Publishable Executive Summary 5

The Integrated Project known as ESDRED (Engineering Studies and Demonstrations of Repository Designs) is a joint research effort by major national radioactive waste management agencies (or subsidiaries of those agencies) and by research organisations, representing nine European countries. ESDRED is co-ordinated by the French National Radioactive Waste Management Agency (ANDRA) and is part of the European Commission's 6th Euratom Framework Programme for Nuclear Research and Training. The five year Project started with a total budget of EURO 18.4 million, of which 7.3 million is from the EC's Framework Programme.

The 13 partners (Contractors) from 9 countries in this project are:

Radioactive Waste Management agencies:
ANDRA, France
ENRESA, Spain
NAGRA, Switzerland
NDA, 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

ESDRED is focused on technology and has three main objectives. The **FIRST OBJECTIVE** is 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. The work is organised inside four (4) Technical Modules and essentially involves 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. At all times this work is meant to be carried out within the framework of compliance regarding the requirements for operational safety, long term safety, retrievability and monitoring.

Each of the four technical Modules (listed below) involves from 3 to 7 Contractors and as many as 6 different national disposal concepts may be represented. The work programmes completed within each of the Modules during Year 5 of ESDRED are described on the following pages.

Module # 1: **Buffer Construction Technologies** for horizontal disposal concepts

Module # 2: **Waste Canister Transfer and Emplacement Technology** for horizontal and vertical disposal concepts

Module # 3: **Heavy Load Emplacement Technology** for horizontal disposal concepts

Module # 4: **Temporary Sealing (using low pH cement) Technology** for construction of sealing plugs and for rock support, using shotcrete techniques

A **SECOND** and equally important **OBJECTIVE** is to promote a shared European vision in the field of radioactive waste disposal technology. This is accomplished through the INTEGRATION process, which is one of the key objectives that identify EURATOM's 6th Framework Programme. Among other things, Integration (Module #6) involves working together within Work Packages and/or Modules; sharing information; comparing one another's input data and functional requirements for consistency; ensuring that, where possible, fabricated components are compatible; and coordination of demonstration activities whenever possible.

The **THIRD OBJECTIVE,** involving communication and training, is deemed to be sufficiently important to merit a separate Module #5. Among other things it involves the dissemination of knowledge by way of press releases, pamphlets, technical articles and presentations, videos and eventually an international event. Training, with a focus on New Member States, is to be accomplished via conferences, workshops and courses.

The original project schedule is shown in **Figure 1** below:

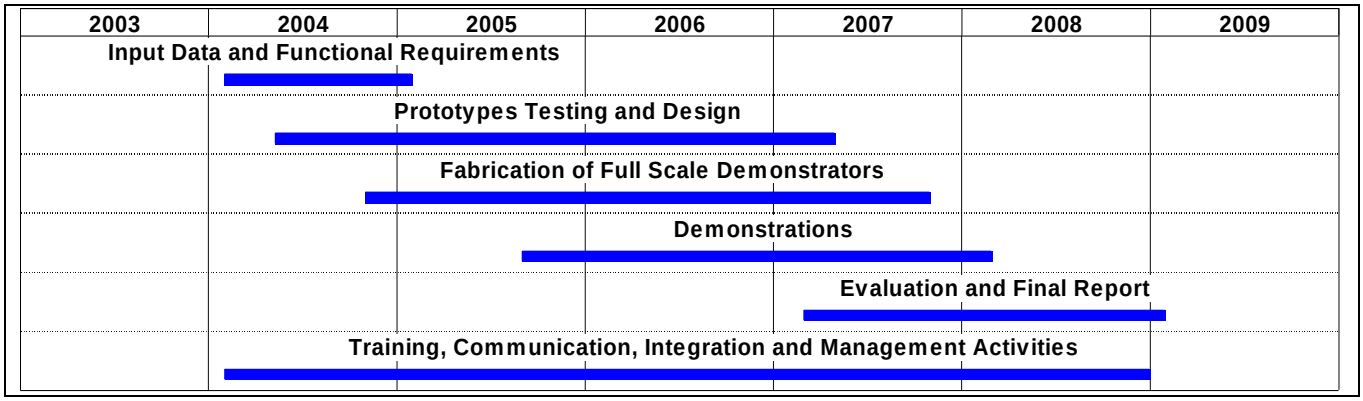

Figure 1: General Schedule of the ESDRED Project

As can be seen from the Figure 1 above all of the design, testing, fabrication and demonstration of the prototypes, and the full scale demonstrators, should have been completed by now, and this is indeed the case. The Final Reports have also been submitted to the EC so that the Project has now been completed. The fifth year of the Project, which terminated at the end of January 2009, can again be characterized as a success, given that all outstanding objectives for the Project were successfully concluded. These include:

- Execution of an annular gap backfilling test on a 30m long surface mock-up of a disposal drift, using a high pH grout and evaluation of the results.

- Technical evaluation and design of an underground sealing plug construction test to be carried out in mid 2009 as part of the Praclay programme.

