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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
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).

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.

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www.posiva.fi/dopas
Appendix 3

DOPAS Demonstration of Plugs and Seals
Posiva Plug Experiment POPLU at URCF ONKALO
Petri Köhö & Johanna Hansen, Posiva Oy, Erika Holt, VTT

POPLU Objectives and Schedule

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

The POPLU experiment includes the development of the detailed design for the deposition tunnel and plug and the methods necessary for the construction and follow-up of the plug’s performance. This includes:
- selection and excavation of plug site location
- modelling of the expected performance 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 materials 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 construction, as well as during accelerated pressurization testing
- evaluating the water tightness 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 RUS 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 of 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 3.5 metres wide. The plug is constructed in two parts, using low-pH concrete around stainless steel reinforcement.

Injection grouting and hermetic sealing will be used around the circumference of the plug to improve water tightness. 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, maintaining 100 years of service life while the central tunnel remains open during facility operation.

Plug and backfill performance is monitored using approximately 100 sensors, assessing pressure, temperature, humidity, strain and displacement. Sensors are fed to the neighboring 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 submitted to EE (Expert Evaluation) process to develop it further.

POPLU Location

The POPLU deposition tunnel and 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 special fuel repository.

Two parallel tunnels of diameter 3.5 metres and length of approximately 25 metres 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 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 fulfills the requirements set for the plug location. The other tunnel shall serve as the pressurization area and instrumentation and monitoring tunnel for the experiment.

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.
The FSS Experiment (Full Scale Seal)

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 (backfilling and sealing) policy is considered as instrumental in serving both technical and social objectives. It is not only essential to unpin 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

Groove filled with swelling clay

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

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

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 entrance of the drift and filled with bentonite at direct contact with the argillite, providing an EOC cut-off. The bentonite swelling pressure in the groove should be around 3 to 5 MPa.

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

1) Demonstrating the industrial capacity to satisfactorily replace large volumes of low pH concrete (shotcrete & cast concrete). Low pH value is equal or less than 9.
2) Demonstrating the industrial capacity to satisfactorily replace large volumes of swelling clay (bentonite) at a satisfactory specific gravity, value.
3) Defining the operational constraints linked to employment activities and compatible with the mechanical or hydraulic properties allocated to the seal components.
4) Defining and operating the conditioning means necessary to check the compatibility of the work during embankment operations.
5) Defining and operating the conditioning means necessary to check the compatibility of the work after embankment operations.

The FSS experiment is completed by a forced embankment test, which is conducted with the same swelling clay material in a lower scale (300 m³) embankment, also carried out within the DOPAS Project. The main milestones are:

1) Studies, formulations & characterization of materials; mid 2012-end 2013.
2) Construction of seal components; end 2013 - end 2015.

The bentonite swelling core construction challenges:

- Some 750 m³ of pellets/precipitates are 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 annular recesses. Its segregation of pellets and powder is allowed, height of core is up to 13 m with a natural stop of some 10°C.
- Observation windows will be positioned at relevant places on the test box frame, to check segregation, radon variants, emissions, brittleness of clays.

The low pH concrete containment plug construction challenges: some 230 m³ for each plug (cast concrete and shotcrete); maximum cracking and shrinkage, limited curing temperature, minimum residual vacuum in annular 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 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.

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

Andera acknowledges the scientific support of NAGRA and the technical contribution of the consortia of companies in charge of implementing FSS: SNF, TDF, CEA-LECRA, Lavoisier-MPC.

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 523273 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 Åspö HRL

Pär Gramm
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 160 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 of the concrete dome leakage can be identified 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 for the 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 flow to ensure that backfill and buffer materials remain in place and do not erode.

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

Åspö Hard Rock Laboratory in Oskarshamn

The DOMPLU test is carried out at Åspö 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 control boreholes were blasted in a separate round.

The test tunnel correspond to the reference design of SKB's deposition tunnels in crystalline rock: 4.9 x 4.2 m (905-5v).

