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DOPAS:
Full-Scale Demonstration Of Plugs And Seals

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Summary

The DOPAS full-scale demonstration project aims to improve the adequacy and consistency regarding industrial feasibility of plugs and seals to be used in disposal facilities in different geological environments. DOPAS project considers the design basis, reference designs and strategies to demonstrate the compliance of the reference design for the experiments' plugs and seals. Full-scale demonstrations require planning and coordination of development, construction, research needed for implementation, test and laboratory work in different scales, monitoring activities and assessment of performance in long-term. Five demonstration experiments for plugs and seals will be partially or wholly implemented during the DOPAS project with participation from 14 European partners. The data from all experiments will be compiled and reported within DOPAS and achieved knowledge and experiences are shared in several dissemination events.

1. Introduction

Fourteen nuclear waste management organisations and research institutes from eight European countries are participating in a technology development project for assessing tunnel plugging and sealing systems in geological disposal facilities for radioactive waste - the DOPAS project ("Full-Scale **D**emonstration **O**f **P**lugs **A**nd **S**eals"). The project is built around a set of full-scale demonstrations, laboratory experiments, and performance assessment studies. It is jointly funded by Euratom Seventh Framework Programme and European nuclear waste management organisations. The project is running from September 2012 to August 2016, and it is being coordinated by Posiva Oy, a nuclear waste management company in Finland. The impetus to the cooperation comes from the Strategic Research Agenda[1] of the Implementing Geological Disposal of Radioactive Waste - Technology Platform (IGD-TP) under Key Topic: "Technical feasibility and long-term performance of repository components".

The DOPAS project aims to improve the adequacy and consistency regarding industrial feasibility of plugs and seals to be used in different geological environments. The main challenges are related to: 1) plug and seal location selection and construction technologies, 2) new material development for the plug and seal components, 3) in-situ instrumentation and performance assessment of the plugs, and 4) quality assurance and work safety during the experiments.

2. Experiments to be demonstrated within DOPAS

2.1 Role and need for plugs and seal experiments

Different types of plugs are needed in repositories worldwide, depending on the geological conditions. Part of these plugs serve as mechanically isolating different parts of the repository from each other, like deposition tunnel plugs in the KBS-3 concept adopted for crystalline rock. Also they serve in isolating the waste packages from water and prevent the possible migration of radionuclides by serving low conductivity conditions with absorbing materials. Further some plugs will have the role as a hydraulic seal to prevent the groundwater flow through the excavated access routes like tunnels, shafts in crystalline host rock or in the clay rock. The controlling design parameters for the plugs are often related to the water tightness and durability over the plug's intended service life. Depending on the host rock geology, the purpose of the plug, and the long term function of the plug, there are then different requirements and reference designs that are site specific. The plugs and seals will be used in a nuclear facility that set common challenges for developing the design basis, creating the plans, showing the compliance with the requirements and assessing the long term behaviour with other barrier components and with the host rock.

European waste management organisations are at different stages of maturity and licensing procedures for implementing geological disposal. Construction license applications for spent fuel disposal facilities have been submitted in Finland and in Sweden, and construction of the facilities is foreseen to commence during this decade. France is also advancing towards licensing during this decade with the construction of the facility foreseen to take place during the next decade. In both Sweden and France, underground research facilities in the foreseen host rock environment of the repositories have been constructed. The ONKALO underground rock characterisation facility is foreseen to be licensed as part of Posiva's disposal facility.

Plugs and seals that are needed during operations are of importance to be developed and assessed before the disposal actions start. Plugs which are mainly needed during the closure phase of the facilities can currently be designed on a more generic level, but the experiences and lessons learned do serve for future development.

These facts have been setting the scope of the DOPAS project, with full scale demonstrations for different type of plugs and seals for geological repositories.

2.2 DOPAS Experiment 1, Full Scale Seal (FSS) in France

The Full Scale Seal (FSS) demonstration will evaluate the full-scale construction of swelling clay core with low pH concrete plugs inside a lined drift model. The model has been fabricated for experiment purpose at above ground conditions, to allow better follow up of technical challenges during emplacement and commissioning. The FSS experiment (Figure 1) implemented by Andra (FR) and Nagra (CH) is a technological demonstration having full-scale dimensions, with the clay core length of 13.5 meters and a width of 7.5 meters. The demonstration includes conditions that are representative for underground construction, such as drift lining with recesses, simulations, temperature 18-30 °C and relative humidity of 75%. In addition a small metric-scale test is performed to obtain source data on material behaviour, which cannot be achieved at full-scale within the project schedule.