- Continuation of the saturation dynamics testing of a lightly compacted sand/bentonite seal in a laboratory mock-up up to the point of water break-through, followed by the initiation of gas injection. Continuation of similar in situ testing of 4 similar borehole seals installed in an underground laboratory.

- Continuation of a programme of non-intrusive seismic based monitoring experiments at the Mont Terri underground laboratory in Switzerland. Final interpretation of the data collected will be completed within the context of a 4 year PhD programme. The programme of work will be continued and further developed at the Grimsel site in Switzerland through the EC 7th Framework Programme under Project **MoDeRn** (outside of ESDRED).

- Design, fabrication and demonstration of a system for the horizontal disposal of vitrified waste canisters including the transport shuttle, the transport shielding cask, gamma gates and related docking devices, pushing robot and mock-ups of the waste container and disposal drift.

- Design, fabrication and demonstration of a system for the vertical disposal of spent fuel canisters which complied with German Mining Regulations and Atomic Energy Act requirements. This system includes the transport cart, the transport shielding cask, canister lifting and disposal gear and related borehole locks and docking devices as well as mock-ups of the waste container and disposal borehole.

- Transfer of ANDRA's heavy load emplacement equipment (as well as other ESDRED demonstrators previously stored at the temporary Show room at Limay) to the new Technology Centre (Cte) at Saudron close to ANDRA's URL site at Bure in France.

- Monitoring of the 4m long plug constructed at the Grimsel URL using low pH shotcrete. This plug is being used as part of the MoDeRn Project and final results will be reported as part of the latter project.

- Continued improvements to the ESDRED web site (www.esdred.info) which had recorded over 16,000 visitors to the end of the year 2008.

- ESDRED partners presented papers and/or participated in conferences and workshops in at least 8 different countries on 3 continents.

- Organising and running (in cooperation with the Czech Technical University in Prague and RAWRA, the Czech national waste management agency) the "International Technical Conference on the Practical Aspects of Deep Geological Disposal of Radioactive Waste" in Prague, in the Czech Republic, June 16-18, 2008 with more than 120 attendees.

- Organising and running an international training workshop on "Transport and Emplacement Technologies for Radioactive waste Packages" in Peine, Germany, November 4-5, 2008.

- Contributions to the EC's EURADWASTE Conference by way of papers, posters, videos and visits to the Bure URL, including a demonstration of ANDRA's ESDRED equipment.

THE TECHNICAL WORK ACCOMPLISHED DURING THE FIFTH YEAR INCLUDES:

Module 1: **Buffer Construction Technology**

ANDRA and NAGRA did not perform any technical work for Module 1 in the 5th Project year.

O/N executed the grout injection backfill test on the 30 m long full-scale mock-up on April 8th 2008. The feasibility of the injection technique was demonstrated, but it was also concluded that the water/cement ratio of the specific grout will need to be reduced in future R&D (outside ESDRED), to ensure that the backfill grout becomes hard shortly after injection. **Figure 2** shows a photograph taken of the front end of the mock-up right after the injection was ended. **Figure 3** show the back end of the mock-up after the lid was removed several months after the injection was completed. It shows a smooth face of hard backfill material, but 20 cm deep into the surface, the backfill material is more paste-like.

Figure 2: End of the grout injection test (picture taken April 8th 2008 at 18:20 pm)

Figure 3: Back end of the mock-up after removal of the lid (picture taken December 2nd 2008)

GRS has continued to run the performance tests on four seals of different clay/sand composition in boreholes at the Mont Terri URL. The results so far of these in situ tests, and also the results obtained from the preceding (and still ongoing) laboratory mock-up tests, confirm the advantageous sealing properties of moderately compacted clay/sand mixtures. The water breakthrough and associated gas injection test on the N° 2 laboratory mock-up took place in January 2009

NDA has continued the non-intrusive monitoring development program based on in situ seismic tomography testing around the HG-A tunnel in the Mont Terri URL. In the 5th project year, the main achievements were the finalization of the software anisotropic model of the clay test environment and the further development of associated full wave inversion code.

EURIDICE completed the design of the steel support structure of the PRACLAY seal. The actual in situ installation of the seal is now scheduled for the second quarter of 2009. **Figure 4** shows an axial cross-section of the design of the seal. **Figure 5** shows the temporary (wooden) lining where the steel support structure will be installed. Also, further computerized scoping calculations and laboratory testing have been performed to improve the understanding of the interaction between the sealing material (for which MX-80 was chosen) and the Boom Clay host rock.

