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DELIVERABLE 3 OF MODULE 6
WORK PACKAGE 2.1
REPORT ON COMMON FEATURES OF DESIGN STUDIES

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1 EXECUTIVE SUMMARY

This report is Deliverable D3 within Work Package 2 of Module 6, "Integration". It follows on the work done within Work Package 1 which resulted in a first Deliverable D1 called "Common Input Data and Functional Requirements" which was issued on 17 January 2005.

It is intended to provide a "Report on Common Features of Design Studies" related to the work executed within the ESDRED technical Modules 1 to 4. It will be submitted for assessment to the designated ESDRED Experts who will accordingly prepare a Deliverable D4 called "Experts Committee Assessment on the Report on Common Features of Design Studies" (just as they provided a Deliverable D2 called "Experts Committee Assessment of Common Input Data and Functional Requirements", based on the Deliverable D1 cited above).

The approach used by the authors, to provide the backbone to this document, was to take a hard and honest look at what integration has really been taking place during the evolution of the first half of the ESDRED Project. This was done in 2 distinct ways. Initially Table 4.4 "Summary of Module Outputs and Links to other Modules" was constructed with input from each of the participants. This was intended to provide the big picture and it showed, among other things that in some instances integration even resulted in the introduction of certain competent subcontractors from one partner to another. This was then followed by developing Chapters 5, 6, 7 and 8 where each Chapter deals with one of the Technical Modules. Within these Chapters the Module Leaders have provided a description of the designs that they were concerned with and the links between their work and that of other partners within the same Module, links with other Modules and sometimes links with other Work Packages.

The main source of information has been the final Deliverables, related to the Technical Modules 1 to 4, covering the conceptual, basic or detailed design phases, which have been issued so far by the Partners of the Technical Modules, under control of the Module Leaders, i.e. ONDRAF/NIRAS, DBE TECHNOLOGY, SKB and ENRESA.

A complete listing of the eight documents referenced can be found in Section 4. In addition, a Glossary and a List of Abbreviations and Acronyms have been included in Appendices 3 and 4 at the back of the report.

The main commonalities and differences found in the various studies and reports supporting this document are summarized below and commented in the Chapters to come.

1. Commonalities

    - All repository concepts considered within ESDESD rely on a system of natural and engineered barriers. Engineered barriers or backfill materials vary first of all in the form i.e. blocks, monolithic rings, cradles or granular materials. The materials themselves may be pure bentonite, bentonite/sand mixture, cementitious grout or low pH concrete or even poor crushed salt or salt concrete. The methods of emplacement are as varied as the materials themselves. However, there is a common understanding that the design and the construction of engineered barriers still is a challenge. To a certain extent technical solutions will be elaborated within ESDRED.

- Use of the shotcrete method, to replace cast in place concrete, for plug construction is an option retained by many Implementers. The shotcrete construction method for plugs has already been demonstrated using low pH cements. Concern with the potential impact of the deleterious plume effect of the high pH OPC cements on the bentonite buffers and the clay host rocks is not shared by all (low pH being a solution retained by most national underground storage concepts, with the noteworthy exception of the Belgian case). An in depth understanding of the choices made is only possible by looking at the complete system and the characteristics of all components, particularly their evolution and interaction with time (the phenomenology). Given the formulations and demonstrations that will occur within Module 1 this could influence one or more of the European National Concepts in the long term.

- There is a common understanding amongst the ESDRED partners, in particular within the group of waste management organisations that there is a need to develop and demonstrate emplacement technologies that are specific to the host rock and to the repository concepts. The experience gained so far from the various prototype demonstrations and from the manufacturing of emplacement devices underlines this necessity. In this context the regular exchange of information has been of benefit for all participants.

- Finally the "Tables" presented in this document show a wide range of national requirements concerning the extent to which the development of a repository should be reversible prior to closure. This has an important impact on the layout of a repository and the durable support of the openings (accessibility). It also impacts the choice of materials for the different components of the disposal package and the choice of engineered barriers which surround it (confinement). The design of the emplacement equipment is affected (retrieval) and finally the elaboration of an appropriate monitoring system must be compatible with the retrievability/reversibility requirements.

2. Differences

- Differences exist in the corporate standards for exposure dose rates and in the maximum annual number of hours of exposure at these doses. In many cases, numbers have not been defined. This has a significant impact on calculations underlying the design of the radiation shielding. Nevertheless all concepts are more or less guided by the EURATOM standards and by the principles of ALARA, so (almost without exception) the "remote control" is the operating mode selected by the various participants for the different applications considered for emplacement of canisters / buffer or backfill material in underground storage cavities.

Throughout this document and especially in the "Discussion" sections an effort was made to identify the main effective points of Integration achieved or identified at this stage, be it between Modules or amongst Participants in a given Module.

Obviously, ESDRED, or similar multinational Projects cannot force any changes in national concepts because these are based on higher level requirements, including availability of host rocks, differences in waste inventory and differences in national regulatory guidelines. It was, however, found that a better understanding of the most striking differences between the various concepts takes place because the partners are sharing information and experiences openly. So, very early in the ESDRED Project, particularly in cases where the emplacement concepts and the characteristics of their payloads showed significant similarities those partners learned to work together constructively and they moved forward while continuously balancing their developments. Also, convening all the Partners for demonstrations of Prototypes was an “Integration First”, which paved the way for similar actions throughout the project. In summary it has become quite clear that most of the Integration occurs through the sharing of information and the learning from each other in cases where concept similarities allow direct and beneficial exchange of knowledge. It seems to us that more integration will continue to be achieved at a later stage, after completion of the prototype testing in workshops and/or in situ, i.e. in many cases post ESDRED.