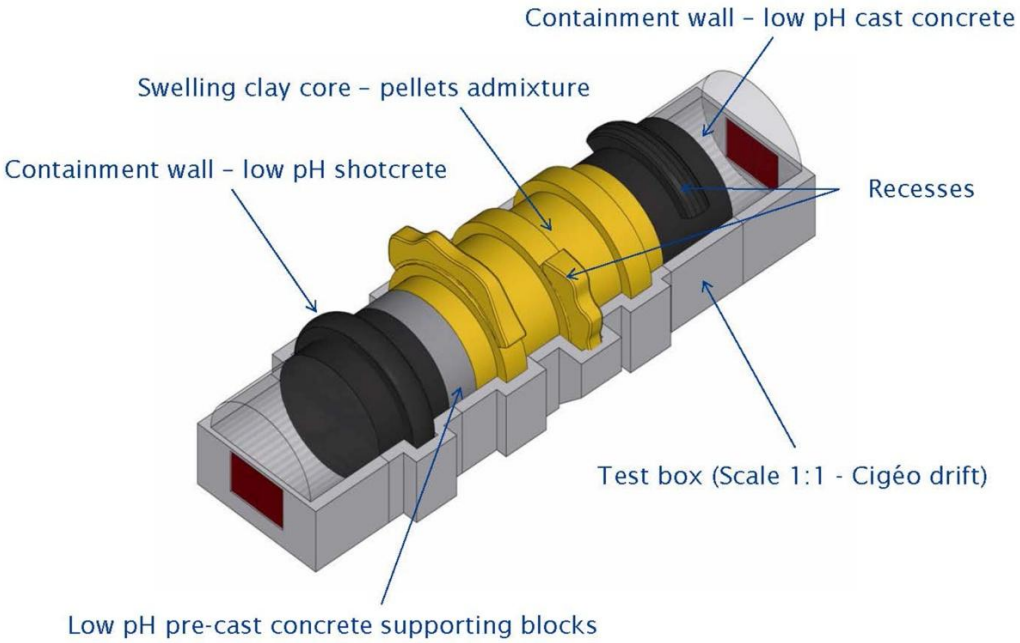

Figure 1Full-Scale Seal (FSS) (c) Andra

2.3. DOPAS Experiment 2, Experimental Pressure and Sealing Plug (EPSP) in Czech Republic

The Experimental Pressure and Sealing Plug (EPSP) demonstration will evaluate the pneumatic emplacement methods for a repository plug for Czech bentonite-based mixtures and low pH concrete developed for repository plug. Czech Technical University (CTU) together with RAWRA and ÚJV Řež, a. s. (UJV) are responsible for the EPSP experiment (Figure 2) performed in underground laboratory Josef Gallery, which is a former exploratory gallery. The instrumentation of the EPSP Experiment is designed so that the processes occurring during the plug's loading may be unambiguously identified, described and assessed. These measurements will also provide the data required for the numerical modelling of the THM processes arising in the plug and its vicinity.