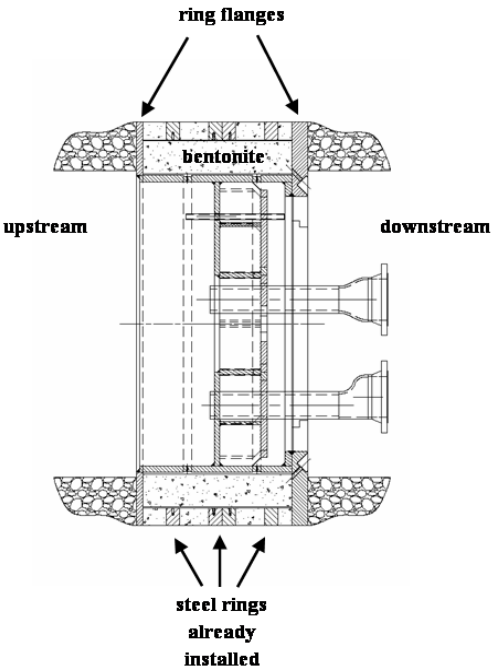

Figure 4: Axial cross-section of the seal general design

Figure 5: Lining of the PRACLAY gallery in the zone where the hydraulic seal will be placed

Module 2: Waste Canister Transfer and Emplacement Technology

DBE TECHNOLOGY has completed the fabrication of the technical components for the vertical emplacement system (BSK 3 concept). The components were fabricated on a full-scale basis between summer 2007 and spring 2008. All the components have been evaluated by external experts confirming the compliance with the requirements of the German Mining Law and Atomic Energy Act. The construction work to prepare a suitable test platform in a former power station in Landesbergen (in the vicinity of the city of Hanover) was successfully completed in April 2008. The individual components (mining locomotive, transport cart, BSK 3 dummy canister, transfer cask, emplacement device and borehole lock) were delivered to the test site between April and June 2008. After the individual components had been accepted on site (SAT), the demonstration programme - performed on a two shift basis because of unforeseen delays in fabrication and installation of the emplacement device - was started in August 2008 and lasted until the end of the project. In the mean time the reliability of the emplacement system was confirmed by means of a large number of demonstration tests (several hundreds of cycles). **Figure 6** shows the test facility in Landesbergen with all the components during the test programme. It can be stated that the development and the fabrication of the individual components as well as the performance of demonstration tests of the BSK 3 emplacement system was a great success.

The successful demonstration programme led to the decision not to dismantle the entire transport and emplacement system after the end of the ESDRED project but instead to test and/or develop the system for a second type of waste canister. The idea is to investigate if the existing system can handle and emplace a so-called “triple-pack” of HLW canisters instead of a single BSK 3 canister. Accordingly additional demonstration tests will be performed in the spring of 2009 outside the scope of the ESDRED Project.

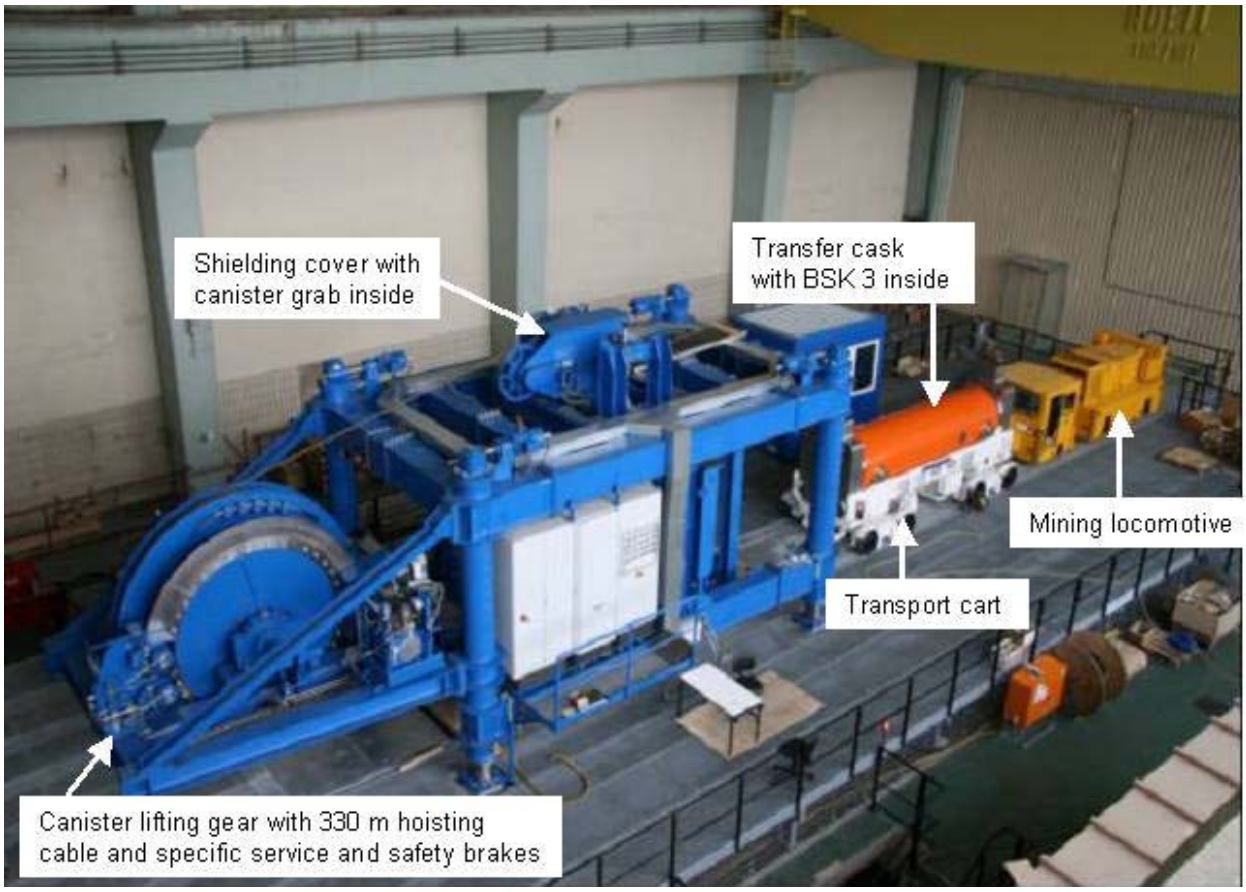

Figure 6: Photo of the Vertical Emplacement test facility in a former power station in Landesbergen, Germany

