EUROPEAN COMMISSION

Community Research

DOPAS (Contract Number: FP7 - 323273)

Deliverable n°7.3

D7.3 DOPAS 2016 Proceedings

Edited by *Posiva Oy, Johanna Hansen*

Start date of project: 01/09/2012 Duration: 48 Months

Scope	Deliverable n°7.3 (WP7)	Version:	1.0
Type/No.	Report	Total pages	2+ 45
		Appendixes	
Title	D7.3 Organisation and publication of an international seminar/ conference in 2016	Articles:	14

ABSTRACT:

This Document is the public version of DOPAS 2016 Proceedings

RESPONSIBLE:

Posiva Oy, Johanna Hansen

http://www.posiva.fi/en/dopas

REVIEW/OTHER COMMENTS:

Reviewed by consortium by the 31st of August 2016

APPROVED FOR SUBMISSION:

by Johanna Hansen 31.8.2016

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

Table of Contents

http://www.posiva.fi/en/dopas

1. DOPAS 2016 FOREWORD

The four year's of research, development and demonstrationr work within DOPAS (Full scale demon stration of Plugs and Seals) Project was summarised in the international DOPAS 2016 Seminar held on May 2016 25th-27th in Turku and Olkiluoto, Finland.

About DOPAS Project

The Full-Scale Demonstration of Plugs and Seals (DOPAS) Project work was jointly funded by the Euratom Seventh Framework Programme of the European Commission (EC) and by European nuclear waste management organisations (WMOs). The DOPAS Project was undertaken during the period from September 2012 to August 2016. Fourteen European WMOs, research and consultancy organisations from eight European countries participated in the DOPAS Project. The Project was coordinated by Posiva Oy (Finland). A set of five full-scale experiments, materials research projects, and performance assessment studies on plugs and seals for geological repositories were undertaken in the course of the Project.

The DOPAS Project was initiated by the Implementing Geological Disposal of Radioactive Waste Technology Platform's (IGD-TP's) Executive Group as part of the deployment of the IGD-TP's Strategic Research Agenda.[1] Plugs and sealing structures are part of the operating modes of the disposal operations or of their closure. The development work is an important part of in industrialising these components of the repository on the way to achieving the IGD-TP vision ("Vision 2025") that *"by 2025, the first geological disposal facilities for spent fuel, high-level waste (HLW) and other long-lived radioactive waste will be operating safely in Europe" (IGD-TP*, 2009).

The RD&D work done is also needed to support the future disposal activities beyond 2025 and so the aim of the DOPAS project was to produce a roadmap and describe the procedures that could be beneficial for those organisations that are in the starting phase in their disposal programme development. However, the work contained in DOPAS is not limited to desk studies but rather involves practical learning using for example, full-scale demonstrations and related work phases and their iteration. This knowledge can be adopted for different development phases (conceptual design, basic design and detailed design) of repositories.

Main Purpose of Plugs and Seals

A variety of plugs and seal structures in different stages of operation and closure of premises is required for the future repositories in different host rock environments. In a generic sense, however, deposition tunnel plugs are needed as part of the operational phase in most geological media as their main functions are to prevent extrusion of the swelling backfill out from the deposition tunnel and prevent the possible formation of piping and erosion channels in the backfill resulting from groundwater inflows during the early stages of repository evolution. Later, either during the operational phase or in connection with the required drift closure, seals or plugs will be needed to isolate the disposal areas from the underground space and tunnels that are temporarily open during the disposal operations. Their mechanical and hydraulic properties are planned to limit the hydraulic flow or to support the maintenance of water

[1] IGD-TP (2011). Strategic Research Agenda. http://www.igdtp.eu/

tightness of the excavated underground openings. During the final closure of access routes and shafts into the disposal facility, plugs are also needed to keep the hydrogeological conditions stable. In addition, plugs are needed to seal the investigation holes that are not kept open for monitoring purposes in the vicinity of the repository.

In practice the plugs have different functions at different periods of their lifetime, and that makes the design of the structures challenging. During the whole assessment period of the repository, all plugs need to be chemically stable and fit together with the host rock where they will be emplaced. The (deposition tunnel) plugs that were further developed within DOPAS Project are first needed for industrial production in the mid-2020s in Posiva's disposal facility and at different times after this for repositories planned by other countries. The DOPAS Project has provided lessons learned and practical aspects for their production and these experiences can be utilised for different repository components.

The full-scale Demonstrations Of Plugs And Seals with related research and development activities culminated in a three-day seminar DOPAS 2016. The first two days (Wednesday and Thursday) were held in Turku on 25 and 26.5.2016 and the third day (Friday, 27.5.2016) was held in Olkiluoto, both in west of Finland. The location of this seminar was selected due the fact that one of the DOPAS experiments was constructed at the nearby Olkiluoto site. The field trip on 27 May 2016 allowed for a site visit and an opportunity to hear more about the POPLU experiment and to see the crystalline host rock formation, where the first purpose-built spent fuel repository will be constructed. The DOPAS 2016 Seminar was originally planned to be held jointly with IGD-TP, but since the DOPAS 2016 was a topical seminar for plugs and seals it was arranged independently, but using IGD-TP as advertisement route to reach all the European WMO's and other participants in the IGD-TP.

What did the DOPAS 2016 seminar give to the audience?

The DOPAS 2016 seminar program was drawn up in such a way that that the lessons learned can be used not only in the development of plugs and seals structures, but also more widely in the demonstration of repository components and structures, and even in other industries.

Still the main target of the seminar was to present the main outcomes from DOPAS Project and this was done in phases. The DOPAS 2016 Seminar was structured to present summary conclusions from the DOPAS Project at the start of the Seminar. In this way, the audience was introduced to key conclusions at the start, which allowed the context of more detailed information to be understood ahead of time. The seminar also benefitted from Panel Sessions in which the experiment leaders were able to provide the benefit of their experience direct to the seminar participants. And, in particular they were able to address audience questions that were submitted to an electronic bulletin board via the internet during the meeting. The Seminar Programme Committee also invited specific presentations from outside of the DOPAS Project to bring in the experiences in the design of plugs and seals f from the other industries e.g. oil and gas, mining, and carbon sequestration.

The seminar allowed people to meet and to exchange knowledge and experiences about the plugs and seals or demonstration related work. The background of the audience was from various waste management organisations to consultants and other organisations, which have commenced or will initiate such demonstrations. Specifically, the 110 participants included representatives from waste management organisations, from technical support organisation's

(TSOs) working with development issues, from universities with both professors and researchers and post-graduate students, design engineers and materials developers, companies producing cementitious and bentonite materials, and safety authorities. Over 50 organisations from sixteen countries, mostly from Europe, participated to the DOPAS 2016 seminar. The programme was well-balanced and the participant expectations were well fulfilled as confirmed by their feedback given for seminar planning team.

DOPAS 2016 Seminar Structure

The DOPAS 2016 Seminar programme was organized as follows:

- During the opening session, the general level background into the demonstrations and status of European research programme was provided as basic introductions to the DOPAS Project. This included presentation of the main achievements and lessons learned by the DOPAS Coordinator, Experiment leaders and Work Package leaders for related demonstration (DEM) and research and technology development (RTD) work. The first afternoon was used for gathering information from the experiences or experiments on plugs and seal developed and implemented for other the geological disposal uses including their state of the art in development areas related to the plugs and seals.
- The second day was initiated by more detailed information on plug and seal design, on host rock and material issues, and on the long-term safety related aspects and how the plugs and seal are treated in the safety case. At the end of the second day, the DOPAS Training Workshop was presented and the Finnish nuclear safety authority highlighted the experiences from supervising the spent fuel disposal programme of Posiva and follow-up procedures of the POPLU experiment. The second day was ended with a panel discussion, where the experiment leaders could answer the questions posted by seminar audience during the two seminar days.
- The third day involved an Olkiluoto site visit for the two busloads of preregistered seminar participants. This visit provided an opportunity to hear more details about one of the DOPAS experiments, POPLU plug. POPLU involved construction and testing of a concrete plug in a demonstration area in the underground rock characterisation facility ONKALO that will be integrated into the underground disposal facility for spent nuclear fuel in, located at Eurajoki, Finland, that has been awarded a construction license in November 2015.

DOPAS 2016 Seminar planning team wishes to thank the European Commission, the waste management organisations, and the independent seminar rapporteur Professor Emeritus Pierre Berest from Ecole Polytechnique, Palaiseau, France. Further thanks goes to all DOPAS 2016 Seminar participants.

http://www.posiva.fi/en/dopas

2. DOPAS 2016 PROGRAMME

DAY ONE, Wednesday 25 May 2016, Turku Radisson Blu

Session 1: Opening ceremony and keynote presentations highlighting European cooperation in demonstrating repository feasibility **Chair: Johanna Hansen** **Co-chair: Matt White**		
Time	Title	Authors
0900-0910	Opening of the DOPAS 2016 Seminar	Johanna Hansen, DOPAS coordinator *Posiva Oy, Finland*
0910-0920	Welcome from Posiva	Erkki Palonen, Corporate Adviser *Posiva Oy, Finland*
0920-0940	Programme status in radioactive waste management and strategic evolution in support to R&D	Christophe Davies, Project Officer *European Commission, Belgium*
0940-1010	Role of demonstrations for a spent fuel repository concept	Monica Hammarström, Director, International Relations *Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden*
1010-1040	Overview of the DOPAS Project	Johanna Hansen, DOPAS Coordinator *Posiva Oy, Finland*
1040-1105	**BREAK**	

Session 2: Key conclusions from the DOPAS Project (Part 1) **Chair: Marjatta Palmu** **Co-chair: Jan-Marie Potier**		
Time	Title	Authors
1105-1110	Introduction	
1110-1130	Objectives and main outcomes from the DOPAS full-scale demonstrators: FSS, EPSP, DOMPLU, POPLU and ELSA	DOPAS Experiment leaders in Panel Régis Foin[1], Jiri Svoboda[2], Pär Grahm[3], Petri Koho[4] and Michael Jobmann[5] *[1]Andra,France,* *[2]Czech Technical University, Czech Republic* *[3]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden* *[4]Posiva Oy, Finland* *[5]DBE TECHNOLOGY GmbH (DBE TEC), Germany*
1130-1200	Design basis of plugs and seals	Matt White[1], Behnaz Aghili[2] and Slimane Doudou[1] *[1]Galson Sciences Limited, United Kingdom* *[2]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden*
1200-1230	Progress on the design and implementation of plugs and seals in the DOPAS Project	Jean-Michel Bosgiraud[1], Matt White[2] and Slimane Doudou[2] *[1]Andra, France* *[2]Galson Sciences Limited, United Kingdom*
1230-1400	**LUNCH AND POSTER SESSION**	