2 INTRODUCTION

2.1 OVERVIEW OF ESDRED PROJECT

The ESDRED Project is a major research/demonstration effort involving thirteen (13) radioactive waste management agencies and research organisations from nine (9) European countries. This Project provides an opportunity for demonstrating, at an industrial scale the technical feasibility and the safety of certain equipment, materials or procedures designed for disposing spent fuel and other high level long-lived radioactive waste, in deep geological formations, thereby potentially underpinning the development of a common European view on the main issues related to the management and disposal of radioactive waste. At the very least all parties involved will have a better understanding of the similarities and of the differences between the various national concepts.

The primary objective of the ESDRED Project is to demonstrate the technical feasibility, at an industrial scale, of certain very specific activities related to the construction, operation and closure of a deep geological repository. The Project therefore focuses on four activities which are currently addressed, neither by existing nor by easily adaptable technologies within the mining, civil or nuclear fields. These technological challenges are organised into the following four technical Modules:

- **Module #1 Buffer Construction Technology;** the design, manufacture and construction or emplacement of the buffer/backfill material within horizontal disposal cells or drifts,

- **Module #2 Waste Canister Transfer and Emplacement;** the design, manufacture and construction of emplacement equipment for horizontal disposal cells and vertical boreholes,

- **Module #3 Heavy Load Emplacement;** the design, manufacture and construction of emplacement equipment for very heavy loads in horizontal disposal cells or drifts,

- **Module #4 Temporary Sealing;** the design and characterization of low-pH cements which can be used in shotcrete for rock wall reinforcement and for plugging disposal cells or drifts.

In all cases the final product(s) resulting from the work conducted within the framework of the 4 Technical Modules will be the subject of one or more formal demonstrations which will take place in a workshop and/or in one of several underground research laboratories (URL's) available to the participants in the Project. These include:

- Äspö in Sweden,
- Mol in Belgium,
- Mt Terri in Switzerland.

A second but equally important objective of the ESDRED Project is to encourage maximum Integration between the concepts to be developed within the four Technical Modules. This is a new approach for the EURATOM Framework Programmes and therein lies one of the main challenges of the Project. Integration involves extensive and comprehensive sharing of information between the partners, looking for consistency of Input Data and Functional Requirements and ensuring that, to the extent practical and feasible the designs developed in one Module will be coherent with the designs in another related Module. As a minimum, it involves developing a clear understanding of the similarities and of the differences between the national concepts. At its best, it results in common logic, compatibility of designs, and inter-Module coherence of components and coordination of demonstration planning. Since the ESDRED Project objectives do not include trying to harmonize the different national concepts, optimum Integration occurs more easily within national concepts rather than between them.

On the other hand a lot of more subtle Integration takes place at the Module level where there are always at least 3 different national agencies / organizations represented and sometimes as many as six. The ESDRED programme therefore provides an opportunity for radioactive waste management implementers to work together efficiently to generate solutions, systems and technologies which can be shared.

2.2 OVERVIEW OF WORK PACKAGE 1 (REPORT Mod6-WP1.1-D1 17 JANUARY 2005 & REPORT Mod6-WP1.2-D2 06 APRIL 2005)

Two reports, to be prepared by the Integration Project Coordinator (IPC), are intended to deal specifically with tangible Integration. The first of these 2 reports is part of Work Package 1 and the second, referred to in section 2.3 below, is part of Work Package 2. The objective of the first report (Deliverable D1 issued on January 17, 2005) was to summarize the common Input Data and Functional Requirements across the spectrum of the four technical Modules. A summary of the results of Work Package 1, as reported in Deliverable D1, are presented in Section 3 of this report. A subsequent assessment of this first document was made by the Experts Committee, appointed by the ESDRED Consortium, and presented as Deliverable D2 on April 2005.

2.3 OVERVIEW OF WORK PACKAGE 2 OF MODULE 6

The second report, i.e. this Deliverable D3, is intended to deal with the common features of the various design studies which were undertaken after the Input Data and Functional Requirements had been established. Like D1, D3 will also be submitted to the ESDRED Experts Committee which will report independently to the ESDRED Governing Board. Their report will constitute Deliverable D4 of this Module 6.

The Conceptual approach to the Integration Module 6 is described in Annex 1 to the Contract ("Description of Work" or D.O.W.) as follows:

"*As an integrated Project, ESDRED must at all phases of its development plan of the technical Modules, abide by a logic of commonly shared information and consistency of Input Data and Functional Requirements. Compatibility of designs, coherence and compatibility of components fabrication, co-ordination of demonstration planning and protocol have also to be looked after between the partners. The IP must finally make sure throughout its progress about the relevancy of its technical concepts.*"

The D.O.W provides the following guideline for this report, D3:

"*The studies developed within a Module are to be coherent with the studies developed in other Modules in at least 3 technical Modules out of the 4.*"

The intent here is that the fourth Module which deals with low pH cement is a bit apart from the 3 other Modules.