ANDRA has completed the design and fabrication of the components for the Horizontal Emplacement system (Pushing Robot System). All the components have been designed in detail. The fabrication of all the system components was completed as planned. The components were delivered to the test site between June and mid August 2008. After the individual main components had been accepted during the FAT (Factory Acceptance Tests) during the months of April and May 2008, the complete test bench was progressively assembled and erected in Saint Chamond (near Saint-Etienne). The erection was completed in September 2008. Then the Site Acceptance tests (SAT), which lasted from October to November 2008, were started. The demonstration programme continued with an endurance test campaign and with a special "S" curve test (outside of ESDRED) which lasted until the end of 2008.

It can be stated that the development, the fabrication and the performance of demonstration the tests of the Pushing Robot system were a success. The whole system turned out to be very rugged and reliable. No mechanical failures or design flaws could be identified. All the performance requirements were met, including the pushing of 3 canisters at a time instead of one as initially programmed at the start-up of ESDRED Module 2. Only one piece of equipment (the upper part of the electrical screw jacks used for elevating the docking table) showed any abnormal wear (but no breakage occurred) when a dismantling of all the moving pieces took place for inspection and evaluation of the "wear factor". This weak point (which does not put the disposal system in question) is still undergoing investigation at time of writing. **Figure 7** shows the test configuration of the Horizontal Emplacement Demonstrator at the test site in Saint Chamond.

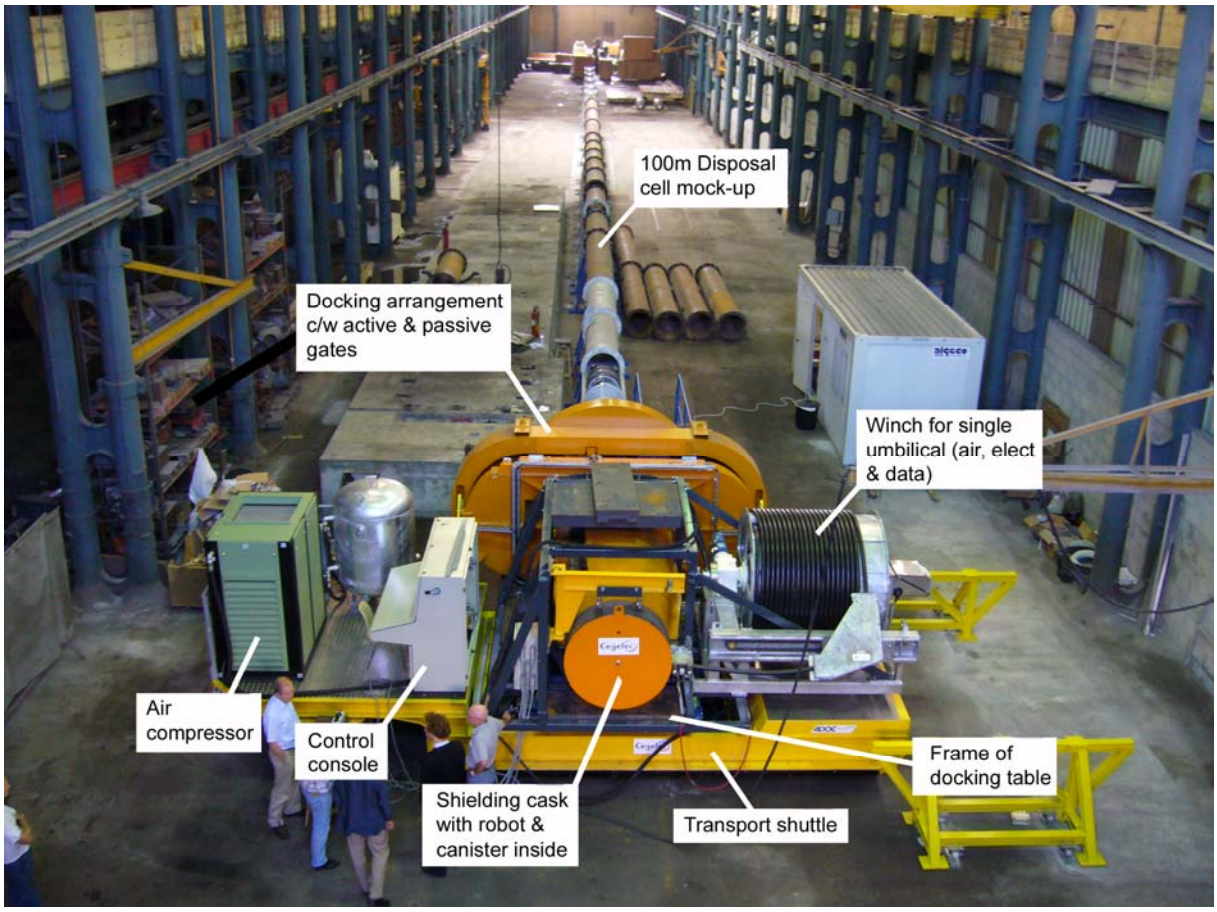

Figure 7: General view of the Horizontal Emplacement Demonstrator as set in St. Chamond, France