Session 2: Key conclusions from the DOPAS Project (Part 2) **Chair: Jan-Marie Potier** **Co-chair: Marjatta Palmu**		
Time	Title	Authors
1400-1425	Performance assessment of plugs and seals	André Rübel, *Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Germany*
1425-1450	Application of lessons learned during the DOPAS Project to less advanced waste management programmes – Case study: Radioactive Waste Management Ltd	Dean Gentles[1], Wolfgang Kickmaier[2], Matt White[3], Slimane Doudou[3] and Alastair Clark[2] *[1]Radioactive Waste Management Limited, United Kingdom* *[2]McCombie, Chapman, McKinley Consulting, Switzerland* *[3]Galson Sciences Limited, United Kingdom*
1450-1515	**BREAK**	
Session 3: Plugging and sealing experiences from other applications **Chair: Dean Gentles** **Co-chair: Jiri Svoboda**		
Time	Title	Authors
1515-1520	Introduction	
1520-1540	Treatment of seals and sealing systems in total system performance assessment	Mark Crawford[1], Dan Galson[1] and Lucy Bailey[2] *[1]Galson Sciences Limited, United Kingdom* *[2]Radioactive Waste Management Limited, United Kingdom*
1540-1600	Full-Scale tunnel and shaft seals: Tunnel Sealing Experiment (TSX) and Enhanced Sealing Project (ESP) at the Underground Research Laboratory (URL) in Canada	D.A.Dixon[1], D.Priyanto[2], J.B.Martino[2], P.Korkeakoski[3], R.Farhoud[4] and K.Birch[5] *[1]Golder Associates Ltd., Canada;* *[2]Canadian Nuclear Laboratories, Canada;* *[3]Posiva Oy, Finland;* *[4]Andra, France;* *[5]Nuclear Waste Management Organization (NWMO), Canada,*
1600-1620	The Gas-Permeable Seal Test in the Grimsel Test Site	Thomas Spillmann[1], B. Lanyon[2], R. Senger[3], Paul Marschall[1] and Jörg Rüedi[4] *[1]Nagra, Switzerland* *[2]Fracture Systems, United Kingdom* *[3]Intera, USA* *[4]Pöyry, Switzerland*
1620-1640	Experiences from an *in situ* test site for a sealing element in shafts and vertical excavations in rock salt	Beatrix Stielow[1], Jürgen Wollrath[1], Matthias Ranft[1], Monika Kreienmeyer[2], Thomas Schröpfer[2] and Jan Bauer[2] *[1]Bundesamt für Strahlenschutz (BfS), Germany* *[2]Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH (DBE), Germany*

1640-1700	Development of a UK approach to sealing deep site investigation boreholes: knowledge transfer from other industries	Francois Groff[1], Nick Jefferies[2] and Simon Norris[3], *[1]Schlumberger, United Kingdom* *[2]Amec Foster Wheeler, United Kingdom* *[3]Radioactive Waste Management Limited, United Kingdom,*
1700-1715	Posiva plans and experiences for borehole closure	Taina Karvonen[1] and Johanna Hansen[2] *[1]Saanio & Riekkola Oy, Finland* *[2]Posiva Oy, Finland*
1715-1730	Conceptual sealing strategy and initial performance assessment for the Chandler Storage and Isolation Facility	Steve Reece *Tellus Holdings, Australia*

DAY TWO Thursday 26 May 2016, Turku Radisson Blu

Session 4: Design, siting and construction of plugs and seals (Part 1) **Chair: Jean-Michel Bosgiraud** **Co-chair: Behnaz Aghili**		
Time	Title	Authors
0810-0815	Introduction	
0815-0835	Initial plug and seal design for the Dutch repository concept	Philip J. Vardon[1], Jiao Yuan[1], Michael A. Hicks[1], Yajun Li[1] *[1]Geo-Engineering Section, Delft University of Technology, the Netherlands*
0835-0855	Development and performance of various low-pH cementitious materials for plugs and seals in geological disposal demonstrations (DOPAS Project)	Erika Holt[1], Markku Leivo[1], Tapio Vehmas[1], Jari Dunder[2], Elina Paukku[3], Behnaz Aghili[4], Jiří Svoboda[5], Petr Večerník[6], Xavier Bourbon[7], Sandrine Bethmont[7], Jean-Michel Bosgiraud[7] and Matt White[8] *[1]VTT Technical Research Centre of Finland Oy, Finland* *[2]Posiva Oy, Finland* *[3]Sweco Rakennetekniikka Oy, Finland* *[4]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden* *[5]Czech Technical University, Czech Republic* *[6]ÚJV Řež a.s, Czech Republic* *[7]Andra, France* *[8]Galson Sciences Limited, United Kingdom*
0855-0915	FSS (Full-Scale Seal) Experiment transposition from laboratory tests to full-scale emplacement reality (DOPAS Project)	Regis Foin and Jean-Michel, Bosgiraud *ANDRA, France*
0915-0930	Preparations before experiments - production for plug locations for DOMPLU and POPLU (DOPAS Project)	Sanna Mustonen[1] and Pär Grahm[2] *[1]Posiva Oy, Finland* *[2]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden*
0930-1000	**BREAK**	

Session 4: Design, siting and construction of plugs and seals (Part 2) **Chair: Jean-Michel Bosgiraud** **Co-chair: Behnaz Aghili**		
Time	Title	Authors
1000-1020	DOMPLU plug filter and seal design, construction and results (DOPAS Project)	Pär Grahm[1] and Mattias Åkesson[2] *[1]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden* *[2]Clay Technology AB, Sweden*
1020-1035	Bentonite based materials for the Full-Scale Emplacement (FE) experiment: design and production steps	Benoit Garitte[1], Herwig R. Müller[1], Hanspeter Weber[1], Frank Ooms[2], Martin Holl[3] and Sébastien Paysan[4] *[1]National Cooperative for the Disposal of Radioactive Waste (Nagra), Switzerland* *[2]CEBO, The Netherlands* *[3]JRS, Germany* *[4]Laviosa MPC, France*
1035-1050	Horizontal bentonite backfilling and concrete plug for the Full-Scale Emplacement (FE) experiment at the Mont Terri URL: requirements, design, instrumentation and emplacement	Benoit Garitte[1],Sven Köhler[1], Herwig R. Müller[1], Toshihiro Sakaki[1], Tobias Vogt[1], Hanspeter Weber[1],Martin Holl[2], Michael Plötze[3], Volker Wetzig[4], Moreno Tschudi[5], Heinz Jenni[6], Tim Vietor[1] Eric Carrera[7], Gerd Wieland[7], Sven Teodori[8], José-Luis García-Siñeriz Martínez[9] and Frank Jacobs[10] *[1]National Cooperative for the Disposal of Radioactive Waste (Nagra), Switzerland* *[2]J.Rettenmaier & Söhne, Germany* *[3]ETH, Switzerland* *[4]VersuchsStollen Hagerbach, Switzerland* *[5]Belloli, Switzerland* *[6]Rowa, Switzerland* *[7]Amberg Engineering, Switzerland* *[8]ÅF-Consult, Switzerland* *[9]AITEMIN, Spain* *[10]TFB, Switzerland*
1050-1110	Hydro-mechanical and chemical-hydraulic behaviour of different types of shaft sealing materials (DOPAS Project)	Oliver Czaikowski, Kyra Jantschik, Helge C. Moog, Klaus Wieczorek and Chun-Liang Zhang *Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Braunschweig, Germany*
1110-1130	Performance of Czech Bentonite Material in the Plug in Geological Disposal Demonstrations.	Večerník Petr[1], Vašíček Radek[2], Šťástka Jiří[2],Trpkošová Dagmar[1], Havlová Václava[1], Hausmannová Lucie[2], Smutek Jan[2], Svoboda Jiří[2] and Dvořáková Markéta[3] *[1]ÚJV Řež,; Czech Republic* *[2]Czech Technical University, Czech Republic* *[3]SURAO, Czech Republic*
1130-1255	**LUNCH AND POSTER SESSION**	

Session 5: Performance of plugs and seals **Chair: André Rübel** **Co-chair: Pär Grahm**		
Time	Title	Authors
1255-1300	Introduction	
1300-1320	Instrumentation and monitoring systems for evaluation of plug responses in geological disposal demonstrations (DOPAS Project)	Erika Holt[1], Edgar Bohner[1], Torbjörn Sandén[2], Richard Malm[3], Jaroslav Pacovsky[4], Jiri Svoboda[4] and Matt White[5] *[1]VTT Technical Research Centre of Finland Oy, Finland* *[2]Clay Technology AB, Sweden* *[3]Sweco AB, Sweden* *[4]Czech Technical University, Czech Republic* *[5]Galson Sciences Limited, United Kingdom*
1320-1340	REM (Resaturation test at metric scale): Preliminary hydraulic simulation (DOPAS Project)	Antoine Pasteau[1], Jacques Wendling[1], Nathalie Conil[1] and Claude Gatabin[2] *[1]Andra DRD/EAP, France* *[2]CEA/LECBA, France*
1340-1400	Integration Of demonstrator activities in performance assessment: analysis of processes and indicators (DOPAS Project)	Jaap Hart, Ecaterina Rosca-Bocancea, Thomas Schröder and Jacques Grupa *Nuclear Research and Consultancy Group (NRG), The Netherlands*
1400-1420	Quantitative versus qualitative performance assessment of closure	Heini Reijonen[1], Pirjo Hellä[1], Nuria Marcos[1], Barbara Pastina[2] *[1]Saanio and Riekkola Oy, Finland* *[2]Posiva Oy, Finland*
1420-1440	Towards robust models of well seals and plugs in CO_2 storage sites	Richard Metcalfe, James Wilson and Steven Benbow *Quintessa Limited, United Kingdom*
1440-1510	**BREAK**	

Session 6: Concluding remarks: current status of repository plugging and sealing **Chair: Erika Holt** **Co-chair: Frédéric Bernier**		
Time	Title	Authors
1510-1530	DOPAS Training Workshop 2015	Marjatta Palmu[1] and Radek Vašíček[2] *[1]Posiva Oy, Finland* *[2]CTU, Czech Republic*
1530-1550	Regulatory point of view on the demonstration of the feasibility of plugs and seals for the final	Pekka Välikangas *Radiation and Nuclear Safety Authority (STUK), Finland*

	repository of radioactive nuclear waste	
1550-1630	Current status of repository plugging and sealing and remaining technical and operational issues (DOPAS Experiments)	Panel session facilitated by Erika Holt[1], with an introduction by Matt White[2], followed by DOPAS Experiment leaders: Régis Foin[3], Jiri Svoboda[4], Pär Grahm[5], Petri Koho[6] *[1]VTT Technical Research Centre of Finland Oy, Finland* *[2]Galson Sciences Limited, United Kingdom* *[3]Andra,France,* *[4]Czech Technical University, Czech Republic* *[5]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden* *[6]Posiva Oy, Finland*
1630-1650	Rapporteur's summary	Pierre Berest *Ecole Polytechnique, Palaiseau,, France*
1650-1700	Closing remarks	Johanna Hansen *Posiva Oy, Finland*

3. DOPAS 2016 RAPPORTEUR'S SUMMARY

RAPPORTEUR COMMENTS: IMPRESSIONS FROM THE DOPAS 2016 MEETING

Pierre Bérest, Ecole Polytechnique, Palaiseau, France

Containment of radionuclides is provided by several complementary barriers, waste forms, engineered barriers (canister, buffer, backfill, seals) and the geological formation. The DOPAS 2016 Seminar arranged in Turku, Finland, was a topical seminar dedicated to a presentation of the results of a 48-months effort in the frame of DOPAS (Full-Scale Demonstrations of Plugs and Seals), a project supported by the European Union's Seventh Framework Programme (Euratom), which addresses demonstration of engineered barriers (and especially seals and plugs).

The scientific rapporteur, who did not take part in the project, was asked to summarize the DOPAS 2016 Seminar. Remarkable syntheses of the seven work packages were presented during the six Sessions of the meeting (White et al. (a,b), Palmu and Vašíček). In this brief summary, the objective of the rapporteur is to choose several topics addressed during the meeting and to provide a transversal view of these topics.

A great asset of this meeting was that extended abstracts and presentations were not restricted to the DOPAS Project alone, allowing comparison with experiments performed in different frameworks and providing a broader perspective and a clearer picture of the state of the art. Therefore, in this summary, a distinction is made between DOPAS-related experiments and other experiments belonging to the same scientific field. All references mentioned in this summary are available at DOPAS 2016 web site:
http://www.posiva.fi/en/dopas/dopas_2016_seminar

"*Plugs and seals are composite structures, with specific components required to deliver the safety functions.*" (DOPAS, Gentles et al.) A seal basically comprises five elements: the host rock (rock salt, indurated clay, plastic clay and crystalline), the plugs (or abutments), the bentonite seal and the various interfaces between these three first elements, interfaces of which the Excavated Damaged Zone (EDZ) and the contact surfaces are the most important.