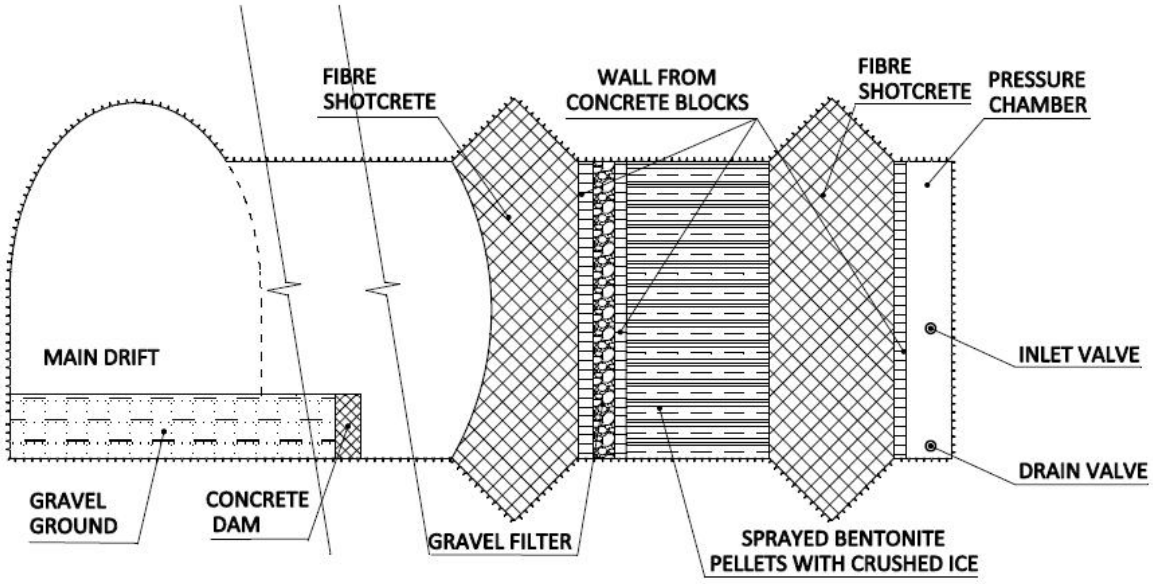

Figure 2. Experimental Pressure and Sealing Plug (EPSP) (c) CTU

2.4 DOPAS Experiment 3, Dome Plug (DOMPLU) in Sweden

The Dome Plug (DOMPLU) demonstrates the monitoring and pressurising of a deposition tunnel end plug consisting of an arched low-pH concrete dome, a bentonite seal, filter materials and delimiters. DOMPLU plug (Figure 3) was constructed jointly by SKB (SE) and Posiva (FI). The design of the DOMPLU Experiment was completed during 2011 and the plug was emplaced in March 2013 in a tunnel at depth of -460 m in the Äspö Hard Rock Laboratory (Oskarshamn, Sweden), but the design phase and major parts of the installation were conducted prior to the onset of the DOPAS project. In the DOMPLU design many technical challenges have been considered related to the practical implementation of plugs, including issues like the Excavation Damaged Zone (EDZ) in the tunnel; plug -backfill interactions with pressure conditions at repository depth; and smoothness of surfaces required for controlled concrete fitting. A full-scale demonstration is vital to validate the underlying assumptions and the performed numerical simulations of the concrete dome. In addition, the functions of the filter and the bentonite seal will be thoroughly monitored and the water leakage through the plug will be determined under realistic conditions. The work of DOMPLU within DOPAS is focused on the monitoring and performance assessment of the full-scale plug.