The final technical report for Module 2 was finished mid February 2009. Members of Module 2 also provided input to the final report for the ESDRED project.

Module 3: **Heavy Load Emplacement Technology**

All the technical work was completed in Year 4 however a brief history of the final events follows. Factory Acceptance Tests (FAT) for the KBS-3H deposition machine, a concept developed jointly by SKB in Sweden and Posiva in Finland, based on water cushion technology, were completed at the supplier's workshop, CNIM, during February 2006. The deposition machine and associated components were then transported to the Äspö HRL in Sweden and the installation was completed in March 2006. The preparation for the Site Acceptance Tests (SAT) started at the end of March 2006 and the equipment was shown during the ESDRED meeting at Äspö HRL, 28th and 29th March, 2006. Due to a number of technical problems the official SAT, initially scheduled to commence on April 3rd 2006 was postponed almost one year and were effectively performed on 16th February 2007. The KBS-3H deposition machine has since been subject of extensive testing and operation. To January 2009 the KBS-3H deposition machine has transported the Super Container back and forth in the 95m long demonstration drift at Äspö HRL, over a total length of about 47 km. The installation of the equipment in the niche at 220 m level below ground at Äspö HRL can be seen on **Figure 8**.

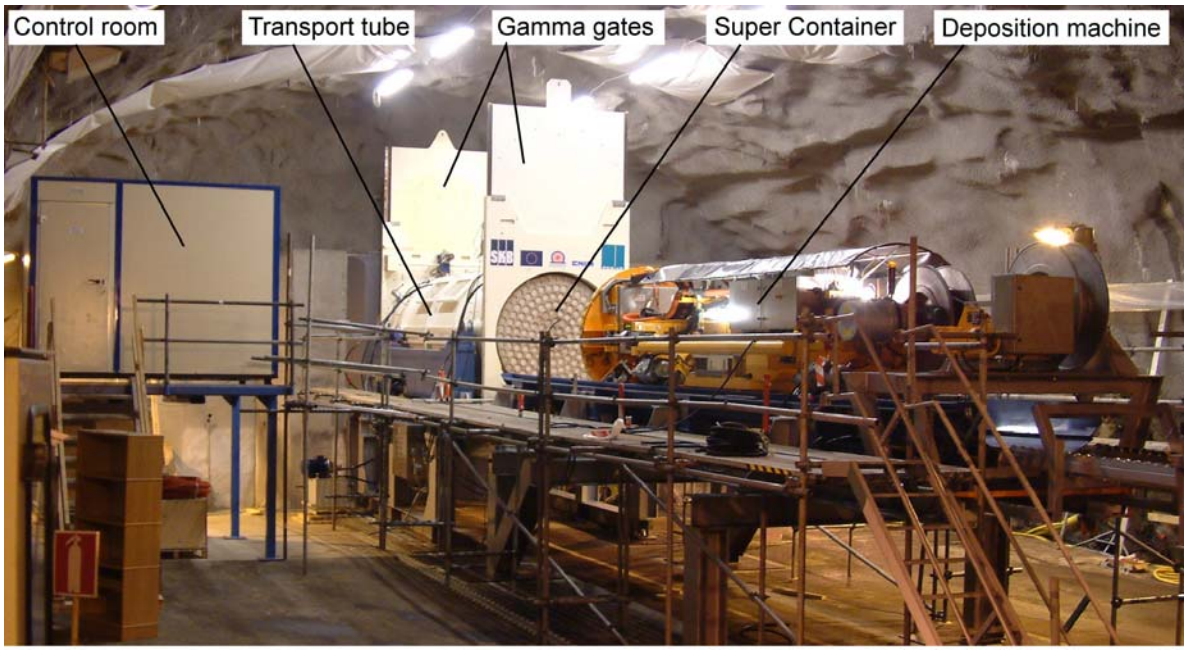

Figure 8: Photo of the KBS-3H deposition equipment at Äspö HRL in Sweden

The tests and operations performed so far have shown that the emplacement equipment, designed and fabricated within the scope of the ESDRED Project, can effectively transport and emplace 45 tonne Super Containers in 1.85m diameter horizontal drifts mechanically excavated in hard rock.

ANDRA's deposition equipment is designed for emplacing 17 tonne sets of bentonite buffer rings and 43 tonne CU1 spent fuel canisters. The full scale demonstration of the CU1 canister emplacement using air cushion technology was performed from May 2006 to September 2006. After some modifications the required performance specifications were all achieved and the ESDRED Partners, together with the EC Project Officers attended the early period of the test campaign, in June 2006.