Contributions to the study of these elements are presented first, followed by some general comments.

Note that in this summary, the word *swelling clay*, which usually is montmorillonite-rich bentonite (bentonite), denotes materials used as part of the plug composite structure or other engineered barrier system (EBS) components like backfill or buffer. The bentonite material can be used alone, in several forms and densities (powder, pellets, blocks), or mixed together with other materials (crushed rock, sand, cementitious materials etc.), depending on the specific design of plugs or seals.

HOST ROCK

The host rock itself was not a topic studied in the DOPAS project, but host rock have constraints and conditions for implementing plugs and seals structures. The plug locations needs to be carefully selected and the requirements and procedure for selection of host rock was one of the key issues and were presented during the DOPAS 2016 site visit. However**,** Mikake et al. described experiments performed in the Mizunami Underground Research Laboratory (URL) in Japan; they proved that groundwater inflow in a crystalline host rock can be reduced significantly by optimizing the pre- and post-excavation grouting.

PLUGS

Plugs (also called « abutments ») must fill several functions: first, they must withstand swelling pressure from other parts of the engineered barriers (e.g., buffer or backfill consisting of bentonite) and from possible swelling clay element in the plug structure; but also, to a certain extent, prevent fluid outflow and bentonite erosion. A low initial permeability to air (and water) might be required before bentonite swelling is completed. To ensure initial tightness, the rock/concrete interface is grouted, and bentonite tapes (to support the tight contact between rock/concrete) are installed. In the long term the cementitious material used in the plug has no tightness requirement but it contributes to voids filling. The ability for cementitious plugs alone to hinder fluid flow was studied in the POPLU Experiment. Low hydration heat (to minimize cracking during cooling) and a low-pH plume, in the order of 11 or less, are needed to maintain the desired properties of the plug, i.e., to keep the plug materials water tight and to limit chemical interactions with other components. A remarkable synthesis of the lessons learned from the DOPAS full-scale demonstrations, Experiment 1 FSS (France), 2 EPSP (the Czech Republic), 3 DOMPLU (Sweden), 4 POPLU (Finland), regarding material development and monitoring and implementation were presented in DOPAS, Holt et al., (b) and (a), respectively. Other aspects presented during the seminar are described in more detail in the DOPAS Experiment summary reports (Foin & Bosgiraud et al., 2016, Svoboda et al., 2016, Grahm et al., 2015 and Holt & Koho, 2016).

The Full Scale Seal (FSS) experiment was built inside a drift model in a hangar at ground level (Foin and Bosgiraud). The objective was to test the clay core and containment walls in conditions close to scale 1 and to examine the scale aspects. A low-pH Self Compacting Concrete (SCC) and a low-pH shotcrete were tested. Before the test, many iterations allowed determination of the three best compositions, which were actually tested. For the low-pH SCC, the results were quite successful. For the low-pH shotcrete, the hydration temperature was too high (67 °C instead of less than 50 °C), and cracks in the downstream containment wall were observed.

The Experimental Pressure and Sealing Plug experiment (EPSP) investigates the various processes underway inside the components of a plug. The test, performed in the Josef URL in

the Czech Republic, is generic, as the future host rock and disposal site are unidentified. The inner and outer concrete plugs used sprayed glass-fibre concrete with relatively low pH. The inner chamber can be filled with air, water or bentonite slurry. Emphasis is put on development of instrumentation and monitoring, and data acquisition (Svoboda et al.)

The dome plug test (DOMPLU) constructed at Äspö Hard Rock Laboratory, Sweden, consists of a bentonite seal whose displacements are restrained by an octagonal plug (diameter 8.8 m, thickness 1.79 m) cast in situ with low-pH concrete (DOPAS, Grahm and Åkeson). The design load is 7 MPa, and the water flux through the plug must be smaller than 0.1 l/min. Water pressure behind the plug was increased incrementally to 4 MPa. Several months later, the flow was 44 ml/min; one year later, it was divided by a factor of two. An alternative design, consisting of a wedge-shaped reinforced concrete structure, is tested in the POPLU project implemented in ONKALO underground rock characterisation facility (DOPAS, Mustonen and Grahm, reported in Holt and Koho). In POPLU, bentonite seal was excluded and it was possible to pressurise the concrete part only; the location of plug drilling, was changed; wedging and grinding (instead of wire sawing) was used. Factors influencing tightness were analysed, another type of production and different recipes and designs were tested.

Several other presentations summarized experiments, which had not been performed in the DOPAS framework. Vardon et al. suggest an initial design for the plugs that will seal off the drifts of a disposal in the Dutch repository in Boom clay. Two designs, with or without lining removal, are proposed. Emphasis is put on mechanical stability. The swelling pressure is transferred to the rock mass via friction (when the lining is removed) and via compression to the concrete lining beyond the plug (when the lining is not removed). Length of the seal is optimized to minimize water flow and pressure gradient.

The plug of the Full-Scale Emplacement (FE) test at the Mont Terri URL (Opalinus clay) was designed as a friction-controlled plug (Garitte et al. (b)) to withhold a potential swelling pressure of 3.5 MPa (dry density 1.45 t/m^3). However, oxygen sensors close to the retaining wall are sensitive to atmospheric pressure in the access tunnel, proving that it is difficult to achieve absolute tightness of a seal crossed by 750 instrumentation cables.

BENTONITE COMPOSITION

Plug tightness in most designs rely on a swelling material core, or a special swelling material seal behind the concrete plug, and sometimes in the backfill behind the concrete plug. In experiments and tests conducted as part of DOPAS, the objective was to study the whole plug structure, including all its components and, therefore, the behaviour of bentonite alone is not assessed.

For the DOPAS FSS experiment, a pure Wyoming sodium bentonite (Montmorillonite) was used, with the objective of reaching a dry density around 1.62 t/m^3 (hydration pressure of 7 MPa), Foin and Bosgiraud. During the REM experiment the same materials as in FSS with similar specifications, a mixture of pellets and crushed pellets of bentonite was used (Pasteau et al.) to study the hydration properties of the bentonite core.

For the DOPAS EPSP experiment, Večernik et al. characterized a Czech Ca-Mg bentonite: for 40-mm long and 12-mm diameter pellets, the maximum dry density was around 1.8 t/m^3.
The DOMPLU bentonite seal consists of a 0.5 m stack of highly compacted MX-80 bentonite blocks, with water content of 17 % with a resulting dry density of about 1.7 t /m^3, and a surrounding MX-80 pellet filling closest to the rock.

In the frame of the DOPAS THM-ton project, a part of the ELSA phase 2 supporting studies (Czaikowski et al.), crushed Callovo-Oxfordian (Cox) claystone produced by excavation is considered for backfilling the openings and, mixed with bentonite, for sealing boreholes, drifts and shafts. Compacted samples have a water permeability of 10^{-19} m^2 at a 30% porosity (gas permeability is higher). Various Cox claystone/MX80 bentonite ratios were tested. High swelling capacities and low permeability were observed.

Other projects in which bentonite seals have been studied were presented during the DOPAS seminar, providing an opportunity for information exchange between other ongoing projects and organisations working on similar issues. In the FE experiment, conducted as part of LUCOEX project, highly compacted bentonite granules were used; a minimum dry density of 1.45 t/m^3 was targeted; different assessment methods were run; and uncertainties were assessed. The overall as-measured density is 1.489 ± 0.006 t/m^3 (Garitte et al. (b)). A clear and simple recipe for a granular bentonite mixture at industrial scale was proposed. An average bentonite density of 1.78 kg/m^3 was achieved through adjustment of the initial water content and of the compaction pressure. For the possible German repository in clay formation (Jobmann and Herold), canisters are emplaced in short vertical boreholes equipped with a bentonite seal and concrete abutment. The seal is an in-situ compacted mixture of pellets (70-80% mass) and loose bentonite, which is expected to have dry bulk densities between 1.6 and 1.8 t/m^3. During the Gas-Permeable Seal Test in the Grimsel Site (GAST), an 8-m long, 3-m diameter seal composed of 20% bentonite - 80% quartz sand was used. The objective of this test was to prove that such a composition allows releasing gas generated in the repository, as such a mixture has a low gas-entry pressure, a low water permeability (10^{-18} m^2), and enhanced gas permeability. The target

was 1.7 t/m^3; the obtained dry densities ranged between 1.6 and 1.73 t/m^3 (Spillmann et al.). When modelling reactive transport in bentonite shaft seals, Wilson et al. consider a 70/30 bentonite/sand mixture.

PLUG INTERFACES: THE EDZ AND CONTACT SURFACES

THE EDZ

The excavation damaged zone (EDZ) is an annular zone, at the wall of any deep gallery, in which micro-fractures develop and possible chemical changes take place. Rock permeability in the EDZ may increase accordingly; see for instance European Commission (2003). The EDZ is present in any host rock: crystalline rock, rock salt, indurated or plastic clay. It is an issue in safety assessment, as this rock sheath around a seal or a plug might be a short cut for nuclide transport or groundwater flow. However, one must not be interested in the EDZ as it is after excavation but, rather, as it will be in the long term. The seal must play its role effectively over several thousands of years (Rübel). Significant evolution of the EDZ is possible during this period.

The role of the EDZ is studied in organisations participating to the DOPAS and reported elsewhere. The DOPAS experiments have tested the practical methods to remove the EDZ using the slot excavation methods in crystalline rock (both DOMPLU and POPLU), and recesses in clay rocks (FSS). The EDZ will be removed in salt rock (Bollingerfehr et al. 2013) as well, but the corresponding methods were not tested in the DOPAS Project.

This topic was also addressed in presentations of other experiments (not belonging to the DOPAS programme). For example, Su et al. measured the post-failure behaviour and permeability increase of the Cobourg limestone, considered as a possible host rock in Canada. A preliminary evaluation of the possible EDZ thickness in such a rock formation is 1.1 m. Increased porosity in this zone was considered by Wilson et al. when modelling reactive transport model. Spillmann et al. suggest that in a tunnel in the Grimsel test site excavated by a tunnel boring machine from Opalinus clay at a 400-m depth, the hydraulic conductivity of the EDZ is "*in the same range or lower than that of the seal.*" Vardon et al. presented a conceptual design of a repository in Boom clay in which "*the bentonite seal may be able to reseal the EDZ via swelling behaviour.*" Jobmann and Herold discuss the example of German repository design in clay formations. The permeability of the sealing location includes the EDZ, the contact zone and the seal itself; only limited data are available when the EDZ is concerned.

INTERFACES

Večernik et al. described the Physical Interaction Model (PIM) between bentonite, concrete and water, as part of the DOPAS EPSP project. Synthetic granitic water was used as the liquid phase. Some interaction process occurs, but the rate was not significant and did not influence the material safety properties. Still the duration was too short to derive definite conclusions.

Several authors discussed the long-term evolution of the bentonite-rock interface in a seal, a possible weak point in the long term when alteration degrades the bentonite properties. Wilson et al. compute the behaviour of shafts sealed with a 70/30 bentonite/sand mixture in contact with a highly saline and Mg-rich thick shale formation above the Cobourg limestone formation. Timescales of up to 100 000 years were investigated. Dissolution/precipitation kinetics was fully coupled with the evolution of the porosity. Pore-water salinity is high, and the Pitzer approach was preferred to standard models. Over 100 000 years, alteration of the primary phases is restricted to a narrow band around the shaft seal-rock interface.