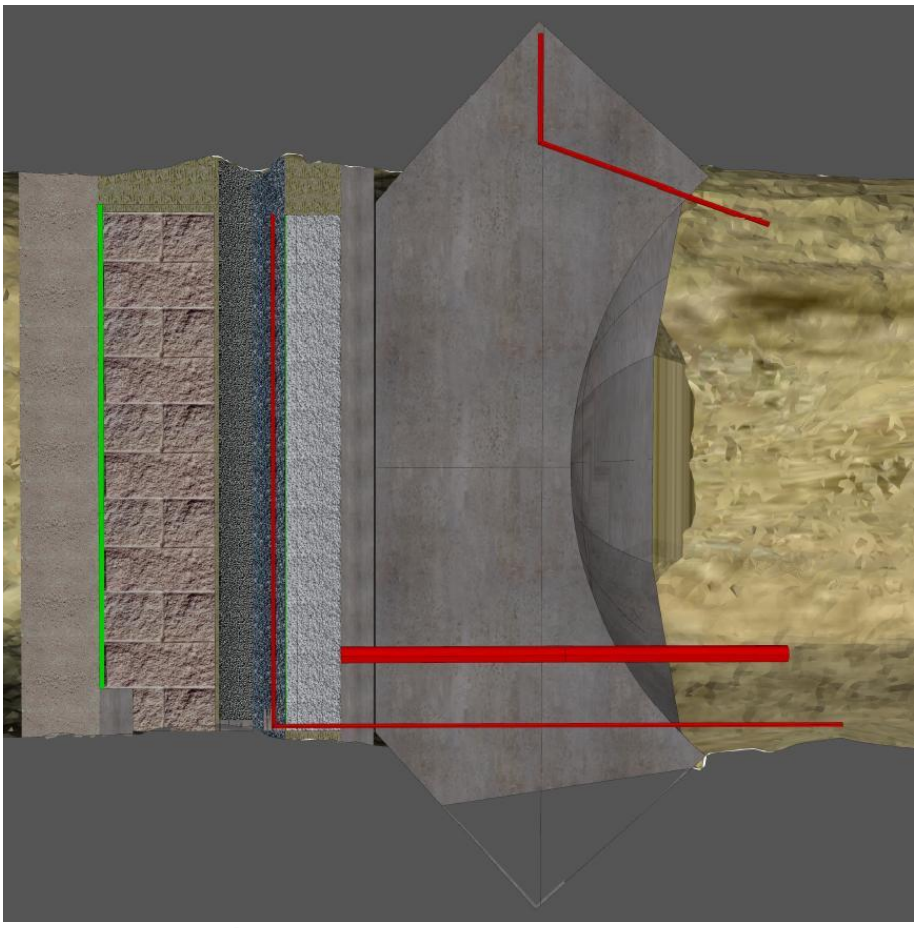

Figure 3. Dome Plug Experiment (DOMPLU) (c) SKB

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

The deposition tunnel plug (POPLU) aims to be the first underground full-scale engineered barrier system (EBS) component construction and demonstration at Posiva's future repository site in ONKALO. The experiment is carried out jointly by Posiva (FI) and SKB (SE) together with VTT (FI) and BTECH (FI). The POPLU experiment includes aspects related to the oversight of the work by the STUK - Radiation and Nuclear Safety Authority, Finland, as the ONKALO will be part of Posiva's future repository. The POPLU practices for information exchange procedures with the authorities and the procedures for various long-term safety and quality assurance approval (i.e. of stray materials and the requirements related to the classified nuclear safety related components) are important issues in additional to the construction and monitoring implementation of the experiment.

The POPLU experiment (Figure 4) will be constructed in a new demonstration tunnel at ONKALO at the actual disposal depth (-420 m level), postulated that the rock suitability classification completed during tunnel and plug slot excavation confirms with the site suitability. The POPLU design is based on a wedge type plug design in a wire-sawed location in the tunnel, having a full-scale size of only 14 m^2. New material recipes are developed and verified for the low-pH concrete, accounting for the shrinkage and heat development being handled in alternative methods than evaluated in DOMPLU. DOMPLU and POPLU experiments have many common aspects despite their different structural designs. Thus the two experiments have been designed to have similar type of plug slot excavations, accelerated loading, and monitoring activities so that their performance can be compared. The performance experiences are collected and compared jointly and reported within the DOPAS project.

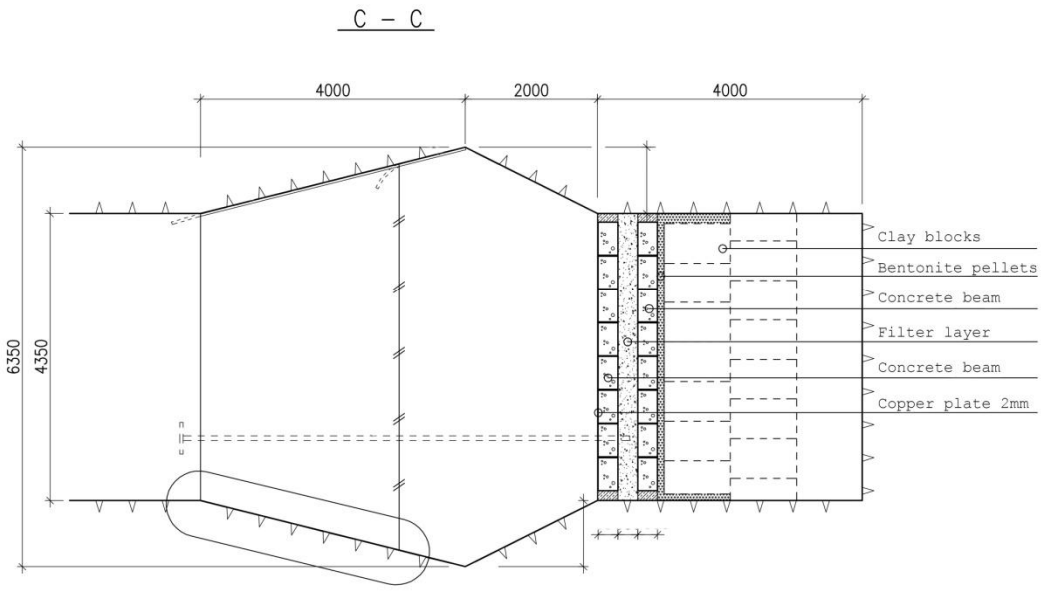

Figure 4. Posiva's deposition tunnel plug experiment (POPLU) (c) Posiva

2.6 DOPAS Experiment 5. In-situ demonstration test for shaft sealing components (ELSA) in Germany

In-situ demonstration test for shaft sealing components of the future ELSA (DE) experiment are also a part of the DOPAS project. The work will be initiated with process level modelling activities to increase process understanding. In parallel a couple of laboratory test will be performed which

