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ESDRED – An Integrated European Project Focused on Technology Development

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Summary

ESDRED (Engineering Studies and Demonstrations of Repository Designs) is an Integrated Project focused on technology development. Over the course of the last 56 months the participants have designed, fabricated, tested and shown a number of static and dynamic demonstrators related to the emplacement of HLLL radioactive waste all of which met or exceeded the design specifications. Other work related to the formulation of low pH cement/concrete/shotcrete mixes and subsequent application/demonstration of these for repository construction and for rock support. Still other work related to the formulation of various material mixes which were then demonstrated as prefabricated or cast in place engineered barriers (or backfill).

The results achieved within ESDRED are now on display, or ongoing, at various underground locations including Äspö in Sweden as well as Mont Terri and Grimsel in Switzerland. Andra’s demonstrators have recently been moved to the Saudron Technological Centre near the Bure URL in France while the Ondraf / Euridice work can be seen at the MOL facility in Belgium. DBE TEC’s vertical emplacement demonstrator is set up in the turbine hall of a former thermal power station located near Landesbergen, Germany. All these demonstrators contribute to public confidence building, regarding the societal issues related to underground disposal of radioactive waste.

1. Introduction

The Integrated Project known as ESDRED has been a joint research and development effort by major national radioactive waste management agencies (or subsidiaries of those agencies) and by research organisations. ESDRED was co-ordinated by the French National Radioactive Waste Management Agency (Andra). The original five year budget of EURO 18.4 million, of which 7.3 million was provided by the European Commission (EC), was overspent because several of the participants elected to do either more work or more elaborate work than originally envisaged.

The 13 participants (Contractors) in this project, from 9 European countries, are:

Radioactive Waste Management Agencies:
ANDRA, France
ENRESA, Spain
NAGRA, Switzerland
NDA (Originally NIREX), United Kingdom
ONDRAF/NIRAS, Belgium
POSIVA, Finland
SKB, Sweden

Technological R&D Organisations:
AITEMIN, Spain
CSIC, Spain
DBE TECHNOLOGY, Germany
ESV EURIDICE EIG, Belgium
GRS, Germany
NRG, the Netherlands

2. Methodology

ESDRED has been focused on technology and has had three main objectives.

The **FIRST OBJECTIVE** was to demonstrate, at an industrial scale, the technical feasibility of some very specific activities related to the construction, operation and closure of a deep geological repository for high level radioactive waste. This part of the work was organised inside four (4) Technical Modules (and numerous work packages) and essentially involved the conception, design, fabrication and demonstration of equipment or products for which relevant proven industrial counterparts (mainly in the nuclear and mining industry) do not exist today. Execution of the work was often by third party sub-contractors (especially the detailed design, fabrication and testing of new equipment) although, depending on the participant, more or less of the work was done in-house.

Each of the four technical Modules involved from 3 to 7 participants thus ensuring that the know-how and experience from several different national disposal concepts could be integrated into the work. The results of the work within each of these Modules are provided in the next Section.

A **SECOND** and equally important ESDRED **OBJECTIVE** was to promote a shared European vision in the field of radioactive waste disposal technology. This was accomplished through the INTEGRATION process, which is one of the key objectives that identify EURATOM's 6th Framework Programme. Among other things integration resulted from working together, sharing information, comparing input data and functional requirements, learning from one another's difficulties, developing common or similar tender documents and bidder lists, jointly developing courses and workshops and coordinating demonstration activities whenever possible.

Generally at least 2 Integration meetings were convened annually so that all ESDRED participants were updated on the progress of the work in all the Modules. Whenever practical these meetings were combined with the demonstration of a particular piece of new equipment, process or construction.

The **THIRD OBJECTIVE** focused on training and communication. Over the life of the project the participants wrote many articles, presented numerous technical papers at international conferences, held 2 workshops, developed and presented 17 university lectures, and finished up by organising an international conference on the operational aspects of deep geological disposal. Also a web site (www.esdred.info) was created and maintained over the life of the project. This site will be kept on line until sometime in 2010.

