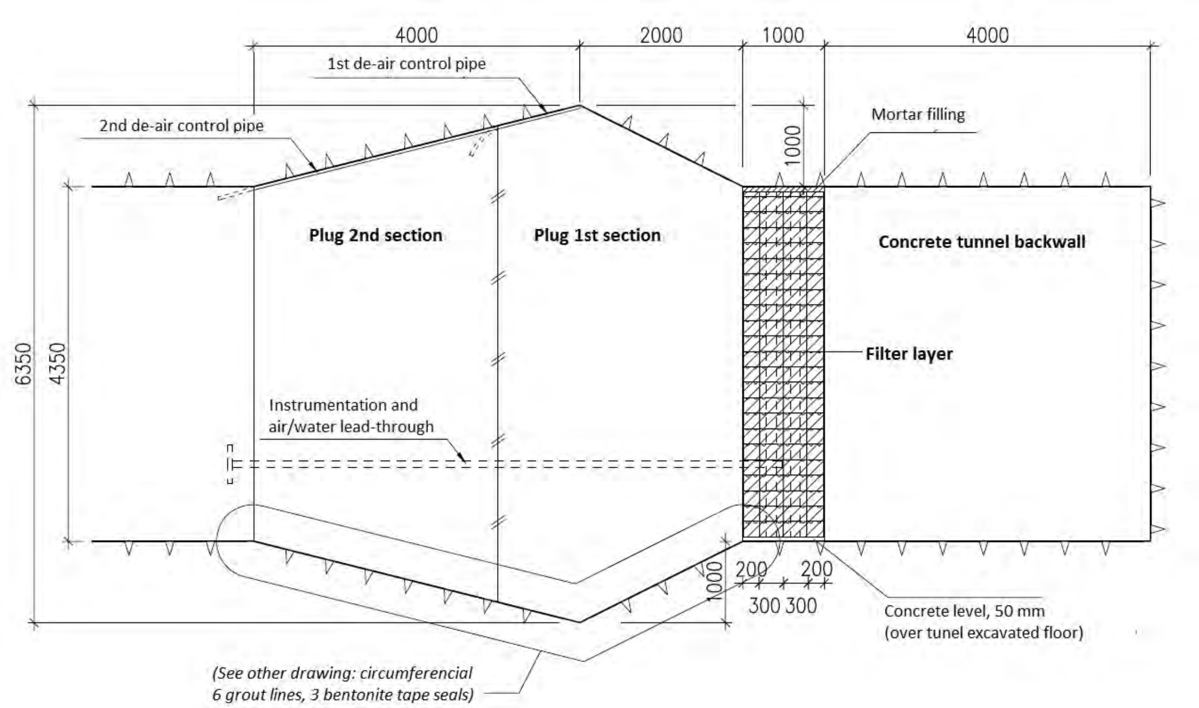

Fig. 4. Posiva's design for the POPLU (Wedge Plug) experiment, with filter layer shown at right.

Sweden's DOMPLU plug consists of an arched low-pH concrete dome, a bentonite seal, filter materials and delimiters, as shown in Figure 5. The design of the DOMPLU experiment was completed during 2011 and the plug was emplaced in March 2013. The low-pH concrete was not reinforced and was cast as one part. A cooling system was installed within the concrete to cool the structure down to +4°C at the time of casting to prevent thermal gradients. The cooling system was also activated later to force contraction and opening of the concrete-tunnel gap to facilitate grouting of the gap between the concrete and the rock contact. The contact grouting was done using ultrafine cement and took place at approximately three months after the casting.

In the DOMPLU design, many technical challenges were taken into account related to the practical implementation of plugs, including issues like the Excavation Damaged Zone (EDZ) in the tunnel; plug -backfill interactions with pressure conditions at repository depth; and smoothness of surfaces required for controlled concrete fitting.

A full-scale demonstration is vital to validate the underlying assumptions and the performed numerical simulations of the concrete dome. In addition, the functions of the filter and the bentonite seal will be thoroughly monitored and the water leakage through the plug will be determined under realistic conditions. As DOMPLU was designed and nearly finished in construction at the start of DOPAS project, the work of DOMPLU within the Euratom project is focused on the monitoring and performance assessment of the full-scale plug.

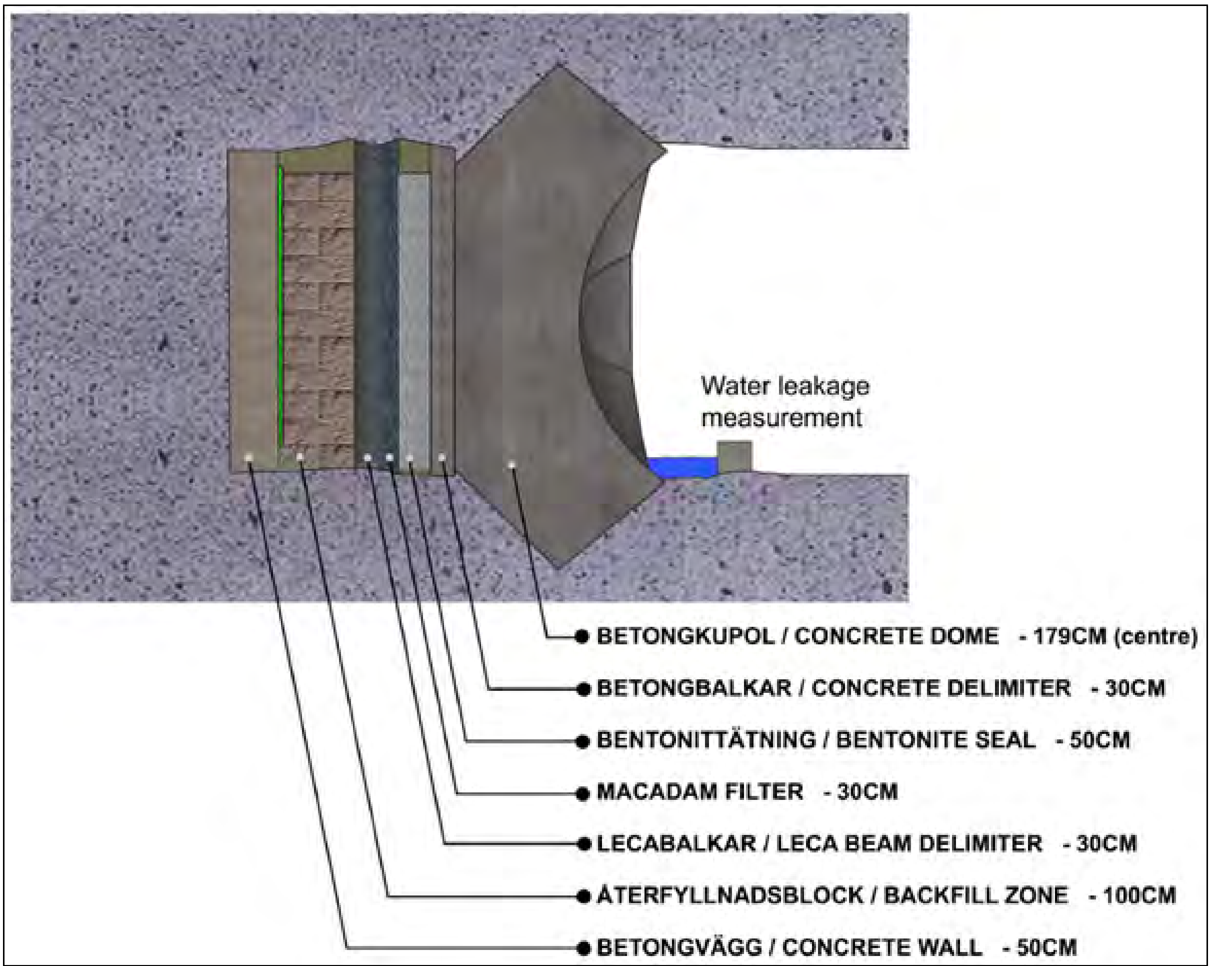

Fig 5. SKB's design for the DOMPLU experiment, with backfill, filter layers and bentonite seal on upstream side of the concrete dome. Water is collected by a tight weir downstream of the concrete dome and the leakage rate is continuously recorded by an on-line scale.

The full-scale demonstrations alone do not provide sufficient information on the performance of the plugs, and therefore modelling has been utilized and implemented in many stages of the design. Theoretical calculations have been done to ensure that the scope and target of the demonstrations are considered and the correct source data are provided for further analysis.

Mechanical, thermal and hydraulic models for the plugs have been developed to estimate the performance evolution over time. Initially, mathematical calculation have determined the stresses in the plug prior to the selection of the concrete grade and required reinforcement. The structure has then been modeled, i.e. with 4-to-8-node brick elements within a linear elastic material model, as shown graphically as displacement and stress plot for POPLU (Figure 6). In the event of an incomplete bond between concrete and rock, the magnitude of the horizontal displacement and the resulting compressive stress perpendicular to the surface in contact with the tunnel have also been estimated.

These various models will be validated and improved based on the monitoring results over the next couple of years and via the accelerated pressurization scenario. The results will be used to update future designs and requirements.

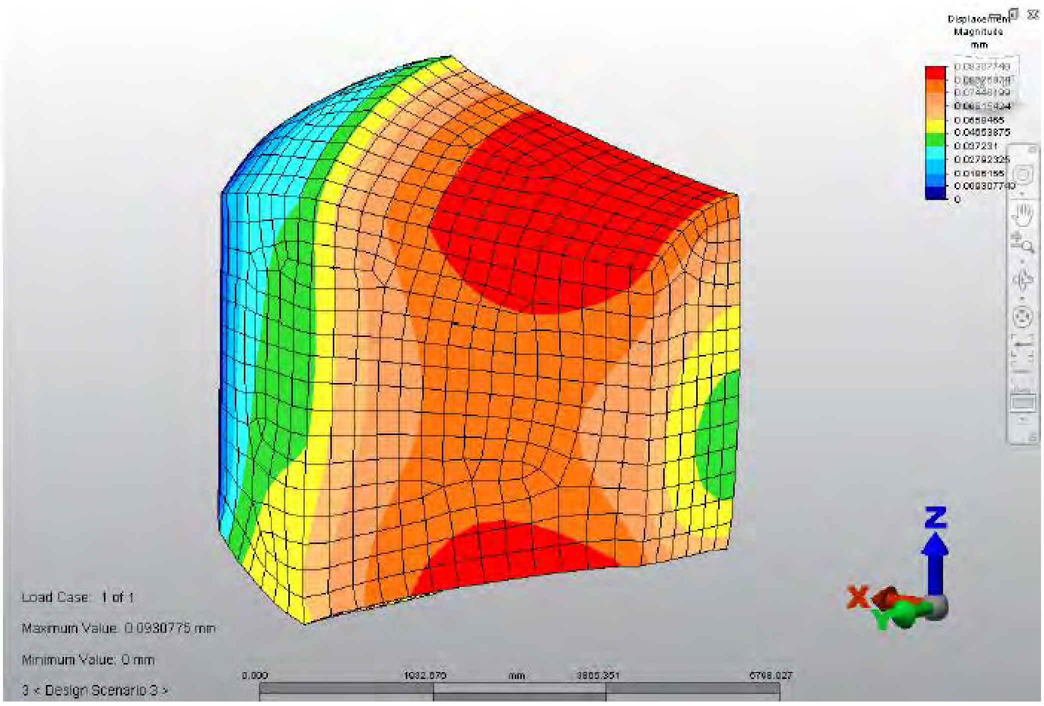

Fig. 6. Example of POPLU mechanical model, showing expected displacements.

The construction material developments within both POPLU and DOMPLU have included advances in cement-based and bentonite-based components used for plugs and seals. Comprehensive laboratory programs have been completed, in order to ensure use of the correct specifications in full-scale experiments and future operational conditions.

Low-pH cementitious materials have been developed in several projects for more than a decade, but still their use at full-scale requires modifications in mixes and laboratory verification of their properties before field use at a decametric scale.

The low-pH concrete recipes and requirements used in Sweden and Finland have been slightly different. The DOMPLU recipe is a self-compacting concrete with a lower maximum aggregate size of 8 mm and a water-to-binder ratio of 0.825. The mixture is composed of cement and silica fume and is designed to have little or no shrinkage. The full details about the DOMPLU recipe B200 and the resulting performance tests are described by Vogt et al. [8, 9]

This Swedish recipe was also considered the initial reference design for Posiva [2] but Posiva has also considered experience from Canadian low-pH concrete used in tunnel and shaft sealing experiments [10]. Within the scope of POPLU, the recipe has now been developed further to account for local materials and higher durability requirements.

The concrete recipe developed for POPLU is also highly workable with potentially slight vibration needed within the mould at the time of placement. The maximum aggregate size is 32 mm, includes granite rather than limestone filler and has a lower water-to-binder ratio ranging from 0.48 to 0.68. The recipe can either be of binary nature, using cement and silica fume as in Sweden, or may also be a ternary blend to replace part of the binder with high quality Danish fly ash. The chemical admixture used as the superplasticizer had to be replaced from a polycarboxylate-based superplasticizer (Glenium51 product) to a naphthalene-based chemical due to the foreign material acceptance criteria that are stricter when working in an actual repository setting such as ONKALO, where the use of organics is prohibited.

Laboratory analyses have been done for both binary and ternary blends recipes to check early age properties of workability, heat of hydration and setting time, as well as checking long term properties. These later-age assessments have focused on evaluating the mechanical and chemical evolution of the materials' performance, such as pH leachate levels, drying and autogenous shrinkage and cracking potential, chloride resistance, sulphate resistance, strength development, watertightness and erosion resistance. An example of the low-pH concrete performance characterizations are given in Table I, including the two alternative recipes (for POPLU.

In addition to the concrete recipe, low-pH grout recipes are also used for sealing the plug to tunnel rock gap in POPLU. These recipes and their performance are described, for instance in [11,12].

TABLE I. Examples of low-pH concrete performance results, compared to traditional high performance concrete and the target values for POPLU.

	POPLU Target	**POPLU Binary**	**POPLU Ternary**	**DOMPLU "B200"** [a]	**"Normal concrete"**
Compressive strength, MPa	> 50	91.5	79.5	67.5	50
Split tensile strength, MPa	3.2	5.6	4.5	-	3.2
Modulus of elasticity, GPa	34	37.4	34.2	-	34
Autogenous shrinkage, mm/m	(min)	0.22	0.15	0.03	0.1
Drying shrinkage, mm/m	(min)	0.17	0.22	-	0.6
Water tightness, mm	max 50	4.0	5.0	5.3	25
Chloride diffusivity, m^2/s	(min)	$2.1*10^{-12}$	$2.8*10^{-12}$		$10\text{-}20*10^{-12}$
pH of leachate at 90 days (reference/Groundwater)	< 11	11.4 / 10.3	11.4 / 10.3	11.4 / 10.3	>12,5

[a] *Results are based on re-production of mix in Finland*

The production of the bentonite components like pellets, backfill blocks, and seal layer blocks for the large-scale tests has demanded understanding of manufacturing and emplacement processes, including quality assurance, storage and transport of the materials, ensuring achievement of planned design and accounting for the interactions between cementitious- and bentonite-based components in field conditions. These bentonite components have been manufactured following the existing backfill reference designs in both Sweden and Finland, as given in Table II. The DOMPLU experiment has used the backfill materials, though the POPLU experiment uses only the concrete without backfill and sealing layers.

TABLE II. Backfill component, full-scale test design parameters.

	DOMPLU, Sweden	**POPLU, Finland**
Backfill & seal block dimensions	500 x 571 x 300 mm (180 kg)	550 x 470 x 330 mm
Backfill material & dry density	Asha, small bricks	Friedland clay, 1990-2070 kg/m^3
Seal layer, block material & density	MX-80 (w 17%), compaction by 20 MPa to 1680 kg/m^3	MX-80 (17% w), >1400 kg/m^3
Pellet fill material & dry density	MX-80, >900 kg/m^3	MX-80, 900-1100 kg/m^3

Instrumentation for Monitoring the Performance

Instrumentation and monitoring of full-scale experiments is required to gain information on plug feasibility, but also for assessment of the plug and seal behavior during accelerated testing conditions. Great emphasis was put on planning the monitoring needs and techniques, to ensure optimal use of results for performance and safety assessments. Full-scale tests offer a possibility to develop and test the monitoring of Engineered Barrier Systems, which is required by the regulatory guides in some of the DOPAS project's partner organizations.

DOMPLU was constructed with 45 sensors in the backfill and seal layer and another 56 sensors within the concrete. These were placed on-site at the same time as the backfill blocks. The sensors in the backfill and seal layer are lead through pipes in the rock to the neighboring tunnel, a distance of about 21 meters. Sensors within the concrete are lead out the front face of the concrete plug. The properties being measured by the array of sensors includes temperature, relative humidity, strain, displacement, pore pressure and total pressure.

The POPLU experiment has also been designed to include about 65 sensors in the concrete (Figure 7) and an additional 10 in the filter layer. Possible disturbances by monitoring are mitigated by using new techniques as much as possible, such as wireless sensors in parallel to traditional wired sensors, so that the full-scale experiments give the basis for future needs within plug and seal technologies for nuclear waste management. The instrumentation of POPLU is described in a separate paper in this same conference [13].

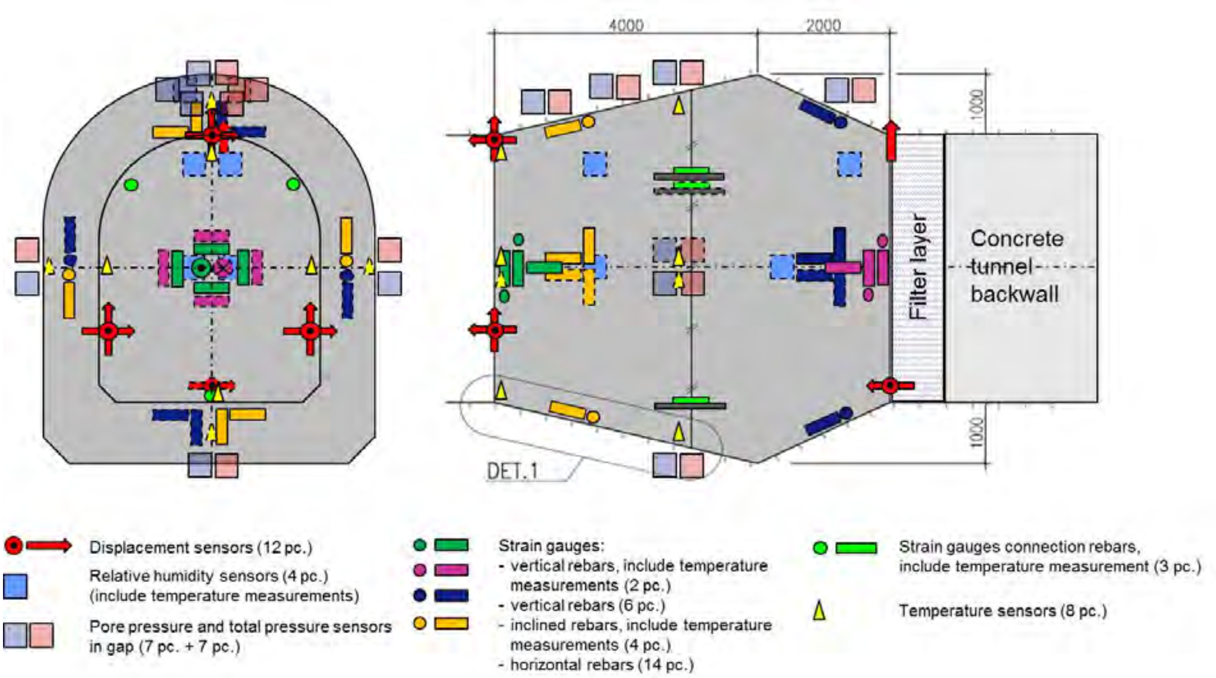

Fig. 7. Example of POPLU sensor locations for concrete instrumentation

Monitoring the Performance

Great emphasis is put on planning the monitoring needs and techniques during the accelerated loading of the plugs, to ensure optimal use of results for performance and safety assessments that can be collected, analyzed and used to forecast lifetime engineering. Part of the experimental planning is evaluating alternatives and verifying performance of alternative materials and their combinations to be used in the plug components.

DOMPLU and POPLU experiments have many common aspects despite their different structural and materials designs. Both of these Nordic plug experiments are located in crystalline rock type geological conditions and the plugs' functionality requirements are nearly identical. The plugs will have similar accelerated performance test durations and levels for evaluating the watertightness and mechanical integrity of the two alternative designs.

With the principal goal of monitoring water leakage though the plugs over time, a water collection system is installed downstream from each plug. The plugs are sheltered by a plastic sheet to create a tight atmosphere around the plug. Leakage water is collected by gravity to a suspended scale for on-line registration of the water-flow. The accelerated testing is achieved by using artificial pressurization with water behind the plug, and having incremental increases in pressurizing in steps over a one year period. The pressure is raised incrementally to 7 MPa for the actual tightness test and up to 10 MPa for a verifying strength test.

The monitoring of the DOMPLU experiment started in September 2013 (month 0) when the bentonite seal had been artificially wetted by flooding of the filter during the summer. When the drainage valves to the filter were closed, pressurization of the experiment started by the natural groundwater inflow, corresponding to about 100 kPa per week (month 1-2). From month 3, the pressurization system is operational, pumping in water for a faster pressure increase (about 250 kPa per week). At the end of month 3, the hydrostatic pressure had reached 1,1 MPa and the measured leakage rate past the plug was very low: 0.2 liters/hour. The leakage rate has been stable during the pressure increase, indicating a watertight function of the plug at prevailing pressure. The sensors are performing well (>95% are operational) and the monitoring is showing the expected trends. The swelling pressure of the bentonite seal is increasing slowly as expected. At the end of month 3 the measured swelling pressures in the bentonite seal were between 75-400 kPa. A fully watertight function of the seal is expected at about 500 kPa of swelling pressure. The total pressure is to be increased stepwise until 7 MPa is reached, holding this dimensioning pressure for some months. It is expected that the POPLU monitoring program will run from June 2014 through 2016.

The results of the monitoring program are used to evaluate the performance and compliance of the plugs to the requirements and safety functions of the plugs. At the conclusion of the pressurization test approximately two years after construction, monitoring data will be compared with the initial modeling forecasts. The structural and material reference designs as well as plug requirements may then be updated based on the experimental results obtained in both POPLU and DOMPLU. Sensitivity analysis is carried out, uncertainties and risks are also evaluated over the course of the project and the will be based on monitoring and model verification. These actions through these demonstrations allow for a higher level of confidence in the stakeholders by ensuring that future operation of repositories will meet the design and expectations on safety. In the future, the level of in-situ monitoring can be reduced based on the increased confidence gained by these early demonstrations.

CONCLUSIONS

The DOPAS -project has been running for nearly half of its four year duration and already major progress has been made. The achievements include for the concepts for deposition tunnel end plugs in Finland and Sweden that they have been designed and modeled based on the expected performance of over a 100 year plug lifetime. The two experiments of POPLU and DOMPLU are in similar types of geological environments, i.e. crystalline rock supporting the KBS-3V deposition concept. The plugs have been designed with similar performance requirements and thus will have similar accelerated loading and monitoring activities so that their performance can be compared.

New low-pH concrete materials have been developed and demonstrated for workability and durability properties. Elaborate monitoring systems have been designed and over 100 sensors have been installed in Äspö HRL at Sweden's on-going dome-plug experiment, which was built in early 2013. The POPLU wedge plug experiment in ONKALO; Finland is schedule to be in place in early 2014 in a drier environment compared with Äspö HRL and instrumented with about 80 sensors. The monitoring systems focus on the leakage and displacements within the plug, but are also used to track the evolution of the plugs and backfill evolution over time as a result of accelerated performance simulation, which is achieved through pressurization in steps. The expected mechanical and hydraulic performances of the plugs have been modeled during the design stage and the experimental results will be used to update the models, requirements and the designs.

All these actions carried out in the experiments of the DOPAS project support long-term safety demands and improving stakeholder confidence in repository operation. The plug performance experiences are collected and compared jointly between the two countries, and will be reported in 2015-16 within the DOPAS project.

The project outcomes can be used by the international waste management community to enhance the safety and especially location selection, design, construction and quality management practices for future tunnel plugs and seals used in various types of repository configurations and geological conditions.

