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

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ABSTRACT

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

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

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

INTRODUCTION

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

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

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

THE DOPAS PROJECT

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

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

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

THE FSS RATIONALE

Drift Sealing Concepts in the French Deep Geological Repository

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

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

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

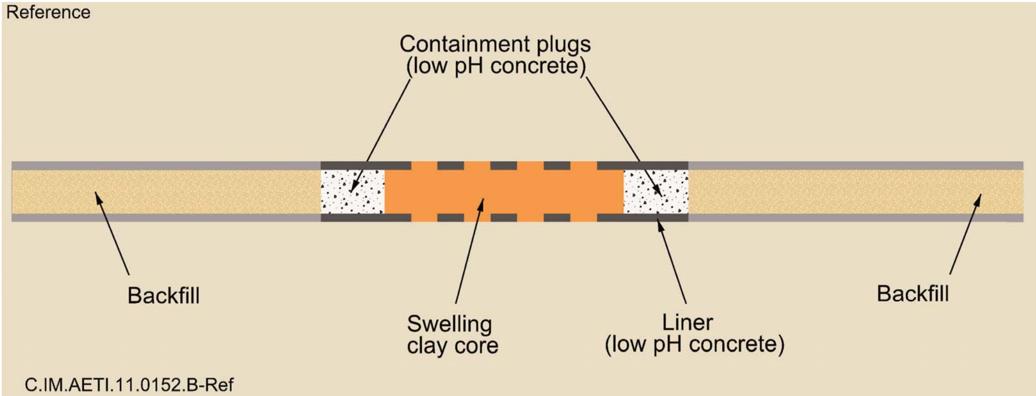

Fig. 1. Reference drift sealing and backfilling concept.

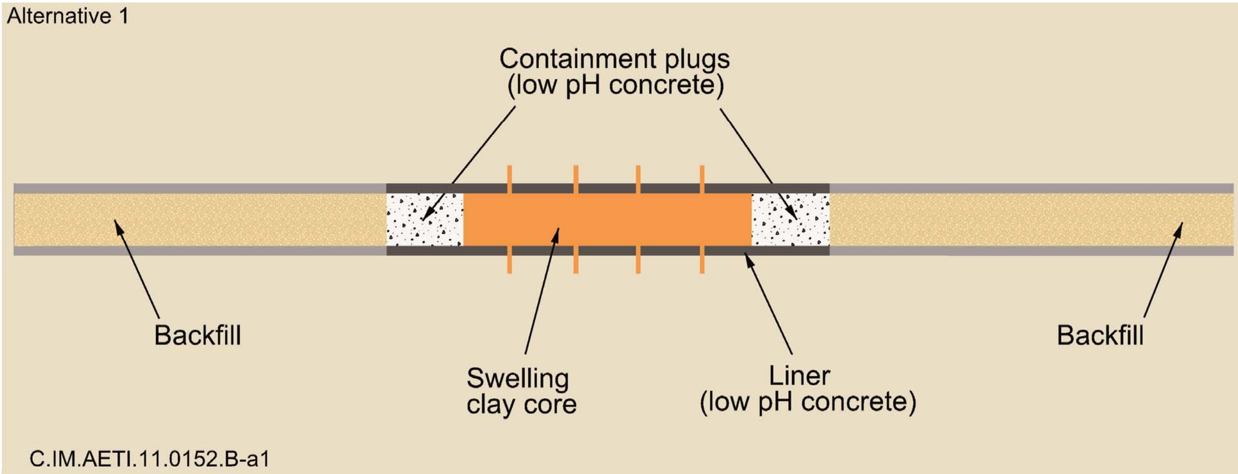

Fig. 2. Alternative drift sealing and backfilling concept.