During the drafting of the Second 18 Month Implementation Plan the description of the work related to this report was described as follows:

"*At the end of the design studies carried out in 2005 (conceptual/basic/detailed) for each technical Module (Modules 1 to 4), 7 Deliverables are produced by the participants in the concerned Modules by latest January 2006. On the basis of such documents, a compilation is implemented by the IPC (mainly with the help of the Module Leaders), in order to establish a comprehensive Report, where the main output are listed, as well as all the communalities evidenced or the logics of the most striking differences. Any specific output obtained in a given Module likely to be used for the Demonstration Phase of another Module will also be pinpointed*."

In the end the authors of this report D3 have opted to describe, to the best of their abilities, how the Integration process did, or did not, work during the development of the various conceptual and basic designs. Besides providing some historical perspective it is hoped that this endeavour will help shed some light on how an "Integrated Project" such as this one evolves and therefore maybe provide some indications as to how the process might be improved in the future.

3 RESULTS OF WORK PACKAGE 1 OF MODULE 6

3.1 OVERVIEW

Since the work/information which constitutes the input to Work Package 2 is directly linked to the work/information which constituted the output of Work Package 1, and thus to the Report D1 of Module 6, a review of the Summary and Conclusions of report D1 "Common Input Data and Functional Requirements" **(CIDFR)** seems to be in order. In other words one should look at the input data and functional requirements which underpin the conceptual and basic design which followed.

Deliverable D1 was:

- Submitted to the Commission on 17 January 2005
- Reviewed and commented by the ESDRED Experts Committee on 06 April 2005
- Revised on 08 June 2005 following a review by the European Commission's Experts

The first Deliverable of Module 6, (i.e. Mod6–WP1.1-D1), was intended to be a report which summarised the Common Input Data and Functional Requirements developed by the four Technical Modules (Module 1 to Module 4) as documented in their respective first Deliverables. It did this to the extent possible and also presented a series of Tables which summarised the main similarities and the main differences between the REFERENCE NATIONAL CONCEPTS, (or in some cases the ALTERNATE NATIONAL CONCEPTS, such as SKB's horizontal disposal concept), which are part of ESDRED.

Deliverable D1 was submitted to the ESDRED "Experts Committee" for review and comment. Their Summary Report was submitted directly to the ESDRED Board of Governors and subsequently to the EC Project Officers.

For its part the Commission submitted Deliverable D1 to its own team of "EC Experts" for review and comment. Their comments resulted in a decision to make certain revisions to the document D1 and a version "Revision 2" was issued on 08 June 2005.

3.2 "SUMMARY AND CONCLUSIONS" OF THE CIDFR REPORT

For the sake of completeness and hopefully to assist the reader in getting a better understanding of the present report, which deals with the design concepts that have evolved ***after*** the input data and functional requirements were established, the **Chapter 6 – "SUMMARY AND CONCLUSIONS"** of the first Deliverable D1, of Module 6 is presented below in its entirety.

"SUMMARY AND CONCLUSIONS

The various contexts (waste nature and inventory, geological, political and legal) in which the different national Contractors are implementing their research programmes have a direct effect on their respective concepts of a repository. Thus, the selection of a disposal concept is a strategic decision made by the national waste management organizations, based on considerations and constraints which are different from one country to the other and which can and do change with time.

These considerations seriously limit, if not totally stymie, any direct harmonization between the national concepts and the overt convergence of the technical solutions developed for designing, constructing and operating the national repositories. The real Integration therefore effectively passes through other ways and means.

Identification of common Input Data and Functional Requirements within a technical Module

Example from Module 3:

There is a commonality in 3 fields:

A. *a multi-barrier concept (i.e. including all or some of the following: glass matrix, a canister with an overpack, a bentonite buffer and a host rock),*
B. *heavy loads to be emplaced, which are pretty equivalent (either for the OD & for the weight),*
C. *an as small as possible annular gap between the package and the outer wall.*

These pre-requisites have naturally led to a similar reference solution for emplacement: a remote controlled fluid (air or water) cushion technology.

Identification of end results which definitely will have some applications in certain national programmes

Example from Module 4:

The low pH shotcrete could be used in various situations to improve long term performances:

- *Example 1: as a local support in disposal drifts excavated in granite or clay host rock, instead of using standard shotcrete (low pH shotcrete would improve long term performances of bentonite buffer, e.g. for Swedish Super-Containers).*
- *Example 2: as a temporary support in sections of drifts to be sealed, instead of using standard shotcrete (low pH shotcrete would improve long term performances of bentonite seals).*
- *Example 3: as an efficient means to construct small diameter concrete plugs, instead of using standard cast concrete (shotcrete is known as a quick procedure). As far as low pH cement is concerned, it would improve the long term performance of the adjacent bentonite seal. It would also contribute to minimize the alkaline plume that could jeopardize the glass integrity of nearby vitrified waste canisters and the integrity of the SF canister copper envelope (Swedish case). It could also minimize the risk of solubility of the Spent Fuel itself when leached.*

A better understanding of the most striking differences between the various concepts

Example from Module 1:

The Module 1 partners have identified the following main reasons for the differences between the various disposal concepts:

- *different characteristics of the available geological media,*

- *different regulations from the national authorities,*
- *different waste inventory,*
- *different strategic choices made by the waste management organizations.*

Different characteristics of the available geological media

The main similarity between the available geological media is that all exhibit a very low hydraulic conductivity under undisturbed conditions. However, the types of geological media span a wide range, from crystalline rock to indurated and plastic clays to rock salt. This means that elasto-plastic materials with high strength and significant brittleness are involved as well as visco-elastic materials with low strength and ductile behaviour.