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ACKNOWLEDGEMENT

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EU-Projekt DOPAS

(Full Scale **D**emonstration **o**f **P**lugs **a**nd **S**eals)

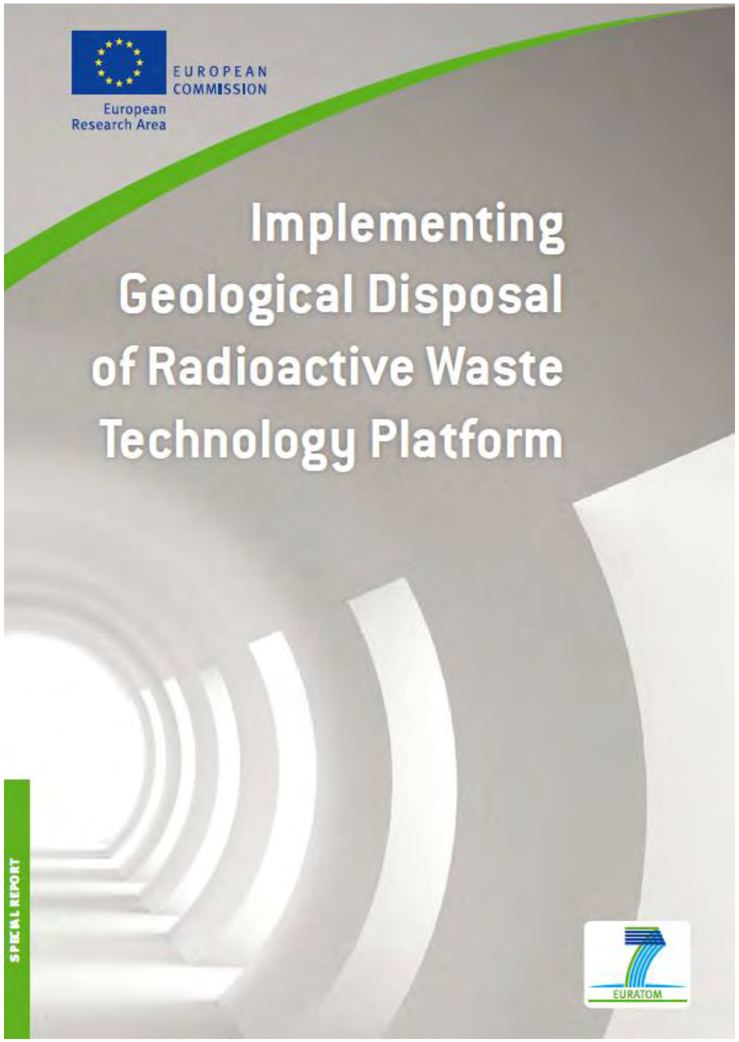
Deutsche Beiträge und ihre Verknüpfung mit dem Projekt ELSA

Oliver Czaikowski, Tilmann Rothfuchs
GRS-Bereich Endlagersicherheitsforschung

ELSA-Workshop 19. September 2012, Peine

DOPAS ist ein EU-Projekt von 10 IGD-TP-Mitgliedern

(POSIVA, ANDRA, **DBE TEC**, **GRS**, Nagra, NDA, Rawra, SKB, CTU, NRG)



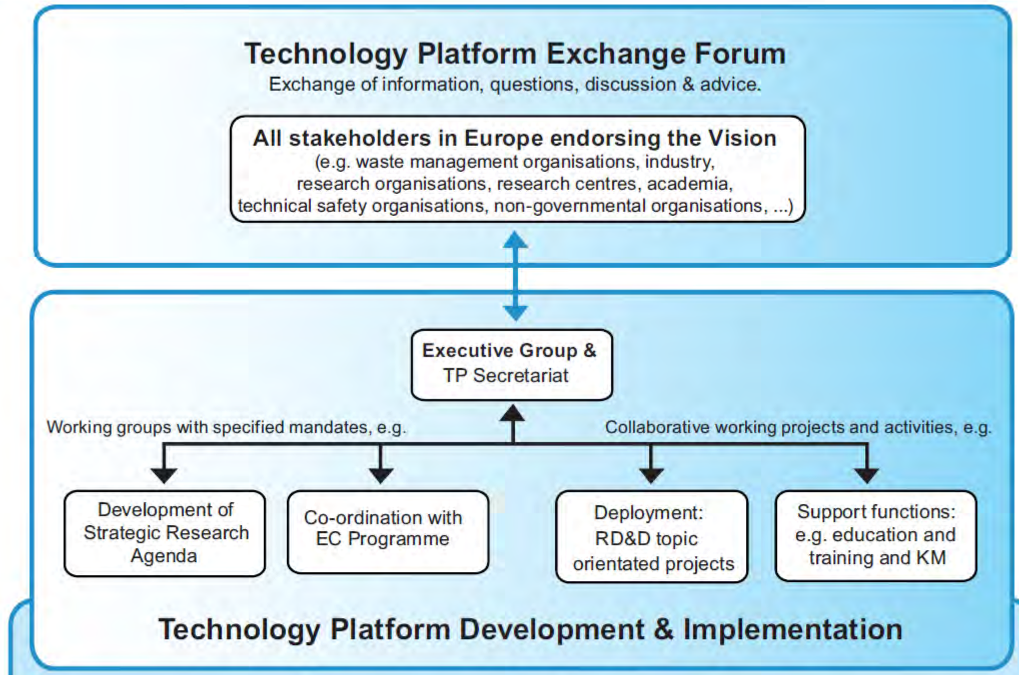


Figure 3. The organisation of the technology platform based on the CARD recommendation.

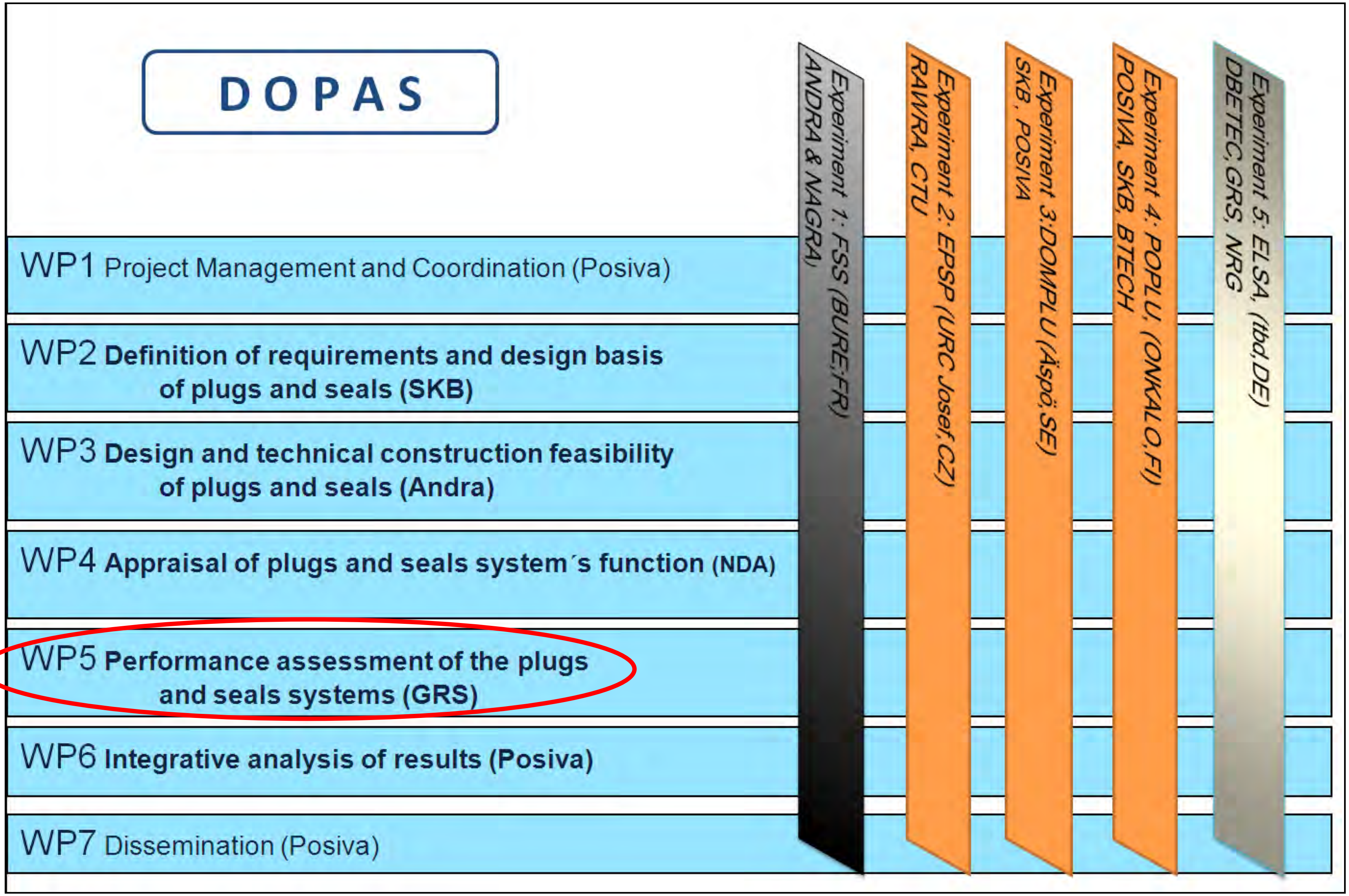
Strategic Research Agenda der IGD-TP

Key Topics of the Strategic Research Agenda
Key Topic 1: Safety case
Key Topic 2: Waste forms and their behaviour

Key Topic 3: Technical feasibility and long-term performance of repository components
Plugging and sealing (Topic 6)

Topic 4: Development strategy of the repository
Topic 5: Safety of construction and operations
Topic 6: Monitoring
Topic 7: Governance and Stakeholder

DOPAS Projekt-Struktur mit 5 Demonstrationsversuchen



DOPAS Experiments (DoW, 20/08/2012)

Experiment 1: FSS 1 (Full Scale Sealing)

Andra will be responsible for the Full Scale Seal (FSS) project which will be built inside a preexisting drift / tunnel or (more likely) inside a drift model fabricated for the purpose at ***URL Bure***.

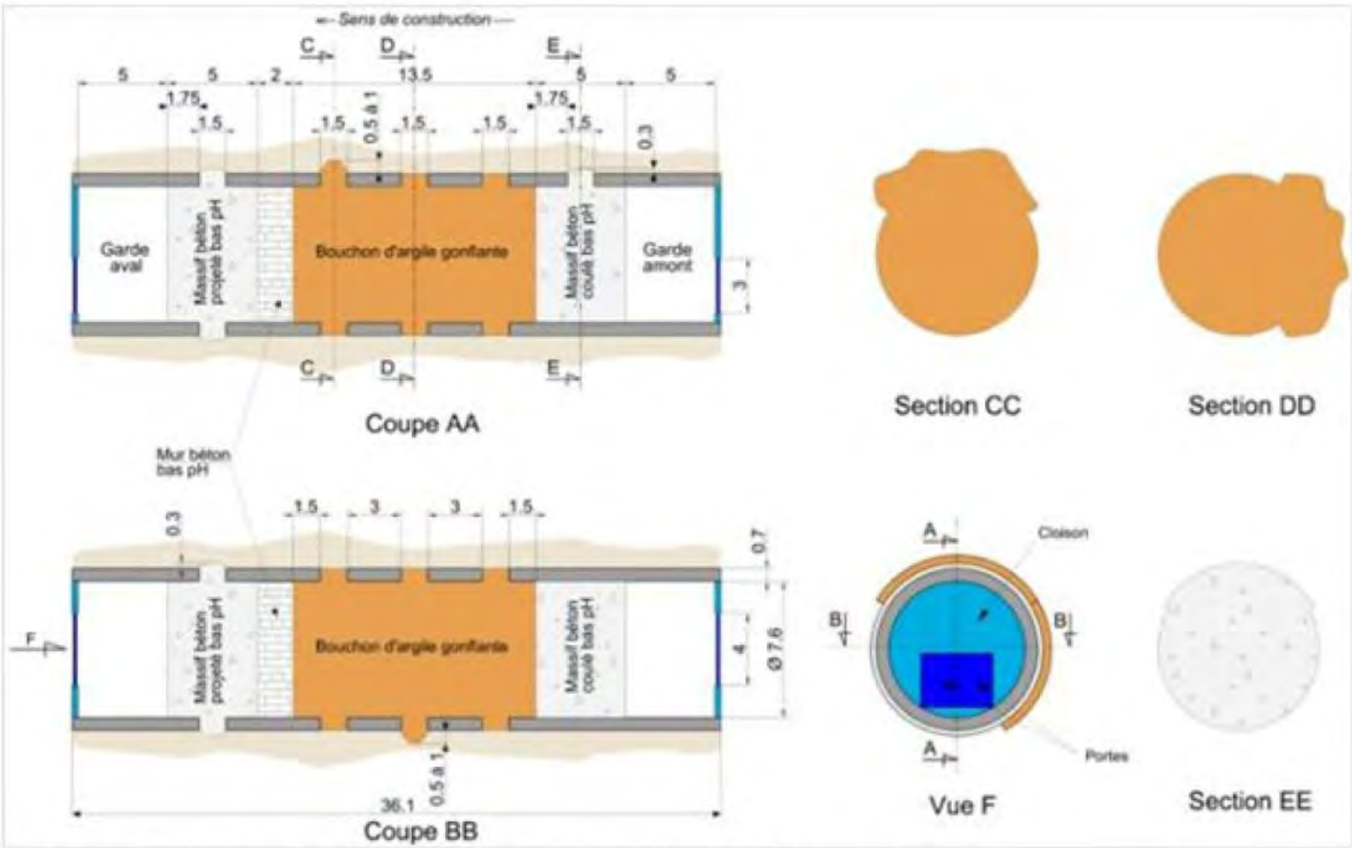


 Figure 1-6. The principal layout of the Full scale seal test

DOPAS Experiments (DoW, 20/08/2012)

Experiment 2: EPSP (Experimental Pressure and Sealing Plug)

CTU together with RAWRA is responsible for the demonstration test performed in ***Josef underground facilities***. The Experimental Pressure and Sealing Plug (EPSP) Demonstrator will be constructed and operated in a small niche. In the Czech reference concept, bentonite from Czech deposits and new developed low pH–concretes are foreseen

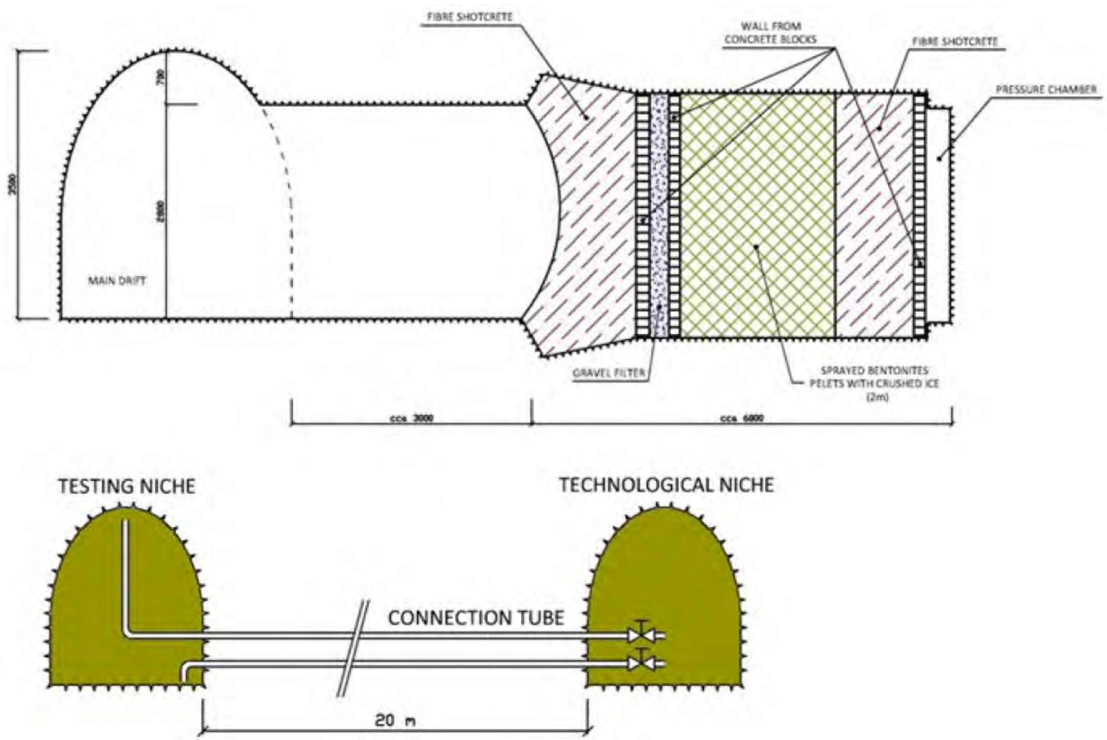


Figure 1-7. Schematic drawing of the Experimental Pressure and Sealing Plug

DOPAS Experiments (DoW, 20/08/2012)

Experiment 3: DOMPLU (full-scale DOMe shaped PLUg)

The design of the Swedish full-scale deposition tunnel end plug test was completed during 2011. In 2012 detailed activity plans are being compiled to be able to install the plug in a controlled manner. The SKB full-scale dome shaped plug demonstration (DOMPLU) with sealing parts will take place at ***Äspö Hard Rock Laboratory*** (Oskarshamn, Sweden).

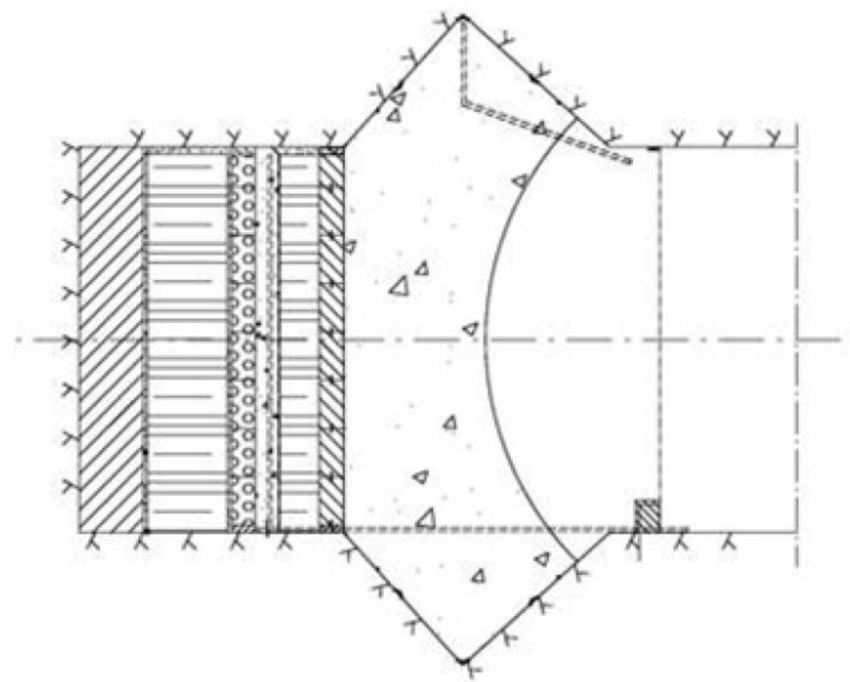


Figure 1-8. A design drawing of the full-scale demonstration DOMPLU

DOPAS Experiments (DoW, 20/08/2012)

Experiment 4: POPLU (POsiva PLUg)

This field work is a full-scale deposition tunnel plug experiment (POPLU) at the ***ONKALO*** demonstration area including a new and innovative way of excavation the plug location and installing a monitoring system for studying the plug performance in addition to the normal construction work.

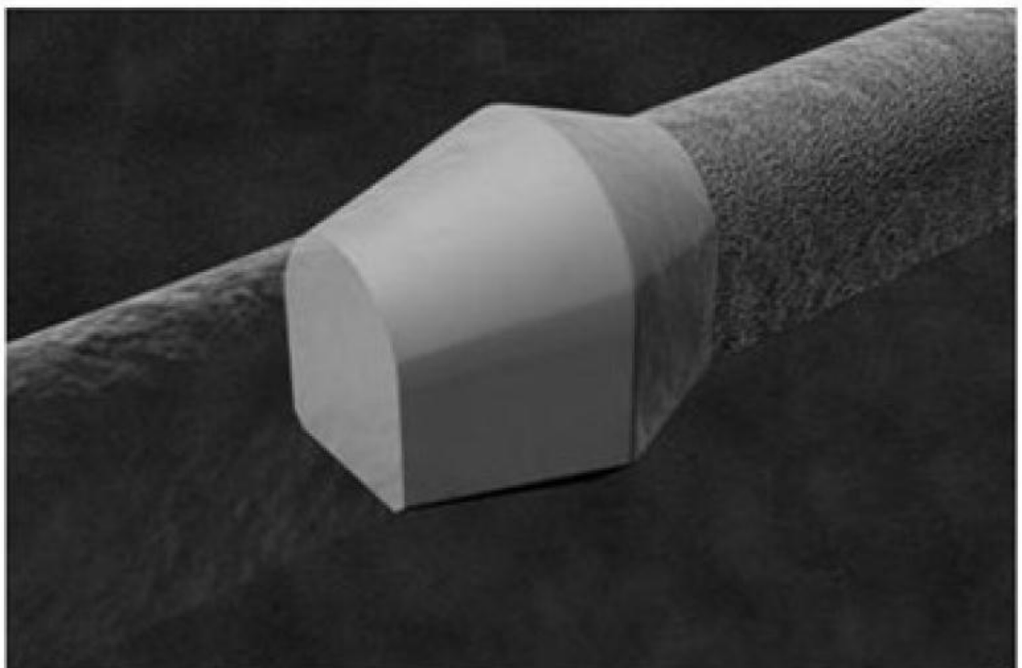


Figure 1-9. Posiva plug (POPLU), which will be designed more detail within WP3 Task 1.

DOPAS Experiments

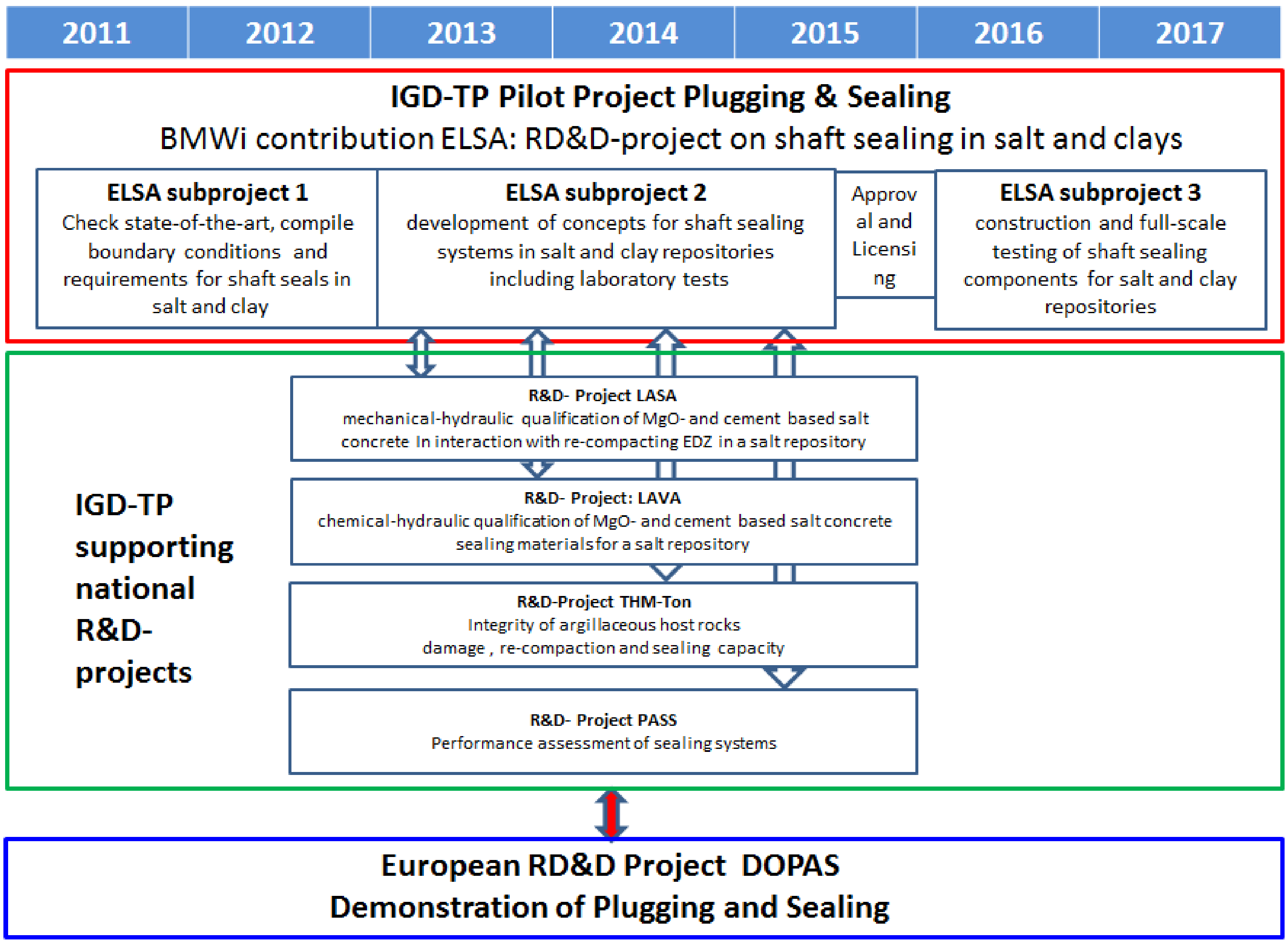
Experiment 5: ELSA

The German Ministry of Economics and Technology (BMWi) contracted DBE TEC and GRS to pursue R&D-works for the development of shaft sealing concepts and for the qualification of sealing materials and elements for the safe closure of repositories in geological salt and clay formations containing heat generating high-level radioactive waste (HLW)

The supporting R&D projects (co-financed by BMWi and EC)

- **LASA** focusing on *mechanical-hydraulic* properties of candidate seal materials (GRS)
- **LAVA** focusing on *chemical-hydraulic* properties of candidate seal materials (GRS)
- **THM-Ton** focusing on the sealing capacity of argillaceous host rocks (GRS)
- **PASS** focusing on model improvement and integrated long-term performance assessment with associated uncertainty and sensitivity analysis (GRS, DBE TEC, NRG)

Deutsche Beiträge zum Projekt DOPAS und ihre Verknüpfung mit dem Projekt ELSA



Deutsche Beiträge zum Projekt DOPAS und ihre Verknüpfung mit dem Projekt ELSA

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ELSA subproject 2
development of concepts for shaft sealing systems in salt and clay repositories including laboratory tests

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R&D- Project LASA
mechanical-hydraulic qualification of MgO- and cement based salt concrete In interaction with re-compacting EDZ in a salt repository

R&D- Project: LAVA
chemical-hydraulic qualification of MgO- and cement based salt concrete sealing materials for a salt repository

R&D-Project THM-Ton
Integrity of argillaceous host rocks
damage , re-compaction and sealing capacity

R&D- Project PASS
Performance assessment of sealing systems

Requirements defined by current R&D work (Gorleben - Preliminary Safety Analysis)