addresses sealing materials planned to be utilised in the shaft seals. The programme aims at providing experimental data needed for the theoretical analysis of the long-term behaviour of MgO and cement based salt concrete in interaction with the host rock and fluids. The data gained will be needed to show the long-term preservation of the required permeability of the seals. The modelling work with required laboratory analyses will be used for planning the shaft seal concept for salt environment and for clay environment. The actual in situ ELSA demonstrations are not yet implemented within DOPAS project, but at a later stage after the DOPAS project has ended.

3 Integration of DOPAS demonstrations from the desk in to the field

3.1 Planning the experiments

For any experiment it is usually that it has changes and deviations compared to the existing reference designs and to the actual designs that will be implemented in the repositories, as is the case also for DOPAS experiments. Therefore it is an essential part of the experimental work to have separate requirements also for the experiments and careful consideration of the scope and target of the experiments. Usually these changes relate to the experimental site, test scale, duration of the test, interactions with other components, conditions like temperature and moisture. Selection of the location for hosting the plug and its excavation, which will be an ordinary industrial process in future disposal facilities, has previously been tested at full-scale only to a limited extent. During the planning phase for plug location selection and excavation, best practices are established in the project related to occupational and operational safety, selection of excavation methods, and design of unique tunnel reinforcement to preserve the initial geological conditions. The experiment site selection in geological formations has challenges about identifying a representative site which in the best possible way give answers to the experimental needs, which are not necessarily the same as in a real repository, and the basis for the selection needs to be documented.

Practical considerations need to be taken into account for plug emplacement, such as methods that perhaps are modified for the experimental purpose and do not represent the actual vehicles or equipment to be used in the future. Also the use of sensors and measuring systems for monitoring of the experiments influences the experiment design. Great emphasis is put on planning the monitoring needs and techniques during the accelerated loading of the plugs, to ensure optimal use of results for performance and safety assessments that can be used to forecast lifetime engineering. Part of the experimental planning is evaluating alternatives and verifying performance of alternative materials and their combinations to be used in the plug components. The material development includes advances in cement-based and bentonite-based components used for plugs and seals. A comprehensive laboratory programme is required in order to ensure use of the correct specifications in full-scale experiments and future operational conditions. Low-pH cementitious materials have been developed in several projects for more than a decade, but still their use at full-scale requires modifications in mixes and laboratory verification of their properties before field use at a decametric scale. Laboratory analyses for mechanical and chemical evolution of the materials' performance, such as pH verification, sulphate resistance, shrinkage cracking, strength development, water tightness and erosion resistance, takes several months. The laboratory information is also needed as source data for the assessment of behaviour over time in repository conditions, in the early stage of the project. The production of bentonite components for large-scale tests requires understanding of manufacturing and emplacement processes, including quality assurance, storage and transport of the materials, ensuring achievement of planned design and accounting for the interactions between cementitious- and bentonite-based components in field conditions.

3.2 Implementing the experiments

How much implementation of the plugs and seals experiments deviates from the actual operation phase depends on the scope of the experiment. On one hand, if the scope is purely industrial to show the production phase even with new methods, the construction should be quite a similar process as it will be during actual future operations. On the other hand, if the scope is more research orientated, the emplacement can be totally different compared to the real disposal actions. Within DOPAS the planned experiments have variation in their scope and purpose. The first Experiment, FSS resembles the production of one EBS component with an industrial purpose of the experiment and it will serve the information for timing of work phases and working with prototype equipments. FSS has a large development programme for different fabrication and emplacement methods prior the actual field activities. Experiments two EPSP, three DOMPLU and four POPLU are more related to the research and development and the scope of demonstration is to study the performance of the component, bearing in mind all the challenges related to the construction in underground conditions and learning how to monitor the experiments. The plugs are very much a craft that requires feasible methods on an industrial scale for the purpose of their installation into final repository tunnels. Material types, detailed measurements of components, fastenings and connections to the surrounding host rock, which varies depending on the host rock, mixing, handling and emplacement of different components with their initial quality control and the work phases and quality control after emplacement (like casting the concrete or installing the pellets and blocks or sprayed bentonite mixture) are examples of areas that must be evaluated for further optimization. The methods of plugging and sealing need to be improved regarding their reliability to meet the safety functions and requirements derived from those. The logistics also need to be adapted and demonstrated as the function of the different access and disposal tunnel sizes used in the underground repositories in different countries and host rock environment.