A different but related topic was discussed by Metcalfe et al., who computed the chemical behaviour of cement plugs in abandoned access boreholes of an underground CO_2 storage facility. Here, again, the Pitzer approach was selected, and the modelling results were compared to 30-year old samples cored from a cemented well. Cement's porosity is sealed with amorphous silica and calcite after about 100 years. The authors recognize that geochemical degradation is likely to be less significant than defects associated with cement emplacement.

PERMEABILITY OF BENTONITE

In principle, the flow through the bentonite seal can be described by Darcy's law, which describes a linear relation between the flow rate and the pressure gradient. Bentonite studies in DOPAS Experiments (and in other plug-and-seal related works) have contributed to a better understanding of bentonite behaviour. Several papers proved that advanced modelling might be necessary.

Czaikowski et al. proved that when a COX claystone powder + MX-80 bentonite mixture (60/40 or 40/60) is compacted, water permeability can be as low as $2\text{-}3\cdot10^{-20}$ m^2 (similar to intact Bure-clay permeability); compacted claystone (with no bentonite) also exhibits low permeability. The permeability to the gas in a coarse-grained (d < 10 mm) sample is larger than that of water. This result suggests that the poro-hydro-mechanical behaviour of a seal might be complex. Pasteau et al. discuss the preliminary results of a re-saturation test (REM) performed at a metric scale with a mixture of bentonite pellets and powder. They conclude that coupled hydro-mechanical modelling (and longer test duration) will be needed for more in-depth investigations: a double porosity model might be required. Trpkošova explained that, after 10 000 years (the minimum requirement for the lifetime of a container of spent fuel), the bentonite will be saturated and could be exposed to increased water flow and erosion, with significant consequences for the effective dose rate and the dominant radionuclides. Spillmann et al. discussed a Gas-Permeable Seal Test in which the sand/bentonite ratio, 80/20, is larger than usual, and the permeability to gas is significantly higher than the permeability to water. Such notions as generalized Darcy flow (to gas and water), and poro-mechanical coupling may prove to be needed.

EMPLACEMENT

Measuring permeability of a bentonite seal at full scale (with respect to time and space) is a difficult challenge. Within the DOPAS Project, several ways to meet this challenge are tested and presented. Some of the tests have been done at various scales; some of the tests have been modelled; in other tests, the objective was to reach the initial state, as required in the planned conditions; the expected results will be reached after a period of time longer than the duration of the DOPAS Project. In principle, permeability of saturated bentonite is related closely to its initial dry density. However, emplacement is an important factor for the initial dry density, and heterogeneity in dry density is difficult to avoid, especially in places where compaction is more difficult. In this context, quality assurance is a key item for emplacement and has been developed further within DOPAS.

The FSS experiment, a part of the DOPAS project, is an example of the challenges raised by upscaling. In this experiment, a drift model at ground level is used, with its diameter and length close to those of an actual drift (Foin and Bosgiraud). The objectives were an overall permeability (after saturation) of 10^{-18} m^2 and a swelling pressure of 4 MPa. A 1.62 t/m^3 dry density was achieved in the laboratory; however, at larger scale, this figure was revised downward, to 1.5 t/m^3. In the lower part of the mock drift, a 1.58 t/m^3 density was reached, but it was 1.29 t/m^3 at the top of the model.

The emplacement issue was also raised in other field experiments. It is interesting to note that Metcalfe et al., in a very different context (sealing of access boreholes to a CO_2 storage) recognize that, here again, emplacement (of cement) is the main issue when permeability performance is discussed. More generally, knowledge transfer from the oil and gas industry to that for a waste repository is the topic of Groff et al. The issue of borehole plugging (in the context of a nuclear waste repository) was discussed also by Karvonen and Hansen, who discussed closure plans for the 58 existing investigation boreholes drilled in Olkiluoto Island. The sections of the borehole are filled with dense bentonite to ensure water tightness and the rest of the hole can be filled with concrete, without tightness requirements. In 2013, many lessons for future R&D needs were drawn from over-coring of a borehole plug in which materials (both bentonite and concrete) were installed in 2005.

The sand/bentonite element of the GAST test in Opalinus clay is 8-m long and 3-m in diameter (Spillmann et al.). The permeability requirement was a 10^{-18} m^2; and a corresponding average 1.7 t/m^3 dry density was chosen as target value, with a minimum of 1.6 t/m^3 in locations where compaction cannot be done efficiently. In the FE test (Garitte et al. (b)), both kinds of bentonite blocks (with high and low water contents, respectively) achieved a 1.78-t/m^3 dry density (a higher density can be reached, but each block density is characterized by an equilibrium relative humidity: in particular, a stable block is difficult or impossible to build when % RH is larger than 70%). A granulated bentonite mixture (GBM) is used to backfill the tunnel. An emplacement dry density of 1.45 t/m^3 was targeted and reached.

For other reasons, emplacement also was an issue in the test of a vertical shaft seal performed in the Bartensleben salt mine in Germany (Kreienmeyer et al.). The seal concept implied gravel and asphalt and/or bitumen; the setting temperature was 190°C, raising health and safety concerns. A test in a 12-m^2 x 6-m sealing element proved the technical feasibility of hot asphalt emplacement.

PRESSURES AND FLUIDS

The Darcy law, when applied to a bentonite seal, stipulates that the flow rate of a viscous fluid through the seal is proportional to the pressure gradient and inversely proportional to the fluid viscosity. However, which fluid and which pressures must be taken into account are not always easy to determine. Spillmann et al., when designing the GAST test, take into account both water flow (from the repository access) and gas flow (from the repository). Hart et al. proved that liquid flow through a shaft seal first is downward, as brine permeates slowly to the repository until full saturation is reached after ≈ 41 000 years: after this first period, brine is squeezed out from the repository, whose creep closure rate is ≈10^{-4}/yr. The travel-time indicator was judged useful in this context.

GENERAL COMMENTS

An impressive set of tests were presented. They include the DOPAS Experiments FSS, EPSP, DOMPLU, POPLU, ELSA, REM and similar field experiments, the FE and GAST projects. Dixon et al. described the Tunnel Sealing Experiment (TSX) in 1997-2007 and the post-closure Enhanced Sealing Experiment (ESP) 2009-2016 (ongoing), performed in a granitic pluton within the Canadian Shield.

Difficulties were met: *"There have been some problems with water leakage into sensors during high pressure tests"* (Svoboda et al.); "*The saturation process was interrupted by a leakage event*" (Spillmann et al.); and "*Despite the fact that the plug was installed with the highest possible care, a full disconnection* [between the outer gallery and the sealing element] *could thus not be achieved"* (Garitte et al.(a)).

Despite these difficulties, which are unavoidable in environments in which high water pressure is involved and in which many cables cross the concrete plugs, the tests where highly successful, and the quality of measurement and data acquisition was high. Holt et al. (a) proved that an extensive measurement system can be used and that tests at full scale (with respect to space) are possible. The Rapporteur's opinion is that, among various issues, bentonite emplacement and emplacement quality assurance appear as two of the most demanding requirements for effective sealing of a repository.

Time scale is probably the main issue for hydraulic plugs, and the bentonite seal in the plugs. The seals play an active role during the time period from full saturation until the canister

degradation (varies depending on concept 10 000 years- over 100 000 years). Saturation is a slow process and during that time the information gathered from plugs and seals is important to be able to get information on processes influencing the behaviour. Only a few if any natural analogues are available (Wilson et al.) and "*Patience is needed*." to be able to get results from hydraulic behaviour (oral presentation Bosgiraud). In such a context, the fact that the remarkable Experiment TSX, which started 20 years ago (Dixon et al.) cannot be reached any longer due the closure and flooding of AECL URL in Manitoba, is unfortunate from the whole waste community point of view. DOPAS proved that, from a geometrical point of view, tests at full scale are possible, an important result from the perspective of industrialisation of the sealing process. From a temporal point of view, testing the bentonite behaviour at full scale cannot be done in realistic way. As diffusive processes are expected to play a major role, a supporting test performed at a smaller geometrical scale should imply much shorter durations. However, "*Even for the metric scale experiment* (REM, by Andra, Pasteau et al*.), the full resaturation time was estimated to be about 30 years"* (Rübel) and "*upscaling is a major concern*" while the material specifications may change due the different emplacement methods and several iteration rounds are needed (Foin and Bosgiraud) — i.e., the processes might not be the same when long periods of time are considered: "*The relevant processes are rather slow and exceed the operational life time of the DOPAS demonstrators."* (Hart et al.)

The main answer to this challenge is the Safety Case. The Safety Case includes a description of how the disposal works and an estimate of the possible nuclides fluxes outside the repository, together with their consequences for human beings and the environment. The weight of each parameter or process is discussed; weaknesses are identified; the needs for further scientific advances can be emphasized; and the significance of remaining uncertainties can be assessed (Trpkošova et al., Hart et al., Jobmann and Herold, Rübel, Reijonen et al., Crawford et al.).

REFERENCES

References related to DOPAS

Crawford M., Galson D., Bailey L. *Treatment of seals and sealing systems in total system performance assessment. (DOPAS Project)*

Czaikowski O., Jantschik K., Moog HC., Wieczorek K., Zhang CL. *Hydromechanical and chemical-hydraulic behaviour of different types of shaft sealing materials (DOPAS Project).*

Foin R., Bosgiraud JM. *FSS (Full Scale Seal) experiment transposition from laboratory tests to full scale emplacement reality. (DOPAS Project)*

Gentles D., Kickmaier W., White M., Doudou S. *Application of Lessons Learned for Less Advanced Waste Management Programmes During the DOPAS Project – Case Study: RWM. (DOPAS Project)*

Grahm P. and Åkeson M. *DOMPLU – Filter and seal design, construction and results (DOPAS Project).*

Hart J., Rosca-Bocancea E., Schröder T., Grupa J. *Integration of demonstrator activities in performance assessment: analysis of processes and indicators. (DOPAS Project)*

Holt E. (a), Bohner E., Sandén T., Malm R., Pacovsky J., Svoboda J. *Instrumentation and monitoring systems for evaluation of plug responses in geological disposal demonstrations (DOPAS Project)*

Holt E.(b), Leivo M., Vehmas T., Dunder J., Paukku E., Aghili B., Svoboda J., Večerník P., Bourbon X., Bethmont S., Bosgiraud JM. *Development and performance of various low-pH cementitious materials for tunnel end plugs in geological disposal demonstrations. (DOPAS Project)*

Holt E. and Koho P. *Deliverable n°D4.5, D4.5 POPLU Experimental Summary Report (DOPAS Project)*

Mustonen S. and Grahm P.: see Holt and Koho 2016.

Palmu M. and Vašiček R. Translating the experience from full-scale plugs and seals into a comprehensive DOPAS Training Workshop 2015. *(DOPAS Project)*

Pasteau A., Wendling J., Conil N., Gatabin C. *REM (resaturation test at metric scale). Preliminary hydraulic simulation. (DOPAS Project)*

Rübel A. *Performance assessment of plugs and seals. (DOPAS Project)*

Svoboda J., Vašiček R., Št'ástka J., Smutek J. *DOPAS EPSP experiment monitoring.*

Trpkošova D., Večernik P., Gondolli J., Havlová V. *Testing the influence of bentonite sealing property for safety of deep geological repository.*

VečernikP., Vašiček R., Št'ástka J., Trpkošova D., Havlova V., Hausmannova L., Smutek J., Svoboda J., Dvořakova M. *Performance of Czech bentonite material in the plug in the geological disposal demonstrations. (DOPAS Project)*

White M. (a), Aghili B., Slimane D. *Design basis of plugs and seals: Summary of WP2 of the DOPAS Project*

White M. (b), Doudou S., Bosgiraud JM., Foin R., Czaikowski O., Gentles D. Gram P., Holt E., Jobmann M., Koho P., Svoboda J. *Dopas work package 4. Deliverable 4.4: WP4 Integrated Report: Summary of progress on design, construction and monitoring of plugs and seals. (DOPAS Project)*

Other references

Bollingerfehr, W., Buhmann, D., Filbert, W., Keller, S., Krone, J., Lommerzheim, A., Mönig, J., Mrugalla, S., Müller-Hoeppe, N., Weber, J R., and Wolf, J. *Status of the safety concept and safety demonstration for an HLW repository in salt Summary report* TEC-15-2013-AB FKZ 02 E 10719 and 02 E10729 1

European Commission (2003). *Impact of the excavation disturbed or damaged zone (EDZ) on the performance of radioactive waste geological repositories*. Proceedings of a European Commission Cluster Conference and workshop, Luxembourg, 3 to 5 November 2003.