Material properties (**THM**)
⇒ Salt concrete
⇒ EDZ

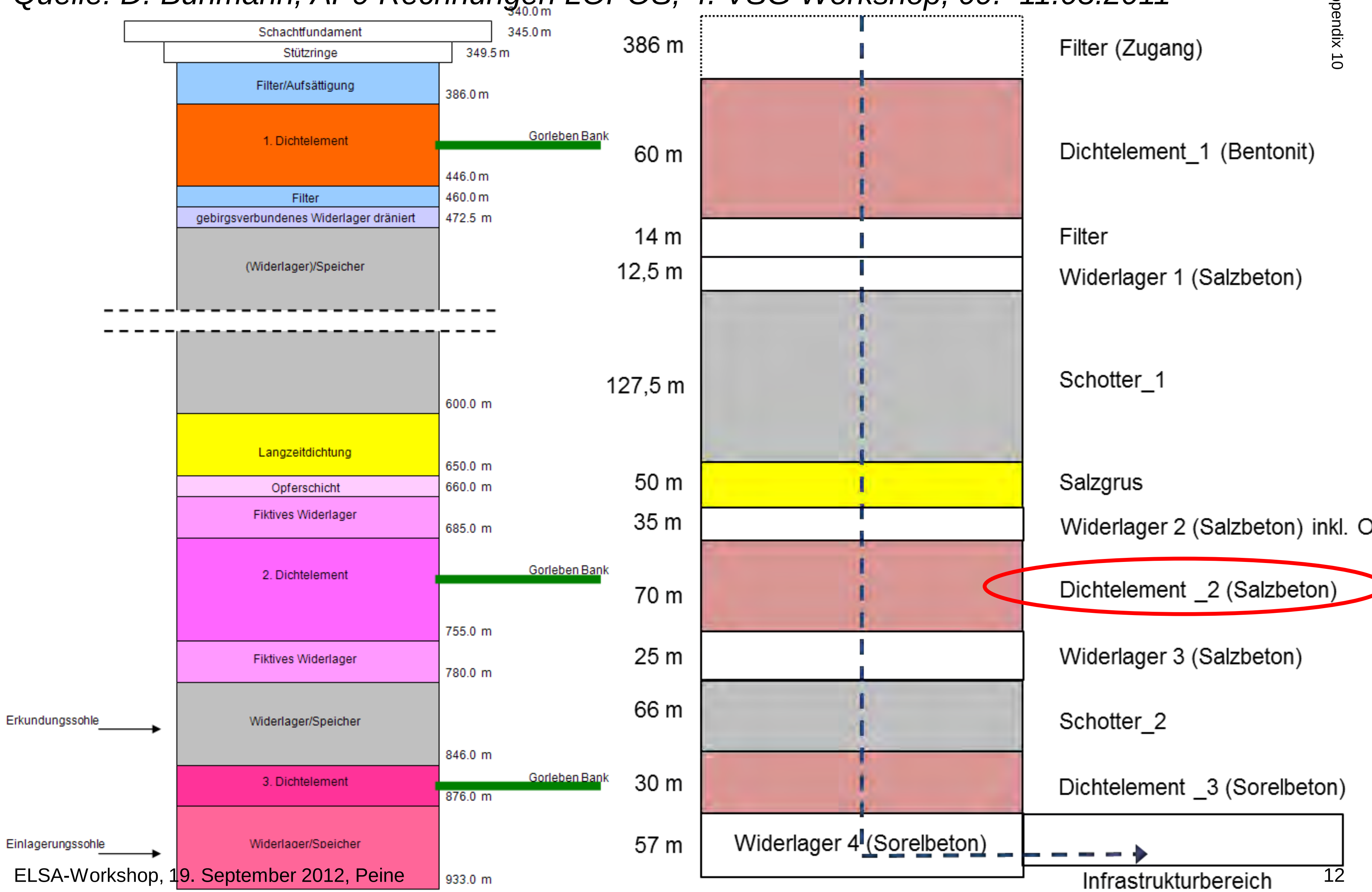
Material properties (**CH**)
⇒ Salt concrete

Material properties (**THM**)
⇒ EDZ
⇒ Backfill

System behaviour
⇒ Process-level Modelling
⇒ TSPA-level Modelling

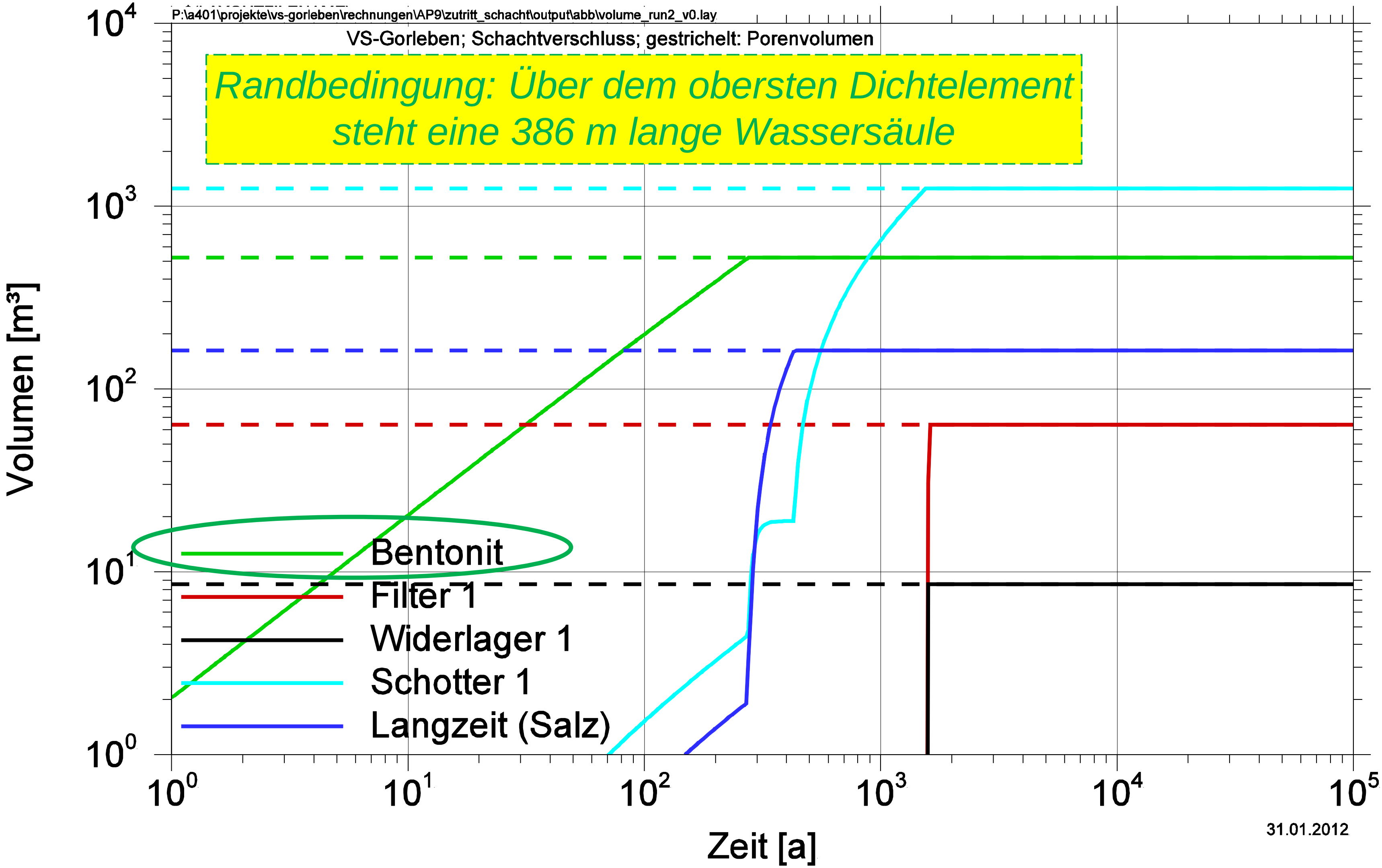
Auslegungsrechnung mit LOPOS für Verschlusselemente (Normalentwicklung)

Quelle: D. Buhmann, AP9 Rechnungen LOPOS, 4. VSG Workshop, 09.–11.05.2011



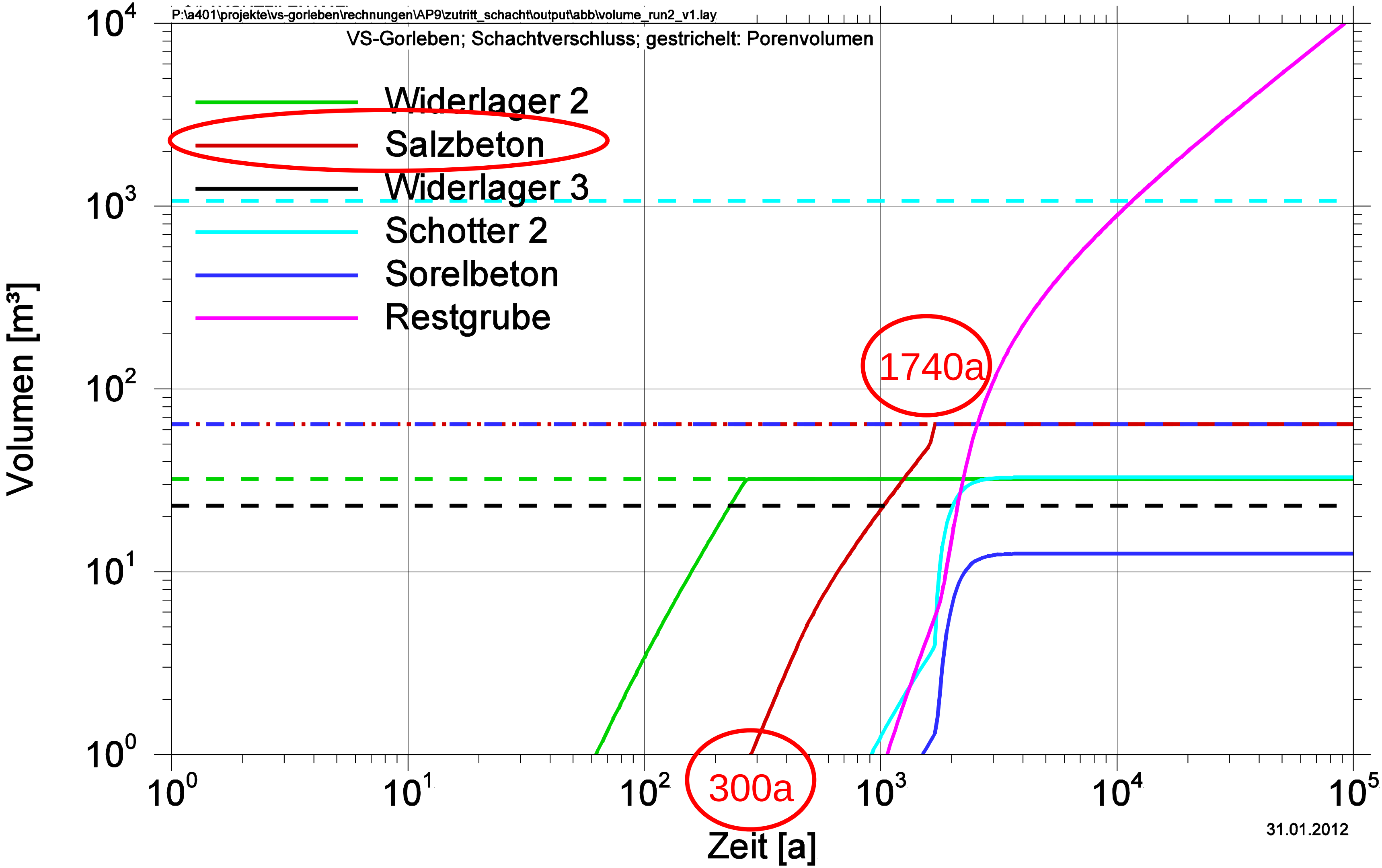
Schachtverschluss intakt: Lösungsmengen im oberen Bereich

Quelle: D. Buhmann, AP9 Rechnungen LOPOS, 4. VSG Workshop, 09.–11.05.2011



Schachtverschluss intakt: Lösungsmengen im unteren Bereich

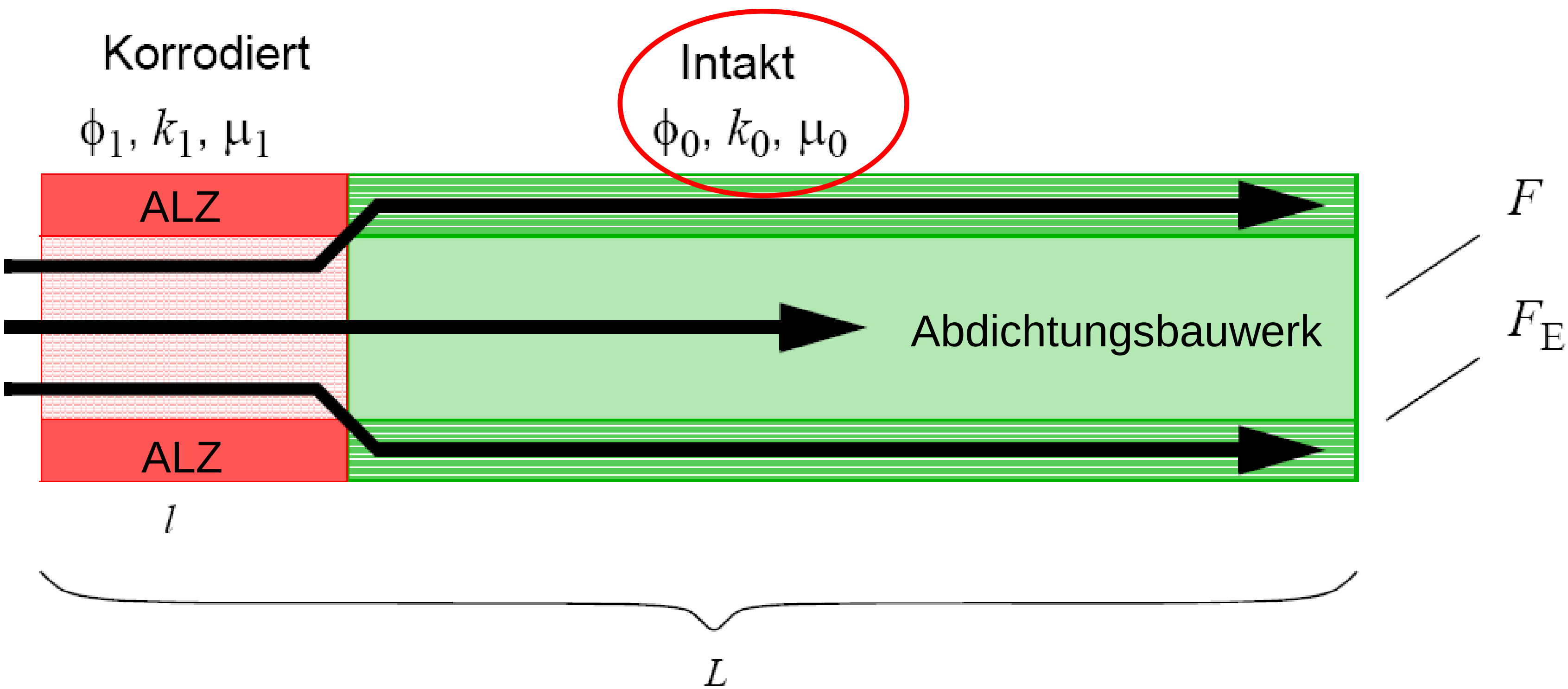
Quelle: D. Buhmann, AP9 Rechnungen LOPOS, 4. VSG Workshop, 09.–11.05.2011



Darstellung zum analytischen Modell der Korrosion einer Abdichtung mit ALZ

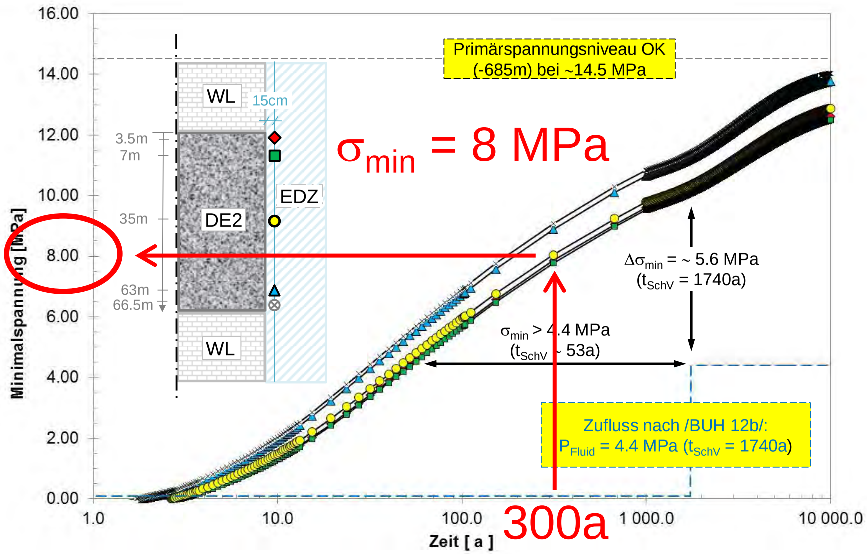
Quelle: GRS-A-3454 (Sicherheitsanalyse ERAM)

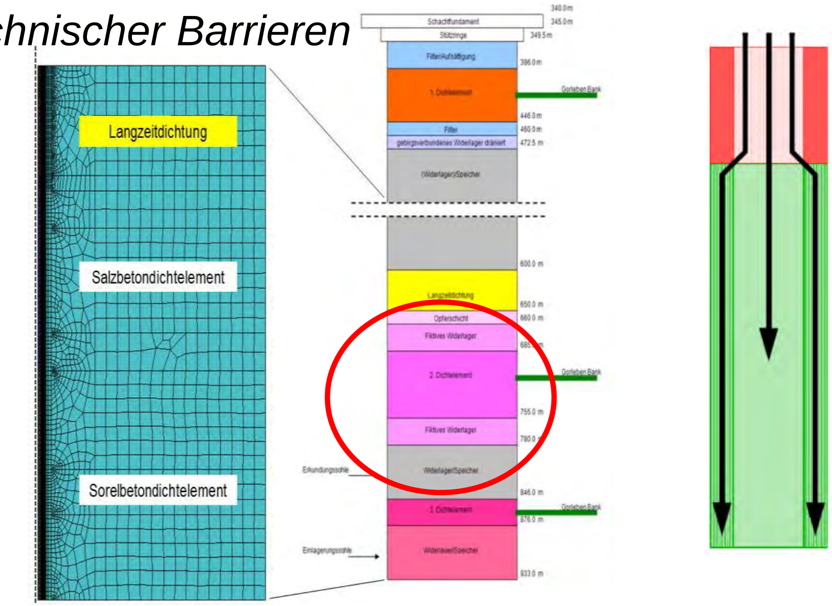
⇒ Materialparameter der ALZ nach 300a ?

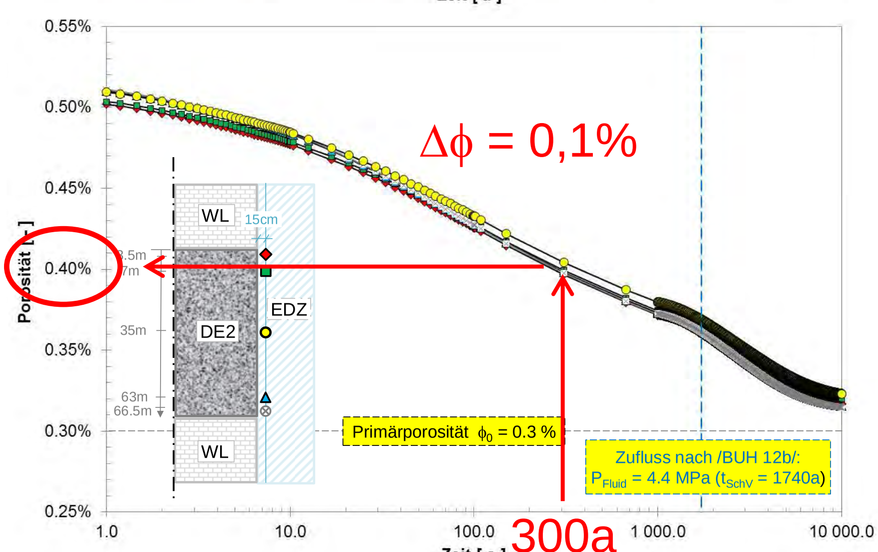


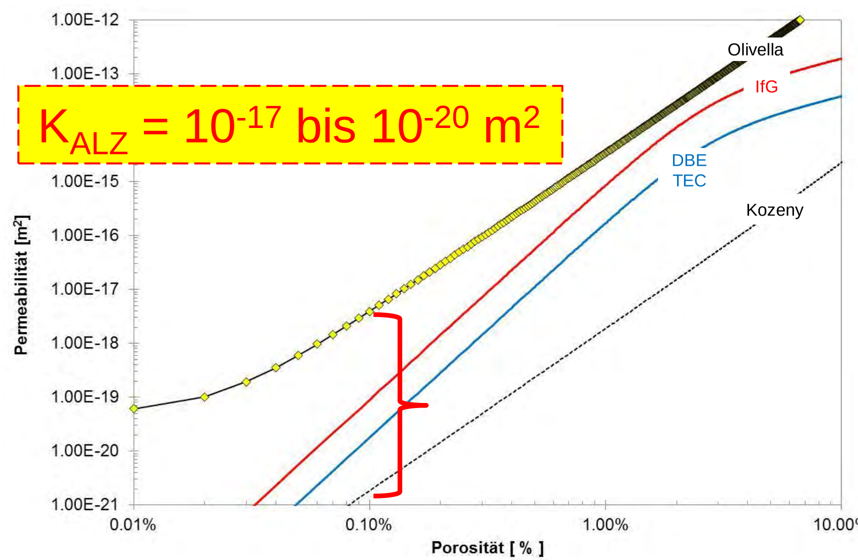
Ergebnisse zur Porositätsentwicklung in der ALZ im Bereich des 2.Dichtelements

Quelle: VSG, ASB AP9.2 Teil B: Integrität geotechnischer Barrieren





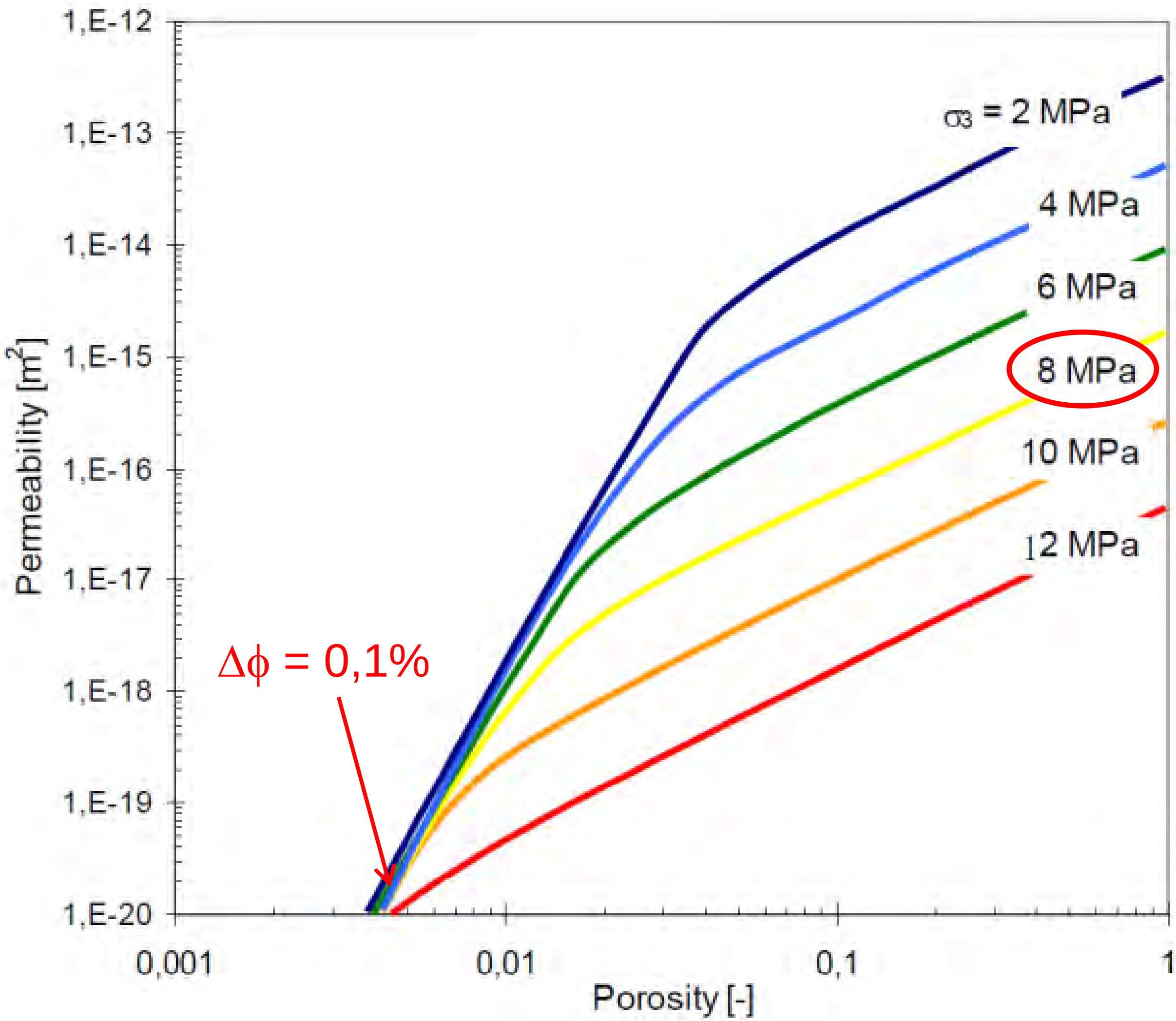




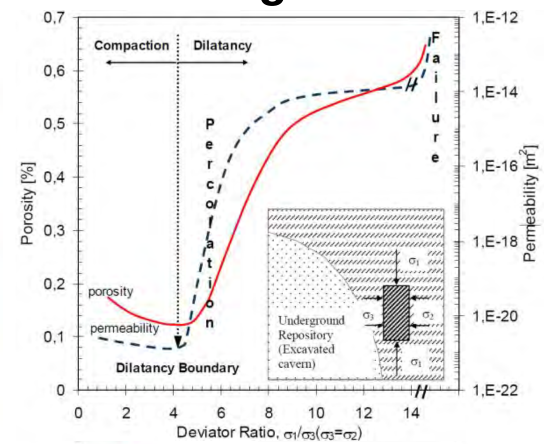
$\Delta\phi$ = 0,1%

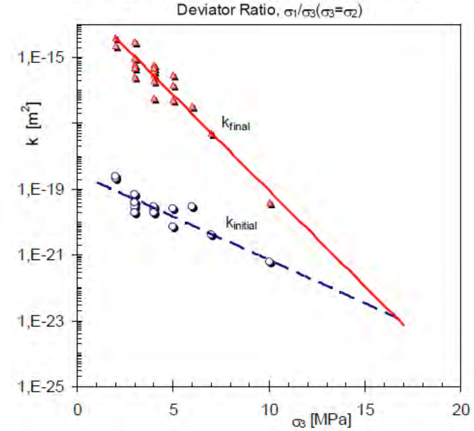
Ansätze zur Beschreibung der Porositäts-Permeabilitätsbeziehung

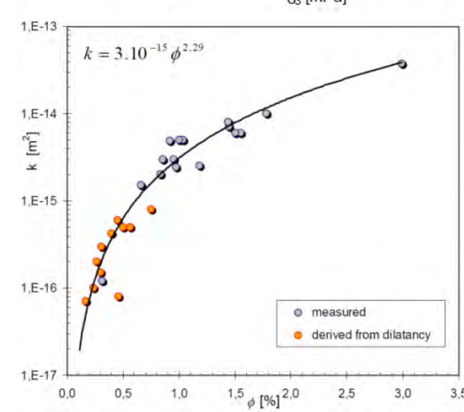
Quelle: Ergebnisse der Literaturstudie im Rahmen VIRTUS



Porositäts-Permeabilitäts-Beziehung mit Minimal-spannungsabhängigkeit /ALK 08/, /POP 07/







Beurteilung des EDZ-Einflusses auf das Verschlusssystem auf der Grundlage von abgesicherten Daten

Für die Beurteilung des Rückbildungsverhaltens der EDZ im Bereich von Schacht- oder auch Streckenverschlüssen sind im Salz drei Zustände zu betrachten.