The repository, to be constructed inside the host rock, may not result in a decrement of the radionuclide retention performance of the host rock. To make the "repository system", i.e. the combination of repository and host rock, safe, redundant and robust, the functions and requirements of the engineered components of the repository should therefore be adapted to the specific characteristics of the host rock.

Different waste inventories, regulations and strategic choices

Even for host rocks with similar physical and chemical properties, like the Opalinus Clay and the Callovo-Oxfordian argillites, the disposal concepts exhibit important differences, mainly due to:

- *different waste inventories,*
- *different authority positions with respect to retrievability,*
- *different strategic and logistical approaches (e.g. leading to different temperature requirements).*

The length of the disposal drift is a typical design element that is subject to the above design inputs; short emplacement units give more flexibility in arrangement of tunnels, thermal loading and retrievability; long tunnels have advantages with respect to radionuclide transport and a reduction in the number of seals.

The performance of the waste container or overpack is a design element that is typically subject to the strategic choices made by the waste management organizations, based on considerations and constraints which can be different from one country to another, or which can change over time. The selected performance requirements impact the selection of materials for the overpack and the engineered near field. The use of high pH cementitious materials in the near field is an example of such an impact. By surrounding the overpack with a stable high pH environment instead of a clay environment, the corrosion resistance and integrity of the steel overpack could be increased by several multiples of the values applicable to clay environments. Moreover, in seeping water will only reach the waste matrix after a time period that should be at least equivalent to the combination of the overpack integrity and glass matrix leaching time in the case where a clay buffer is used.

On the other hand, the consistent use of low pH cement is a designated choice in the context of a disposal concept in which a clay-based buffer is used. In such cases, with the thickness of the buffer component generally not extending beyond 1 meter, the dimensions of any alkaline plume effect are significant. Especially for disposal concepts in granite, where the role of the buffer component is of paramount importance, protecting the buffer against changes in its characteristics is an important design consideration.

<u>Example from Module 2: No overpack required in repository in rock salt</u>

If one excludes the various seals or plugs which are typically installed at the open end of a disposal cell, drift or borehole the typical engineered barriers that surround a waste package may include an overpack and a buffer material (bentonite or cement based). The final non-engineered barrier is the geological formation itself. In the case of the German salt concept there are fewer engineered barriers involved in the repository near-field. The system relies on the entire encapsulation of the disposal package by the geological salt formation itself, or together with the salt gravel (also acting as a compacting buffer) which surrounds the disposal package, and its unique plastic properties which enable it, in a very short time frame, to fill any remaining annular gaps and to fully and tightly encapsulate the disposal package. Thus, an overpack and additional buffer material are deemed dispensable.

A common vision regarding Monitoring needs

Monitoring is recognised by the ESDRED partners as an important part of the development of any repository system.

When the engineered barrier systems are monitored locally, using conventional electric or fibre optic cables, the routes for the cables through or around seals and bulkheads to the accessible location on the outside of the barrier, could have a potentially detrimental effect on the quality and performance of the seals and bulkheads. With the use of "wireless" technology, a sensor can be located within the engineered barrier but the information from the sensor (or sensors) is transmitted to a receiver located on the other side of a seal or bulkhead.
This type of system relies upon:

1. *the durability of the power source to allow the information to be transmitted;*
2. *the durability and reliability of the sensor and associated instrumentation to provide accurate data.*

The need for monitoring techniques which are wholly non-intrusive was recognised in a recently completed EC Thematic Network on Monitoring. However, monitoring techniques which are wholly non-intrusive have not yet been completely developed for the type of applications considered. Non-intrusive techniques (geophysical) have been applied in the oil and mineral exploration for many years but these techniques have not yet been applied and tested for repository monitoring conditions.

The approach to identify and trial non-intrusive monitoring is viewed by the ESDRED partners as innovative with the potential to have wider impact and value across other industries. The benefit of developed and tested non-intrusive monitoring techniques for radioactive waste repositories is that it can ensure control of the monitoring systems for as long as required; it allows barriers to be constructed without the need to accommodate intrusive monitoring systems; monitoring systems can be replaced if they fail without interrupting the performance of the barrier.

The monitoring programme will be progressed under Module 1, which has seven partner organisations involved but the developments under this Module have potential benefits to all national programmes."

3.3 DISCUSSION

On rereading the Summary and Conclusions of Module 6 Deliverable 1, written a year ago, one could easily get the opinion that the **COMMON** Input Data and Functional Requirements were in fact not so **COMMON**! Whereas the parameters themselves are very common, the specifics, for reasons explained in the report, are often quite variable. However, it is important to take a step back to analyse the reasons for these differences and then to assess what benefits might arise in this programme through the experiences shared during the design, manufacture and demonstration of a range of different technical solutions. This analysis should provide an insight into the accumulated and potential benefits resulting from the Integrated ESDRED Project.