Dixon DA., Priyanto D., Korkeakoski P., Farhoud R., Birch K., Man A. *Full-Scale Tunnel and Shaft Seals: Tunnel Sealing Experiment (TSX) and Enhanced Sealing Project (ESP) at Canadian Underground Research Laboratory (URL).*

Garitte B.(a), Köhler S., Müller HR., Sakaki T., Vogt T., Weber H., Holl M., Plötze M., Wetzig V., Tschudi M., Jenni H., Vietor T., Carrera E., Wieland G., Teodori S., Garcia-Sińeriz Matinez JL., Jacobs F. *Horizontal bentonite backfilling and concrete plug for the Full-Scale Emplacement (FSE) Experiment at the Mont Terri URL: Requirements, design, instrumentation and emplacement.*

Garitte B.(b), Müller HR., Weber H., Ooms F., Holl M., Paysan S. *Bentonite-based materials for the Full-Scale Emplacement (FE) experiment: Design and production steps.*

Groff F., Jefferies N., Norris S. *Development of a UK approach to sealing deep site investigation boreholes: Knowledge transfer from other industries.*

Jobmann M. and Herold P. *Compliance assessment for plugs and seals in Germany.*

Karvonen T. and Hansen J. *Posiva plans and experiences for borehole plugging.*

Kreienmeyer M., Schröpfer T., Bauer J., Stielow B., Wollrath J., Ranft M. *Experiences from an in-situ test site for a sealing element in shafts and vertical excavations in rock salt.*

Metcalfe R., Wilson J., Benbow S. *Towards robust models of well seals and plugs in CO_2 storage sites.*

Mikake S., Iwatsuki T., Matsui H., Sasao E. *Current status and next five-year plan of R&D activities of Mizunami URL.*

Reijonen H., Hellä P., Marcos N., Pastina B. *Quantitative vs. qualitative performance assessment of closure.*

Spillmann T., Lanyon B., Senger R., Marschall P., Rüedi J. *The gas-permeable seal test in the Grimsel test site.*

Su G., Nguyen S., Li Z., Nasseri MHB., Young RP. *Laboratory and numerical investigation of the hydro-mechanical behaviour of the Cobourg limestone.*

Wilson J., Benbow S., Metcalfe R., Leung H. *Reactive transport modelling of bentonite shaft seals under hypersaline conditions.*

Vardon P.J., Yuan J., Hicks M.A., Li Y. *Initial plug and seal design for the Dutch repository concept.*

4. DOPAS 2016 ORAL SESSIONS

In the following chapters (5 through 12) the session agendas and presentation titles are provided with the extended abstracts submitted for DOPAS 2016 Seminar. The oral presentations and posters are available at DOPAS 2016 public web and the links to the documents are available for each Session separately. Session names and chair and co-chair with a short CV are presented in the beginning of each chapter.

Figure 4-1. The DOPAS 2016 audience

5. DOPAS 2016 Seminar Session 1

Session 1 provided an introduction to the roles of full scale sealing demonstrations and in development of disposal concepts.

Chair: Johanna Hansen is R&D coordinator at Posiva Development, Finland and she is a system responsible for Closure of disposal facility. She has M.Sc. in Geology and Mineralogy from Åbo Akademi University in Finland. She has been working for over 15 years at Posiva with site investigations, and development of the disposal concept (both cementitious and bentonite materials aspects and Posiva) and she is the DOPAS Project Coordinator and WP7 Leader. She was also the chair of the DOPAS 2016 Seminar.

Co-chair: Matt White is a Principal Consultant with Galson Sciences, United Kingdom. He has a Ph.D. in Geology (Scaled Analogue Modelling of Tectonic Structures). Matt has provided consultancy support to radioactive waste disposal projects for 23 years, including repository design, requirements management, monitoring, safety assessment, site characterisation and waste packaging amongst other subjects. In the DOPAS Project he has supported the development of the design basis and led the editing of work-package-level summary reports.

Session 1 Schedule and direct links to the DOPAS 2016 Session 1 presentations

0900-0910	Opening of the DOPAS 2016 Seminar	Johanna Hansen, DOPAS coordinator *Posiva Oy, Finland*
http://www.posiva.fi/files/4140/1.1_DOPAS_2016_DOPAS_opening.pdf		
0910-0920	Welcome from Posiva	Erkki Palonen, Corporate Adviser *Posiva Oy, Finland*
http://www.posiva.fi/files/4141/1.2_Palonen_DOPAS_WELCOME_TO_POSIVA.pdf		
0920-0940	Programme status in radioactive waste management and strategic evolution in support to R&D	Christophe Davies, Project Officer *European Commission, Belgium*
http://www.posiva.fi/files/4137/1.3_EC_at_DOPAS_Seminar_2016_-_C._Davies.pdf		
0940-1010	Role of demonstrations for a spent fuel repository concept	Erik Thurner Director, International Relations *SKB International, Sweden*
http://www.posiva.fi/files/4138/1.4_Role_of_demonstration_Dopas_conference_2016_final_Erik.pdf		
1010-1040	Overview of the DOPAS Project	Johanna Hansen, DOPAS Coordinator *Posiva Oy, Finland*
http://www.posiva.fi/files/4170/1.5_Overview_of_DOPAS_project_Johanna_Hansen.pdf		

:

6. **DOPAS 2016 Seminar Session 2**

Session 2 integrated the outcomes from the DOPAS Project including development of the design basis for plugs and seals, lessons learnt from construction of plug and seal demonstrations as well as performance assessment of plugs and seals.

Chair: Marjatta Palmu obtained in 1980 her Master of Science (Technology) in Mining from Helsinki University of Technology (now Aalto) and teacher qualification in 1995. She has worked in geological disposal since 2002 at Posiva Oy, Finland. Her present position is Senior Adviser in Posiva's Development and she is engaged in working with various Euratom FP7 projects in demonstrations and education and training. She has worked with the DOPAS Project from the project preparation phase since 2010 while being the coordinator of the IGD-TP Secretariat FP7 Project SecIGD. She is the Work Package Leader of WP6, Integrating analysis including cross-review of each other's work.

Co-chair: Jan-Marie Potier is a senior expert in radioactive waste management who provides consulting services since his retirement from IAEA and Andra in 2010. As a graduate engineer from Ecole Centrale des Arts et Manufactures in Paris he has over 40 years of professional experience in nuclear fuel cycle activities, mostly uranium mining and radioactive waste management. Mr. Potier acted as the main elicitation expert for the DOPAS Project's external peer review during 2015-2016.

For several years, Mr. Potier worked for the IAEA as Head of the Waste Technology Section, in the Department of Nuclear Energy. Before joining the IAEA, Jan-Marie Potier held several managerial positions within the French National Radioactive Waste Agency, ANDRA, including the position of Technical Director.

Session 2 Schedule and direct links to the DOPAS 2016 Session 2 presentations:

1110-1130	Objectives and main outcomes from the DOPAS full-scale demonstrators: FSS, EPSP, DOMPLU, POPLU and ELSA	DOPAS Experiment leaders in Panel Régis Foin[1], Jiri Svoboda[2], Pär Grahm[3], Petri Koho[4] and Michael Jobmann[5] *[1]Andra,France,* *[2]Czech Technical University, Czech Republic* *[3]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden* *[4]Posiva Oy, Finland* *[5]DBE TECHNOLOGY GmbH (DBE TEC), Germany*
http://www.posiva.fi/files/4146/2.1_Experiment_summaries_SHORT-PR.pdf		
1130-1200	Design basis of plugs and seals	Matt White[1], Behnaz Aghili[2] and Slimane Doudou[1] *[1]Galson Sciences Limited, United Kingdom* *[2]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden*
http://www.posiva.fi/files/4142/2.2_White_design_basis.pdf		

1200-1230	Progress on the design and implementation of plugs and seals in the DOPAS Project	Jean-Michel Bosgiraud[1], Matt White[2] and Slimane Doudou[2] *[1]Andra, France* *[2]Galson Sciences Limited, United Kingdom*
http://www.posiva.fi/files/4143/2.3_JMB_Key_Learnings_on_Design_Implementation_of_Plugs_Seals_-_Session_2.pdf		
1400-1425	Performance assessment of plugs and seals	André Rübel, *Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Germany*
http://www.posiva.fi/files/4144/2.4_DOPAS_seminar_ruebel.pdf		
1425-1450	Application of lessons learned during the DOPAS Project to less advanced waste management programmes – Case study: Radioactive Waste Management Ltd	Dean Gentles[1], Wolfgang Kickmaier[2], Matt White[3], Slimane Doudou[3] and Alastair Clark[2] *[1]Radioactive Waste Management Limited, United Kingdom* *[2]McCombie, Chapman, McKinley Consulting, Switzerland* *[3]Galson Sciences Limited, United Kingdom*
http://www.posiva.fi/files/4145/2.5_Gentles_DOPAS_Seminar_-_Application_of_Lessons_Learned.pdf		

7. DOPAS 2016 Seminar Session 3

Session 3 presented plugs and seals experiences from past projects or work done for purposes like borehole sealing and underground hazardous waste disposal facilities. The reason for this session was to examine the topic of plugs and seals in broader context and also gain an understanding of how plugs and seals are treated in safety cases.

Chair: Dean Gentles works for the Radioactive Waste Management Limited, United Kingdom – Engineering Department. He is an Engineering Manager with a Master's degree in civil and structural engineering, and is responsible for various aspects of design development during the RWM generic development phase. This position includes consideration of plugs and seals. He is DOPAS Work Package Leader for WP4, Appraisal of plug and seals systems function.

Co-chair: Jiri Svoboda is an Assistant Professor at Czech Technical University in Prague, Czech Republic. He has over 15 years of research experience, with a Ph.D. (Physical and Material Engineering Branch, 2004) and a Master's degree (Structures and Transportation - Geotechnics, 1999) both in Civil Engineering from the Czech Technical University. He is the Experiment Leader for the EPSP in the DOPAS Project.