(1) Die Auflockerungszone hat keinen Kontakt mit feuchten Grubenwettern oder zutretender Lauge (trockener Zustand).

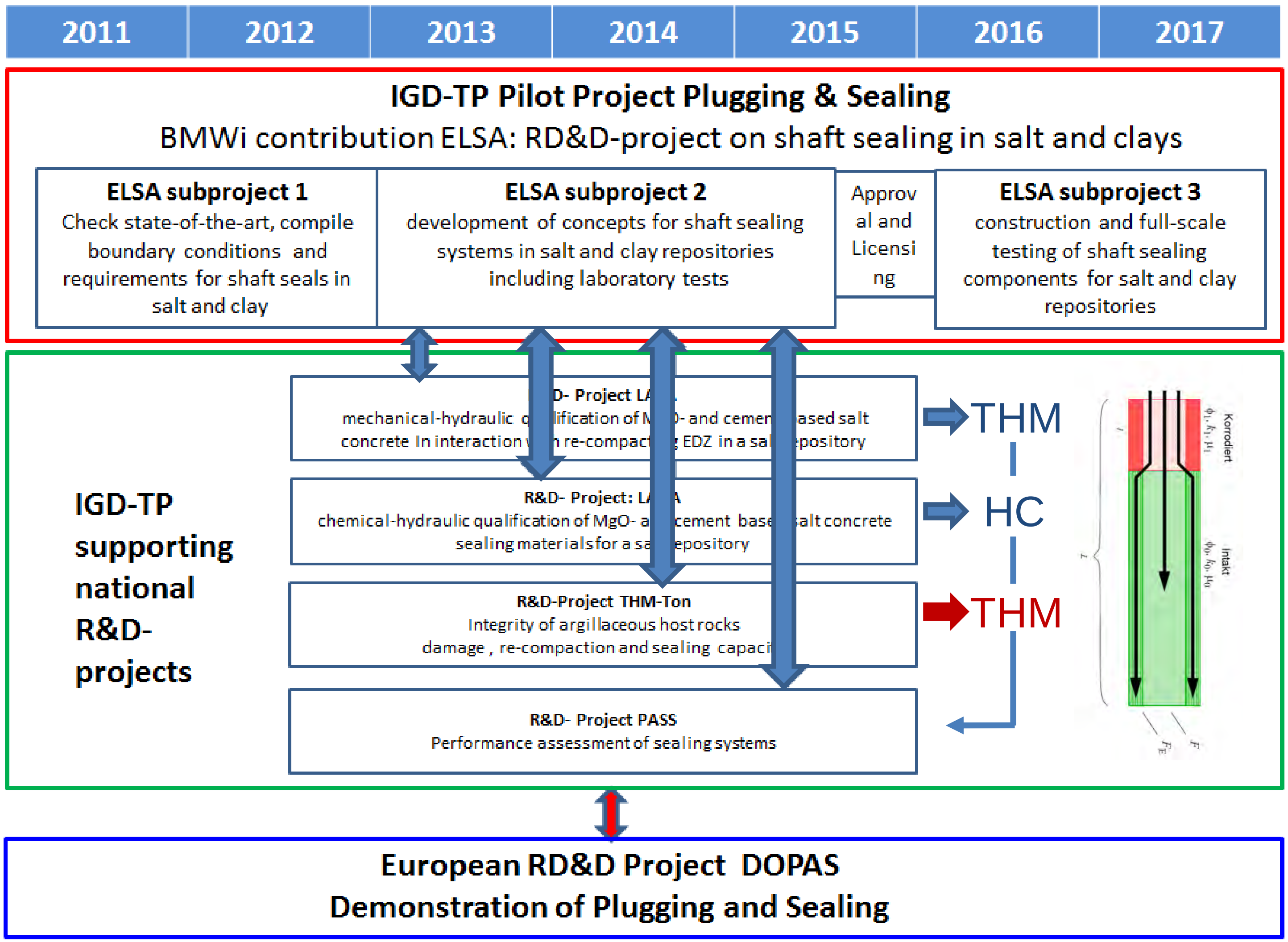
- *Verbundprojekt Stoffmodellvergleich FKZ 02 E 10810 bis FKZ 02 E 10860 (lfd. Vorhaben)*
- *TIMODAZ-THERESA Workshop, Luxembourg, 29.9-1.10.2009,*
- *THERESA Subproject MOLDAU Final Report, FKZ 02E10236, GRS-262, 2010*
- *Workshop zu Verschlusssystemen in einem Endlager für wärmeentwickelnde Abfälle in Salzformationen, GRS, Braunschweig, 24.-25. August 2010*
- *Mechanical Behavior of Salt VII. Proceedings of the 7th Conference, Paris, 16-19. April 2012,*

(2) Die Auflockerungszone ist feuchten Grubenwettern oder einem Laugenzutritt ausgesetzt und es kommt zur Teilsättigung des Porenraums.

(3) Durch zutretende Lauge ist die Auflockerungszone aufgesättigt.

Während zu (1) umfangreiche nationale Arbeiten durchgeführt worden sind, sind zu (2) und (3) weitere laborative Arbeiten mit expliziter **Berücksichtigung fluider Phasen zur Ermittlung konsistenter Materialparameter** zwingend erforderlich.

Deutsche Beiträge zum Projekt DOPAS und ihre Verknüpfung mit dem Projekt ELSA



UJV Rez Research activities in the field of deep geological disposal: from lab to the field.

Václava Havlová

Dept. Of Fuel Cycle Chemistry,
ÚJV Řež, a.s.

Regional Seminar 2013, Senec

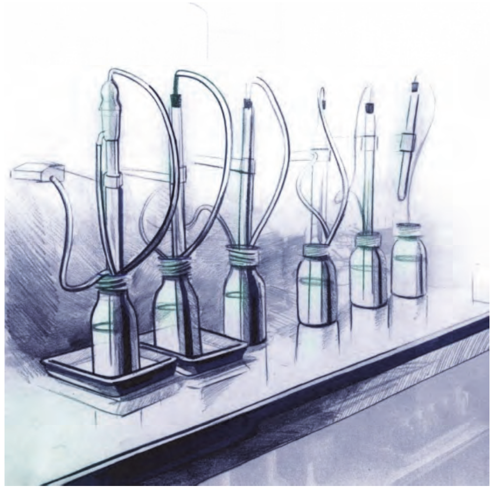
Presentation outline

1. **Fuel Cycle and Waste Management Division**
2. **Fuel Cycle Chemistry Dept.: Research**
3. **Laboratory Research**
4. **In-situ Research**
5. **Examples of projects**
   - Corrosion study – lab&in-situ
   - Plug&Seal project DOPAS

Chemistry of Fuel Cycle and Waste Management Division

- **Radioactive waste management**
  - Services and technologies of processing, treatment and conditioning of radioactive waste
  - Radiochemical analyses, characterization of radioactive waste, radiation monitoring
  - Transport of spent nuclear fuel
- **Research and engineering support to the Deep Geological Disposal Project and for L&ILW Repositories**
  - Barriers, safety assessment, WAC development, design, monitoring
- **Decommissioning of nuclear facilities, fragmentation and decontamination**

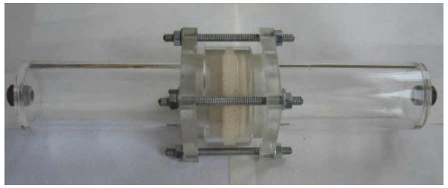
Department of Fuel Cycle Chemistry

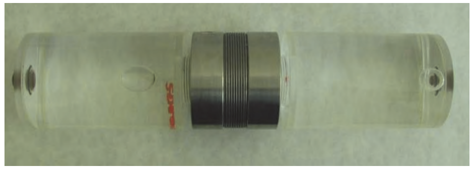


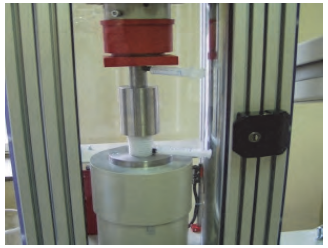
Research and engineering support to the Deep Geological Disposal Project and for L&ILW Repositories

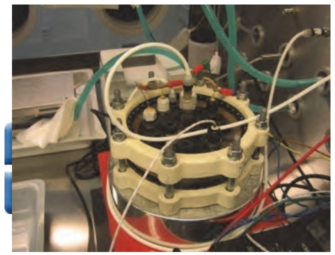
- Evaluation of migration properties of the rock environment, laboratory and in-situ experiments
- Evaluation of migration properties of materials of near field interactions and research of processes, laboratory and in-situ experiments
- Evaluation of the degradation degree of engineering barriers of radioactive waste repositories and research of processes
- Safety analyses and modelling
- Analyses of new nuclear fuel cycles
- Public communication on acceptability of radioactive waste repositorie
- Use of nanomaterials for radionuclide retention
- CO_2 storage

Department of Fuel Cycle Chemistry: lab experiments





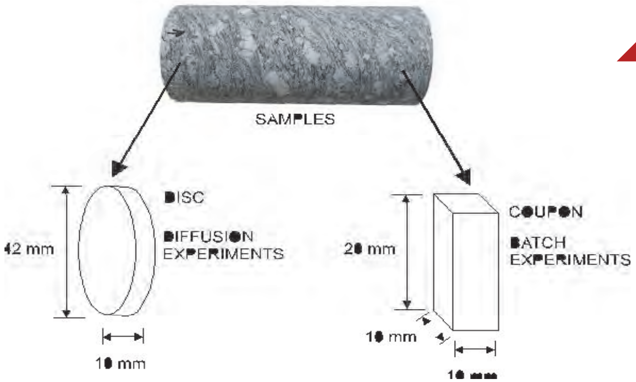


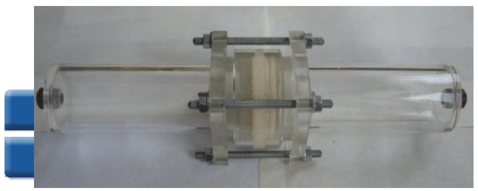


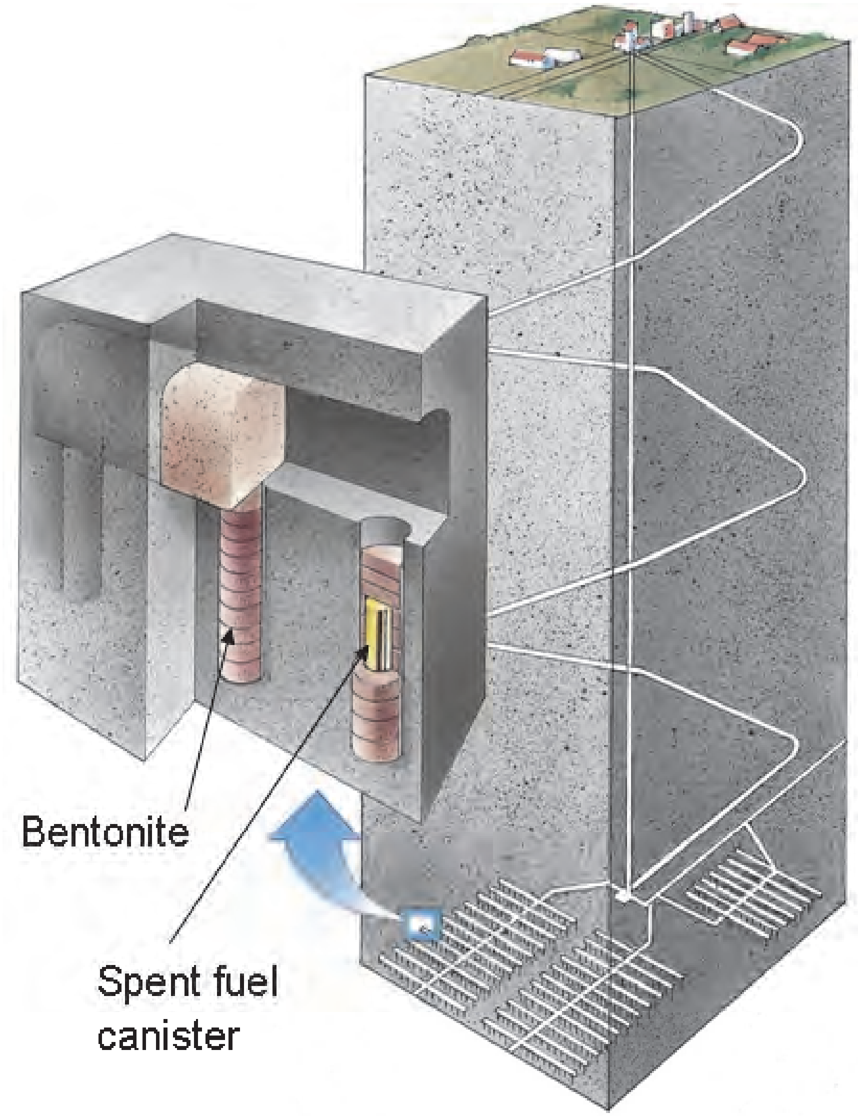
Wide range of laboratory experiments

- Batch sorption experiments (granite, bentonite)
- Diffusion experiments (granite, bentonite)
- Electromigration experiments (granite)
- Gas evolution (H_2 ,due to container corrosion)
- Canister material corrosion (including increased temperature)
- Engineered material and granite properties (porosity, hydraulic permeability, strength)
- Low pH cements
- Chemical evolution of the system (bentonite pore water development; Material interaction (steel/bentonite etc.)
- Bentonite colloid formation and interaction with RN

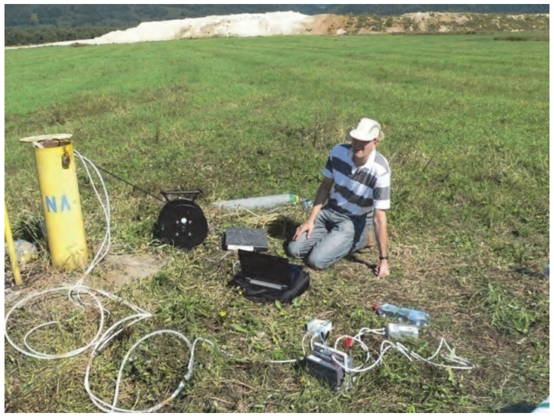
From lab to the real scale







Department of Fuel Cycle Chemistry: in-situ activities



Activities in the real scale

Underground research lab Josef

- - testing of in-situ methodologies and up-scaling (corrosion study, permability measurement, cement-bentonite-granite interaction)

Grimsel Test site

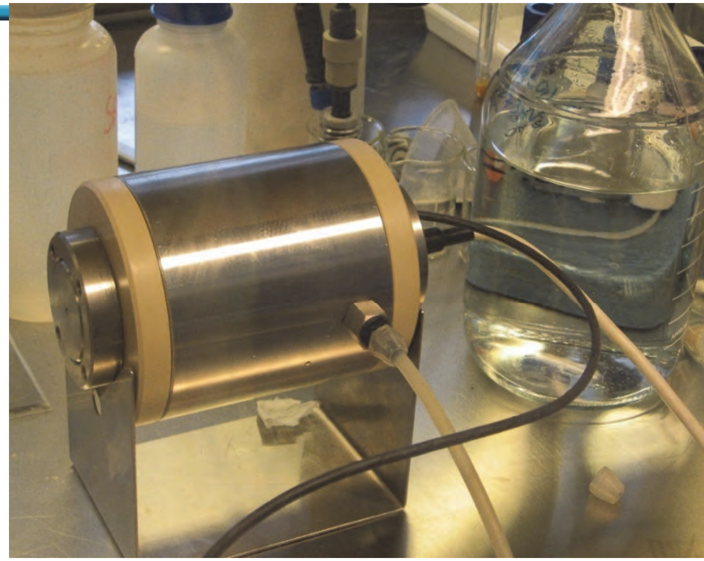
- Long term diffusion (LTD) experiment

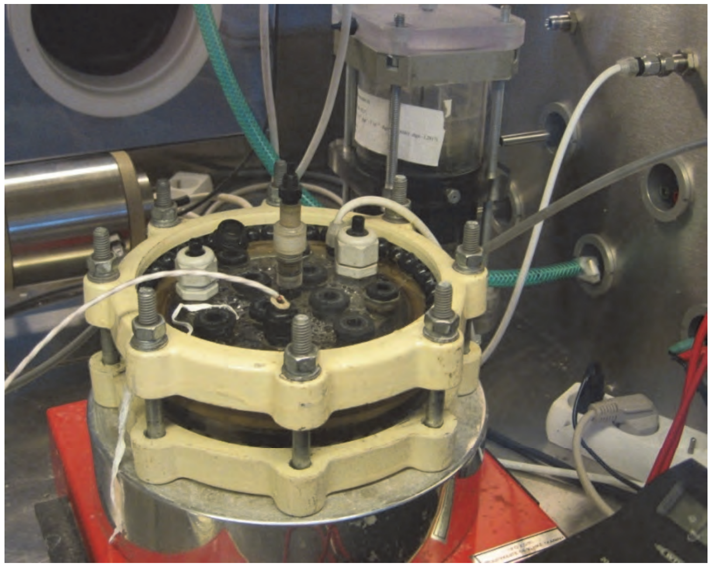
Ruprechtov natural analogue site (W Bohemia)

- - observation of U migration in the system clay – granite - groundwater

Corrosion study: from the lab to UEF Josef

- **Laboratory corrosion experiments**
  - Samples
    - Carbon steel
  - **The experimental conditions**
    - Anaerobic conditions ($O_2 < 0.1$ ppm)
      - – Glove box
    - **Temperature**
      - – 40 – 80 °C
    - **Duration of the experiments**
      - – Short-term experiment (mainly 30 days)
      - – Long-term experiments (1 year)
    - **Synthetic bentonite porewater**
      - – Corresponded to the composition of sodium bentonite Volclay



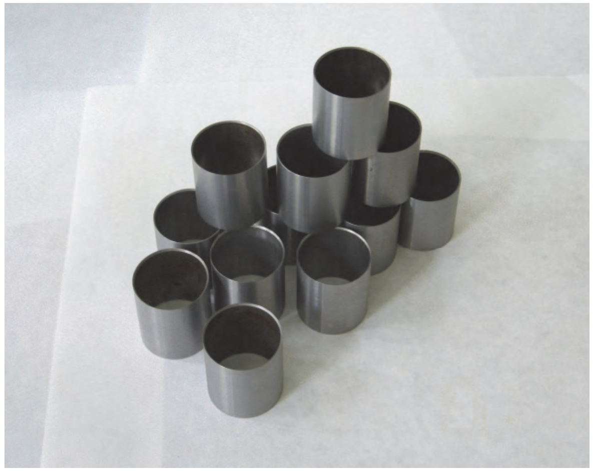


Corrosion study: laboratory experiments

- **The experimental conditions**
  - Corrosion experiment with bentonite
    - Czech bentonite B75
      - $\rho = 1.6$ g.cm^{-3}
  - Saturation of bentonite
    - Synthetic granitic water
    - Pressure 50-100 bar
- **Determination of corrosion rate**
  - Weight loss measurement
  - Hydrogen generation measurement
- **Determination of corrosion products**
  - Raman spectroscopy
  - X-ray diffraction
  - ESCA (Electron Spectroscopy for Chemical Analysis)

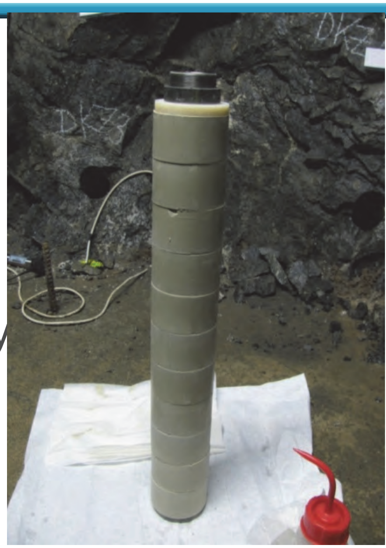
Corrosion study: in-situ experiment in UEF Josef

- **Corrosion experiment in host rock**
  - **Corrosion probe**
    - 10 carbon steel samples/probe
      - Samples on metal core
    - **Bentonite**
      - Czech bentonite B75
    - **Temperature**
      - 60, 70 and 80 °C
  - **Testing laboratory**
    - Josef Underground Laboratory
      - Testing laboratory
    - **Aerobic conditions**
    - Bore holes
      - ϕ 80 mm, 1m length



Corrosion study: in-situ experiment in UEF Josef

- **Corrosion probe**
  - Monitoring system
    - Temperature of the probe/samples is controlled by regulator
    - Data logger
      - – Measuring temperature
- **Removing the probes from boreholes**
  - Mechanical removing
    - Screw rod
  - Drilling
    - ϕ 150 mm



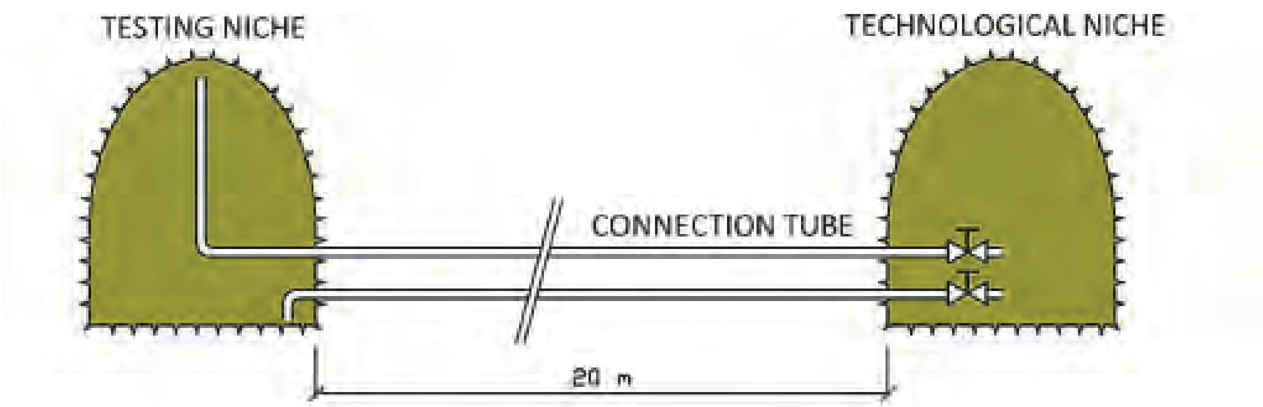
Activities within this study were funded within the frame of FR-TI1/362 project „Behaviour of barrier materials of deep geological repository under Czech conditions.“, funded by Czech Ministry of Trade and Industry.

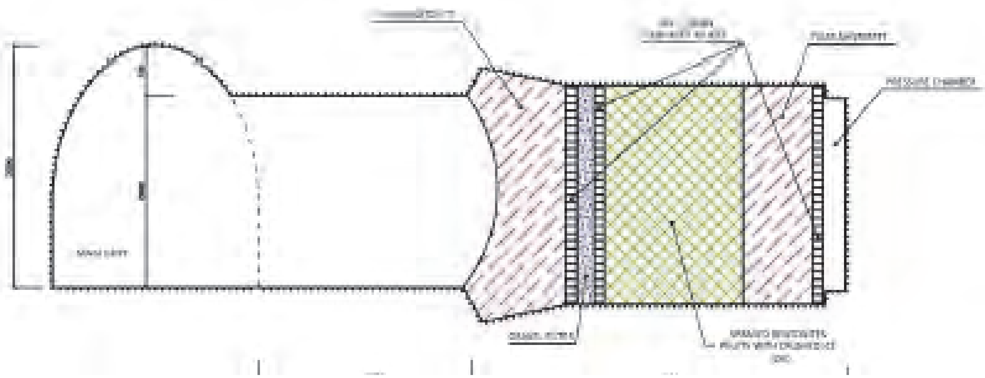
FP7 Plug&Seal Project
DOPAS

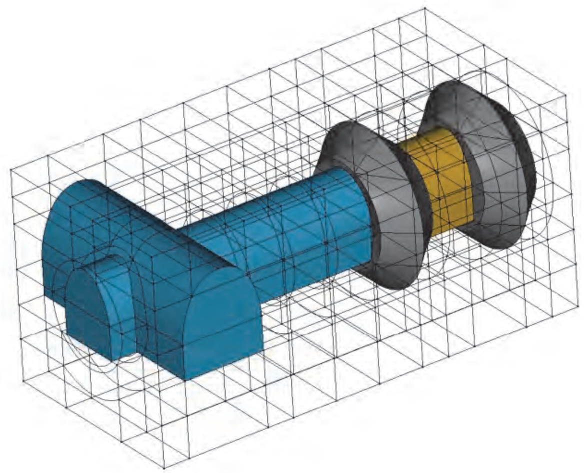
Experimental plug and seal plug (EPSP)
UEF Josef

CTU, RAWRA, UJV Rez, a.s.