3. Results

3.1 Overview

Details of the results, organised by Module are presented in the next 5 Sections. As stated earlier the work within ESDRED was primarily focused on Technology Development. In many instances the participants were able to develop and demonstrate equipment, processes or systems for which there are no industrial equivalents anywhere. Among others these include:

- A simplified and partially scaled down version of an air cushion transporter,
- A 1:1 scale air cushion emplacement system for 43t spent fuel canisters,

- A 1:1 scale water cushion emplacement system for 45t spent fuel Super Containers,
- A 1:1 scale pushing robot for horizontal emplacement of 2t vitrified waste canisters,
- A 1:1 scale transport shuttle, docking table, transport shielding cask and second generation pushing robot for horizontal emplacement of 2t vitrified waste canisters (to be completed by year end),
- A 1:1 scale system for emplacement of vitrified waste and spent fuel canisters in long vertical boreholes; including the rail mounted transport and the borehole locking equipment (to be completed by year end),
- 14 four ton rings/discs of highly compacted bentonite/sand material for use as prefabricated buffer material (used in the construction of horizontal disposal cells); including the mould utilised to produce them and the custom built equipment needed to manipulate them,
- A system for backfilling the annular gap between a canister and a circular tunnel with granular bentonite while achieving important in situ design characteristics of the backfill,
- The formulation of various backfill materials which were subsequently successfully tested on surface in a short mock-up of a disposal tunnel, to backfill the annular gap between a circular tunnel and a Super Container. Subsequently a specially formulated grout was tested for the same purpose in a 30m long mock-up,
- Formulation of low pH cement mixes for incorporation in shotcrete and then used to construct a 1m and also a 4m long closure plug. The first was loaded to destruction; the second loading test is ongoing. Low pH shotcrete was also tested as rock support material.
- Field testing of wireless monitoring techniques using seismic tomography is still ongoing.

3.2 Module 1 - Buffer Construction Technologies for Horizontal Disposal Concepts

Within **Module 1** Andra was able to successfully design the mould (Fig. 1) and the necessary formulation (70/30 of MX80 bentonite/sand) and thereafter produce 4 ton bentonite rings (Fig. 2) to be used as an engineered barrier. Ondraf/Niras (Fig. 3) demonstrated backfilling of the annular gap between a waste canister and the disposal drift wall using a variety of wet and dry products. Nagra (Fig 4) developed the product and the technique for backfilling disposal drifts with bentonite pellets. The evolution over time and the performance of bentonite based seals, particularly in relation to gas permeability, was assessed by GRS and is in fact on-going beyond ESDRED. Finally non-intrusive monitoring techniques based on seismic tomography were also developed and demonstrated by the NDA.

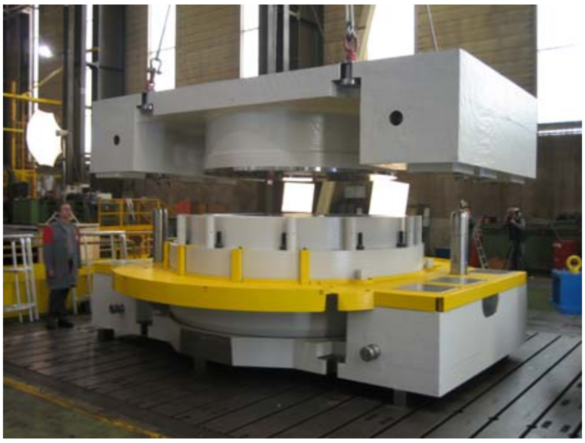

Figure 1: *100 Ton Mould for Pressing Sand/bentonite Rings (Andra)*

Figure 2: *4 Ton, 2.25m diameter bentonite/sand ring after 45 000 tons of pressure & stripping from mould (Andra)*

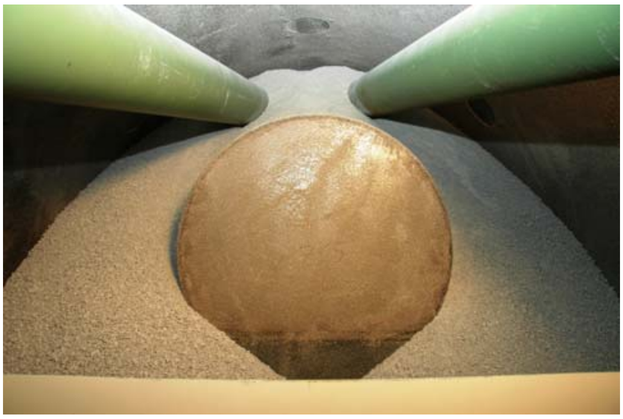

Figure 3: *Reduced scale mock-up after backfill testing (Ondraf / Niras & Euridice)*

Figure 4: *Double Auger (green) Placement of Bentonite Pellets Around a Canister (Nagra)*

Rock support tests, gas seal tests and non-intrusive monitoring tests were all conducted underground. On the other hand the EBS rings and the backfilling tests were conducted on surface at reduced and at full scale. The only underground in situ EBS test is the hydraulic plug still to be completed in the Praclay Gallery at MOL, Belgium. This work will be conducted by Ondraf/Niras and Euridice.