In addressing national programmes for repositories, several factors have influenced the approach taken, namely:

- differences in the nature (and volumes) of spent fuel and long-lived wastes arising from different reactor designs and the approach to fuel management (e.g. re-processing);
- the potential to select different geological environments and the focus of individual national programmes influenced by the choice of available geological environments;
- the early development of repository concepts and progressive development of specifications and designs with less opportunities for wider integration;
- the acceptance that there are alternative techniques available to provide effective technical solutions and that these have been influenced by their development at the national level often as a result of different specifications, drivers or influences.

The ESDRED IP represents the first significant programme by the main European radioactive waste management agencies to conduct integrated studies centred around the demonstration of different aspects of repository engineering. The most natural starting point for the ESDRED programme was to progress the development and demonstration of components of existing designs which were drawn from individual national programmes.

The benefit of progressing different demonstrations within ESDRED is that the programme in its entirety provides a range of technical solutions for different wastes in a range of geological environments. The knowledge gained from these demonstrations and from the exchange of views and experiences from the partner organisations will do much to help underpin the development of a common European understanding of the main issues related to the management and disposal of radioactive waste. These demonstrations are helping the partner organisations to understand the application of alternative technical solutions and the applicability of those solutions to their particular geological environment. Examples include: emplaced bentonite rings versus granular bentonite versus the Super-Container; the relative merits of air cushion and water cushion lifting technology; vertical and horizontal emplacement technology. It is within the next generation of technical development that the work within ESDRED will be expected to provide more opportunities for common features to be adopted applying the experiences arising from the ESDRED programme.

The demonstrations will also help provide confidence both to technical and non-technical groups outside ESDRED. They will highlight the range of technical solutions available and will also provide a clearer understanding that, given the different circumstances specific to individual national programmes, the 'one size fits all' will not necessarily be appropriate to all situations.

Later in this report, there are several examples where there is effective commonality in some modules due in part, to the strong cooperation and elaborate exchange of views and information between some of the Partners.

4 WORK PACKAGE 2 OF MODULE 6

4.1 OBJECTIVES

- List the main outputs of the Design Studies
- Describe the Design Communalities where they exist
- Summarize the Integration, if any, which took place during the design work
- Where it exists describe how the output from one Module was integrated into the "Demonstration" executed within another Module.

4.2 INPUT REPORTS

The input to this report comes from the collective experience of all those involved in the work described in the following deliverables:

- Module 1 Report: Mod1-WP2-D2.2 – 11 January 2006
  "Basic Design of Several Buffer Configurations (Final)"

- Module 2 Report: Mod2-WP2.1-D2 – 14 October 2005
  "Conceptual Design"

- Module 2 Draft Report: Mod2-WP3-D3.1 – 06 July 2006
  "Basic Design"

- Module 2 Report: Mod2-WP2.2-D9 – 10 March 2006
  "Report on Pushing Robot Prototype Test"

- Module 3 Report: Mod3-WP2-D2 – 15 April 2005
  "Report on Prototype Test for Spent Fuel Canister CU1"

- Module 3 Report: Mod3-WP3-D3 – 31 January 2006
  "Detailed Design and Manufacturing of Equipment"

- Module 4 Report: Mod4-WP3.2-D4.1 – 20 July 2005
  "Low pH Short Plug Construction and Testing"

- Module 4 Report: "Design of Low pH Concrete for the Construction of Shotcrete Plugs" – 29 June 2006, consisting of Mod4-WP2-D2.1 "Report on formulations of low pH cement plug" and Mod4-WP3.1-D3.1 "Interim Report on selected solutions of low pH cement shotcrete techniques (plug)"

- Module 4 Report "Low pH Shotcrete For Rock Support - Report on Development of Recipe Including Test Plan for Pilot and Field Testing" 15 March 2006, consisting of Mod4-WP2-D2.2 "Report on Adequate Formulations of Low pH Cement (rock support)", Mod4-WP3.1-D3.1 "Interim Report on Selected Solutions of Low pH Shotcrete Techniques (rock support)" and Mod4-WP3.2-D4.2 "Test Plan for the Rock Support Demonstration"

4.3 METHODOLOGY

Finding the right approach to be taken in the preparation of this report, to ensure that something meaningful and hopefully also useful would be produced, was not easy. Dissecting the title, which was contractually provided in the D.O.W, was not much help either since in reality the partners did not really spend a lot of time figuring out how to integrate "STUDIES". Looking at the description of Deliverable D3, as provided in the D.O.W., was some help but this description evolved a bit with each new writing of the "Revised 18 Month Implementation Plan". Some of the text used in the D.O.W. to describe Deliverable D3 has been reproduced in Section 2.3.

Ultimately the approach used by the authors, to provide the backbone to this document, was to take a hard and honest look at what integration has really been taking place during the evolution of the first half of the ESDRED Project. This was done in 2 distinct ways. Initially Table 4.4 "Summary of Module Outputs and Links to other Modules" was constructed with input from each of the participants. This was intended to provide the big picture and it showed, among other things that in some instances integration even resulted in the introduction of certain competent subcontractors from one partner to another. This was then followed by developing Chapters 5, 6, 7 and 8 where each Chapter deals with one of the Technical Modules. Within these Chapters the Module Leaders have provided a description of the designs that they were concerned with and the links between their work and that of other partners within the same Module, links with other Modules and sometimes links with other Work Packages.