3. Test site

Three 21-m-long 9200 mm bore holes for lead-through pipes to the monitoring niche:

- Two for sensor casing (out)
- One for water pressurization pipe (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 delimitter

7. Injection grouting tubes

8. Cooling system and sensors in the dome

9. Casting of the unreinforced concrete dome

- Ø 8,5 m
- Filled w/ low-cp SCC "B2000"

10. The Concrete Dome Plug

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 plugs 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 partly funded by the Euratom's Seventh Framework Programme and European nuclear waste management organisations.

The DOMPLU installation at Åspö 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 Programmes FP7/2007-2013 under grant agreement no. 323273, 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

DOPAS is a four year (2012-2016) integrated project, co-funded 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 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 FSS experiment conducted at Saint-Dizier, near the Bure Laboratory (URL) is a demonstration of plugs and seals. The concept involves a specific plug designed to achieve a specific barrier.

Main milestones:

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,

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 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.
- 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.

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.

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).

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.

**FULL-SCALE DEMONSTRATION OF PLUGS AND SEALS**

Appendix 7

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)
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.](image-url)
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.
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 summittal 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 summittal 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 summittal 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 summittal 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.
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 Åspö 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 Åspö 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
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 m² (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 m².
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.

**RESULTS**

**Structural Designs**

The POPLU plug will 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”  | “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, m²/s     | (min)        | 2.1*10⁻¹²     | 2.8*10⁻¹²     | 10-20*10⁻¹²    |                |
| pH of leachate at 90 days      | < 11         | 11.4 / 10.3   | 11.4 / 10.3   | 11.4 / 10.3    | >12.5          |

*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.**

<table>
<thead>
<tr>
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<th>DOMPLU, Sweden</th>
<th>POPLU, Finland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill &amp; seal block</td>
<td>500 x 571 x 300 mm (180 kg)</td>
<td>550 x 470 x 330 mm</td>
</tr>
<tr>
<td>dimensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backfill material &amp; dry</td>
<td>Asha, small bricks</td>
<td>Friedland clay,</td>
</tr>
<tr>
<td>density</td>
<td></td>
<td>1990-2070 kg/m³</td>
</tr>
<tr>
<td>Seal layer, block material &amp; density</td>
<td>MX-80 (w 17%), compaction by 20 MPa to 1680 kg/m³</td>
<td>MX-80 (17% w), &gt;1400 kg/m³</td>
</tr>
<tr>
<td>Pellet fill material &amp; dry density</td>
<td>MX-80, &gt;900 kg/m³</td>
<td>MX-80, 900-1100 kg/m³</td>
</tr>
</tbody>
</table>

**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].
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.

REFERENCES


ACKNOWLEDGEMENT

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. We thank the Euratom for their support.
EU-Projekt DOPAS
(Full Scale Demonstration of Plugs and Seals)

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)

Implementing Geological Disposal of Radioactive Waste Technology Platform

Technology Platform Exchange Forum
Exchange of information, questions, discussion & advice.

All stakeholders in Europe endorsing the Vision
(e.g. waste management organisations, industry, research organisations, research centres, academia, technical safety organisations, non-governmental organisations, ...)

Executive Group & TP Secretariat

Working groups with specified mandates, e.g.

Development of Strategic Research Agenda
Co-ordination with EC Programme

Deployment: RD&D topic orientated projects
Support functions: e.g. education and training and KM

Collaborative working projects and activities, e.g.

Technology Platform Development & Implementation

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

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<td>WP3</td>
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**Experiment 1:** ESS (BURE.FR)
**Experiment 2:** EPSP (URC, Josef, CZ)
**Experiment 3:** DOMPLU (Aspö, SE)
**Experiment 4:** POPUL (OMALO, FI)
**Experiment 5:** ELSA (incl. DE)

ELSA-Workshop, 19. September 2012, Peine
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*
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.
**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).