3.3 Module 2 – Waste Canister Transfer and Emplacement Technology

In **Module 2** two participants (Andra and DBE Technology) were able to design, fabricate and demonstrate the equipment needed for the **Transfer and Emplacement of Waste Canisters** weighing between 2 and 5 tons. The respective equipment is designed for emplacement in **either** horizontal or vertical disposal boreholes with very small annular clearances between the canister and the wall of the disposal boreholes. A desk study related to retrievability was produced by the third participant, NRG, based on the 2 emplacement concepts.

Figure 5: *First prototype Pushing Robot & 2t canister (Andra)*

Figure 6: *Second prototype Pushing Robot (Andra)*

The horizontal emplacement equipment (Fig. 5) which was produced can be seen by the public at Andra’s Prototype Exhibition Hall in Saudron near the Bure URL in France. The current second generation pushing robot is shown in (Fig. 6). The vertical emplacement equipment (Fig. 7) can currently be seen at DBE TEC's temporary test facility at Landesbergen, near Hannover Germany. Most of the documents related to the design, fabrication and testing are public.

Before being put on display, either at Saudron in France or at a facility to be determined in Germany, both emplacement systems will have been functionally demonstrated in surface facilities using inert waste canisters that were otherwise accurate geometrically and with regard to mass.

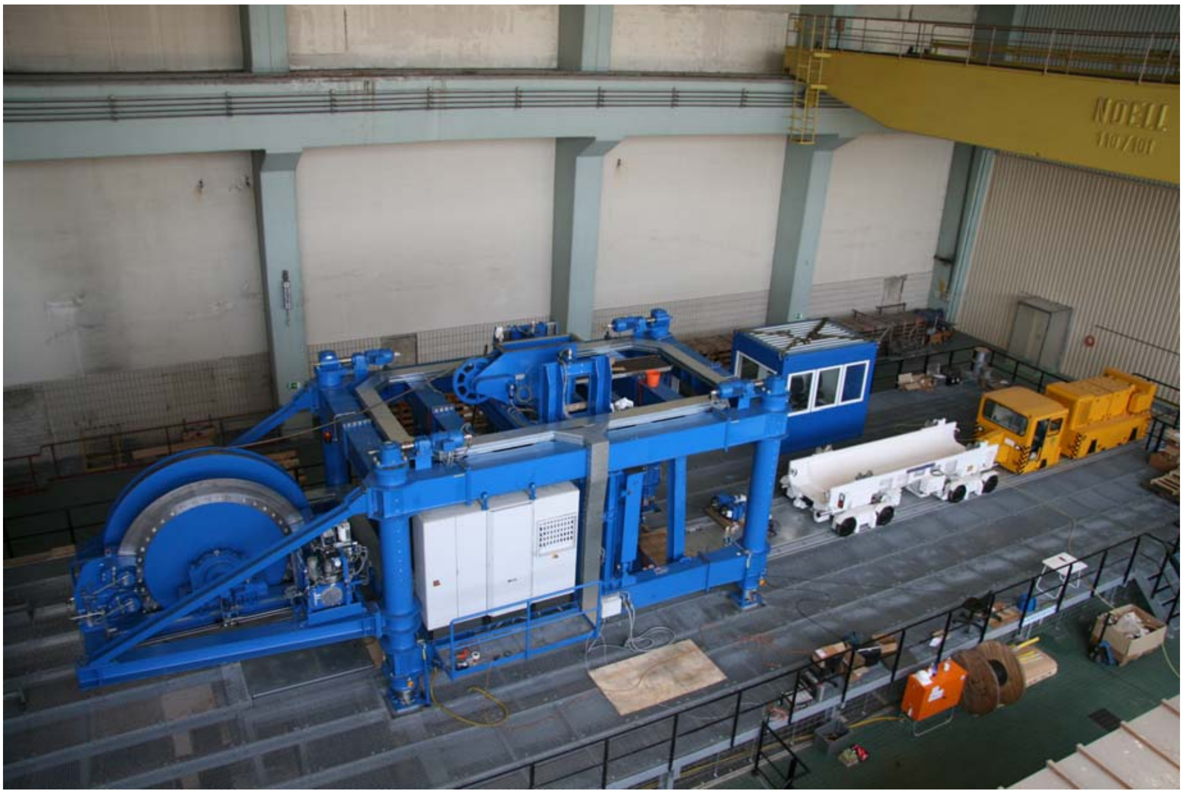

Figure 7: *Tilting frame of vertical emplacement system including transport cart and locomotive (DBE TEC)*

3.4 Module 3 - Heavy Load Emplacement Technology

Heavy Load Emplacement Technology for horizontal disposal concepts was the only focus of **Module 3.** The participants active in this work (SKB/Posiva & Andra) each successfully produced a machine for emplacing 43/45 ton waste canisters in horizontal bored disposal tunnels while maintaining only a very small annular gap between the canister and the walls of the tunnel. One machine was based on air cushion technology while the other used water cushions. The latter machine was subsequently adapted to demonstrate the emplacement of packages of 4 pre-assembled bentonite/sand rings produced in Module 1, weighing 17 tons per package.