Session 3 Schedule and direct links to the DOPAS 2016 Session 3 presentations:

1515-1520	Introduction	
1520-1540	Treatment of seals and sealing systems in total system performance assessment	Mark Crawford[1], Dan Galson[1] and Lucy Bailey[2] *[1]Galson Sciences Limited, United Kingdom* *[2]Radioactive Waste Management Limited, United Kingdom*
http://www.posiva.fi/files/4147/3.1_Galson_DOPAS_2016_Presentation_TSPA_for_Seals_V3.pdf		
1540-1600	Full-Scale tunnel and shaft seals: Tunnel Sealing Experiment (TSX) and Enhanced Sealing Project (ESP) at the Underground Research Laboratory (URL) in Canada	D.A.Dixon[1], D.Priyanto[2], J.B.Martino[2], P.Korkeakoski[3], R.Farhoud[4] and K.Birch[5] *[1]Golder Associates Ltd., Canada;* *[2]Canadian Nuclear Laboratories, Canada;* *[3]Posiva Oy, Finland;* *[4]Andra, France;* *[5]Nuclear Waste Management Organization (NWMO), Canada,*
http://www.posiva.fi/files/4148/3.2_Dixon_DOPAS_2016_TSX_ESP.pdf		
1600-1620	The Gas-Permeable Seal Test in the Grimsel Test Site	Thomas Spillmann[1], B. Lanyon[2], R. Senger[3] ,Paul Marschall[1] and Jörg Rüedi[4] *[1]Nagra, Switzerland* *[2]Fracture Systems, United Kingdom* *[3]Intera, USA* *[4]Pöyry, Switzerland*
http://www.posiva.fi/files/4149/3.3_DOPAS2016_Spillmann_etal_-_2.pdf		

1620-1640	Experiences from an *in situ* test site for a sealing element in shafts and vertical excavations in rock salt	Beatrix Stielow[1], Jürgen Wollrath[1], Matthias Ranft[1], Monika Kreienmeyer[2], Thomas Schröpfer[2] and Jan Bauer[2] *[1]Bundesamt für Strahlenschutz (BfS), Germany* *[2]Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH (DBE), Germany*
http://www.posiva.fi/files/4150/3.4_Kreienmeyer_DOPAS-2016-MKr-ohne-video.pdf		
1640-1700	Development of a UK approach to sealing deep site investigation boreholes: knowledge transfer from other industries	Francois Groff[1], Nick Jefferies[2] and Simon Norris[3], *[1]Schlumberger, United Kingdom* *[2]Amec Foster Wheeler, United Kingdom* *[3]Radioactive Waste Management Limited, United Kingdom,*
http://www.posiva.fi/files/4151/3.5_Jefferies_development_of_UK_approach_B_230516.pdf		
1700-1715	Posiva plans and experiences for borehole closure	Taina Karvonen[1] and Johanna Hansen[2] *[1]Saanio & Riekkola Oy, Finland* *[2]Posiva Oy, Finland*
http://www.posiva.fi/files/4152/3.6_Posiva_borehole_closure_-_DOPAS_KTAI-EJOH_ver2.pdf		
1715-1730	Conceptual sealing strategy and initial performance assessment for the Chandler Storage and Isolation Facility	Steve Reece *Tellus Holdings, Australia*
http://www.posiva.fi/files/4153/3.7_Reece_FULL_-_Conceptual_Sealing_Strategy_and_Initial_Performance_Assessment_for_the_Chandler_Storage_and_Isolation_Facility_DOPAS_May_2016vB_(FULL_VERSION).pdf		

8. **DOPAS 2016 Seminar Session 4**

Session 4 concentrated on the more detailed examination of the plug and seal designs, materials used in the plugs and on the implementation of demonstrations. The presentations provided the audience with case examples of how e.g. the plug location is selected, how to develop and use in design concretes, bentonite and other materials as part of the plugs, and how to install plugs and seals using different DOPAS related or other experiment information.

Chair: Jean-Michel Bosgiraud is a Technological Programme manager at Andra, France, with a background in Mechanical Engineering & Petroleum Engineering. Jean-Michel is currently involved in all the Cigéo related sealing-closure operational and design issues, and as such has participated in DOPAS activities and in previous EC funded projects dealing with buffer material issues (ESDRED and LUCOEX)". He is the Work Package Leader of WP3, Design and technical construction feasibility of the plugs and seals.

Co-chair: Behnaz Aghili Behnaz has a degree in Material Science (M.Sc) in 1986 from Royal Institute of Technology (KTH) in Stockholm, Sweden. And is an expert in concrete material and a project manager at SKB, Swedish Nuclear Fuel and Waste Management Co. She has almost 20 years of experimentation experience in the field of nuclear power both from her time at SKB and also from working at the Swedish Nuclear Power Authority, SSM. She is the Work Package Leader for WP2, Definition of requirements and design basis of the plugs and seals to be demonstrated (DOPAS Project).

Session 4 Schedule and direct links to the DOPAS 2016 Session 4 presentations:

0815-0835	Initial plug and seal design for the Dutch repository concept	Philip J. Vardon[1], Jiao Yuan[1], Michael A. Hicks[1], Yajun Li[1] *[1]Geo-Engineering Section, Delft University of Technology, the Netherlands*
http://www.posiva.fi/files/4154/4.1_Li_Dopas_seminar_Phil_et_al.pdf		
0835-0855	Development and performance of various low-pH cementitious materials for plugs and seals in geological disposal demonstrations (DOPAS Project)	Erika Holt[1], Markku Leivo[1], Tapio Vehmas[1], Jari Dunder[2], Elina Paukku[3], Behnaz Aghili[4], Jiří Svoboda[5], Petr Večerník[6], Xavier Bourbon[7], Sandrine Bethmont[7], Jean-Michel Bosgiraud[7] and Matt White[8] *[1]VTT Technical Research Centre of Finland Oy, Finland* *[2]Posiva Oy, Finland* *[3]Sweco Rakennetekniikka Oy, Finland* *[4]Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden* *[5]Czech Technical University, Czech Republic*

		[6]*ÚJV Řež a.s, Czech Republic* [7]*Andra, France* [8]*Galson Sciences Limited, United Kingdom*
http://www.posiva.fi/files/4155/4.2_Erika_lowpH_Materials_-_Holt_v2.pdf		
0855-0915	FSS (Full-Scale Seal) Experiment transposition from laboratory tests to full-scale emplacement reality (DOPAS Project)	Regis Foin and Jean-Michel, Bosgiraud *ANDRA, F* *rance*
http://www.posiva.fi/files/4156/4.3_Regis_DOPAS_Seminar_Session_4_Transposition_from_laboratory_to_reality.pdf		
0915-0930	Preparations before experiments - production for plug locations for DOMPLU and POPLU (DOPAS Project)	Sanna Mustonen[1] and Pär Grahm[2] [1]*Posiva Oy, Finland* [2]*Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden*
http://www.posiva.fi/files/4157/4.4_Mustonen_DOPAS_slot_excavation_SMRN_240516.pdf		
1000-1020	DOMPLU plug filter and seal design, construction and results (DOPAS Project)	Pär Grahm[1] and Mattias Åkesson[2] [1]*Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden* [2]*Clay Technology AB, Sweden*
http://www.posiva.fi/files/4158/4.5_DOMPLU_Seminar_Session_4_Akesson_update_2016_05_26.pdf		
1020-1035	Bentonite based materials for the Full-Scale Emplacement (FE) experiment: design and production steps	Benoit Garitte[1], Herwig R. Müller[1], Hanspeter Weber[1], Frank Ooms[2], Martin Holl[3] and Sébastien Paysan[4] [1]*National Cooperative for the Disposal of Radioactive Waste (Nagra), Switzerland* [2]*CEBO, The Netherlands* [3]*JRS, Germany* [4]*Laviosa MPC, France*
http://www.posiva.fi/files/4159/4.6_Weber_DOPAS_Seminar_Nagra_Web_final.pdf		

1035-1050	Horizontal bentonite backfilling and concrete plug for the Full-Scale Emplacement (FE) experiment at the Mont Terri URL: requirements, design, instrumentation and emplacement	Benoit Garitte[1],Sven Köhler[1], Herwig R. Müller[1], Toshihiro Sakaki[1], Tobias Vogt[1], Hanspeter Weber[1],Martin Holl[2], Michael Plötze[3], Volker Wetzig[4], Moreno Tschudi[5], Heinz Jenni[6], Tim Vietor[1] Eric Carrera[7], Gerd Wieland[7], Sven Teodori[8], José-Luis García-Siñeriz Martínez[9] and Frank Jacobs[10] *[1]National Cooperative for the Disposal of Radioactive Waste (Nagra), Switzerland* *[2]J.Rettenmaier & Söhne, Germany* *[3]ETH, Switzerland* *[4]VersuchsStollen Hagerbach, Switzerland* *[5]Belloli, Switzerland* *[6]Rowa, Switzerland* *[7]Amberg Engineering, Switzerland* *[8]ÅF-Consult, Switzerland* *[9]AITEMIN, Spain* *[10]TFB, Switzerland*
http://www.posiva.fi/files/4160/4.7_Garitte_2016_05_26_FE_emplacement_DOPAS.pdf		
1050-1110	Hydro-mechanical and chemical-hydraulic behaviour of different types of shaft sealing materials (DOPAS Project)	Oliver Czaikowski, Kyra Jantschik, Helge C. Moog, Klaus Wieczorek and Chun-Liang Zhang *Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Braunschweig, Germany*
http://www.posiva.fi/files/4161/4.8_Czaikowski_160526_dopas_seminar_cza.pdf		
1110-1130	Performance of Czech Bentonite Material in the Plug in Geol ogical Disposal Demonstrations.	Večerník Petr[1], Vašíček Radek[2], Šťástka Jiří[2],Trpkošová Dagmar[1], Havlová Václava[1], Hausmannová Lucie[2], Smutek Jan[2], S voboda Jiří[2] and Dvořáková Markéta[3] *[1]ÚJV Řež,; Czech Republic* *[2]Czech Technical University, Czech Republic* *[3]SURAO, Czech Republic*
http://www.posiva.fi/files/4162/4.9_Vecernik_DOPAS_performace_of_Czech_bentonite_final.pdf		

9. **DOPAS 2016 Seminar Session 5**

Session 5 highlighted the role of plugs in safety and performance assessment even though the long term safety related issues were handled in almost all of the DOPAS 2016 presentations. Monitoring of plugs and seals and case studies related to the DOPAS were given in this session.

Chair: Dr. André Rübel works at Gesellschaft für Anlagen und Reaktorsicherheit (GRS), Germany. Dr. Rübel belongs to the Safety Analyses group of the Repository Safety Research division and is physicist with a PhD in Environmental Physics. He has 19 years of experinece in the field of nuclear waste disposal and 15 years at GRS. He is mainly working in the field of integrated safety assessment for national and international projects and is the Work Package Leader of WP5, Performance assessment of plugs and seals system.

Co-chair: Pär Grahm has a degree in Mechanical Engineering (B.Sc) 1993 and a degree in Energy Systems (B.Sc) 1997 from Mälardalen University, Sweden. He is head of the Repository Technology Unit at SKB, Swedish Nuclear Fuel and Waste Management Co, Sweden. He has 18 years of experience within the nuclear waste management area and is Experiment leader for the Dome Plug (DOMPLU) test in the DOPAS Project.

Session 5 Schedule and direct links to the DOPAS 2016 Session 5 presentations:

1300-1320	Instrumentation and monitoring systems for evaluation of plug responses in geological disposal demonstrations (DOPAS Project)	Erika Holt[1], Edgar Bohner[1], Torbjörn Sandén[2], Richard Malm[3], Jaroslav Pacovsky[4], Jiri Svoboda[4] and Matt White[5] *[1]VTT Technical Research Centre of Finland Oy, Finland* *[2]Clay Technology AB, Sweden* *[3]Sweco AB, Sweden* *[4]Czech Technical University, Czech Republic* *[5]Galson Sciences Limited, United Kingdom*
http://www.posiva.fi/files/4163/5.1_Bohner_DOPAS_Instrumentation_Holt-Bohner_et_al_20160526_final.pdf		
1320-1340	REM (Resaturation test at metric scale): Preliminary hydraulic simulation (DOPAS Project)	Antoine Pasteau[1], Jacques Wendling[1], Nathalie Conil[1] and Claude Gatabin[2] *[1]Andra DRD/EAP, France* *[2]CEA/LECBA, France*
http://www.posiva.fi/files/4164/5.2_Pasteau_REM_resaturation-assessment_Seminar-DOPAS-mai-2016_-_format_DOPAS.pdf		
1340-1400	Integration Of demonstrator activities in performance assessment: analysis of processes and indicators (DOPAS Project)	Jaap Hart, Ecaterina Rosca-Bocancea, Thomas Schröder and Jacques Grupa *Nuclear Research and Consultancy Group (NRG), The Netherlands*
http://www.posiva.fi/files/4166/5.3_Hart_NRG-DOPAS-v2.pdf		

1400-1420	Quantitative versus qualitative performance assessment of closure	Heini Reijonen[1], Pirjo Hellä[1], Nuria Marcos[1], Barbara Pastina[2] *[1]Saanio and Riekkola Oy, Finland* *[2]Posiva Oy, Finland*
http://www.posiva.fi/files/4168/5.4_DOPAS_reijonen_et_al_2016_final.pdf		
1420-1440	Towards robust models of well seals and plugs in CO_2 storage sites	Richard Metcalfe, James Wilson and Steven Benbow *Quintessa Limited, United Kingdom*
http://www.posiva.fi/files/4169/5.5_Metcalfe_etal_DOPAS_CO2_WellSeals(v1.0_230516a).pdf		

10.**DOPAS 2016 Seminar Session 6**

Session 6 examined topics related to training, information dissemination and regulatory supervision of plugs and seals. In addition, questions related to the lessons learned were collected via Panel discussion, and where DOPAS Experiment leaders were addressing the questions of the attendees submitted via the message wall during the seminar.