After adaptation of the test bench, the test campaign for the emplacement of the sets of bentonite buffer rings was performed from October 2006 through January 2007. The test bench was then dismantled and since mid 2008 it is installed in ANDRA's new Technology Centre (Cte) in Saudron, near the Bure URL. Here it is configured for the demonstration of CU1 canister emplacement using air cushion technology, as shown on **Figure 9.**

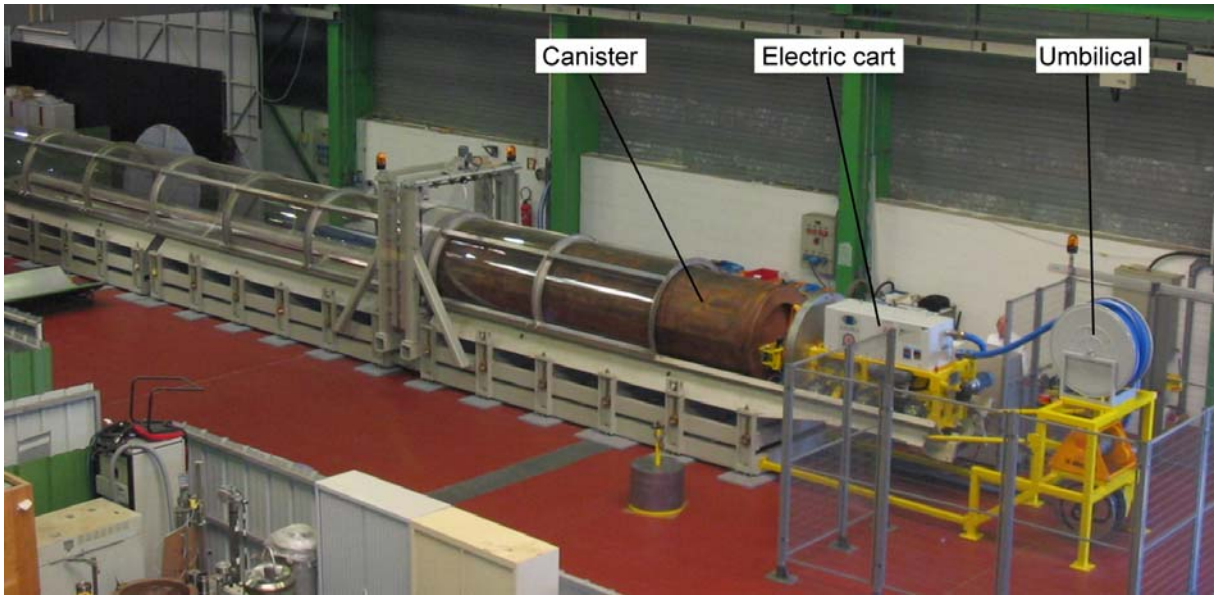

Figure 9: Photo of the ANDRA deposition equipment for canisters with spent nuclear fuel

The only ESDRED related activity during the fifth year of the Project year has been report writing. The final technical report for Module 3 was submitted at the end of September 2008. Members of Module 3 have also provided input to the final report for the ESDRED project.

Module 4: Temporary Sealing Technology

The Module 4 participants have produced an integrated final report that summarizes the work carried out in both sub-modules. It was a joint effort of all the participants, with the aid of ANDRA. The report content and responsibilities was outlined in August 2007 and all related activities ended on January 15th 2009.

Module 4 participants provided input to the final report of Module 6 during the 5th year of the project