EPSP experiment in Josef gallery



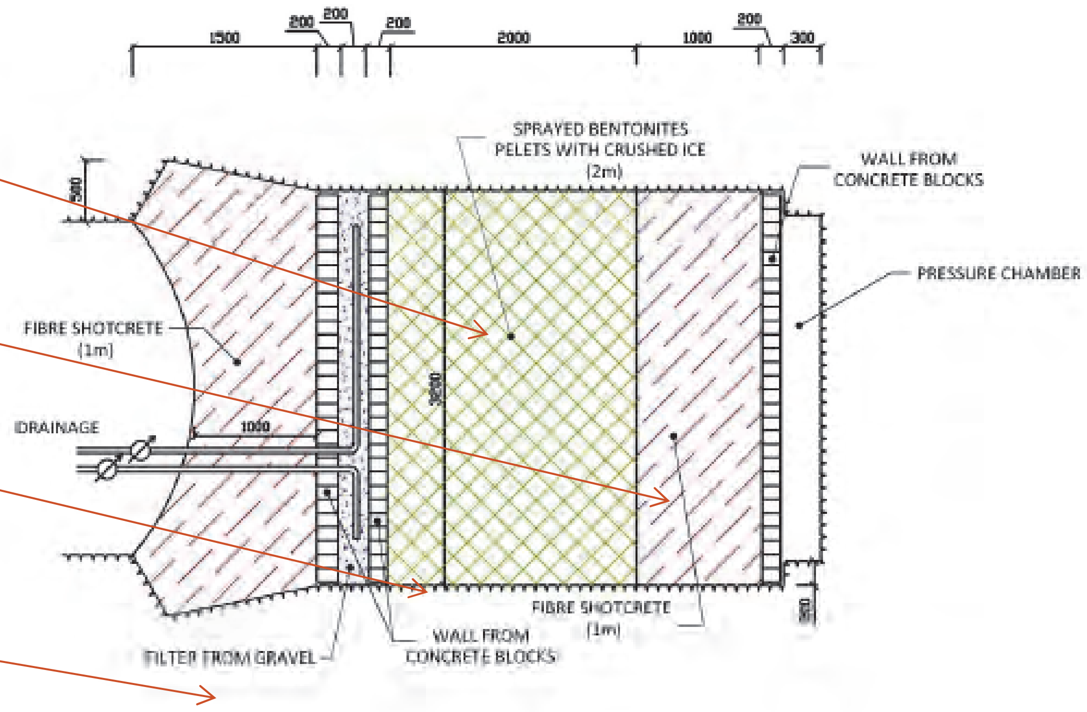




Design Basis

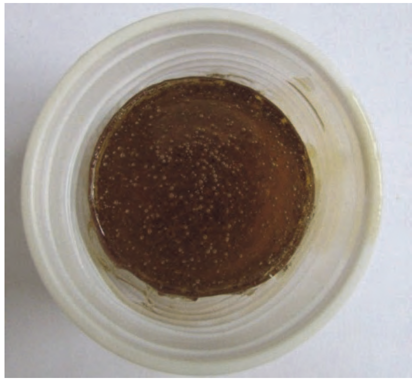
- Pressure: 7MPa
- Temperature up to 90°C
- Life time minimum 150 years
- Use Czech material (bentonite B75 Rokle)

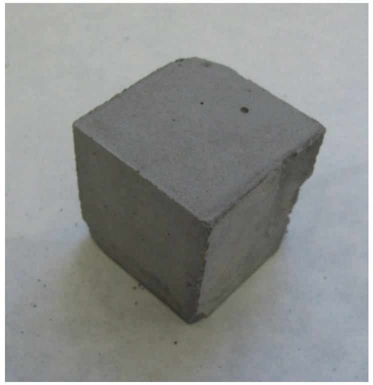
- Czech Ca/Mg bentonite (B75 type)
- Low Ph cement
- Czech polymer resin
- Rock



Lab experiments, supporting building and performance of the plug + modelling

1. **Confirmation of material properties** to be used for plug construction
(grouting, concrete, bentonite)

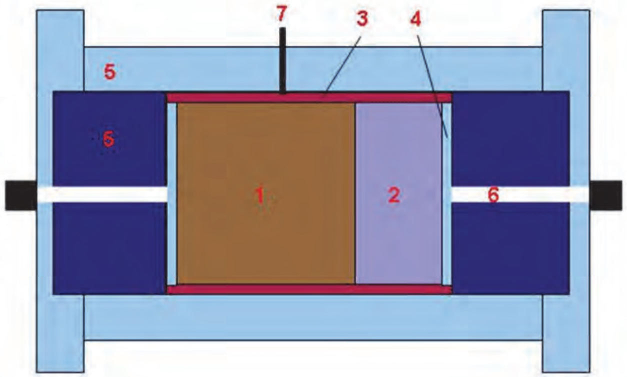




2. **Lab investigations of basic parameters necessary for mathematical modelling** of the plug behaviour (permeability, diffusivity, porosity, etc.)

Lab experiments, enabling study of plug performance and material interactions

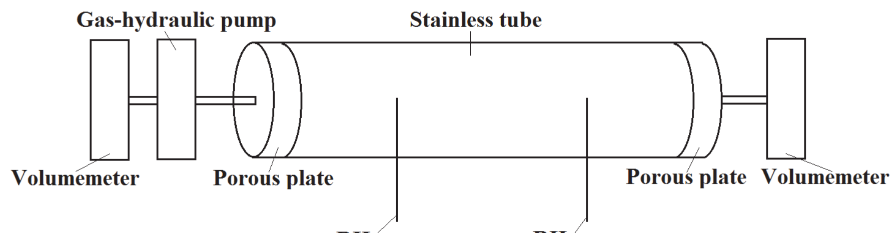
3. **Lab investigations of material behaviour** and interactions important for L-T performance of the plug



Schematic view of the physical model for the verification of the long-term stability of the interfaces. 1: Compacted bentonite/concrete, 2: Grouted granite, 3: Sealing, 4: Filter, 5: Supporting elements, 6: Water saturation input/output, 7: Pressure sensor

4. **Physical model of field scale experiment** (e.g. the small scale interface models)

Schematic view of the physical model for bentonite saturation testing



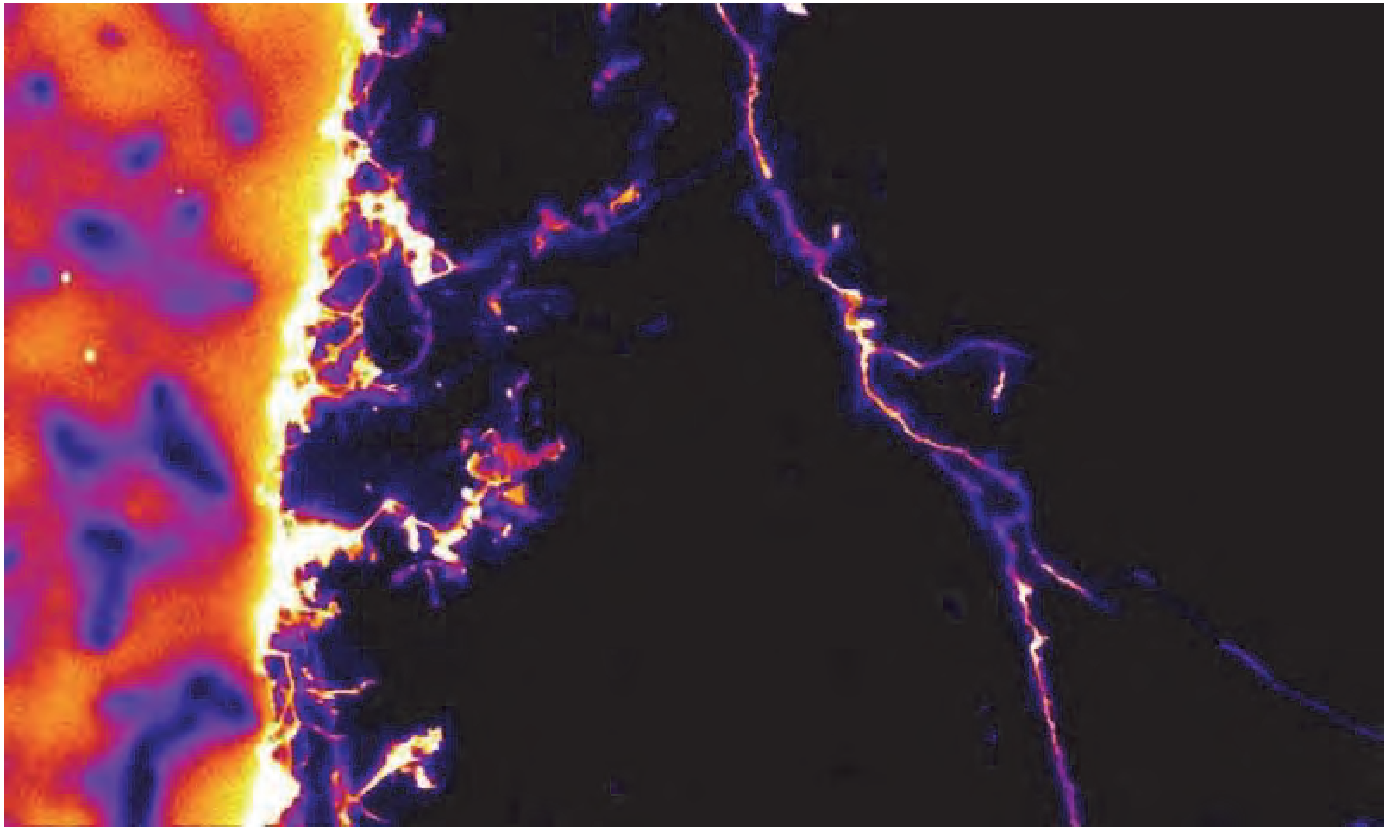
The research leading to these results has received funding from the European Union's European Atomic Energy Community's (Euratom) Seventh Framework Programme FP7/2007-2011 under grant agreement no 323273, the DOPAS project Schematic view of the physical model for bentonite saturation testing

CONCLUSIONS

- Transfer of infomation from the lab to the real scale in needed due to use of small samples, sample disturbance and different conditions

- however, work in situ is expensive and time-consuming, need infrastructure and not everytime RN can be used

Thank you for your attention



Granitic sample edge, disturbed by sawing (Melechov granite, sample MEV1_70, Czech Massive). Confocal microscopy. Project FR-TI/367.

www.ujv.cz

Appendix 12

DOPAS

Full-scale in situ demonstration of tunnel plugs and shaft seal in clay, crystalline and salt repository host-rock formations

Appendix 12

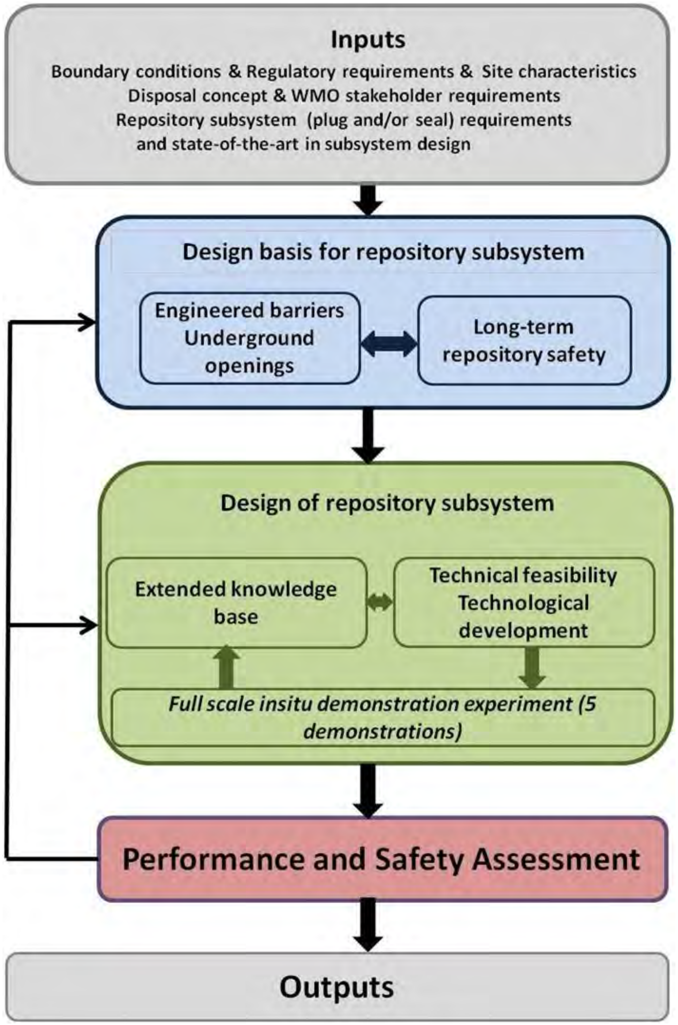
FSS
Full Scale Seal / DOPAS project
ESSAI DE SCELLEMENT
À PLEINE ÉCHELLE
ANDRA

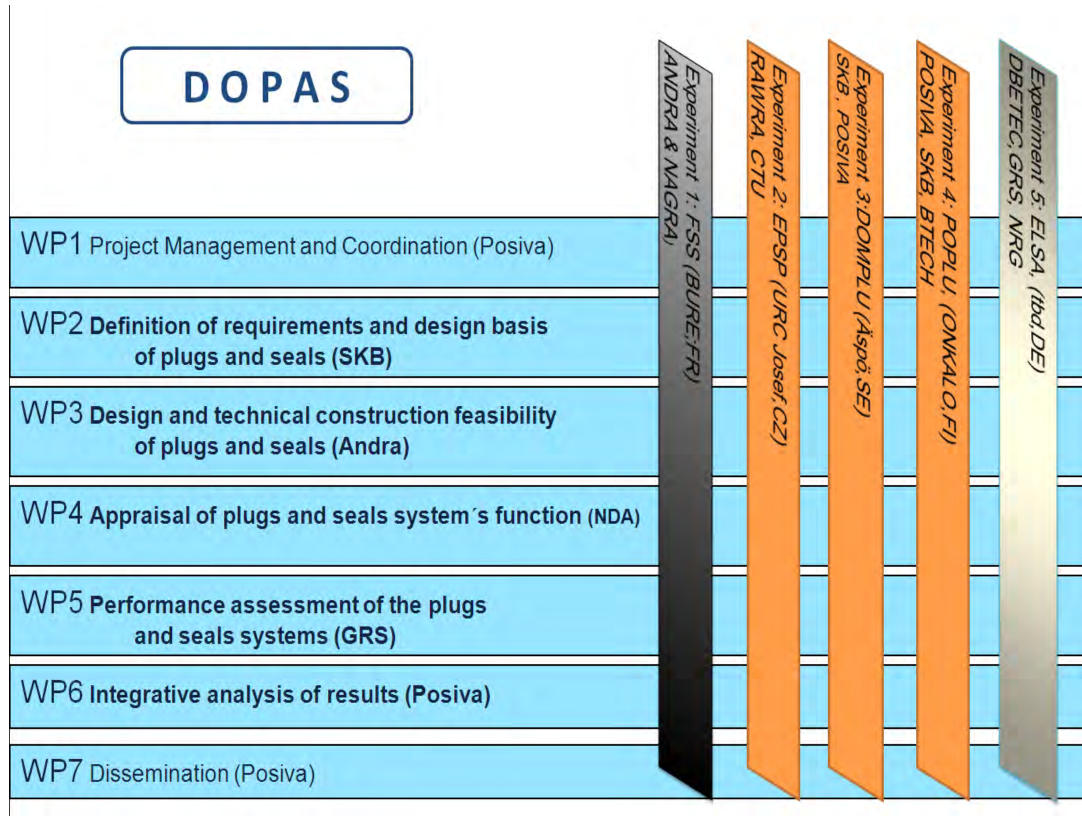
EURADWASTE '13

8th EC Conference on the Management of Radioactive Waste

14-16 October 2013, Vilnius, Lithuania

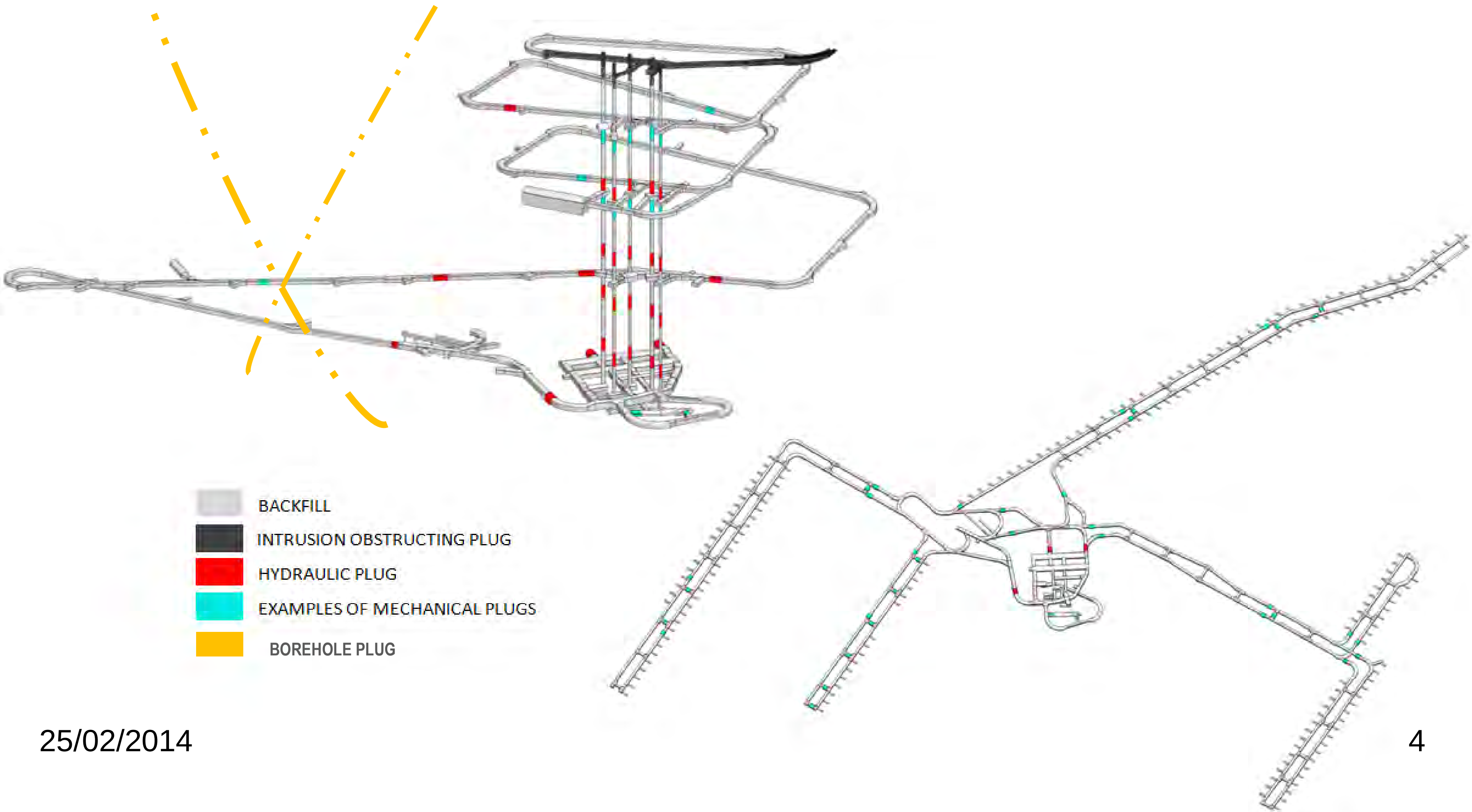
Co-organised by





EURADWASTE '13
8th EC Conference on the Management of Radioactive Waste
14-16 October 2013, Vilnius, Lithuania
Co-organised by

Role of plugs and seals



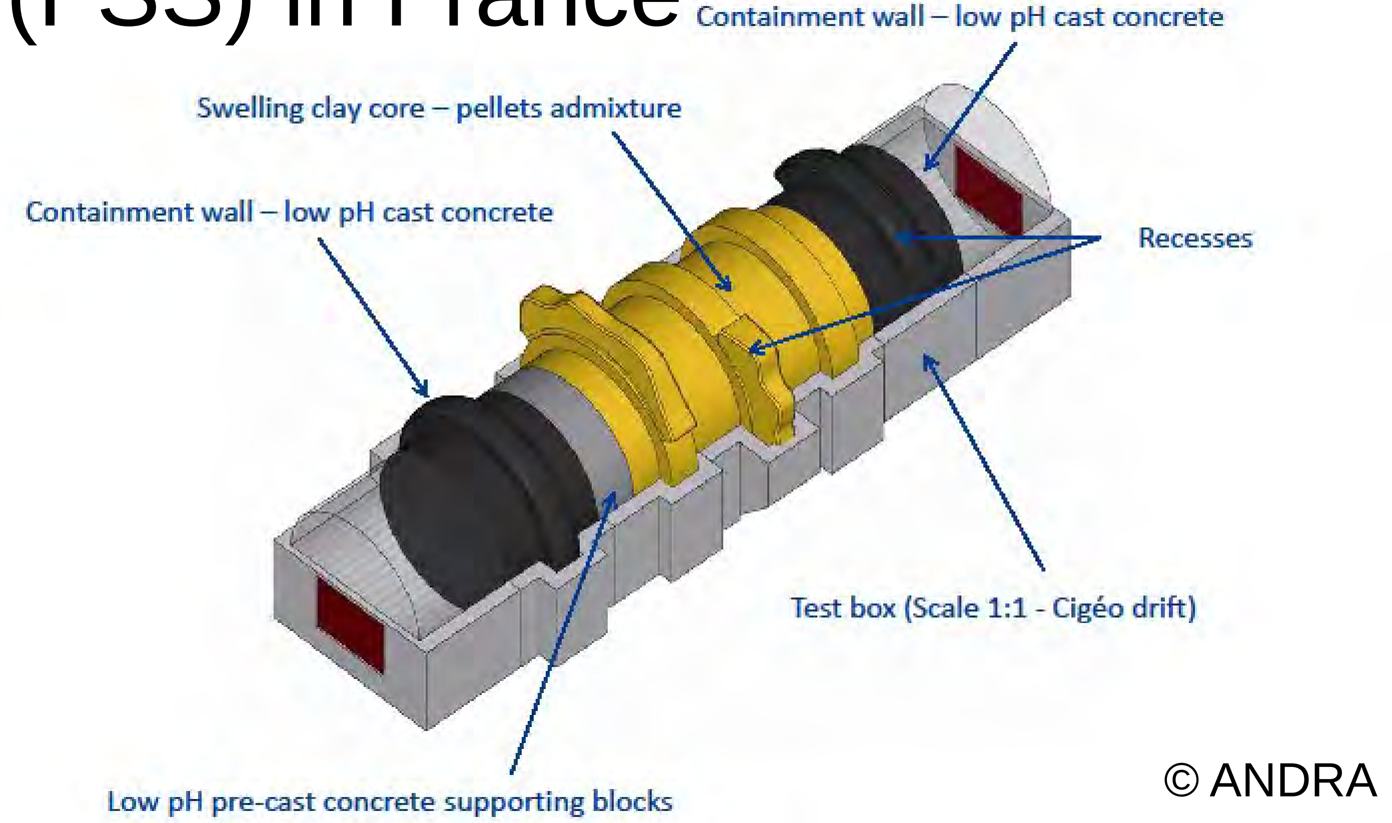
DOPAS main challenges

1. Plug and seal location selection and construction technologies,
2. New material development for the plug and seal components,
3. In-situ instrumentation and performance assessment of the plugs,
4. Quality assurance and work safety during the experiments.