4.4 SUMMARY OF MODULE OUTPUTS AND LINKS TO OTHER MODULES

A summary, by Module, of the technical outputs achieved to date is presented in Table 4.4 below. This table is intended to provide the reader with a quick overview of the type of work being undertaken and also to indicate the status of that work as of April 30, 2006. During the reading of the next chapters, which provide a lot more detail, it is hoped that this Table 4.4 will serve as a handy reference guide.

Important work, such as NIREX's non-intrusive monitoring experiment, which is ongoing at Mont Terri, has been excluded from this Table 4.4, and from the related chapters which follow, because it does not involve classical conceptual/basic/detailed design resulting in a fabricated piece of demonstrable equipment. The same logic was used to exclude GRS borehole sealing experiment which is running right now both in their laboratory in Braunschweig and at the Mont Terri URL. Finally the NRG desk study related to Retrievability was also excluded here for the same reasons.

Table 4.4 Summary of Module Outputs and Links to other Modules

Module	Partner	Demonstrator	Utilisation	Main Components	Type	Scale	Link to other ESDRED Module	Main Contractors: Design	Main Contractors: Fabrication	Main Contractors: Main Sub-Contractors	Estimated Total Cost	Status of Demonstrator at 30/04/06: Conc Design	Basic Design	Detailed Design	Fabrication	Demonstration (A = Actual, F = forecast): Workshop	URL	Media Event
1	**ANDRA**	Bentonite Rings	Engineered barrier installed inside a disposal cell for vitrified waste (ie C type canister) or spent fuel (ie CU2 canister)	Buffer material mixture (70% MX80 bentonite sand / 30% Quartz sand); Mould for pressing rings; 12 concrete rings; 12 bentonite rings; 3 transport boxes; handling device	Industrial	1:1	Bentonite rings sized for 2.25m Ø of vitrified waste or CU2 disposal cells and 0.7m Ø of inner steel sleeve (Module 2)	GME (Consortium)	GME members: MPC/CEA/ Segula	Ferry Capitain - castings Creusot Mecanique - machining Aubert Duval - pressing	2.4 M€	completed	completed	completed	Mould being fabricated and assembled	F: Aubert & Duval (Issoire) July 2006	none planned	F:Limay 2007 or 2008
	O/N	backfill in horizontal annular gap	backfill around Supercontainer for HLW	spectrum of materials (sand, bentonite, cement, mixtures thereof). Grout option is preferred.	Industrial	2/3 and 1:1	No link to other Modules	EURIDICE	EURIDICE	SOCEA (tubes for mockups), DEGUSSA (grout fabrication), SMET (grout emplacement), VUURVAST (dry-gun machine), BAUDOIN (projection wagon)	1.9 M€	completed (WP3 and WP4.1 mockups)	completed (WP3 and WP4.1 mockups)	completed (WP3 mockups)	completed (WP3 mockups)	EURIDICE	EURIDICE	A: WP3 sand June 2006, F: WP3 other dry materials August 2006, WP3 grout June 2006, WP4.1 grout June 2007, WP4.1 in-situ August 2007
	NAGRA	Granular Bentonite	Engineered barrier installed in disposal tunnel for HLW and SF	Bentonite blocks underneath canister and granular bentonite in the remaining annular space	Prototype	1:1.25	Retaining wall from low-pH shotcrete in Module 4	Nagra / Rowa	Rettenmaier, Rowa, Gasser	Rettenmaier, Rowa, Gasser, ETH-Z	260 k€	completed	completed	completed	completed	F: Summer 2006 at Gasser Facility	no	no
2	**ANDRA**	Prototype Pushing Robot	To prove that 2 ton vitrified waste canisters outfitted with ceramic sliding runners could be pushed inside the 0.7m diameter inner sleeve of a horizontal disposal cell	Dummy canister; Control panel; 3 sections of Test Bench	Prototype	1:1	C type canister is pushed by Robot inside a steel inner sleeve surrounded by an engineered barrier (Bentonite rings - cf Module 1)	Musthane	Musthane	Creativ Alliance (Design) SFEM (casting of dummy canister)	400 k€	completed	completed	completed	Built & successfully demonstrated	A: 25/10/05	none planned	F:Limay 2007 or 2008
	DBE TEC	Vertical Emplacement Equipment	To develop a reliable emplacement system for BSK3 canisters fulfilling German mining and atomic laws	emplacement device, transfer cask, borehole lock, transport cart	Industrial	1:1	No link to other Module	To be selected by competition	To be selected by competition		4 to 5 M€ for all components	completed	completed	launched	Planned in 2007	F: January 2008	none planned	Spring 2008
3	**ANDRA**	Air Cushion Machine	To prove that air cushion technology would work in 1.4m diameter horizontal disposal cells	Air cushion cradle Canister mock-up 2 sections of Test Bench	Prototype	1:1 Ø 1:3 Wt of load	No link to other Module	Bertin Technologies	Bertin	Bertin	115 k€	completed	completed	completed	Built & succcessfully demonstrated	A: January 2005	none planned	F: Limay 2007 or 2008
	SKB	Water cushion Emplacement Equipment	For emplacement of 45 ton KBS-3H Super-Container in a horizontal disposal drift	Transport tube and launch tube with support frames, deposition manchine with water cushion plallet and sliding plate	Industrial	1:1	No link to other Module	CNIM	CNIM	CNIM, Bertin Technologies	1.9 M€	completed	completed	completed	Completed and assembled at Aspo	A: January and February 2006	A: June 2006	A: June 2006
	ANDRA	Air Cushion Emplacement Equipment	For emplacement of 43 ton spent fuel canisters (CU1) inside an inner sleeve installed in a horizontal disposal cell	Protection fence Slide plate Air cushion cradle Electrical cart Dummy canister Gamma gates (2) Test bench (3 sections)	Industrial	1:1	No link to other Module	Mecachimie; Green	Mecachimie	Bertin; Green	1.3 M€	completed	completed		Components being fabricated and Test Bench being erected	F: June 06	none planned	F:Limay 2007 or 2008
		Air Cushion Emplacement Equipment	For emplacement of 17 ton bundles of 4 bentonite rings		Industrial	1:1	The interface with Module 1 is related to handling procedure and loading of bentonite rings on launching table					completed	completed		Components being fabricated	F: June 06	none planned	F:Limay 2007 or 2008
4	**ENRESA**	Low pH Disposal Drift Plug	Sealing of disposal drifts and ancillary galleries	Low pH binder, water, agregates and admixtures	Industrial	1:1	No link to other Module	ENRESA	CSIC & AITEMIN	DM Iberia	1.7 M€	completed	completed	completed	Constructed & loaded to failure at Aspo	A: 15/16 June 2005	A: 29 March 06	none planned
	SKB	Low pH Rock Support Shotcrete			Industrial	1:1 (limited area)	No link to other Module		CBI		150 k€						A: April 2006	
	NAGRA	Low pH Rock Support Shotcrete			Industrial	Pilot tests	No link to other Module		Hagerbach laboratorium		100 k€					F: October 2006		