![Design drawing of the full-scale demonstration DOMPLU](image)

*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

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**IGD-TP Pilot Project Plugging & Sealing**

**BMWi contribution ELSA: RD&D-project on shaft sealing in salt and clays**

**ELSA subproject 1**
Check state-of-the-art, compile boundary conditions and requirements for shaft seals in salt and clay

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

**ELSA subproject 3**
construction and full-scale testing of shaft sealing components for salt and clay repositories

**Approvals and Licensing**

**IGD-TP supporting national R&D-projects**

**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 hostrocks damage, re-compaction and sealing capacity

**R&D- Project PASS**
Performance assessment of sealing systems

**European RD&D Project DOPAS**
Demonstration of Plugging and Sealing

ELSA-Workshop, 19. September 2012, Peine
Deutsche Beiträge zum Projekt DOPAS und ihre Verknüpfung mit dem Projekt ELSA

Material properties (THM) ➞ Salt concrete ➞ EDZ
Material properties (CH) ➞ Salt concrete
Material properties (THM) ➞ EDZ ➞ Backfill
System behaviour ➞ Process-level Modelling ➞ TSPA-level Modelling

Requirements defined by current R&D work (Gorleben - Preliminary Safety Analysis)
Auslegungsrechnung mit LOPOS für Verschlußelemente (Normalentwicklung)

Quelle: D. Buhmann, AP9 Rechnungen LOPOS, 4. VSG Workshop, 09.–11.05.2011
Randbedingung: Über dem obersten Dichtelement steht eine 386 m lange Wassersäule.
Schachtverschluss intakt: Lösungsmengen im unteren Bereich
Quelle: D. Buhmann, AP9 Rechnungen LOPOS, 4. VSG Workshop, 09.–11.05.2011

VERS Gorleben; Schachtverschluss; gestrichelt: Porenvolumen

- Widerlager 2
- Salzbeton
- Widerlager 3
- Schotter 2
- Sorelbeton
- Restgrube

300a
1740a

31.01.2012
Darstellung zum analytischen Modell der Korrosion einer Abdichtung mit ALZ

Quelle: GRS-A-3454 (Sicherheitsanalyse ERAM)

⇒ Materialparameter der ALZ nach 300a?

Korrodierter Teil:
\[ \phi_1, \ k_1, \ \mu_1 \]

Intakter Teil:
\[ \phi_0, \ k_0, \ \mu_0 \]

Abdichtungsbauwerk

\[ I \]

\[ L \]

\[ F \]

\[ F_E \]
Ergebnisse zur Porositätsentwicklung in der ALZ im Bereich des 2. Dichtelements

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

\[ \Delta \phi = 0,1\% \]

\[ K_{ALZ} = 10^{-17} \text{ bis } 10^{-20} \text{ m}^2 \]

Primärspannungsniveau OK (-685 m) bei \( \sim 14.5 \text{ MPa} \)

\[ \sigma_{\text{min}} = 8 \text{ MPa} \]

\[ \Delta \sigma_{\text{min}} = \sim 5.6 \text{ MPa} \quad (t_{\text{SchV}} = 1740a) \]

\[ \sigma_{\text{min}} > 4.4 \text{ MPa} \quad (t_{\text{SchV}} \sim 53a) \]

\[ \Delta \phi = 0,1\% \]

ELSA-Workshop, 19. September 2012, Peine
Ansätze zur Beschreibung der Porositäts-Permeabilitätsbeziehung

Quelle: Ergebnisse der Literaturstudie im Rahmen VIRTUS

Porositäts-Permeabilitäts-Beziehung mit Minimalspannungsabhängigkeit /ALK 08/, /POP 07/

\[ \Delta \phi = 0.1\% \]
Beurteilung des EDZ-Einflusses auf das Verschlussystem 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

|------|------|------|------|------|------|------|

**IGD-TP Pilot Project Plugging & Sealing**
BMWi contribution ELSA: RD&D-project on shaft sealing in salt and clays

- **ELSA subproject 1**
  Check state-of-the-art, compile boundary conditions and requirements for shaft seals in salt and clay