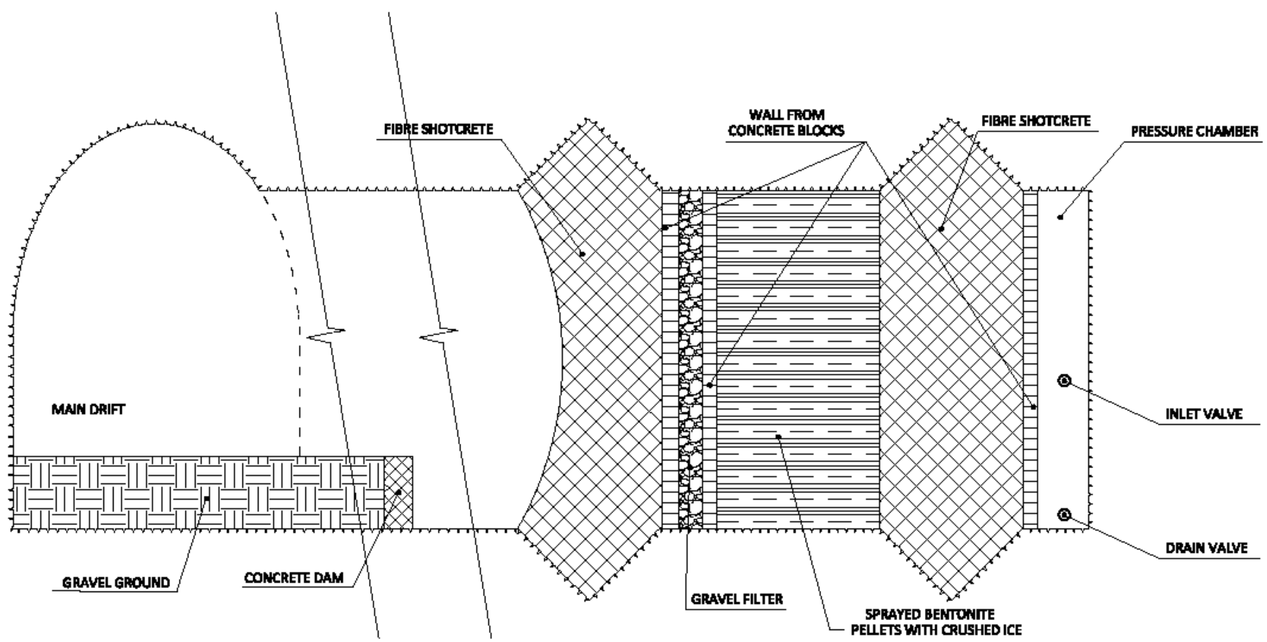
Integration of DOPAS demonstrations from the desk to the field

1. Planning the experiments
2. Implementing the experiments
3. Assessing the experiments

DOPAS Experiment 1: Full Scale Seal (FSS) in France

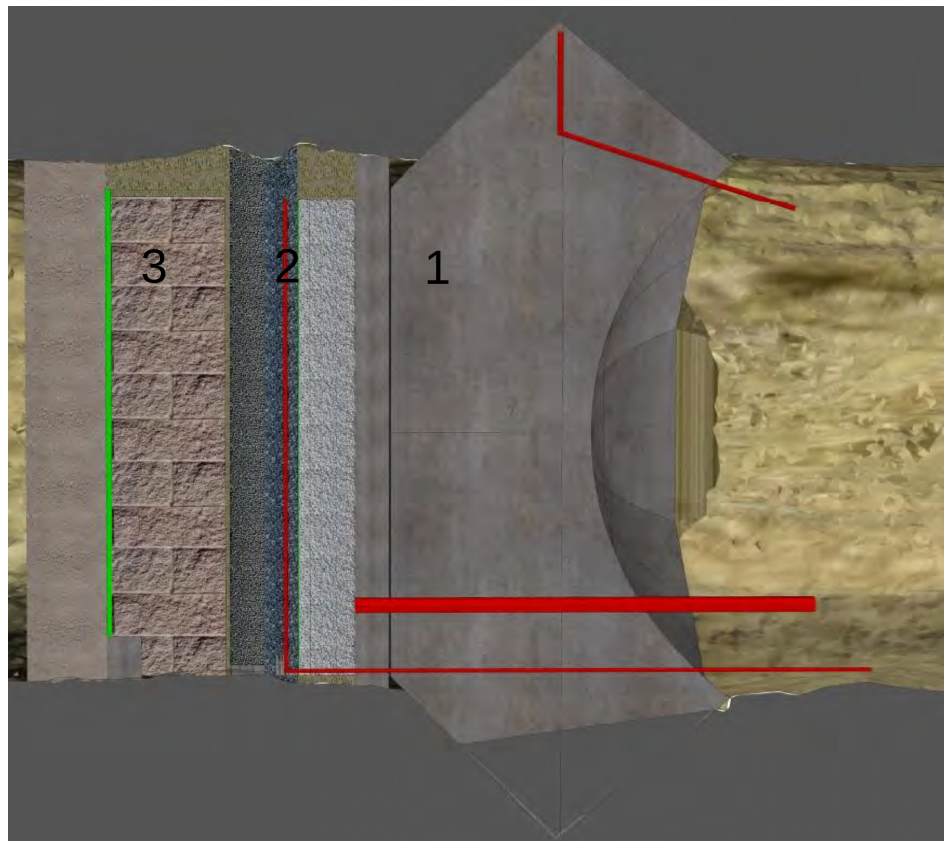


DOPAS Experiment 2: Experimental Pressure and Sealing Plug (EPSP) in Czech Republic

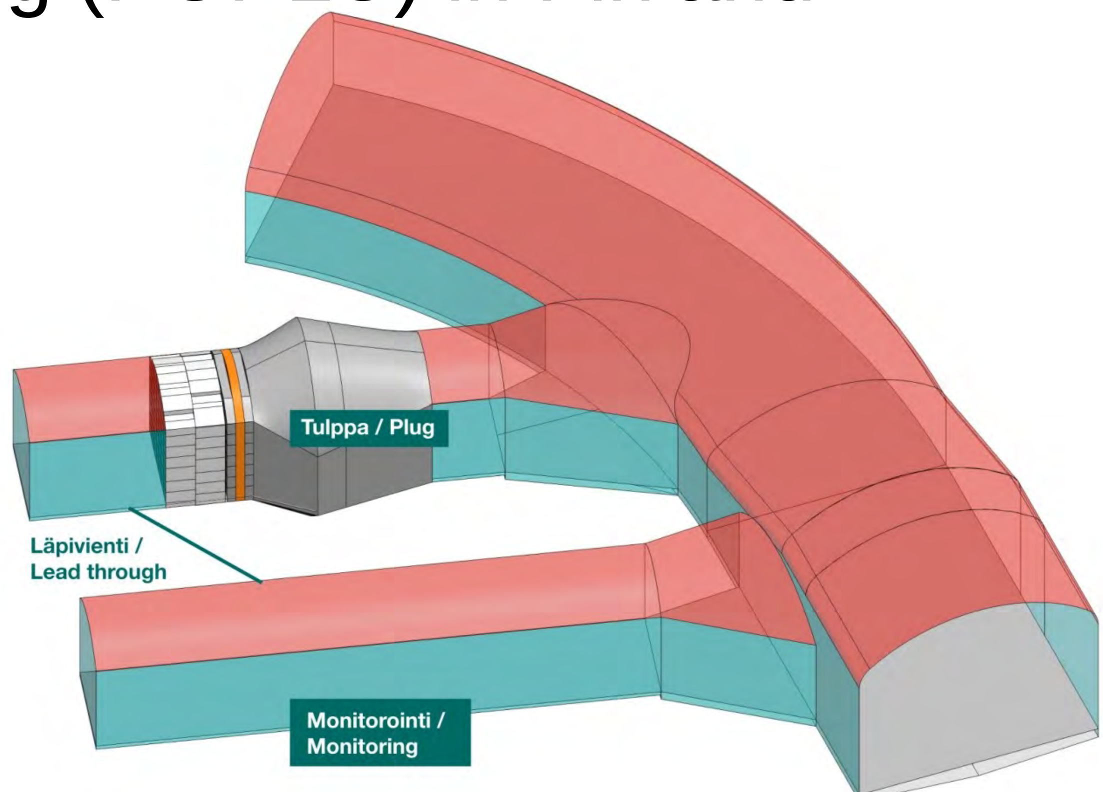


DOPAS Experiment 3: Dome Plug (DOMPLU) in Sweden

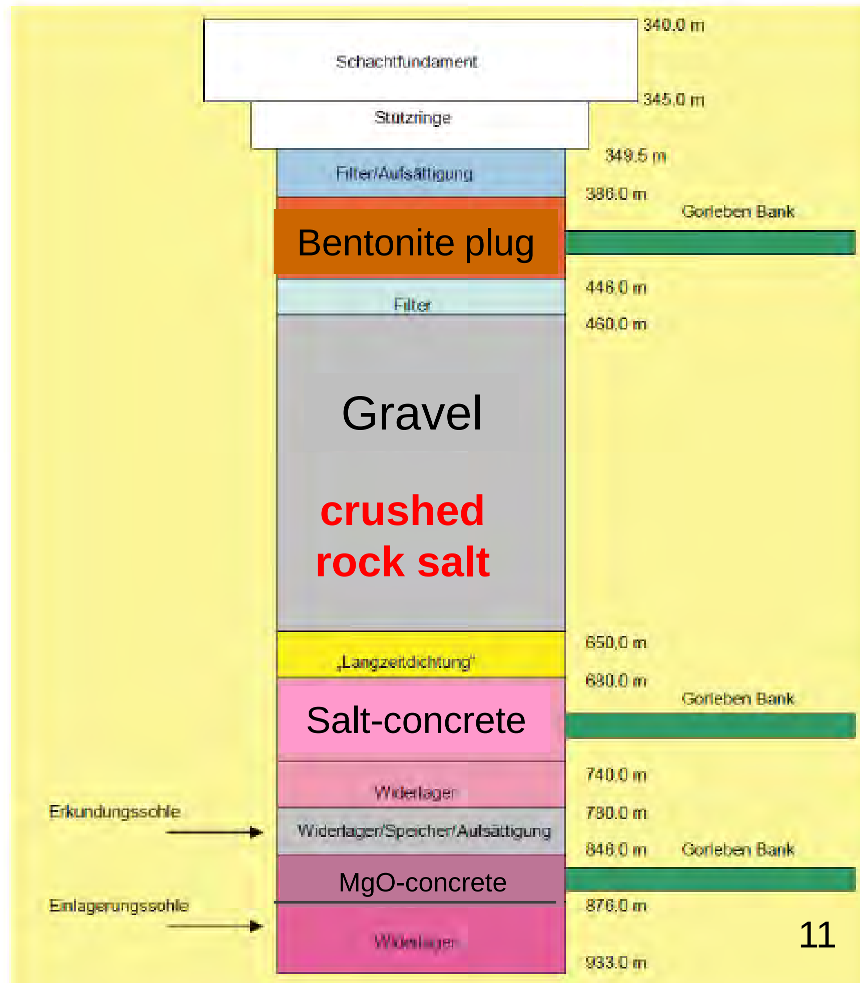
1. Concrete Dome
2. Filter and seal layer
3. Backfill zone



DOPAS Experiment 4: Posiva's deposition tunnel plug (POPLU) in Finland



DOPAS Experiment 5: ELSA shaft seal Experiment in Germany

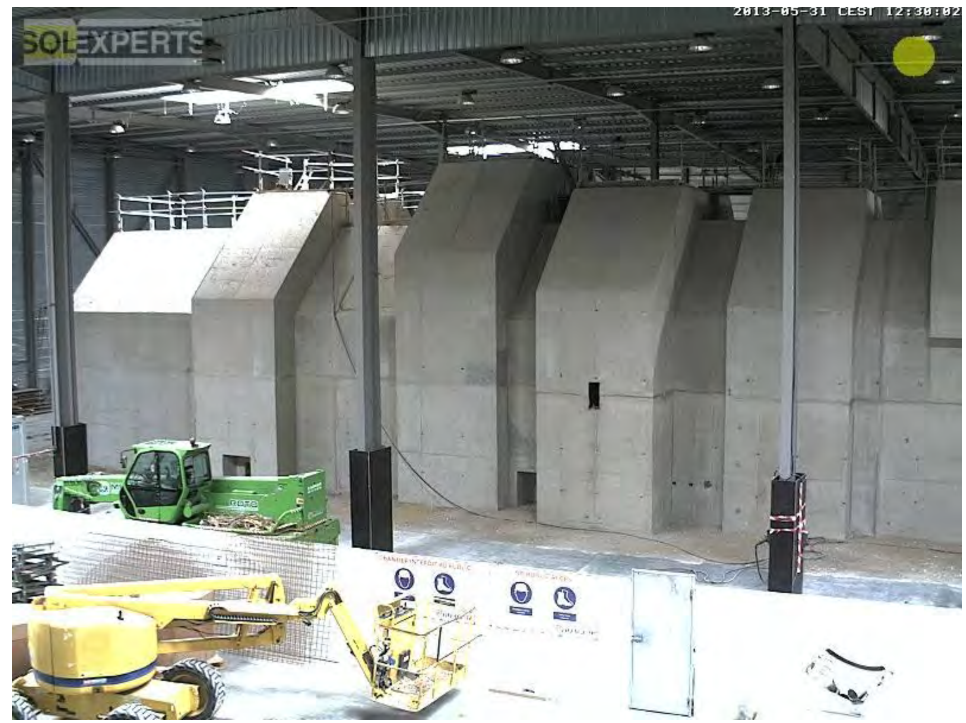


Planning the experiments

- Creation of design basis and reference design
- Purpose of the test
    - industrial feasibility
    - verification of design
    - performance of the component
- Detailed design
- Material characterisation and selection (approval)
- Site and location
- Monitoring planning (instrumentation, testing the behaviour)
- Modeling

Underground or above ground

© SKB



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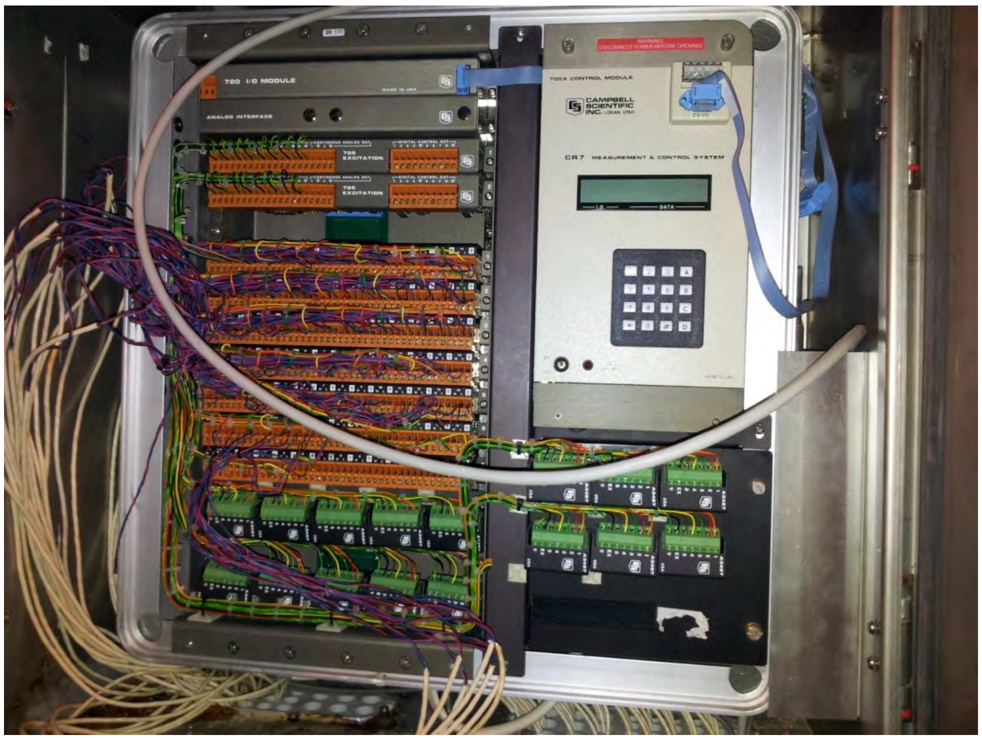
Implementing the experiments

- Specifications of materials
- Manufacturing and emplacement trials preparing the site
- Emplacement of structures and components
- Quality control methods
- Verification of planned design
- Follow up and monitoring
- Testing the behaviour
- Interpretation of results
- Change of design

Monitoring



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Assessing the experiments

- Description of site constraints and future evolution
- Setting performance requirements
- Theoretical calculations to support the design and implementation phase
- Model development
  - PA-methodology,
  - Processes and phenomena
- Integration of results to the overall safety

Joint aspects and benefits for co-operation with plugs and seals

- Preparation for demonstrations before operation phase
- Similar type of materials and methods
- Improved quality and risk management including occupational and long-term safety
- Theoretical calculations to support the design and implementation phase

DOPAS provides further

- Developed and described design basis, reference designs and strategies
- Detailed design and implementation chain for different type of demonstrations
- Experiences on materials to be used in repositories and their interactions
- Improved quality and risk management procedures, which has been used in practice
- New performance assessment tool for plugs and seals

DOPAS foreground and dissemination

- Each experiment produce a public summary report
- Integration of experiments presented in summary reports
- Main DOPAS events:
  - Training workshop 2015
  - Full-fledged international seminar 2016

    focussing on plugs and seals and the lessons learned around DOPAS demonstrations

Appendix 12

ID	Task Name
1	WP1 Project management and coordination
2	WP2 Definition of requirements and design basis
3	Task 2.1 Design Basis
4	Task 2.2 Reference designs
5	Task 2.3 Strategies of demonstrating conformity of reference design to design basis
6	WP3 Design and technical construction feasibility and WP4 Appraisal of plugs and seals function
7	FSS Construction and installation
8	FSS Mock-up for swelling verification and reporting
9	EPSP design
10	EPSP construction
11	EPSP monitoring and final reporting
12	DOMPLU construction
13	DOMPLU monitoring & reporting
14	POPLU design
15	POPLU construction and emplacement
16	POPLU monitoring and reporting
17	ELSA planning and laboratory analyses
18	WP5 Performance assessment of plugs and seals systems
19	Task 5.1 Performance assessment methods and tools for predicting the behavior of sealing systems
20	Task 5.2 Conceptual models and simulation of processes and their evolution
21	Task 5.3 Development of conservative PA models of methodology
22	Integration of results of demonstrators in total repository system's PA by performance indicators
23	WP6 Integrating analysis
24	Task 6.1 Planning for the integrating analysis
25	Task 6.2 Program of exchange of expert staff
26	Task 6.3 EE documentation from Expert Group
27	Task 6.4 DOPAS final project summary report
28	WP7 Dissemination

Thank You to the Audience and the DOPAS Consortium !

http://www.posiva.fi/dopas

POSIVA · ANDRA · DBE TEC DBE TECHNOLOGY GmbH · GRS · nagra · NDA Nuclear Decommissioning Authority · SÚRAO Správa úložišť radioaktivních odpadů Radioactive Waste Repository Authority · IGD-TP · SKB Svensk Kärnbränslehantering AB · ČVUT FSv · NRG · Galson Sciences Ltd · B+TECH · VTT · ÚJV

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

Appendix 13

FSS – The Full Scale Seal Experiment
WM'2013

J.M. Bosgiraud, P. Lebon, R. Foin, G. Armand / ANDRA

DIP.DIR.13.0040

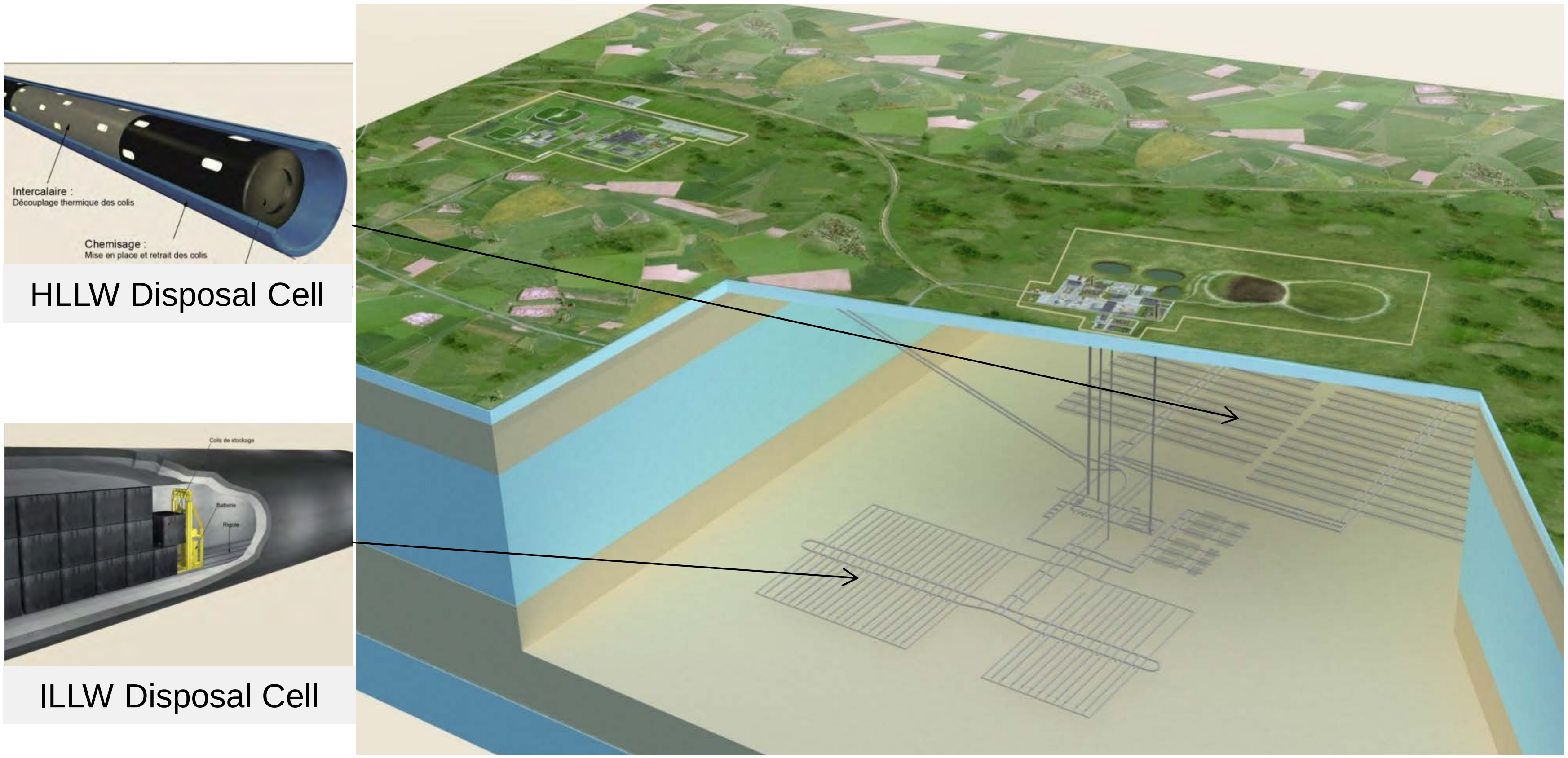
TABLE OF CONTENTS

- FSS Experiment Design Basis
- Practical Applications for the FSS Design
- FSS Experiment Development Status
- FSS Experiment Schedule
- The European Cooperative Project: DOPAS

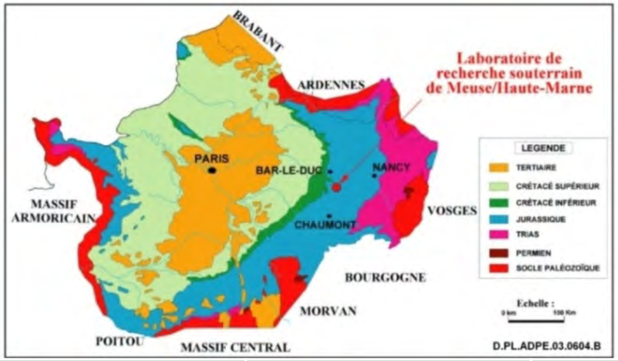
FSS EXPERIMENT DESIGN BASIS

- Cigéo - DGR concept and overall layout
- Hydrogeological background
- Safety function for seals
- Positioning of seals in the DGR,
- Surface to underground access : Seal conceptual design
- Horizontal Drifts & ILLW disposal cells : seal conceptual design
- « High Level » Seal Design Basis

Cigéo Background : Andra’s Industrial Center for Geological Disposal in the Bure area (Conceptual view - ref. Dossier 2009)

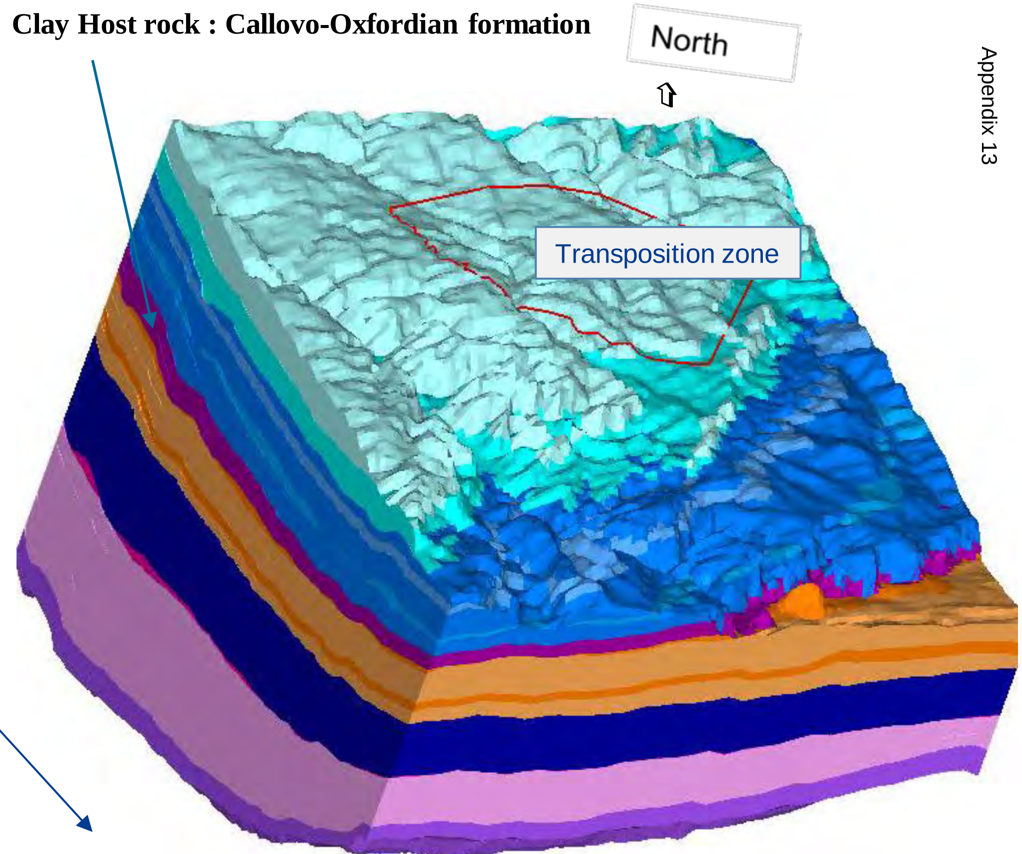


Background : Hydrogeological concept of Meuse/Haute-Marne Sector



Hydrogeologic units	Hydraulic conductivity (m/s)	Porosity (%)
Portlandian	10^{-7}-10^{-5}	10
Kimmeridgian	10^{-12}	13
Oxfordian	10^{-9} -10^{-10}	8-18
Callovo-Oxfordian	10^{-13}	14
Dogger	10^{-10} -10^{-11}	8-12
Lias	10^{-12}	12
Rhaetian	10^{-7}	15
Middle Triassic	10^{-12}	7
Early Triassic	10^{-7}	15