5 MODULE 1 DESIGNS - (BUFFER CONSTRUCTION)

5.1 ANDRA – BENTONITE RINGS

5.1.1 Description of the design

In 04 April 2005, ANDRA contracted GME, a consortium of 3 companies (MPC, CEA and SEGULA) to design, fabricate and supply 3 sets of 4 pre-assembled bentonite rings, complete with handling and boxing devices.

The main objectives established for the design, fabrication and supply of the rings are listed below:

- To define the optimum composition of the material used as a buffer (mixture of quartz sand and MX80 bentonite), the optimum compacting pressure and to characterize the compressed material from a petro-physical point of view,

- To define the optimum shape of the rings, compatible both with the moulding constraints and the overall geometrical tolerances: this geometrical shape had to be compatible with the emplacement of the set of rings inside the Disposal Cell perforated liner and the introduction of the inner steel sleeve inside the rings (cf. **Figure 35** in Chapter 9) and **Figure 1** which depicts a Disposal Cell configuration and the need for annular clearance compatibility.

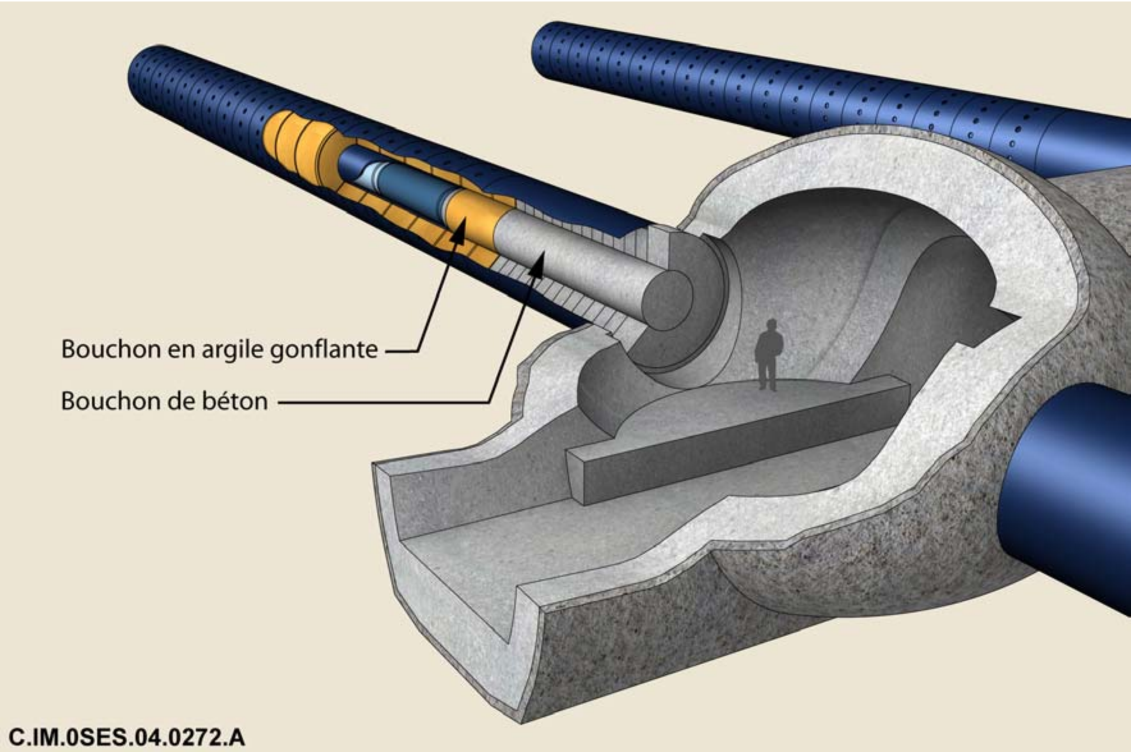


Figure 1: Disposal cell configuration

- To design and build the mould compatible with the press required (only one found in Europe),