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

- **ELSA subproject 3**
  Approval and Licensing
  Construction and full-scale testing of shaft sealing components for salt and clay repositories

**IGD-TP supporting national R&D projects**

- **R&D Project THM**
  Mechanical-hydraulic qualification of MgO-end cement based salt concrete in interaction with compacted EDZ in a salt repository

- **R&D Project HC**
  Chemical-hydraulic qualification of MgO-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

**European RD&D Project DOPAS**
Demonstration of Plugging and Sealing

ELSA-Workshop, 19. September 2012, Peine
UJV Rez Research activities in the field of deep geological disposal: from lab to the field.

Václava Havlová


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 repositories
- Use of nanomaterials for radionuclide retention
- CO₂ 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
Activities in the real scale

- **Underground research lab Josef**
  - testing of in-situ methodologies and up-scaling (corrosion study, permeability 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 (O₂ < 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

- Ø 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
    - $\phi$ 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 Roklé)

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

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

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.
CONCLUSIONS

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

- However, work in situ is expensive and time-consuming, needs infrastructure and not every time RN can be used.

www.ujv.cz
DOPAS

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

© ANDRA
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
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
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<td>POPLU design</td>
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[Graphical representation of task timeline]
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.
FSS – The Full Scale Seal Experiment
WM’2013

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

J.M. Bosgiraud et al.  February 2013  WM’2013
Cigéo Background : Andra’s Industrial Center for Geological Disposal in the Bure area (Conceptual view - ref. Dossier 2009)

HLLW Disposal Cell

ILLW Disposal Cell

DIP.DIR.13.0040
J.M. Bosgiraud et al.

February 2013

WM'2013
Background: Hydrogeological concept of Meuse/Haute-Marne Sector

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<th>Hydrogeologic units</th>
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<td>Portlandian</td>
<td>$10^{-7}$-$10^{-5}$</td>
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<tr>
<td>Kimmeridgian</td>
<td>$10^{-12}$</td>
<td>13</td>
</tr>
<tr>
<td>Oxfordian</td>
<td>$10^{-9}$-$10^{-10}$</td>
<td>8-18</td>
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<tr>
<td>Callovo-Oxfordian</td>
<td>$10^{-13}$</td>
<td>14</td>
</tr>
<tr>
<td>Dogger</td>
<td>$10^{-10}$-$10^{-11}$</td>
<td>8-12</td>
</tr>
<tr>
<td>Lias</td>
<td>$10^{-12}$</td>
<td>12</td>
</tr>
<tr>
<td>Rhaetian</td>
<td>$10^{-7}$</td>
<td>15</td>
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<tr>
<td>Middle Triassic</td>
<td>$10^{-12}$</td>
<td>7</td>
</tr>
<tr>
<td>Early Triassic</td>
<td>$10^{-7}$</td>
<td>15</td>
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Clay Host rock: Callovo-Oxfordian formation

Transposition zone

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

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« 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
- 3D 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
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

J.M. Bosgiraud et al.  February 2013  WM’2013
Practical applications for FSS Design Basis

3 D view of the FSS experiment

J.M. Bosgiraud et al. February 2013 WM’2013
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 m³ 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.
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.

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FSS Experiment Preparation Status

- Characterization & formulations of bentonitic and cementitious materials
- Construction of the drift model (experiment box)
- Development of commissioning means
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
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%)
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,
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
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
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)
DOPAS Experiment 1: Full Scale Seal (FSS) in France

© ANDRA
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

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

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DOPAS Experiment 5: ELSA shaft seal Experiment in Germany

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

Work in different scale

Appendix 14
Parameters to be studied for specifications of bentonite components

- Hydraulic and gas (H₂) permeability
- Porosity
- Swelling pressure
- Retention curve
- Thermal conductivity and heat capacity
Low pH concrete from laboratory to the field
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 (H₂) 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
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!

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