Sub-module for low-pH shotcrete plug

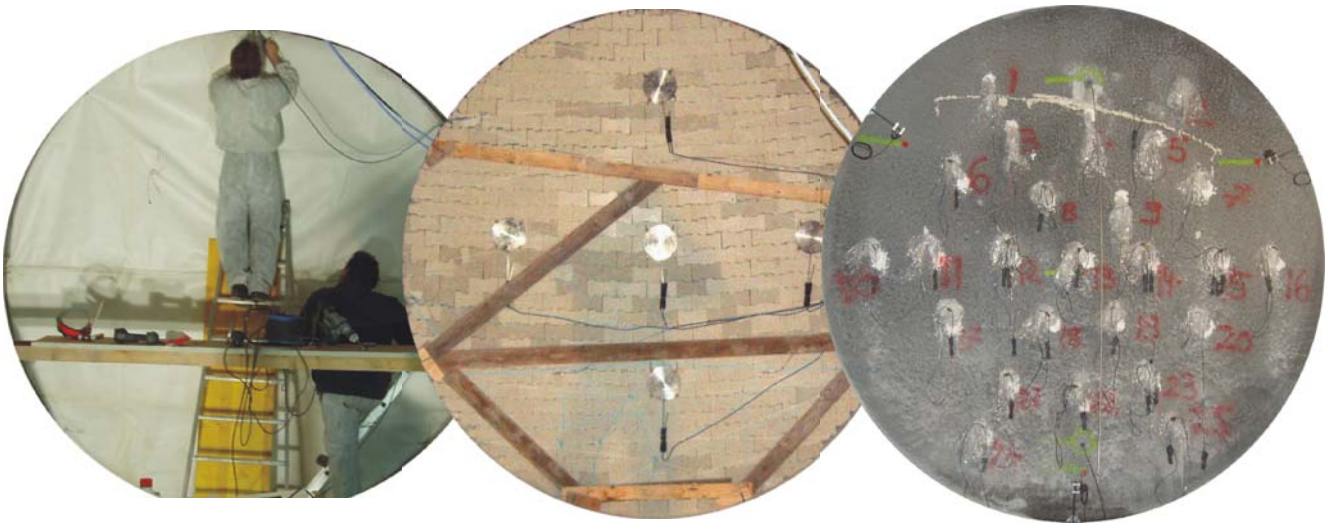

Figure 10: Long plug test main components: hydration mat for artificial hydration (left); bentonite barrier (centre), and shotcrete plug (right)

Once the water leakage through the plug was sealed by the bentonite buffer the operational phase restarted in November 2007. A new version of the test plan, considering an extension of the test period, was then issued in May 2008.

During the fifth year of the project the artificial hydration of the bentonite buffer progressed, water content and pressure increased, and test data were gathered and stored. At the end of December the sensors showed humidity values of 90 %, and total pressure values ranging between 1.4 and 1.8 MPa. Therefore the operational phase of the long plug test within ESDRED IP ended on December 31st, 2008 even though the monitoring of the demonstrator is still going on.

The information of the performance of the long-plug test, in the forthcoming years, will be followed through the MoDeRn project (7th Framework Programme EURATOM), in which most of the ESDRED members are partners.

The long plug test results were described in a deliverable report issued in February 2009 (**Mod4-WP3.2-D4.3**).

Figure 11: View of the Long plug test site

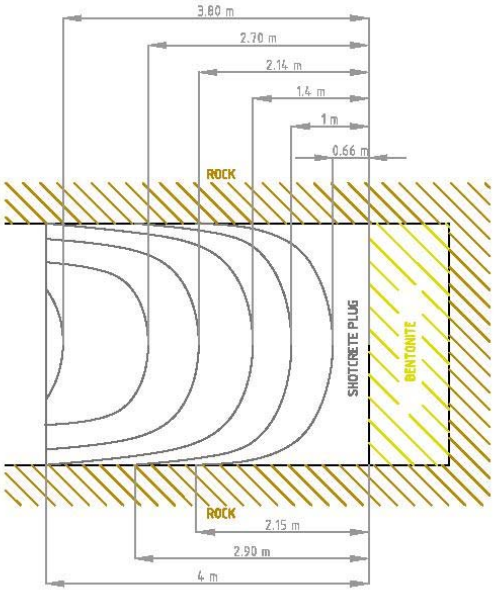

Figure 12: Scheme of the Long plug test showing curved layers of shotcreting

Sub-module for rock support:

All the technical work was completed in Year 4 however a brief history of the programme follows. The development of a low-pH shotcrete formula for rock support for conditions in Sweden started in September 2005. The formula developed in the CBI laboratory in Stockholm was then subjected to pilot tests in February 2006 and field tests at the Äspö HRL in April 2006. The NAGRA work for adaptation of the formula for conditions in Switzerland started after the vacation period 2006 and was finished with fields tests at the Hagerbach test facility in Switzerland in November 2006. The work done in this sub-module has been reported in "Work package 3.2 - Deliverable 8.2 - Low-pH Shotcrete for Rock Support - Report on Full Scale Demonstration - Rock Support". The reporting for the sub-module was completed in June 2007.

Figure 13 (left side) shows the field test with low-pH shotcrete for rock support that was performed at the Äspö HRL in Sweden in April 2006 and the photo to the right shows tests at Hagerbach in Switzerland for NAGRA in November 2006.

Figure 13: The photo to the left shows the field tests at Äspö HRL in Sweden in April 2006. The photo to the right is from field at Hagerbach in Switzerland November 2006 for NAGRA

The only rock support activity during the fifth year of the Project year has been report writing. The final technical report for Module 4 was issued on15 January 2009. Members of Module 4 have also provided input to the final report for the ESDRED Project. Elsewhere, SKB, Posiva and NAGRA have continued working in the field of low-pH cementitious material but outside the ESDRED Project.

COMMUNICATION, TRAINING, AND INTEGRATION PROGRESS DURING YEAR 5:

The fifth year of the project included all of the usual events such as participation at workshops, papers at conferences and articles in technical publications. There were two events specifically organised for the media and several other events at which media were present. The 3 most visible events of the year were a) the *"International Technical Conference on Practical Aspects of Deep Radioactive Waste Disposal"* (Module 5 WP7) held in Prague in the Czech Republic; b) the *Euradwaste '08 Conference* in Luxembourg organised by the EC but with a significant contribution by ESDRED and by ANDRA, especially with regard to the field trip to Bure and c) the *Grand Opening of DBE TECHNOLOGY Vertical Emplacement Concept Test Facility* in Landesbergen Germany.