Figure 8: *Demonstration of emplacement of 43 ton Spent Fuel canister using Air Cushion Emplacement Equipment (Andra)*

Figure 9: *Water Cushion Emplacement Machine with 45 Ton Super Container in Background (SKB / Posiva)*

The air cushion machine (Fig. 8) is on public display at Andra's Prototype Exhibition Hall in Saudron near the Bure URL in France. At time of writing the water cushion machine (Fig. 9) is set up underground on the -220m level at the Äspö URL in Sweden. Design details, test results as well as recommendations for future enhancements are available in the various project reports which have been designated for public access.

3.5 Module 4 - Temporary Sealing (using low pH cement) Technology

The work in **Module 4** consisted first of designing low pH cement formulations and then of preparing several concrete designs suitable for the construction of sealing plugs and for rock support. In both cases shotcreting was used as the construction method. A short plug and a long plug were subsequently constructed in 2 different URL's. The short plug (Fig. 10), constructed at Äspö in Sweden, was very quickly loaded to failure (i.e. until it started to slip) by pumping pressurised water behind the plug. It was monitored during the entire process. The longer plug (Fig. 11), constructed at Grimsel in Switzerland, is currently being loaded using the pressures generated by the swelling of bentonite blocks during rehydration.

Figure 10: *Short Plug Construction at Äspö (Enresa / Aitemin / CSIC)*

Figure 11: *Long Plug in Background with Monitoring Equipment at Grimsel (Enresa / Aitemin / CSIC)*

3.6 Module 5 – Training and Communication

This is an area to which the participants committed many man-days and significant costs. Often the participants were called upon to work very closely together in order to get the job done. Among other things:

- An ESDRED Web Site was set up early in the Programme and updated on a regular basis. Among many other things this site provided an annual summary of activities completed, made important documents (including Proceedings for example) available to the public, advertised important events, etc. This site will be maintained until sometime in 2010.
- A Masters level course (17 lectures) was developed by the ESDRED partners and presented to the students of the University Politehnica of Bucharest, Romania, in November 2006. This involved 8 of the 13 ESDRED participants.
- Two workshops focusing on R&D related to low pH cements were organised by the concerned ESDRED partners and attracted an international audience and authors.
- ESDRED representatives also participated and contributed world wide to workshops organised by others.
- Media events were organised often around the various demonstrators.
- Joint papers were written by representatives from several different national agencies.
- Technical articles appeared in Professional Journals, in in-house magazines, in sub-contractor bulletins and journals; sometimes written by ESDRED personnel and sometimes by others.

Broad dissemination of ESDRED results undoubtedly helped to build confidence in the disposal concepts being considered in the European nuclear area as well as to bring the representatives of the national agencies closer together. As a minimum a better understanding of the issues was shared and a broader knowledge of the available solutions was imparted. Informal networks of engineers, contractors, suppliers and experts were established on a European Scale.

Finally the crowning highlight of the Project came in June of 2008 when an *"International Technical Conference on Practical Aspects of Deep Radioactive Waste Disposal"* was organised by ESDRED partners Andra and GRS in conjunction with the Czech Technical University of Prague (CTU) and RAWRA the Czech national waste management agency. This very successful event, which also included a special Student Session, was held in the facilities of the CTU, Faculty of Civil Engineering, Centre of Experimental Geotechnics, June 16-18, 2008. Nineteen of the 38 papers and posters were related directly to ESDRED, to the national agencies represented in ESDRED or to the sub-contractors that had been engaged by ESDRED. There were papers and posters from 13 countries with registrants from 19 different countries. Total registration (over 130 attendees) exceeded the objective fixed 2 years earlier.

4. Discussion

The main work accomplished in **Module 1** proved that it was possible to prefabricate large (2.3m diameter) bentonite/sand rings and discs with the desired characteristics and which could be safely manipulated and placed in a disposal cell. It also showed that it was possible to cast in place various engineered barriers (and obtain the desired characteristics) consisting of bentonite, of bentonite/sand mixtures, of bentonite pellets, of cement grout and other materials to be used for filling small annular voids or for backfilling disposal drifts and voids around canisters.