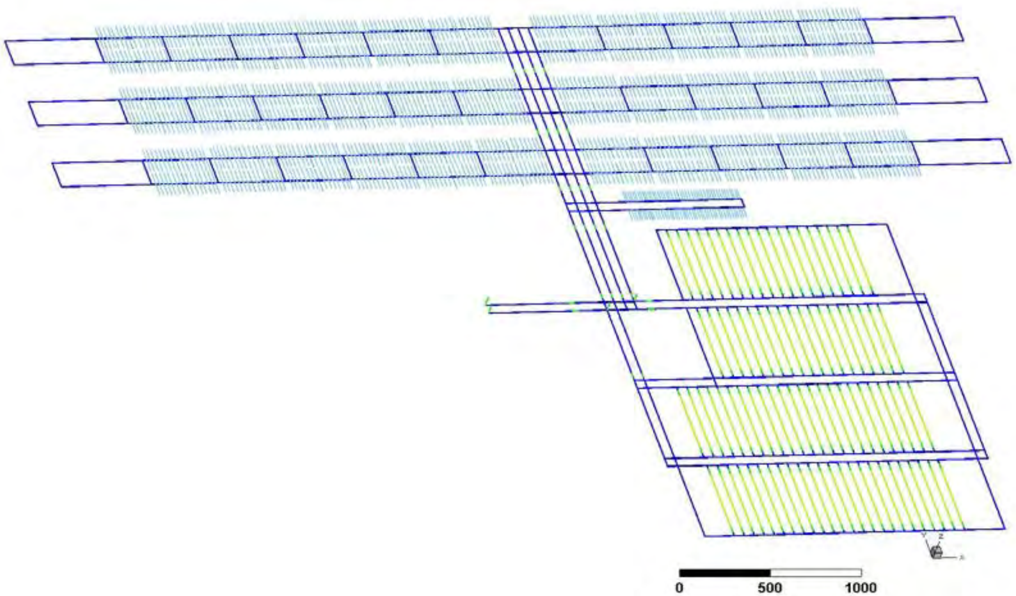
Clay Host rock : Callovo-Oxfordian formation



Aquifer / aquitar formations

J.M. Bosgiraud et al.   February 2013   DIP.DIR.13.0040   WM'2013

Safety Functions for Seals



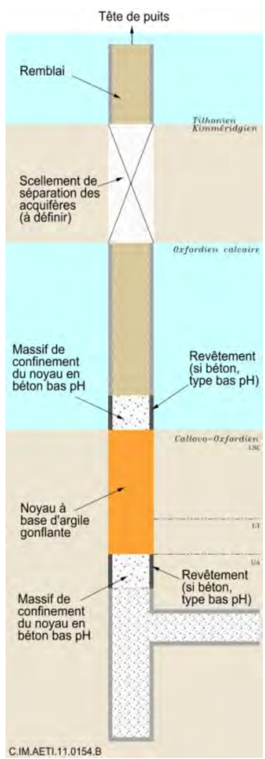
- To limit water inflow from upper surrounding formations during resaturation period
  - ✓ Seals of access facilities (ramps and shafts)
- To limit water flow within the disposal zone
  - ✓ Seals of access facilities
  - ✓ Seals of central zone
  - ✓ Seals of drifts in disposal panels
  - ✓ Seals of disposal cell heads

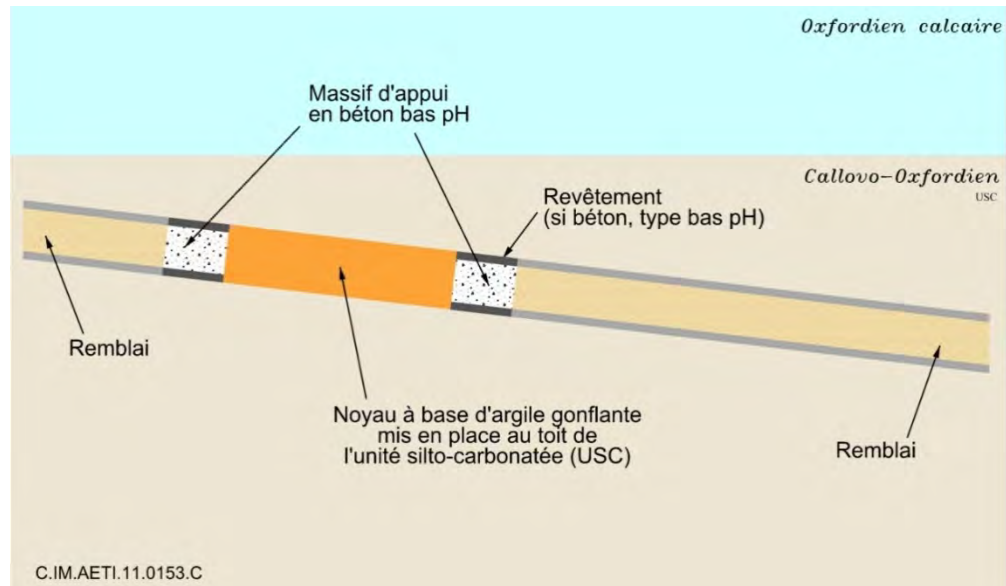
« High Level » Seal Design Basis

- Orientation of seals (i.e. for drifts & disposal cells) as per major in situ stress
- Use of swelling clay (bentonite) for core
  - Swelling clay (MX80 or equivalent)
    - Water permeability of 10^{-11} m/s
    - Swelling pressure : 7 MPa max
  - Length equal to 2 diameters (or 20 m) at least
- No hydraulic cut-off in reference design (alternative option)
- Use of low pH cement for concrete containment plugs
  - To maintain a constant volume of swelling clay core during the saturation phase
  - To preserve swelling clay core properties on a long term basis
- Specific requirements for the concrete liner in sealing area:
  - Use of low pH cement (reduce alkaline plume effect)
  - Total or partial dismantling
- No specific requirement for backfill material, but to avoid long term subsidence

Surface to underground access : Seal conceptual design

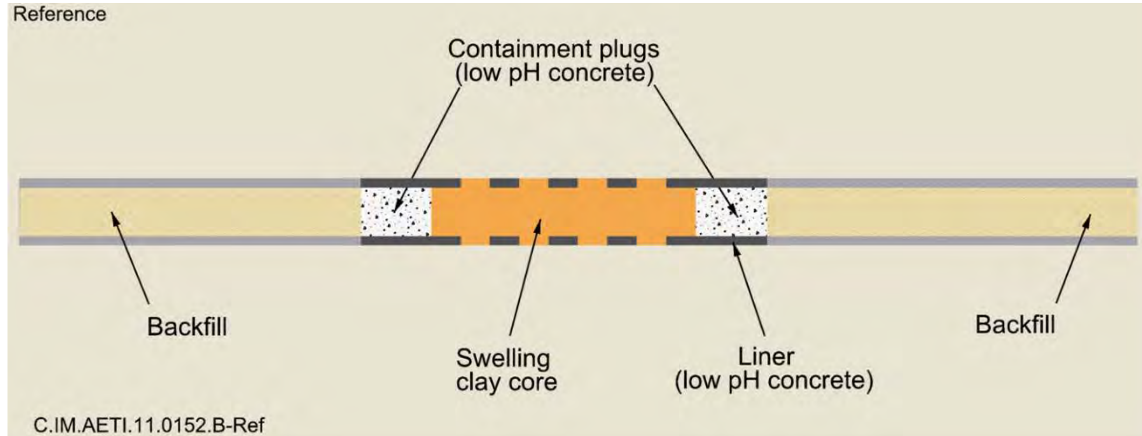
- **Partial or total dismantling of shaft/ramp liner**
- **Seals located in the upper part of the Callovo-Oxfordian formation (i.e. in a zone of limited (or absence of) connected fractures in this part of the argillites formation)**



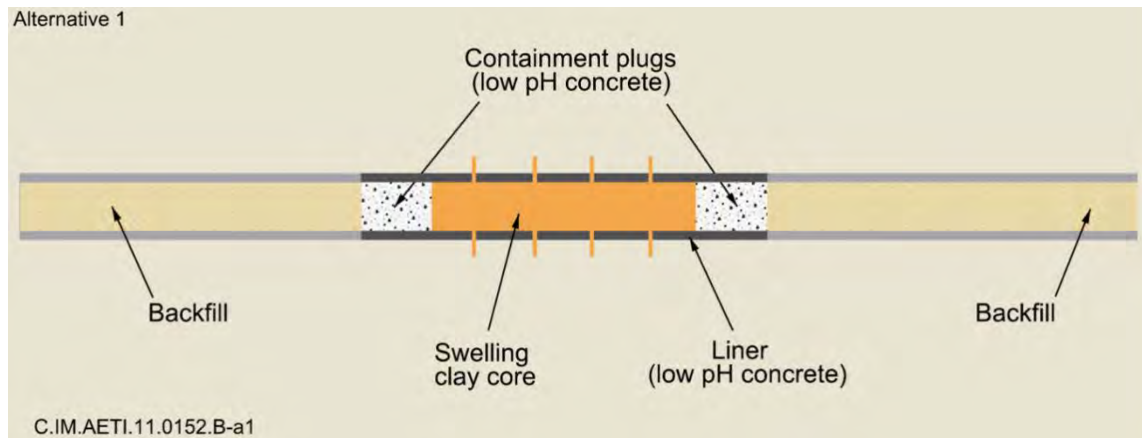


Horizontal Drifts & ILLW disposal cells : seal conceptual design

- **Reference concept**



- **Alternative option**



Practical applications for the FSS Experiment Design

- FSS Objectives
- Overall dimensions of the FSS Experiment
- 3 D view of the FSS experiment
- The swelling clay core
- The containment concrete plugs
- The experiment environmental/operational conditions
- The associated experiments related to seal performance

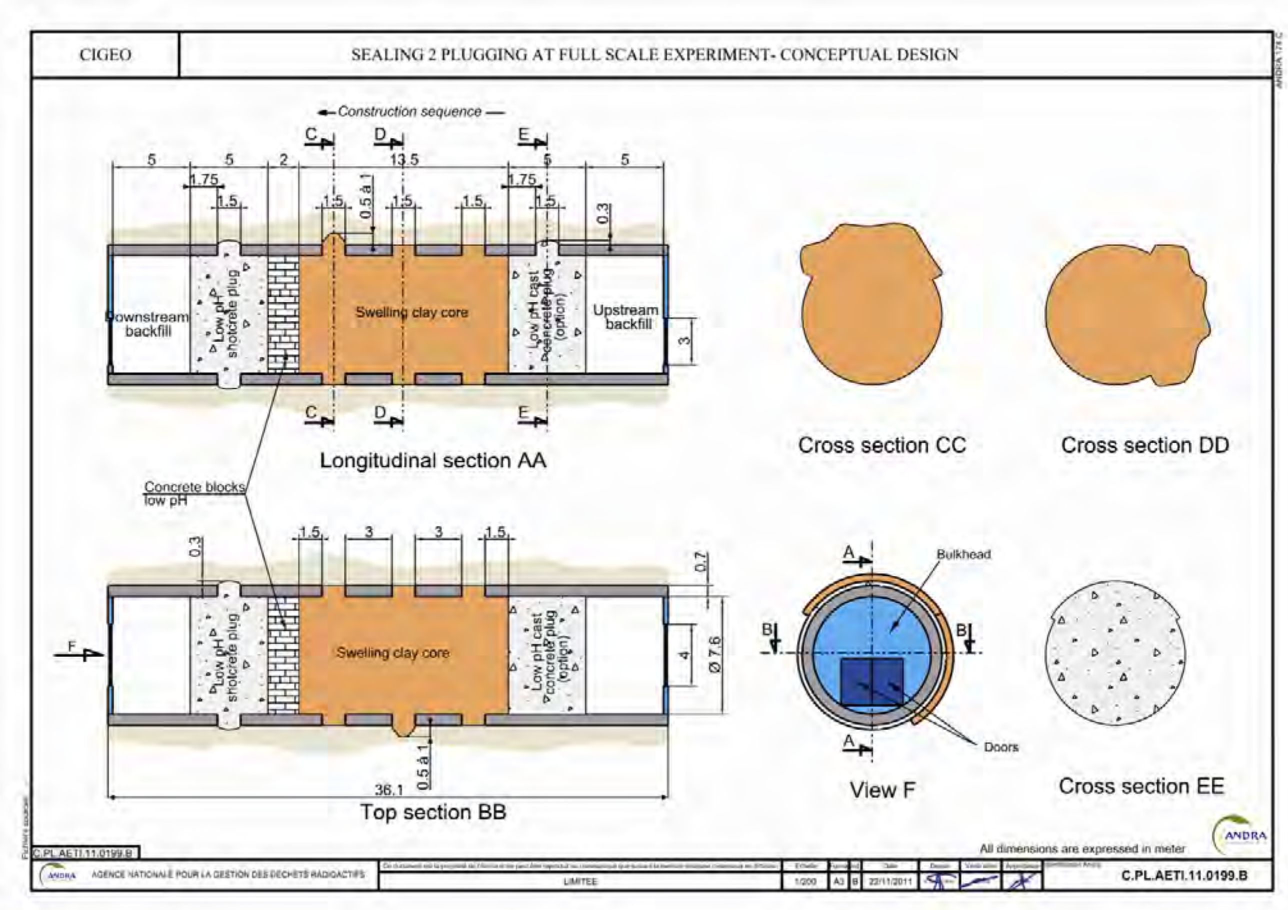
Practical applications for the FSS Experiment Design

Objectives of FSS

- Demonstrating the industrial capacity to satisfactorily emplace large volumes of bentonite material & low pH (less than 11) shotcrete & cast concrete
- Defining the operational constraints linked to emplacement activities and compatible with the mechanical or hydraulic properties allocated to the seal components
- Defining and operating the commissioning means necessary to check the work compliance during emplacement operations
- Defining and operating the commissioning means necessary to check the work compliance after emplacement operations

Practical applications for the FSS Experiment Design

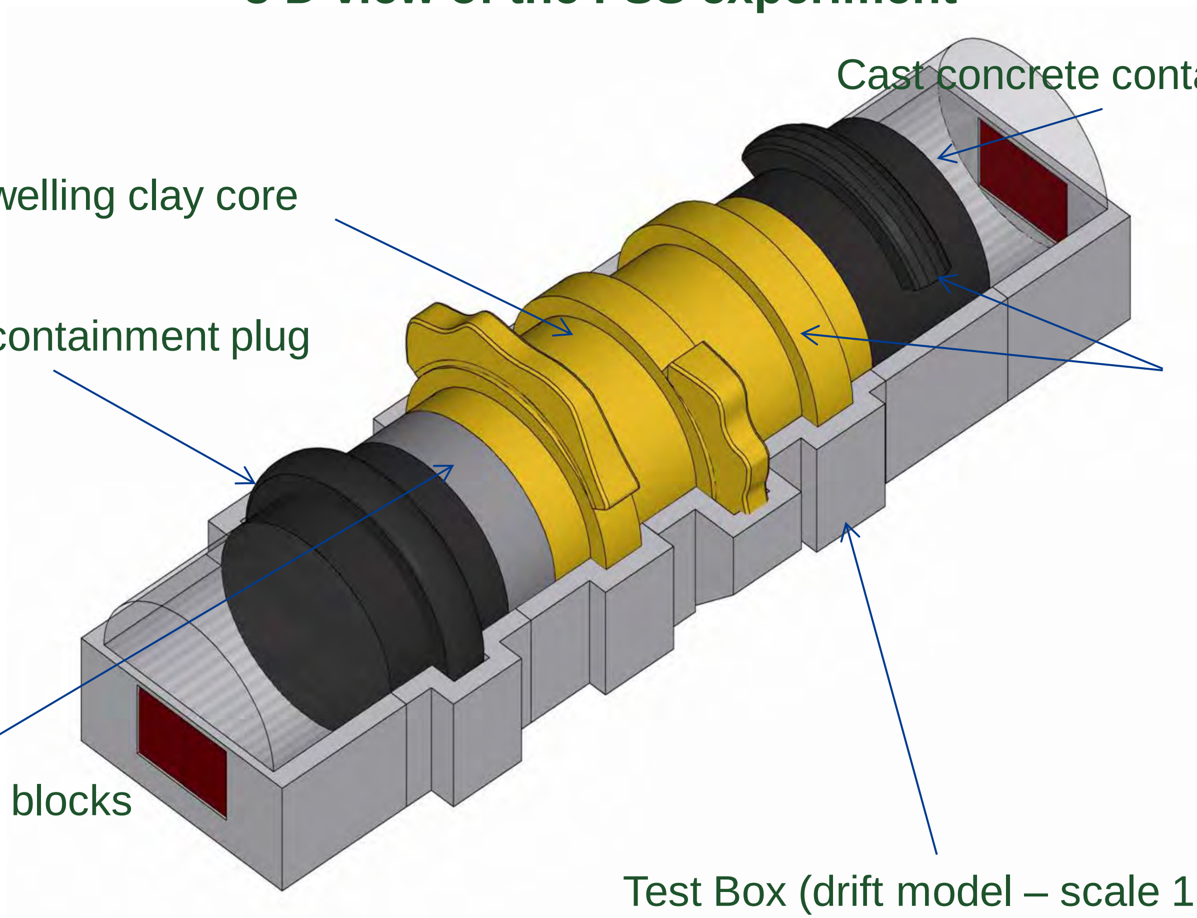
Overall dimensions of the FSS Experiment



Appendix 13

Practical applications for FSS Design Basis

3 D view of the FSS experiment



Practical applications for FSS Design Basis

The swelling clay core

- Some 750 m^3 of bentonite pellets/powder admixture formulated, prepared and emplaced
- Conveyed in DGR environmental conditions (Temperature & Hygrometry)
- Emplaced to reach an effective density of 1,62+
- Limited residual vacuum in *summital* recesses
- No segregation of pellets and powder
- Height of core is up to 10 m with a natural slope of some 27 to 30 %
- Observation windows positioned to check segregation, residual vacuum, subsidence, stability of slope

Practical applications for the FSS Experiment Design

The containment concrete plugs

- 2 low pH concrete containment plugs,
- Some 250 m^3 for each plug,
- Cast concrete and shotcrete (one each),
- Lox pH blocks for support wall,
- Low pH mortar & slurry (bonding grout),
- Minimum cracking and shrinkage,
- Limited curing temperature,
- Minimum residual vacuum in summital recesses.

Practical applications for the FSS Experiment Design

The experiment environmental / operational conditions

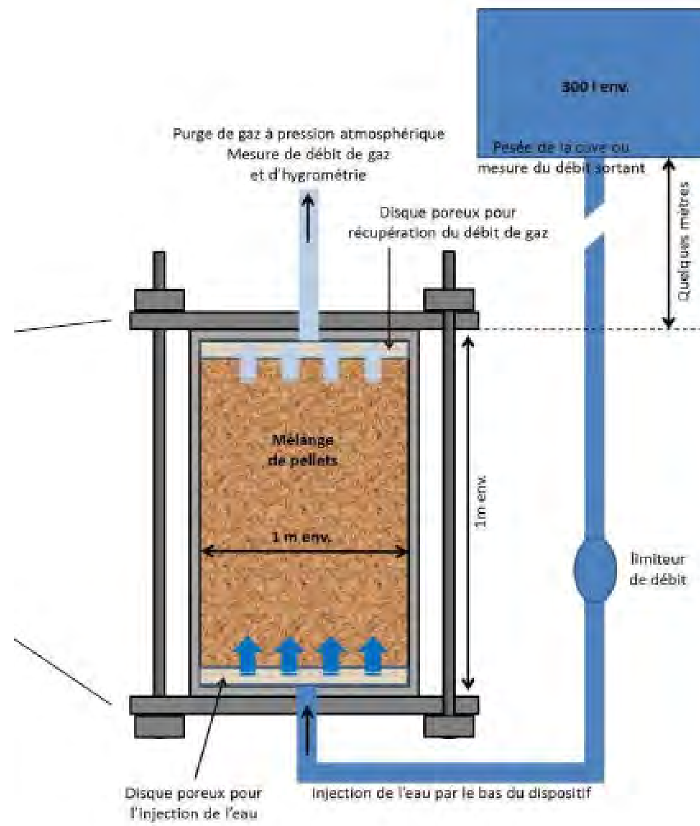
- Seal Construction will be implemented as in real underground situation (→ ventilation constraints in particular),
- Distance factor (time factor) is taken into account for cement transfer and “pumpability”,
- Test Site respecting underground ambient conditions for temperature & humidity

→ 50%<HR< 75% et 18°c < θ < 30°c.

Practical applications for FSS Experiment Design

The associated experiments related to seal performance

- **The FSS experiment per se does not include a saturation test**
- **Such test is conducted with the same swelling clay material at a lower (metric) scale in a separate experiment (REM),**
- **REM experiment is a forced hydration test,**
- **REM will provide confirmation data on hydraulic performance and indication of saturation time for the selected bentonitic material,**
- **A natural hydration scale in situ (i.e. in the Bure URL argillite host rock formation) experiment (BHN) will also be carried-out at a metric scale.**



FSS Experiment Preparation Status

- Characterization & formulations of bentonitic and cementitious materials
- Construction of the drift model (experiment box)
- Development of commissioning means

Appendix 13

Characterization & formulations of bentonitic and cementitious materials

Work on bentonitic material formulation (status on 15 Feb 2013)

- **Bentonite from Wyoming (WH2 - equivalent to MX80)**
- **Admixture is a combination of 32mm pellets and bentonite powder (or/and) crushed pellets (binary or ternary admixtures)**
- **Emplaced material specific gravity target value is 1.62 (to reach a 7 MPa swelling pressure)**
- **Formulation is almost fine so far with 28 mm pellets (only material available for preliminary experiments, specific gravity 2.14) combined with bentonite powder: admixture specific gravity 1.615**
- **But need to reach a higher emplaced specific gravity value (1.63 or 1.65) to compensate (potential marginal) segregation and residual summital voids at time of full scale experiment at time of core construction**
- **Specific gravity of 32 mm pellets (2.3 or 2.4) should help – Pellets to be fabricated as of March 2013**

Appendix 13

Work on bentonite material emplacement procedures (status on 15 Feb 2013)

- Avoid segregation of admixture (no premix)
- Fill in the voids between the pellets with powder by spraying powder every 10cm layer of pellets
- Work is satisfactory at metric scale, but :
  - ➢ plurimetric tests must be carried out with conveyor screw emplacement device
  - ➢ screw emplacement device must show its capacity to backfill the summital voids
  - ➢ Pretests will be carried-out at plurimetric scale before the effective scale 1:1 construction test

Work on cementitious material formulations

(status on 15 Feb 2013)

- **Cast concrete formulations**
  - 3 pastes (bonding) developed with CEM1 or CEM3 cement + silica fume + filler + flying ashes
  - Mechanical resistance and pH values at 28 days and 90 days satisfactory
  - Selection of local aggregates completed
  - Formulations and qualification of concrete ongoing with “BétonLabPro” software
  - Shrinkage could be a concern
  - Need for a bonding grout / slurry
  - Plurimetric pretests before scale 1:1 test

- **Cast Concrete formulations selection process ongoing**
- **Shotcrete formulations**
  - Low pH values at 28 days above target, not known yet at 90 days
  - Mechanical tests not satisfactory yet: more sampling & tests panels
  - Rebound rate is good (less than 11%)

Appendix 13

Construction of the drift model (experiment box)

Development of commissioning means

Seal Construction:

- Swelling Clay Core
  - Monitoring of mass of material emplaced vs. Volume to backfill,
  - FDR detectors to evaluate residual summital voids,
  - Observation windows,
  - Gamma meter (specific gravity)
- Concrete containment plugs
  - Temperature sensors,
  - Extensometers,
  - FDR detectors

Post mortem:

- Observation windows,
- Coring &Wire sawing

FSS Experiment Schedule

Main milestones

- **Project kick-off : July 2012**
- **Characterization, formulations & qualification of backfill (bentonite & cement) materials: mid 2013,**
- **Construction of test box: mid 2013**
- **Emplacement of seal component: fall 2013,**
- **Commissioning : end 2013 – early 2014,**
- **Dismantling – Report & Communication: end 2015.**

The European Cooperative Project: DOPAS

- DOPAS (Demonstration of Plugs and Seals) is a four year (2012-2016) European cooperative project
- 14 Partners (waste management organizations, private companies & research institutes from the EC)
- 4 “scale 1:1” Seal Experiments (Sweden - DOMPLU, Finland - POPLU, Czech Republic - EPSP & France - FSS)
- The impetus to the cooperation comes from the Strategic Research Agenda of the Implementing Geological Disposal of Radioactive Waste - Technology Platform (IGD-TP)
- Andra acknowledges the financial support of the European Commission for the DOPAS project (as per FP7 - Grant agreement 323273)

http://www.posiva.fi/dopas

Appendix 13

Thank You for Attention !

Any questions ?