The Various Seal Related Experiments and Tests Planned by ANDRA

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

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

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

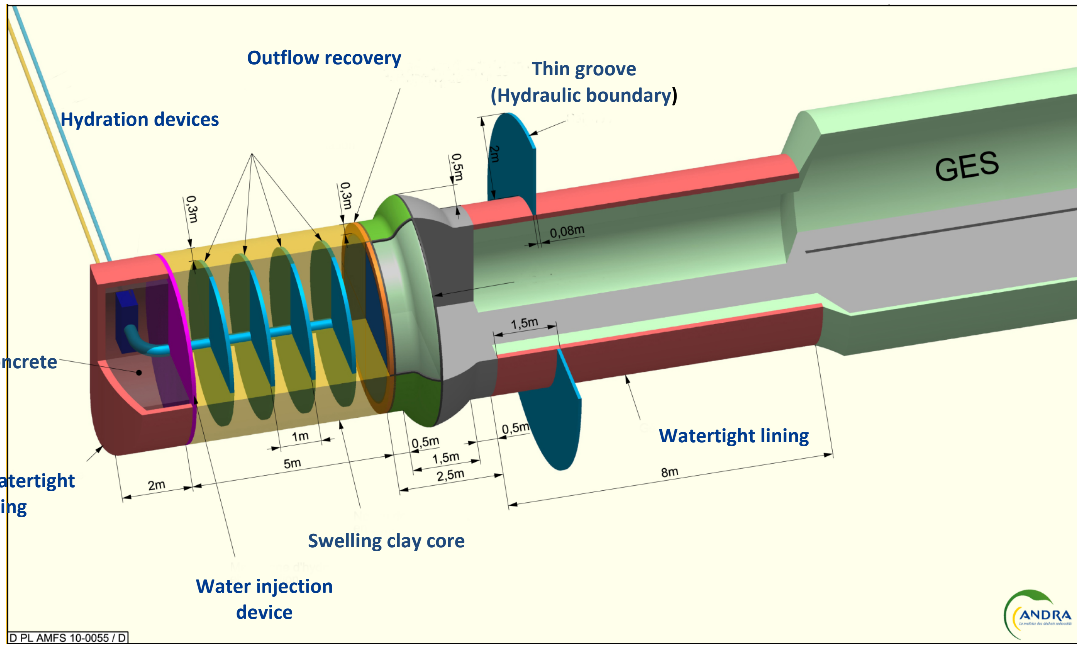

Fig. 3. Scientific seal hydration experiment at Bure underground laboratory.