The various reports produced by the partners in **Module 1**, most of which are available to the public, could enable interested parties:

- To design a sand/bentonite mixture which, when compressed into a ring or produced as pellets, is suitable to be used as an engineered barrier around waste canisters with appropriate physio-chemical characteristics,
- To design and fabricate a mould for producing large EBS rings as well as all the related stripping and handling equipment,
- To formulate various wet and dry materials for use as a backfill and to evaluate different related placement options,
- To design a borehole seal for which the relative permeability to gas and water is optimised and to have an understanding of the performance of such a seal over time,
- To evaluate whether non-intrusive monitoring based on seismic tomography is suitable to their particular application.

Similarly the results of the work completed in **Module 2** would enable interested parties to adapt, to their own repository conditions, the ESDRED equipment and system designs for the disposal of canisters weighing less than 10 tons. Designs are available for both vertical and horizontal disposal. By integrating the Andra and the DBE TEC designs, either track or trackless transport could be possible.

The various reports produced by the partners in **Module 2**, most of which are available to the public, could among other things assist interested parties:

- To design a pushing robot for emplacing canisters in horizontal boreholes with less than 25 mm of clearance between the outside of the canister and the inside of the disposal drift,
- To consider a specific design of ceramic pads or sliding runners as part of their canisters with a view to decreasing friction and creating a non-corrosive interface between the canister and any metal lining installed in the disposal cell,
- To design a transport vehicle complete with transport shielding cask, docking table, and interlocking gamma gates,
- To design a borehole locking device for vertical emplacement,
- To design a transport cask and associated emplacement device which incorporates a unique tilting device to move a horizontal canister into a vertical hole.

The **Module 2** final report will also include recommendations for future modifications and/or additional test work all aimed at further improving the original ESDRED designs.

The work completed in **Module 3** clearly showed that either air or water cushion technology can be used to transport heavy canisters up to 45 tons (heavier loads would simply require more cushions) in situations where minimising the annular clearance between the canister and the inside face of the disposal tunnel is important for technical and/or financial reasons. The choice of air or water depends on the specific conditions. For example water cushions cannot be used in a repository in clay for obvious reasons. The various public reports produced by the SKB/POSIVA and by Andra, the 3 partners in **Module 3**, could help interested parties to adapt the ESDRED designs to their own needs for the emplacement of heavy loads. The final reports also provide recommendations for future modifications and/or additional test work all aimed at further improving the original ESDRED designs.

A variety of **Module 4** project reports that are available to the public, describe in detail the process used to develop the various low pH cements which would meet the project needs. The use of one or more of these special cements to produce shotcrete for the construction of retaining plugs and for rock support is also described. Other reports describe the test plans and the execution related to the construction of the 2 plugs noted in Section 3.5. The short plug constructed at Äspö was monitored during loading and after failure it was demolished and tested. The related results have been evaluated and lessons learned. However the long plug at Grimsel is still intact.

Most of the materials produced within **Module 5** including the Proceedings of the 2 Workshops and the International Conference in Prague, as well as the course provided at the University Politehnica in Bucharest Romania, can be downloaded from the ESDRED web site.

5. Conclusions

Clearly objectives like designing a common European Repository or even designing Repositories for various Europe countries that are all similar did not fall within the ESDRED mandate. In the end the legal framework, the national waste management programme, the existing and the perceived constraints, the stakeholder expectations as well as the physical setting are different in each country. On the other hand by working together the participants were able to observe first hand that they were all facing the same basic challenges and that they all shared a concern for the same fundamental issues that are key to the design of a safe geological HLLLW repository. In other words it quickly became clear that there already existed a common European view regarding deep geological disposal of high level radioactive waste, which was simply reinforced by the ESDRED experience.

The participants in ESDRED believe that they have made a valuable contribution to the body of technical knowledge related to deep geological disposal of HLLL radioactive waste. They have done this by fabricating and demonstrating various pieces of equipment which did not previously exist and which are now available to agencies globally as reference solutions that can be further improved and/or adapted to very specific applications. By communicating widely and by maintaining certain tangible results of the ESDRED work for ongoing public viewing, the partners have already increased the level of the public confidence in the industry's ability to safely dispose of HLLL radioactive waste, and they will continue to do so in the future.

At the end of the ESDRED Project (January 31, 2009) the Final Reports produced by each of the 4 Technical Modules and the Final Project Report will be placed on the ESDRED web site (www.info.com) where they can be downloaded. The European Commission on its site will also carry a list of other public reports produced by the ESDRED partners and how/where they can be obtained.

6. Acknowledgements

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