A General Overview Of DOPAS Project And First Year Achievements For full-Scale Demonstration Of Plugs And seals

Johanna Hansen

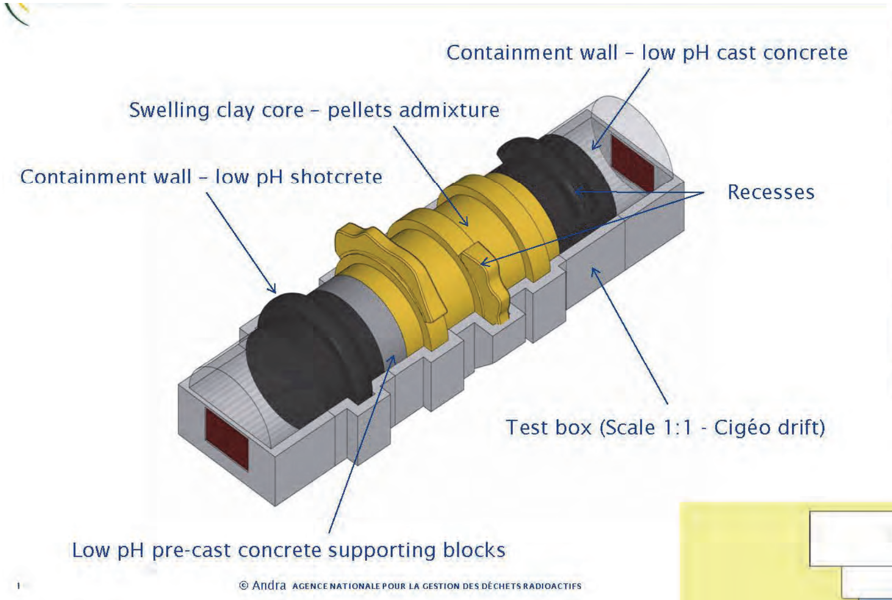
PEBS Final Conference, Hannover 6.-7.2.2014

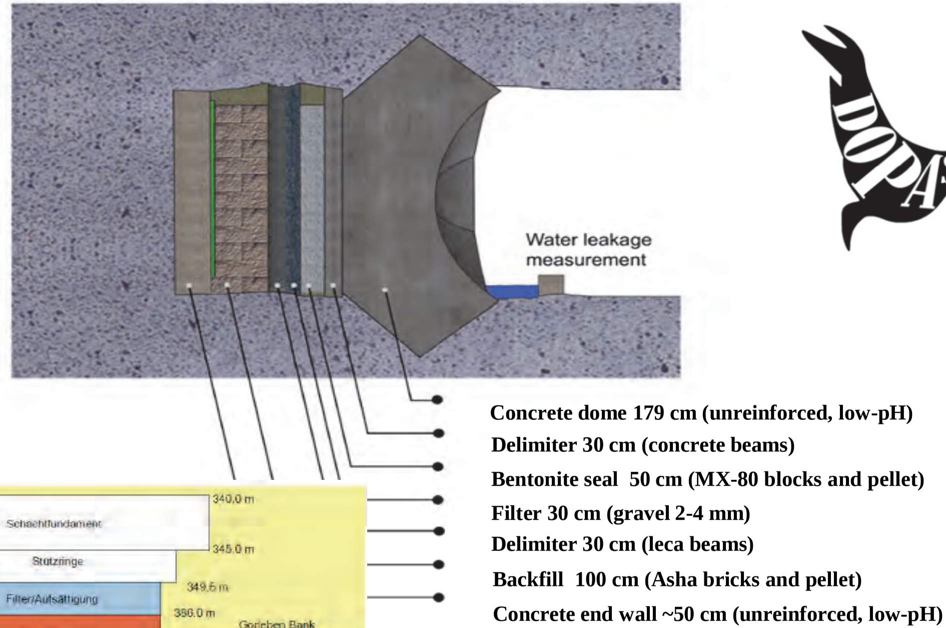
This presentation:

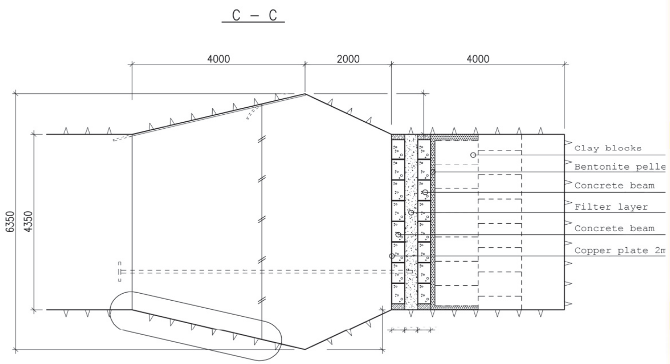
- **Overview of DOPAS project**
- **Main achievements for the first 12 Months**
- **Main targets for year 2014**

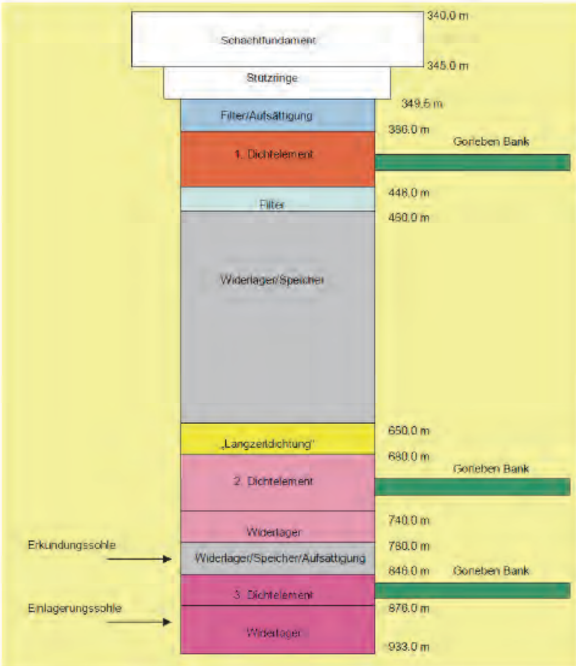
DOPAS facts

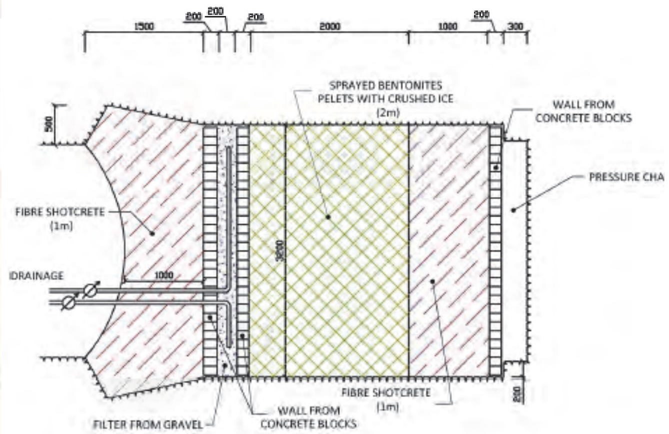
- **Collaboration project by a Consortium of 14 Partners from 8 European countries**
- **Running since September 2012 and ends in August 2016**
- **Budget 15,8 M€**
- **Five full-scale experiments implemented partly or fully by DOPAS project underground or aboveground conditions**
- **Information can be used for planning of LILW and Spent Nuclear fuel repositories**


Containment wall – low pH cast concrete
Swelling clay core – pellets admixture
Containment wall – low pH shotcrete
Recesses
Test box (Scale 1:1 - Cigéo drift)
Low pH pre-cast concrete supporting blocks
© Andra AGENCE NATIONALE POUR LA GESTION DES DÉCHETS RADIOACTIFS

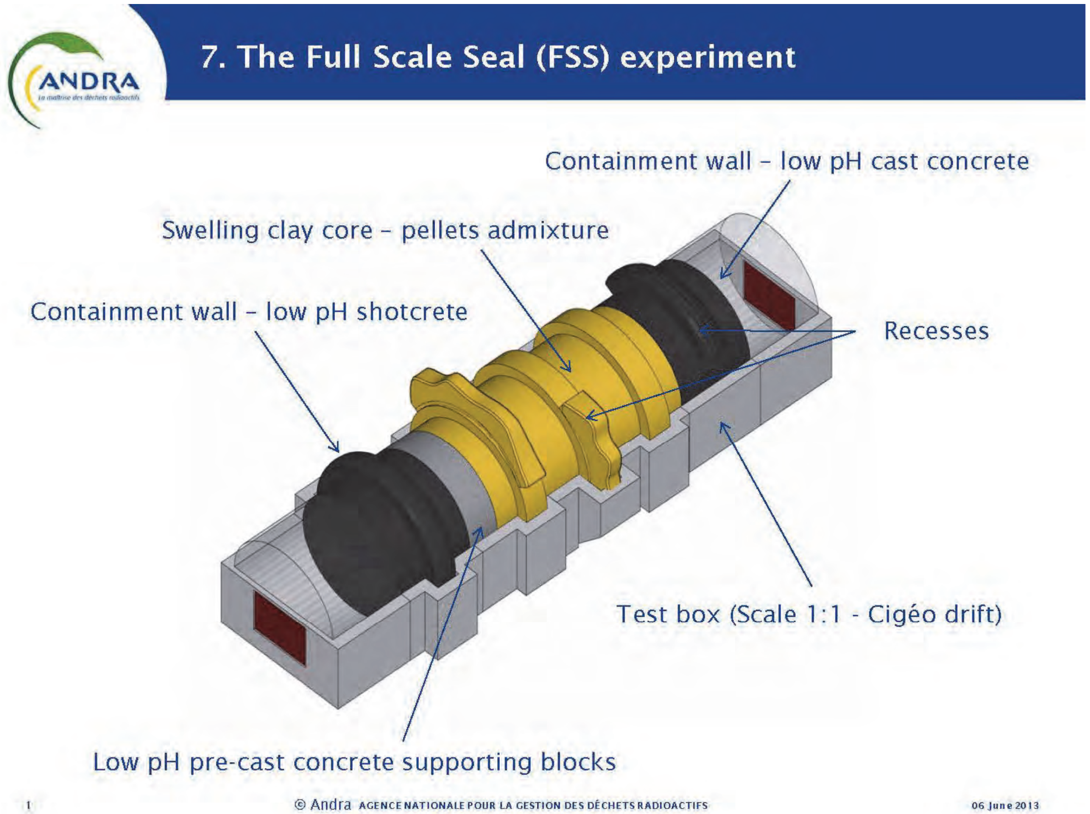

Water leakage measurement
Concrete dome 179 cm (unreinforced, low-pH)
Delimiter 30 cm (concrete beams)
Bentonite seal 50 cm (MX-80 blocks and pellet)
Filter 30 cm (gravel 2-4 mm)
Delimiter 30 cm (leca beams)
Backfill 100 cm (Asha bricks and pellet)
Concrete end wall ~50 cm (unreinforced, low-pH)


C – C
4000
2000
4000
6350
4350
Clay blocks
Bentonite pelle
Concrete beam
Filter layer
Concrete beam
Copper plate 2m

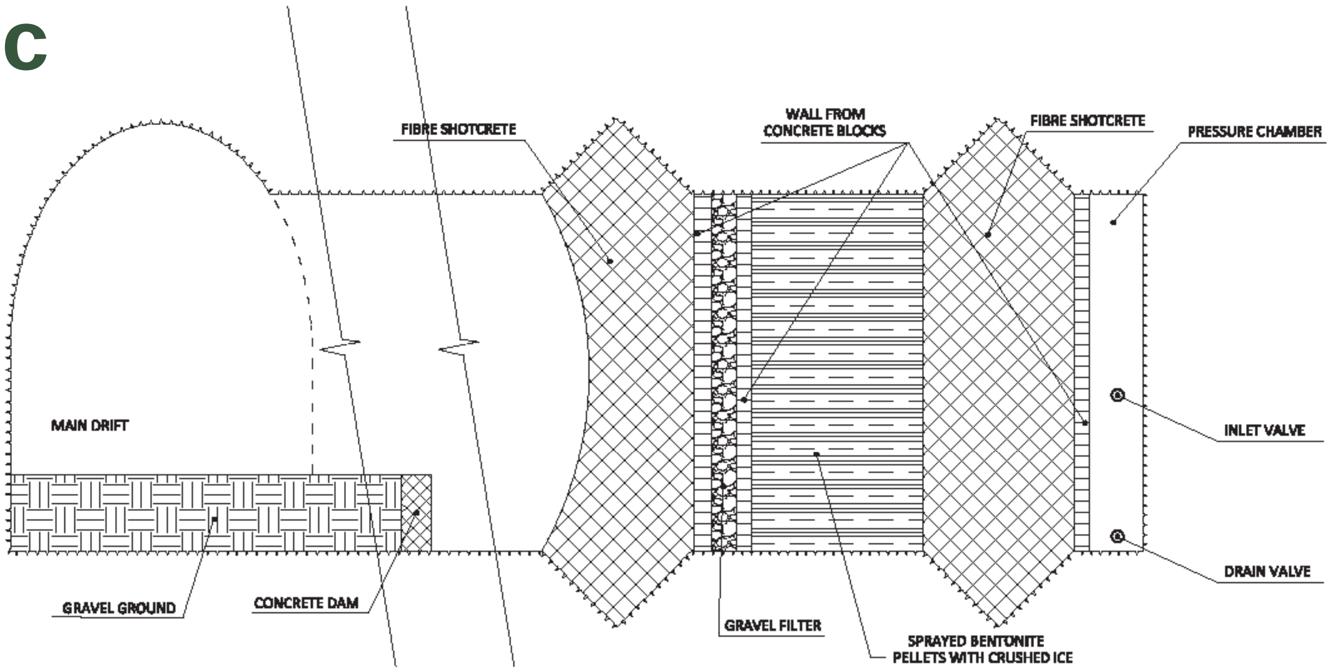

Schachtfundament
Stützringe
Filter/Aufsättigung
1. Dichtelement
Filter
Widerlager/Speicher
„Langzeitdichtung"
2. Dichtelement
Widerlager
Widerlager/Speicher/Aufsättigung
3. Dichtelement
Widerlager
340,0 m
345,0 m
349,5 m
386,0 m
448,0 m
460,0 m
650,0 m
680,0 m
740,0 m
780,0 m
846,0 m
876,0 m
933,0 m
Gorleben Bank
Gorleben Bank
Gorleben Bank
Erkundungssohle
Einlagerungssohle


1500
200
200
200
2000
1000
200
300
SPRAYED BENTONITES PELETS WITH CRUSHED ICE (2m)
WALL FROM CONCRETE BLOCKS
PRESSURE CHA
FIBRE SHOTCRETE (1m)
DRAINAGE
1000
FIBRE SHOTCRETE (1m)
WALL FROM CONCRETE BLOCKS
FILTER FROM GRAVEL

DOPAS Experiment 1: Full Scale Seal (FSS) in France

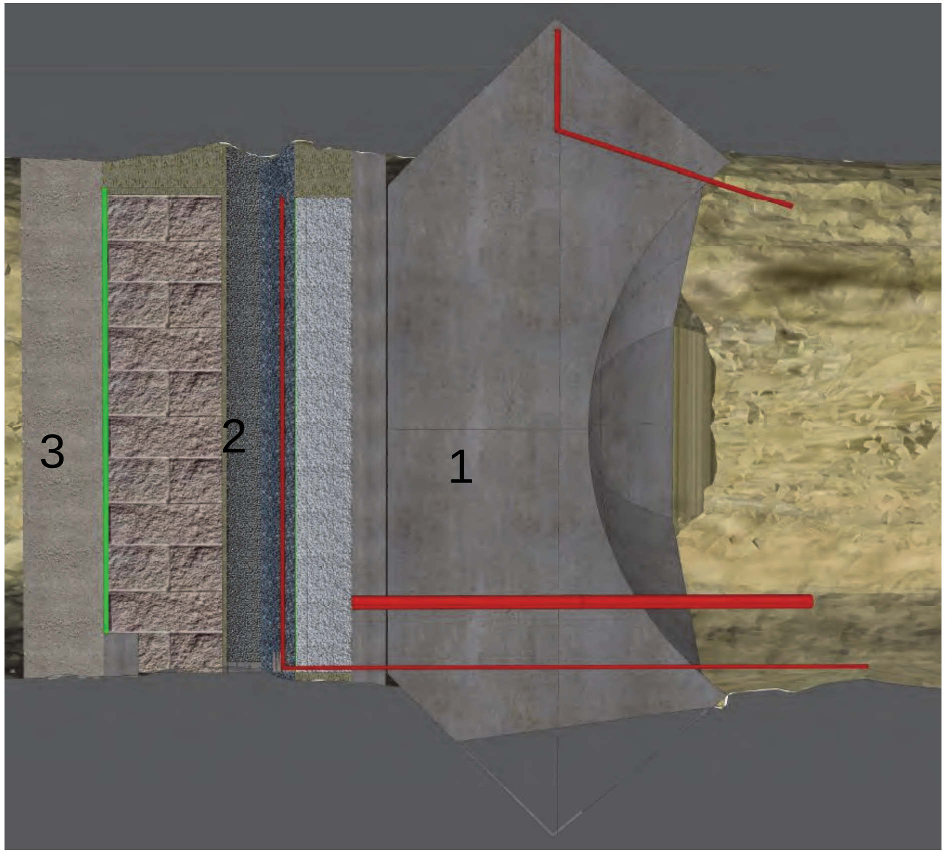


DOPAS Experiment 2: Experimental Pressure and Sealing Plug (EPSP) in Czech Republic

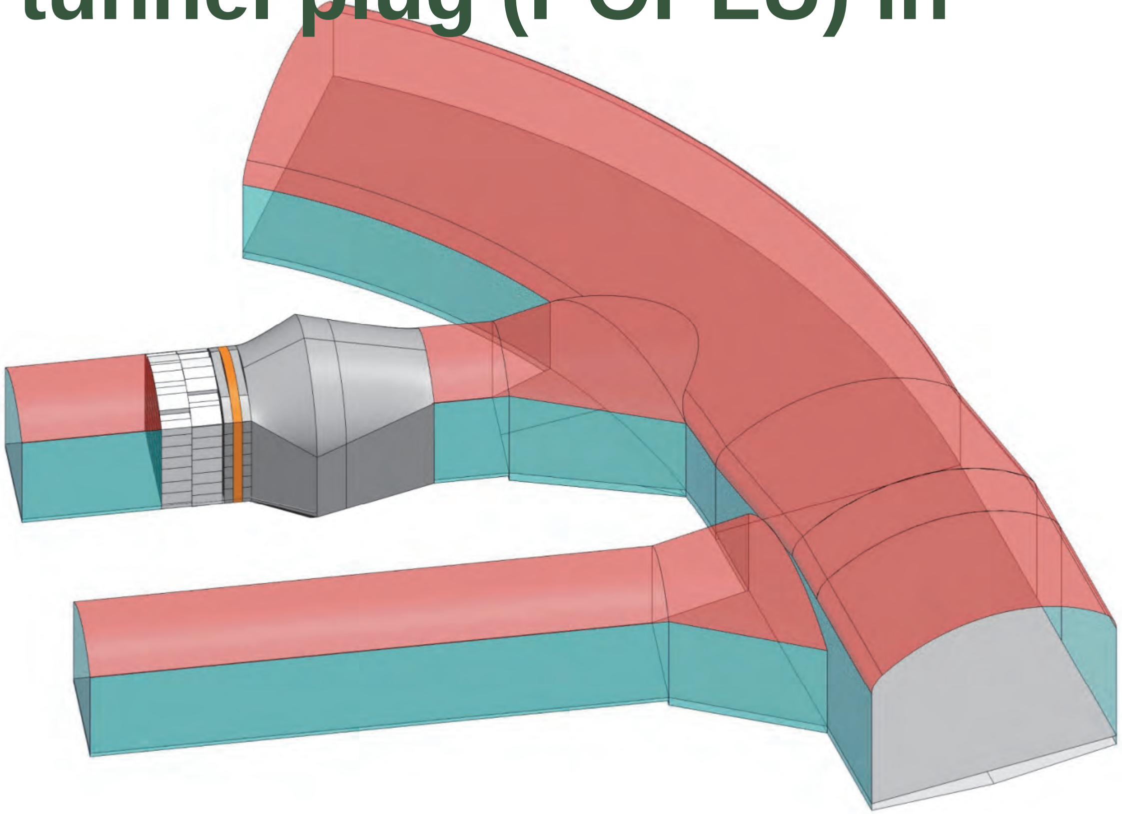


DOPAS Experiment 3: Dome Plug (DOMPLU) in Sweden

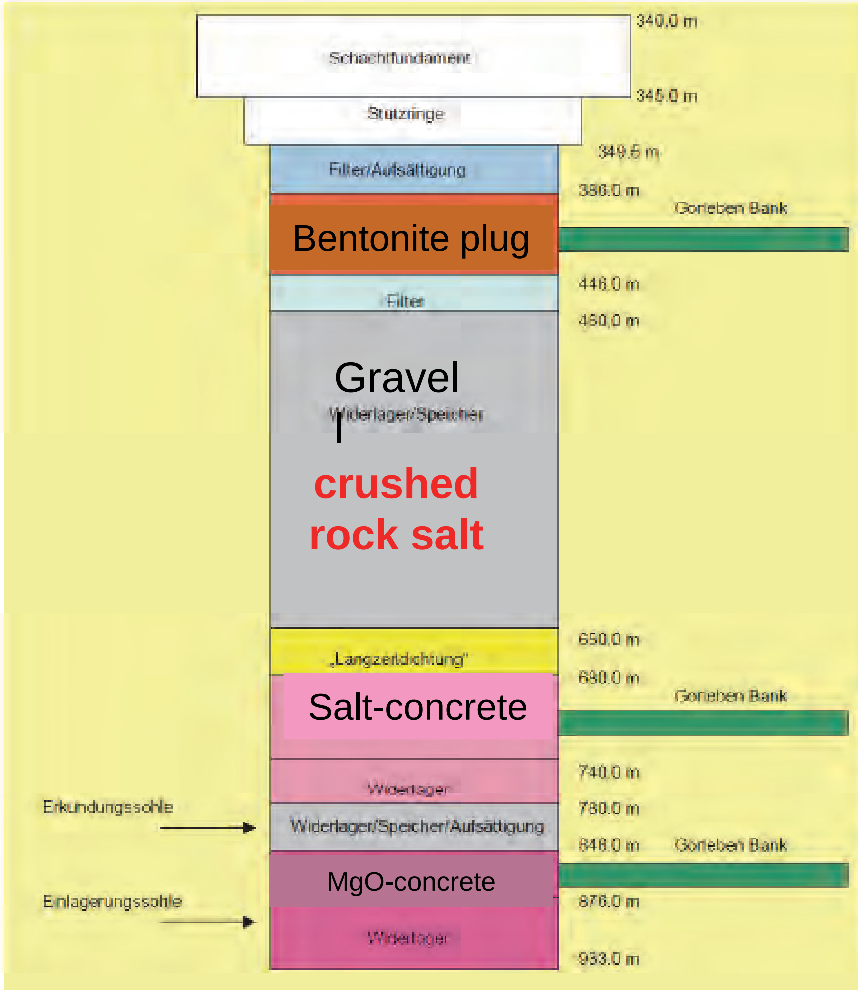
1. Concrete Dome
2. Filter and seal layer
3. Backfill zone



DOPAS Experiment 4: Posiva's deposition tunnel plug (POPLU) in Finland



DOPAS Experiment 5: ELSA shaft seal Experiment in Germa



The main outcome of the DOPAS project will be the full scale demonstrators

- **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 design basis for 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.**

DOPAS experiments will demonstrate:

- **Safe and feasible construction of plugs in tunnels**
- **Manufacturing of plugs and seals components.**
- **Efficient installation of plugs and seals.**
- **Enforcement of accurate control methods for evaluating results versus design basis.**
- **Verification of design compliance to design basis.**

Správa úložišť radioaktivních odpadů Radioactive Waste Repository Authority

Svensk Kärnbränslehantering AB

Galson Sciences Ltd

DBE TECHNOLOGY GmbH

Nuclear Decommissioning Authority

Joint activities in DOPAS

- Selection and excavation of plug locations (EPSP, DOMPLU, POPLU)
- Development of low pH shotcrete (FSS, EPSP)
- Development of low pH concrete (FSS, DOMPLU, POPLU)
- Use of low pH grouting material (DOMPLU, POPLU)
- To specify proper bentonite components in the plug (DOMPLU, FSS, EPSP, ELSA)
- Development of installing methods for bentonite pellets (FSS, EPSP)
- Performance assessment

From proper plug location

To the ready plug

Work in different scale

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© ANDRA

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-high enough density
-emplacement challenges
-efficiency
-quality assurance and control

Parameters to be studied for specifications of bentonite components

- Hydraulic and gas (H_2) permeability
- Porosity
- Swelling pressure
- Retention curve
- Thermal conductivity and heat capacity

Low pH concrete from laboratory to the field

© VTT

© SKB

© ANDRA

Parameters to be studied for specifications of cementitious components

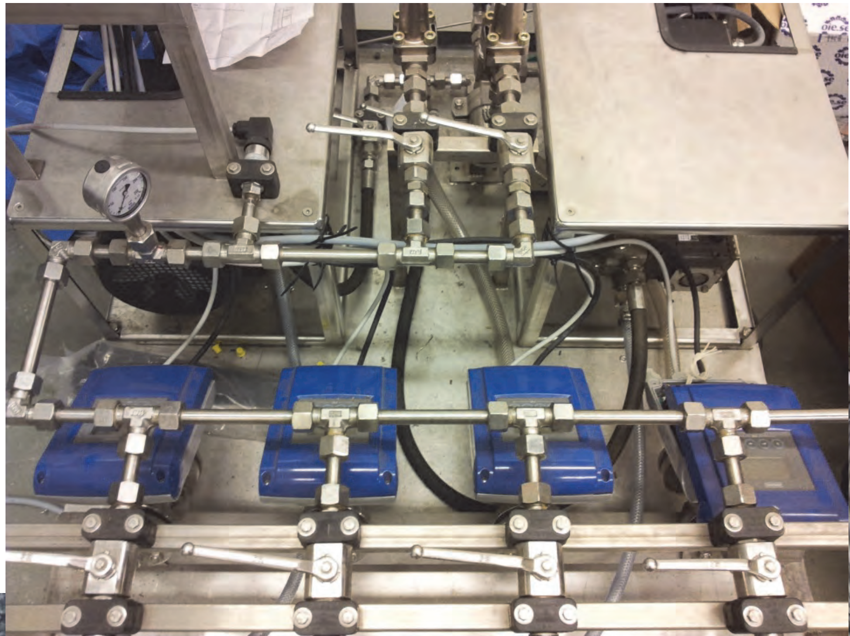
- Fresh mass properties
    - Slump flow
    - Rheological properties
    - Workability over time
    - Air content
    - Density
    - Vibration limit
    - Heat of hydration

Concrete properties after curing

- Hardened state properties
  - Hydraulic and gas (H_2) permeability
  - Porosity
  - Strength properties
  - Thermal conductivity and heat capacity
  - Leachate pH and composition of the cement water
  - Modulus of elasticity
  - Shrinkage
  - Chloride and sulphate resistance

Plug behaviour

© SKB



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New increased information and knowledge about:

- How to locate suitable place for plugs
- Achievable densities for bentonite components
- Construction of plugs (approved materials, logistics, all supporting activities)
- How to monitor the plug and seal behaviour
  - plans ready for POPLU and EPSP
  - ongoing monitoring for DOMPLU
- Fulfilment of requirements

Main targets for 2014

- Design basis and reference designs for plugs to be demonstrated are published
- Design specifications are ready
- FSS, EPSP and POPLU plugs are installed
- Monitoring will produce the information on plug behaviour DOMPLU
- The performance testing of the installed plugs has been initiated
- The work with performance indicators are ongoing

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 Union's European Atomic Energy Community's (Euratom) Seventh Framework Programme FP7/2011-2013, under Grant Agreement No. 323273 for the DOPAS project


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