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

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

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

THE FSS CONSTRUCTION

The FSS Significant Size

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

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

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

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

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

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

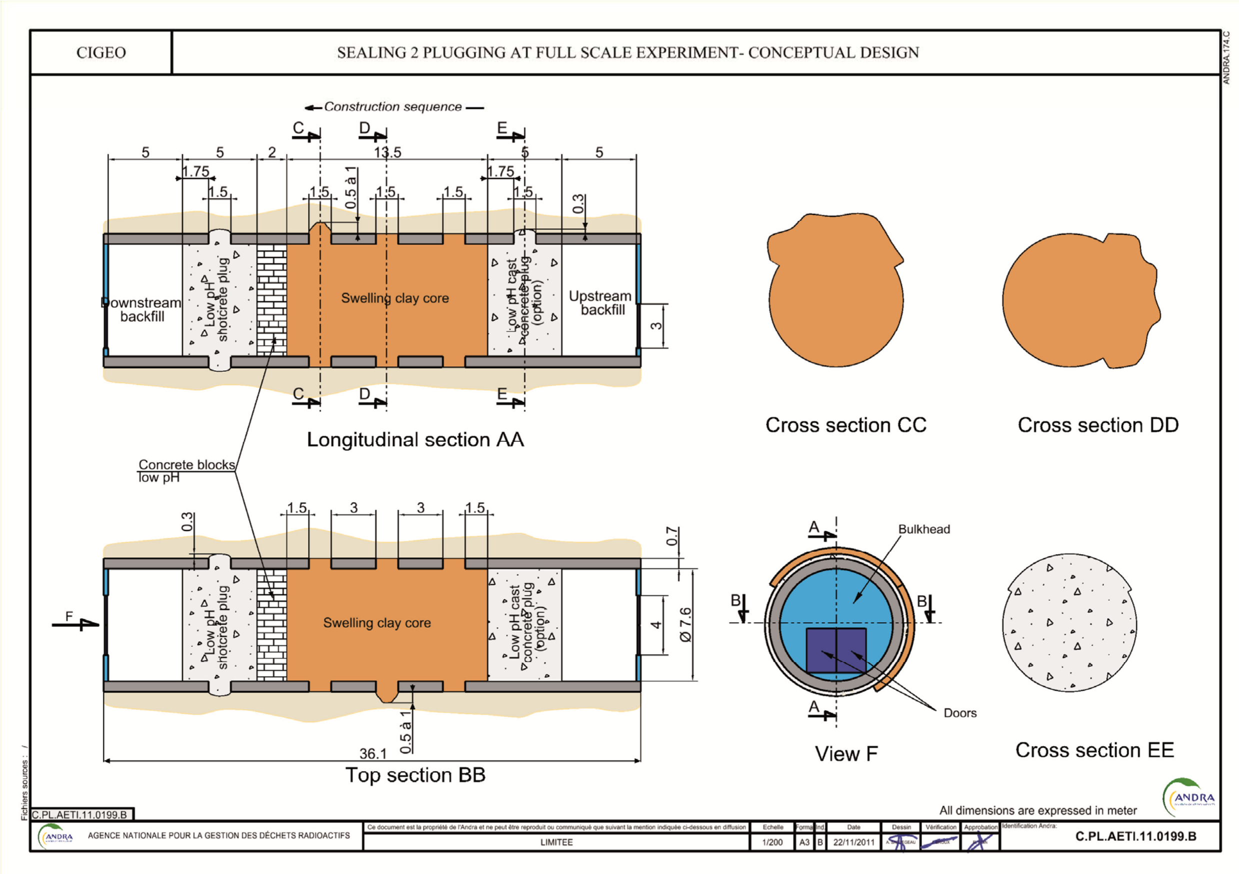

Fig. 5. Longitudinal view of the FSS experiment as built in its box.

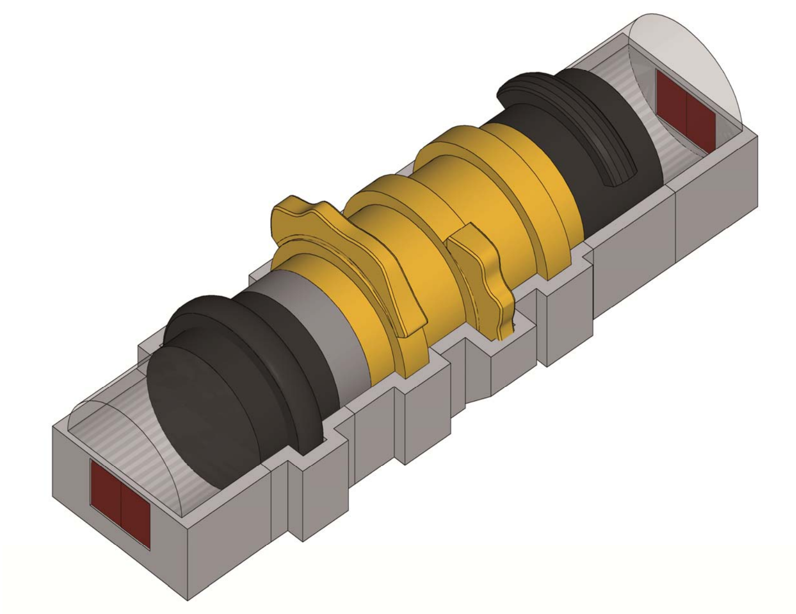

Fig. 6. 3D view of the FSS experiment as built in its box with the breakouts (recesses) in the argillite formation.

The Bentonite Swelling Core and Concrete Plugs Construction Challenge:

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

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

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

Main Milestones and Present Status

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

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

CONCLUSION

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

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

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

REFERENCES

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

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