For all experiments, the common issues are the development of risk management, documentation, quality assurance, change management procedures, approval of materials to be used in repositories. Instrumentation and monitoring of full-scale experiments is required to gain information on plug feasibility, but also for assessment of the plug and seal behaviour during accelerated loading and environmental conditions. After implementation, the main objectives are obtaining accurate performance data, learning how to utilize the data, verifying conceptual models, and potentially modifying the existing reference designs. Although a plug is basically designed to be in compliance with the requirements, it is not entirely clear that a generic design of the plug is always the best solution. During the DOPAS project it will be beneficial to evaluate the level of uncertainty arising in the demonstrated concepts. Possible disturbances by monitoring are mitigated by testing new techniques, such as wireless sensors.

3.3 Assessing the experiments

The full-scale demonstrations alone do not provide sufficient information on the performance of the plugs and therefore modelling is utilized and implemented in many phases. When the design basis with constraints and future evolution has been described, the performance requirements need to be established and already this phase requires information on expected component behaviour in the long-term. Theoretical calculations are needed to ensure that the scope and target of the demonstrations are considered and the correct source data is provided for further analysis. Before the data from the demonstrations can be used in a reliable way, background work is needed for developing the models for plugs and seals, describing the performance assessment methodology, processes and phenomena that are related to the plug and seal behaviour over the long-term.

One part of the work is also to assess the role of the plugs and seals within geological disposal. Therefore the assessment work focuses also on the development of integrated long-term performance assessment methodology to analyse the system behaviour and to demonstrate the contribution of the plugs and seals to the overall safety. Sensitivity analysis and uncertainties are also considered for the implemented experiments to get an understanding how demonstrated plugs and seals might influence safety. Within the DOPAS project, a development and application is planned for safety functions and performance indicators, which are used to measure the performance and to demonstrate the efficiency of the sealing system. One aim with the performance related work is to produce a general application for assessing the role of plugs and seals in different concepts and in different conditions.

4. Conclusions and integration of knowledge

Different types of plugs and seals are needed in all geological repositories and sufficient statistics and proofs must be achieved by theoretical considerations and by evaluating the components in laboratory and in field conditions. This compiled information is used for development and licensing purposes prior to optimisation of operations. The integration of all information from experiments will be taken care by analysing and reporting the results not only in experiment wise but jointly within DOPAS project. The public work package summary reports will be quality assured using Expert Elicitation in addition to the internal quality assurance procedures.

The DOPAS work so far has shown that all parts of the work (design basis and requirements, planning of the Experiments, small scale testing, full scale testing, monitoring and follow up the tests, performance and safety assessment) are related to each other and all parts should have an equal weight. It is obvious that large scale demonstrations and experiences on similar experiments need well planned mitigation activities in the management of the project related risks, too. Outcomes from the DOPAS project will be disseminated via a web site, public reports, papers and presentations at various conferences. Knowledge transfer will benefit from planned workshops and seminars as well as expert staff exchange

The DOPAS project will provide experiences for verifying the design basis and requirements and for reasoning the reference designs. DOPAS produces as an outcome also procedures for the planning, implementation and assessing the future experiments for different EBS components that is not just limited to plugs and seals. Experience does exist, but new aspects related to the industrialisation, monitoring, quality assured work in repository conditions are further developed and give a basis for organisations to proceed in their programmes at different levels.

5. Acknowledgements

The DOPAS project with full-scale experiments provides the basis for future needs related to plug and seal technologies for nuclear waste management. The research leading to these results has received funding from the European Union's European Atomic Energy Community's (Euratom) Seventh Framework Programme FP7/2007-2013 under Grant agreement no 323273, the DOPAS project". Also the writers wish to thank the member organisations of the DOPAS consortium for their contributions for producing this paper.

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