Chair: Erika Holt is program manager for Safe and Sustainable Nuclear Energy at VTT, Finland. She has 20 years of research experience, with a PhD in Civil Engineering from the University of Washington (2001, Seattle, USA). While at VTT she has been the leader of a 30 person research team on topics related to materials and infrastructure, especially for waste management applications. During DOPAS, she was the Project Manager of Posiva's POPLU Project.

Co-chair: Frédéric Bernier is Performance Assessment/Safety Assessment Expert and works at the Belgian regulator FANC (Federal Agency for Nuclear Control) and since 2007 has been in charge of geological disposal. He has worked at the Belgian research organisation SCK.CEN since 1992. First he worked with thermo-hydro-mechanical aspects in disposal, in the Belgian HADES underground laboratory since its construction e.g. as the manager of the PRACLAY heater test and in shaft sealing in-situ experiment, and then as scientific manager of EURIDICE consortium. He has also coordinated and worked with several Euratom projects related to the use of clay materials for disposal and participated in international working groups (at IAEA), steering committees and peer reviews e.g. of the Finnish Radiation and Nuclear Safety Authority STUK. Mr Bernier was an independent expert in the DOPAS expert elicitation, too.

Session 6 Schedule and direct links to the DOPAS 2016 Session 6 presentations:

1510-1530	DOPAS training workshop 2015	Marjatta Palmu[1] and Radek Vašíček[2] *[1]Posiva Oy, Finland* *[2]CTU, Czech Republic*
http://www.posiva.fi/files/4171/6.1_S6_Palmu_et_Vasicek_DOPAS_TWS_Seminar2016_final.pdf		
1530-1550	Regulatory point of view on the demonstration of the feasibility of plugs and seals for the final repository of radioactive nuclear waste	Pekka Välikangas *Radiation and Nuclear Safety Authority (STUK), 11.Finland*
http://www.posiva.fi/files/4172/6.2_Valikangas_DOPAS_20160526_Regulatory_point_of_view.pdf		
1550-1630	Current status of repository plugging and sealing and remaining technical and operational issues (DOPAS Experiments)	Panel session facilitated by Erika Holt[1], with an introduction by Matt White[2], followed by DOPAS Experiment leaders: Régis Foin[3], Jiri Svoboda[4], Pär Grahm[5], Petri Koho[6] *[1]VTT Technical Research Centre of Finland Oy, Finland* *[2]Galson Sciences Limited, United Kingdom*

		[3]*Andra,France,* [4]*Czech Technical University, Czech Republic* [5]*Swedish Nuclear Fuel and Waste Management Co (SKB), Sweden* [6]*Posiva Oy, Finland*
http://www.posiva.fi/files/4173/6.3_-_ErikaHOLT_Panel_Q_A.pdf http://www.posiva.fi/files/4174/6.3_Matt_Panel_Introduction_White.pdf http://www.posiva.fi/files/4176/EXPERIMENT_SLIDE_Final.pdf		
1630-1650	Rapporteur summary	Pierre Berest *Ecole Polytechnique, Palaiseau,, France*
http://www.posiva.fi/files/4177/6.4_Expose_DOPAS.pdf		
1650-1700	Closing remarks	Johanna Hansen *Posiva Oy, Finland*

PANEL DISCUSSION QUESTIONS

(Summarized from message wall, by Erika Holt & Marjatta Palmu, 26.5.2016 at 13.30)

- **EU Project objectives:**
  - Where has cooperation BETWEEN national demos of DOPAS influenced others demos DURING the project? Going forward in programs from OTHERS?
- **DEMOS vs Actual Repository Plugs:**
  - Besides monitoring, what is different in DOPAS demos compared to actual repository plugs?
  - So far, plugging development seems technical. How much attention is paid to economic considerations for all aspects (concept, materials, construction, method statements, etc)?
- **Modeling:**
  - Germany/Oliver: How has formation of Brucite (or other sedimentary processes) been taken into account in modeling?
  - What constitutive model used for Rock salt with FLAC3D?
- **Requirements:**
  - Is it necessary to ensure strict watertightness of plugs used for functionality before closure?
- **Materials/Tunnel:**
  - How well have partners justified allowed tolerances for design/acceptance criteria (as needed for regulatory/compliance verification)?
  - If the slot excavation has sharp edges – will it impact grouting performance?
  - Has there been work on optimal size/shape of manufactured pellets?
  - Posiva: Why does your foreign materials reject SP chemicals (i.e. Glenium) yet allow organics associated with fly ash?
  - UJV: What is the justification for steel canisters in CZ repository?
  - ANDRA: What type of plug will be constructed for CIGEO demo?

  - POPLU/DOMPLU – having similar concrete, what were justifications for reinforced vs non-reinforced?
- **Future:**
  - *SKB (RWM?): Estimated cost and schedule to build (mass produce) a plug?*
  - How much have these demos actually impacted or given feedback to design (iteration) changes as you move forward?
  - What was learned from experiments that influences future information to your regulatory authorities?
  - What is the greatest impact from experiments towards next phase of your program?
  - What would you do differently if starting again?
  - Where would you monitor actual repository, considering these were experiments only?

OTHER (probably not to address, due to time constraint)

- **Dixon/Canada:**
  - Was TSX prepared with contact grouting tubes before casting?
  - Does ESP include conductive features at fracture locations on both sides?

Figure 10-1. DOPAS Experiment leaders in panel Session

12.**DOPAS 2016 POSTER SESSION**

Altogether 26 posters were visible at DOPAS 2016 Seminar exhibition area. The seminar sessions were in conjunction of the lunches and coffee breaks and worked as a space for discussions and networking for the attendees and the presenters. It was found a good idea to bring the different materials used in DOPAS experiments on site and to have the Experiment videos running during poster sessions.

Poster Session	Subject	Presenter
1	DOPAS Project	Johanna Hansen *Posiva, Finland*
http://www.posiva.fi/files/4503/Posiva_DOPAS_2016_general_poster_published.pdf		
2	DOPAS Design Basis Workflow for Plugs and Seals	Matt White and Simane Doudou [1]*Galson Sciences Limited, United Kingdom*
http://www.posiva.fi/files/4479/Galson_Sciences_Limited_Design_basis_of_plugs_and_seals_DOPAS_2016.pdf		
3	Current status and next five year plan of R&D activities of Mizunami Underground Research Laboratory	Shin-ichro Mikake[1], Teruki Iwatsuki[1], Hiroya Matsui[1] and Eiji Sasao[1] [1]*Japan Atomic Energy Agency, Japan*
http://www.posiva.fi/files/4475/JAEA_5_year_plan_for_Mizunami_DOPAS_2016.pdf		
4	A challenging environment for plug design: how can we seal a low-permeability fault core in granite	Kálmán Benedek[1], Péter Molnár[1], József Berta[1] [1]*Puram, Hungary*
http://www.posiva.fi/files/4486/PURAM_plug_design_DOPAS_2016.pdf		
4	Horizontal bentonite backfilling and concrete plug for the Full-Scale Emplacement (FE) experiment at the Mont Terri URL: requirements, design, instrumentation and emplacement	Benoit Garitte[1],Sven Köhler[1], Herwig R. Müller[1], Toshihiro Sakaki[1], Tobias Vogt[1], Hanspeter Weber[1],Martin Holl[2], Michael Plötze[3], Volker Wetzig[4], Moreno Tschudi[5], Heinz Jenni[6], Tim Vietor[1] Eric Carrera[7], Gerd Wieland[7], Sven Teodori[8], José-Luis García-Siñeriz Martínez[9], Frank Jacobs[10] [1]*National Cooperative for the Disposal of Radioactive Waste (Nagra), Switzerland* [2]*J.Rettenmaier & Söhne, Germany* [3]*ETH, Switzerland* [4]*VersuchsStollen Hagerbach, Switzerland* [5]*Belloli, Switzerland* [6]*Rowa, Switzerland* [7]*Amberg Engineering, Switzerland* [8]*ÅF-Consult, Switzerland* [9]*AITEMIN, Spain* [10]*TFB, Switzerland*

http://www.posiva.fi/files/4487/Nagra_FE_LUCOEX_Production_of_bentonite_based_backfill_materials_DOPAS_2016.pdf		
4	Investigation of chemical-hydraulic behaviour of cement based sealing materials in rock salt (DOPAS Project)	Kyra Jantschik[1], Helge C. Moog[1] *[1]Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) GmbH, Germany*
4	Investigation of hydro-mechanical behaviour of cement based sealing materials in rock salt (DOPAS Project)	Oliver Czaikowski[1], Klaus Wieczorek[1] *[1]Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Germany*
4	Hydro-mechanical behaviour of claystone-bentonite-mixture as sealing material (DOPAS Project)	Chun-Liang Zhang *Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Germany*
4/5	Outcomes of FSS, the Full Scale Seal Industrial Prototype for the Cigéo project (DOPAS Project)	Jean-Michel Bosgiraud[1], Régis Foin[1], Gilles Armand[1] [1]*Andra, France*
http://www.posiva.fi/files/4481/Andra_Outcome_of_FSS_DOPAS_2016.pdf		
4/5	REM (Resaturation Test at Metric Scale) setup and first results (DOPAS Project)	Nathalie Conil[1], Pasteau Antoine[1], Jean Talandier[1], Gilles Armand[1] [1]*Andra, France*
4	DOPAS EPSP Experiment (DOPAS Project)	Svoboda Jiří[1], Vašíček Radek[1], Markéta Dvořáková[2], Václava Havlová[3] *[1]CTU, Czech Republic* *[2]SÚRAO (Radioactive Waste Repository Authority), Czech Republic* *[3]ÚJV Řež, Czech Republic*
http://www.posiva.fi/files/4478/CTU_EPSP_Experiment_DOPAS_2016.pdf		
4	The Experimental Pressure and Sealing Plug (EPSP) – Improvement of the geotechnical properties of the rock mass (DOPAS Project)	Markéta Dvořáková[1], Irena Hanusová[1], Lucie Bělíčková[1] *[1]SÚRAO (Radioactive Waste Repository Authority), Czech Republic*
4	Physical interaction model and EPSP materials characterisation (DOPAS Project)	Petr Večerník[1*], Jenny Gondolli[1], Dagmar Trpkošová[1], Václava Havlová[1] *[1]ÚJV Řež, Czech Republic*
http://www.posiva.fi/files/4477/UJV_PIM_and_EPSP_characterisation_DOPAS_2016.pdf		
4	The laboratory models for EPSP experiment in DOPAS project - the saturation of bentonite pellets and bentonite powder (DOPAS Project)	Dagmar Trpkošová[1], Petr Večerník[1], Jenny Gondolli[1], Václava Havlová[1] *[1]ÚJV Řež, Czech Republic*
http://www.posiva.fi/files/4476/UJV_Laboratory_model_PHM_DOPAS_2016.pdf		
4/5	DOPAS EPSP Experiment Monitoring	Svoboda Jiří[1], Vašíček Radek[1], Šťástka Jiří[1], Smutek Jan[1] *[1]CTU, Czech Republic*
http://www.posiva.fi/files/4480/CTU_EPSP_Experiment_MONITORING_DOPAS_2016.pdf		
4/5	Full-scale test of Dome plug (DOMPLU) (DOPAS Project)	Pär Grahm[1], Mattias Åkesson[2] *[1] Swedish Nuclear Fuel and Waste Management Co, Sweden* *[2] Clay Technology AB, Sweden*
http://www.posiva.fi/files/4501/SKB_Domplu_full_scale_test_20160516_A0.pdf		