Module 5: (Training & Communication)

After more than 2 years of preparation the IPC, with help from GRS and Ondraf/Niras, was able to finalise the programme for the *"International Technical Conference on Practical Aspects of Deep Radioactive Waste Disposal"* held in Prague, in the Czech Republic in June 2008. The local co-sponsors were the Czech Technical University in Prague and RAWRA, the Czech waste management agency. The papers and posters presented reflected the work that had been, or was being, carried out in/by 13 countries on 3 continents. Registrants came from 19 different countries with a large representation from recent New Member States. Total registration (over 120 attendees) exceeded the objective fixed 2 years earlier. The proceedings are available on the ESDRED web site at www.esdred.info.

ESDRED partners contributed to 4 different training workshops over the course of the year. Following the successful demonstration of its vertical emplacement system, in September 2008, DBE TECHNOLOGY held a training workshop at its head office in Peine, Germany on November 4, 2008. This effort was supported by the 4 Technical Module Leaders as well as NAGRA. This workshop focused on "*Transport and Emplacement Technologies for Radioactive Waste Packages*" and in all some 23 young professionals (mainly from WMO's) from 10 countries attended.

ESDRED partners were equally active in the area of Communication. Various partners made presentations or provided papers to events in the Czech Republic, France, Germany, Japan, Luxembourg, Poland, Switzerland and the USA. There were publications in four technical journals. There were media events organised around ANDRA's temporary show room in Limay near Paris and later around the permanent home of all ANDRA demonstrators at the Technology Centre (Cte) at Saudron next to the Bure URL. The press was also present at the International Conference in Prague as well as at other events. At least 6 videos were finalised during Year 5.

Module 6: (Integration)

This challenging Module is the responsibility of the ESDRED Project Coordinator, also known as the IPC or Integrated Project Coordinator. Among other things the work in this Module involves managing a committee of independent Experts who are given certain technical documents to review or tasks to perform and who report directly to the Board of Governors, with copy to the Commission. During the course of the first four years of the Project these Experts reviewed and commented favourably on a number of Deliverables and witnessed 3 demonstrations, i.e. two more than the contractual requirement. During Year 5 an additional demonstration was added to the Scope of the Experts' work. Consequently one of the Experts was invited to witness an annular gap backfilling demonstration involving a 30m long scale mock-up of a disposal drift and a cement based grout referred to as "Niras Backfill Mortar". This Expert review resulted in one additional Deliverable (D5.4).

A lot of *Integration* was manifested during Year 5, and in the 45 days following the end of the ESDRED Project, as the partners endeavoured to prepare their final technical reports following an agreement on a common Table of Contents (and format) for all of the Final Technical Reports. They also worked closely together to prepare the Final Project Report and various other common "end of project" reports.

Once again ANDRA & SKB demonstrated considerable cooperation/integration in presenting a common paper to at the WM'08 Conference in Phoenix, Arizona, USA and at the International Conference in Prague. Other partners cooperated on joint papers presented as part of the Euradwaste'08 field trip to Bure, France.

Finally it is worth noting that some of the ESDRED partners demonstrated a desire to continue their cooperation (together with new members) by preparing a proposal for R&D related to "Monitoring" within the EC's FP7 Programme. At time of writing this project, referred to as the *"MoDeRn Project"*, was in the negotiation stage prior to final acceptance by the EC. Some of the other partners, now used to working together for 5 years, have elected to continue cooperating together on various projects outside any EU framework.

Two years ago a number of ESDRED partners embarked (outside of ESDRED) on a related project called TEM or *Test and Evaluation of Monitoring Techniques* at the Grimsel Laboratory in Switzerland. The work is ongoing and one of the techniques being evaluated and compared is the ESDRED non-intrusive approach based on seismic tomography. Once the MoDeRn Project is accepted and underway the TEM Project will be absorbed into the MoDeRn Project.

CONCLUSIONS:

The fifth and final contractual year of the project was dedicated to physically completing all outstanding work, to producing the Deliverables associated with this work and to writing the Final Technical Reports and the Final Project Report. The bulk of the real physical work related to;

MODULE 1: The erection of the 30m disposal drift mock-up and the gap filling demonstration using grout. The design and construction of the Praclay Seal. The final monitoring experiments in situ at Mont Terri and the analysis of the results obtained.

MODULE 2: The fabrication, testing and demonstration of the horizontal and the vertical transport and emplacement systems that were developed by ANDRA and DBE TECHNOLOGY respectively.

There was no physical work left to complete in MODULE 3. In MODULE 4 only simulated natural loading and monitoring of the long plug constructed in situ at the Grimsel URL remained. Likewise in MODULE 1 there was ongoing monitoring of the SB sealing experiment, both in the laboratory in Braunschweig and in situ at the Mont Terri URL.

The entire 5 year ESDRED work programme was successfully completed by the end of the 5th contractual year except for some minor ongoing monitoring and the physical construction of the Praclay seal (it is modelled and designed). All of this work will be completed outside of ESDRED and reported within the framework of other ongoing Projects.

The International Conference in Prague and the Euradwaste'08 Conference in Luxembourg/Bure provided excellent opportunities to show case the ESDRED results.

<u>Project Coordination by</u>

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