4	POPLU Requirements, Design and Construction (DOPAS Project)	Petri Koho, Petri Korkeakoski *Posiva, Finland*
4	POPLU instrumentation (DOPAS Project)	Edgar Bohner, *VTT Technical Research Centre of Finland Oy, Finland*
http://www.posiva.fi/files/4502/VTT_POPLU_instrumentation_17052016_FINAL.pdf		
5	POPLU Pressure testing and Performance (DOPAS Project)	Petri Korkeakoski[1], Petri Koho[1], Kimmo Kemppainen[1], Antti-Jussi Kylliäinen[1] *[1]Posiva Oy, Finland*
http://www.posiva.fi/files/4482/Posiva_POPLU_Pressure_Testing_and_Performance_DOPAS_2016.pdf		
4	Testing grouting and shotcrete materials	Paula Raivio, *Contesta, Finland*
4	Hydraulic Sealing Ability of Bentonite Pellet Filling at Small, Contact Apertures	Jari Martikainen[1], Tim Schatz[1], Kari Koskinen *[1]B+Tech, Finland* *[2]Posiva Oy, Finland*
http://www.posiva.fi/files/4484/BTECH_Gap_Sealing_Poster_DOPAS_2016.pdf		
4	KBS-3V emplacement tests in ONKALO	Keijo Haapala *Posiva Oy, Finland*
http://www.posiva.fi/files/4522/Posiva_LUCOEX_WP5_ASPO_2015_FINAL_Dopas_2016.pdf		
5	Testing the influence of bentonite sealing property for safety of deep geological repository	Dagmar Trpkošová[1*], Petr Večerník[1], Jenny Gondolli[1], Václava Havlová[1] *[1]ÚJV Řež, Czech Republic*
http://www.posiva.fi/files/4485/UJV_bentonite_sealing_property_for_safety_of_deep_geological_repository_DOPAS_2016.pdf		
4	Development of shaft sealing systems for HLW repositories in Germany	Michael Jobmann[1], Philipp Herold[1], Matthias Gruner[2], Wolfram Kudla[2] *[1]DBE TECHNOLOGY GmbH, Germany* *[2]Technische Universität Bergakademie Freiberg, Germany*
5	Compliance Assessment for plugs and seals in Germany	Michael Jobmann[1], Philippe Herold[1] *[1]DBE TECHNOLOGY GmbH, Germany*
5	Reactive transport modelling of bentonite shaft seals under hypersaline conditions	James Wilson[1], Steven Benbow[2], Richard Metcalfe[2], Helen Leung[3] *[1]Quintessa Limited, UK* *[2]Quintessa Limited, UK* *[3]Nuclear Waste Management Organization, Canada*
http://www.posiva.fi/files/4524/Quintessa_DOPAS_2016_ShaftSeal_v2.pdf		
5	Laboratory and numerical investigation of the hydro-mechanical behaviour of the Cobourg limestone	G. Su[1], S. Nguyen[1], Z. Li[1], M.H.B. Nasseri[2], R.P. Young[2] *[1]Canadian Nuclear Safety Commission, Canada* *[2]University of Toronto, Canada*
http://www.posiva.fi/files/4483/Canadian_nuclear_safety_commission_investigation_of_the_hydro_mechanical_response_of_the_Cobourg_limestone.pdf		

Experiment related demonstration materials labelled and exhibited during the poster sessions are listed below.

DOPAS Experiment 1 FSS (France)

1 Low pH concrete (normal vibrated)
2 Low pH self-compacting concrete
3 FSS filling material (blend of pellets 32 mm + crushed pellets' powder)
4 Bentonite powder made with crushed pellets
5 Bentonite Pellets (roller-compacted WH2 bentonite, 32 mm diameter)
6 Strain gauge embedded to concrete

DOPAS Experiment 2 EPSP (Czech Republic)

7 Mini EPSP
Showing examples of materials used for plug construction
8 Pellet sample 1

DOPAS Experiment 3 DOMPLU (Sweden)

9 Diamond-wire
(Used for sawing in crystalline rock)

DOPAS Experiment 4 POPLU (Finland)

10 DOPAS Experiment
11 Diamond-wire
12 Bentonite tape
(Used for sealing circumferential)
13 Bentonite powder (MX-80)
(Used to compact bentonite)
14 Bentonite Cebogel extruded pellets
(Used around blocks in backfill)
15 Compacted bentonite disk (MX-80)
(Similar to backfill block appearance)
16 Reinforcement steel bar
(Used for concrete plug reinforcement)
17 Low pH self-compacting concrete
(Cast in-place for plug)
18 Pellet sample 2
19 ONKALO rock sample

DOPAS Experiment 5 ELSA (Germany)

20 Compacted crushed rock salt (10x5x4 cm, including large salt grains)
21 Compacted crushed rock salt (10x5x4 cm, without large salt grains)
22 Rock salt (host rock) (Part of a drilled core of the salt host rock)
23 Crushed rock salt (salt grit)
(Used as backfill in the drifts of the repository and long-term sealing of the shaft)
24 Compacted salt grit
(Provides the long-term sealing of the repository in salt host rock)

25 Salt concrete
(Can be used in the shaft sealing system as material for one of the sealing elements)
26 Sorel concrete
(Can be used in the shaft sealing system as material for one of the sealing elements)

Figure 12-1. Poster session overview

13. **PROGRAMME OF DOPAS 2016 SITE VISIT TO OLKILUOTO**

Friday 27 May 2016: Visit schedule:

07.15	Departure from the hotel by bus
08.45	Arrival at Olkiluoto Visitor Centre
	Coffee and check-in (passport needed)
09.15	Presentations in the auditorium
	Olkiluoto presentation
	POPLU presentations (Posiva Oy)
10.45	Lunch buffet
11.30	Area tour
	Visit to final underground LILV repository
	Olkiluoto site tour by bus including Olkiluoto 3 construction site
13.30	Transfer back to the Visitor Centre
	Coffee
13.45	Visit ends, departure to Turku
15.30	Arrival to Turku Airport
16.00	Arrival to Turku railway station / Radisson Blu Marina Palace

The third day of the seminar was reserved for the Olkiluoto Site Visit and this opportunity was utilised by 46 DOPAS 2016 participants. The site visit programme was provided to the preregistered visitors at the time of DOPAS 2016 confirmation letters. The visit consisted of two parts: (1) Session on visitor centre auditorium and (2) site tour.

The programme was in English but the participants from Russian waste management company NO RAO had simultaneous interpretation, while the materials presented were not available for pre-visit consideration.

Four presentations were given in visitor centre:

- Olkiluoto site introduction by Anne Niemi, TVO
- Posiva status and plans for spent fuel waste management by Johanna Hansen, Posiva Oy
- DOPAS Experiment 4 POPLU Experiment by Petri Koho, Posiva Oy
- Rock suitability classification for POPLU by Paula Kosunen, Posiva Oy

The afternoon of day 3 was reserved for the area tour and it was arranged in two parts due the size of the group and the tour was hosted by Kimmo Kemppainen, Posiva Oy, Johanna Hansen Posiva Oy, Anne Niemi, TVO, and Kanerva Kuisma, TVO. The first part of the visit was a bus tour. The visitors did visit the ONKALO construction site (surface-only) and received information on the underground working conditions. This was followed by an Olkiluoto 3 (OL3) construction site visit. OL3 includes as a part of this major scientific-technical project

extensive use of reinforced concrete construction for its safety classified components and in that way it has several similarities with implementation of POPLU plug.

The site tour included an underground repository visit to the LILW operating waste facility and to the adjacent ONKALO Exhibition at the depth of 60 meters below surface located in the Olkiluoto host rock. The EBS components and the research topics for final disposal were presented in the ONKALO Exhibition (see Figure 13-1.)

Figure 13-1. ONKALO Exhibition in VLJ repository

14. SUMMARY OF THE DOPAS 2016 ARRANGEMENTS

The DOPAS 2016 seminar was arranged by a programme committee and planning team consisting of the following persons.

- Johanna Hansen, Posiva, Chair
- Marjatta Palmu, Posiva
- Matt White, GSL
- Mary Westermark, SKB, Secretary
- Jean-Michel Bosgiraud, Andra
- Marie Garcia, Andra
- Jiri Svoboda, CTU
- Markéta Dvoráková, SURAO (Irena Hanusová during the maternity leave)
- Dean Gentles, RWM
- Erika Holt, VTT
- Christophe Davies, EC

The DOPAS 2016 seminar planning team was responsible for the organization of the DOPAS 2016 scientific programme, site visit arrangements and selection of independent rapporteur and nominating Chair and co-chair persons for seminar. The advertisement of DOPAS 2016 seminar and publishing the Call for Abstracts and other related material were also arranged by this team.

The first seminar planning group meeting took place in February 2015 in Rauma, Finland in conjunction of DOPAS WP2 meeting. At that time the organizational framework for the seminar was established and the event venue and dates were fixed. The next organizing meeting was held in conjunction with the DOPAS Management team meeting in Stockholm/Oskarshamn June 2015 and the Call for abstracts was published after that meeting. The third meeting was a call-in meeting in January 2016 at which time the programme of the seminar was finalized. The last meeting was in Wettingen, Switzerland in conjunction with the DOPAS Management Team meeting in April 2016, at which the final adjustments and panel discussion topics were decided by the WP leaders and Experiment leaders at the meeting.

The practical DOPAS 2016 arrangements were taken care by Posiva and support services were purchased from TVO (majority owner of the Posiva). SKB supported the Seminar by compiling and uploading the presentations at the seminar to the seminar website. The DOPAS 2016 seminar public web pages were available under http://www.posiva.fi/en/dopas pages and the registrations to the seminar were arranged via web site

The DOPAS 2016 seminar's physical arrangements were arranged in Radisson Blu Marina Palace at Turku, Finland and the meeting buffet dinner was held at the Forum Marinum's Restaurant Daphne.

To facilitate attendee questions and presenter responses during the the course of the seminar special tool was used: The seminar participants could post questions online to the virtual

message wall during the seminar. The questions were compiled, presented and replied at the end of the day 2. The method was quite a novel for this type of venue and subject and so there was no prior experiences on how best to use this tool, and this limited the amount of questions by the audience. However, the method was effective enough that it should be considered for use in future technical/scientific events as its allows for audience interaction during the presentations and would be particularly useful if a means were available for each presenter to see the questions related to them at the time of their presentation questions.

The DOPAS 2016 Seminar in addition to providing an excellent concluding venue for the DOPAS Project, fulfilled the dissemination needs of this project by involving participants from 50 different organisations and 16 countries. The meeting presentations were made available on the internet during the seminar and the facilitators and chairs ensured that there was plenty of opportunity for discussions and information exchange during the three seminar days. The feedback in the end of the seminar were very laudatory.