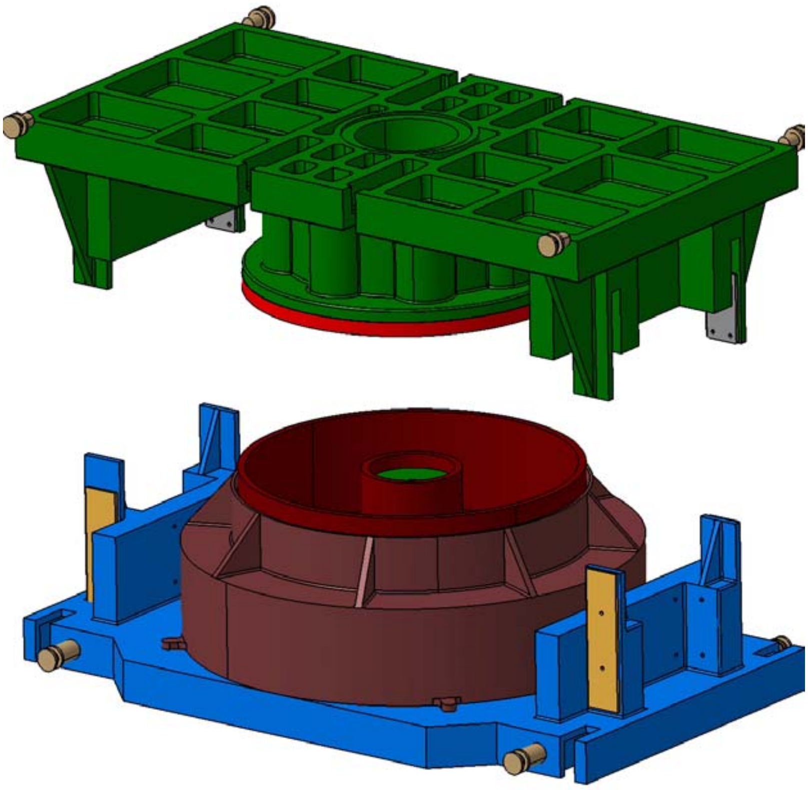


Figure 2: 3D view of the mould

- Define the pressing sequence and produce the bentonite rings,
- Design and fabricate an assembly system for the set of rings, when introduced inside the perforated liner by the air cushion technology (cf. Chapter7),
- Design and fabricate a lifting system to manipulate the set of rings until it is loaded on the launch table of the emplacement system (cf. Chapter 7),
- Design and fabricate a boxing system for transport and temporary storage of a set of pre-assembled rings.

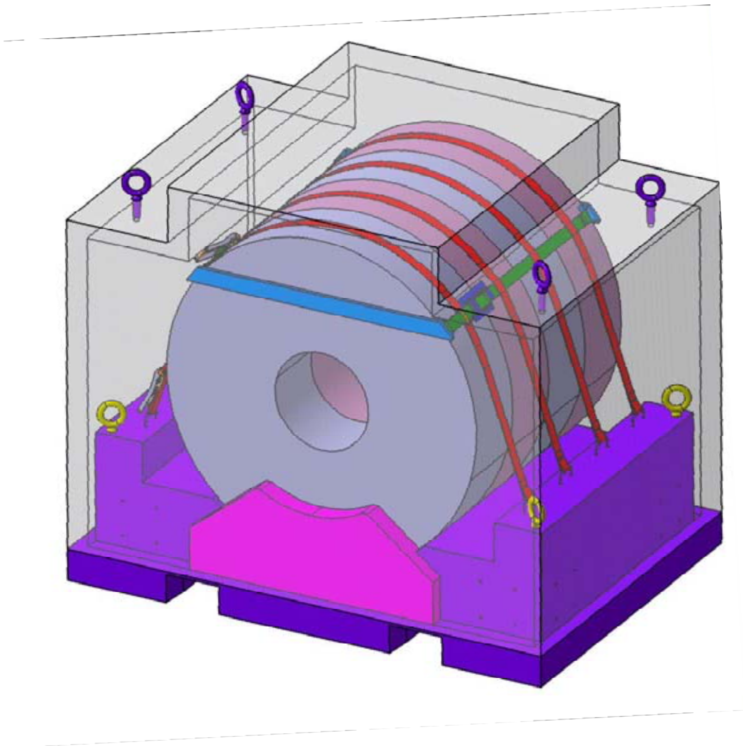


Figure 3: Set of 4 Bentonite rings in crate, ready for transportation to the emplacement test site

5.1.2 Links with other elements of ESDRED

5.1.2.1 Partners

The main link in terms of Integration with the Partners was the good sharing of information and a good understanding of the rationale behind each national programme. At the end of the Project (and outside of ESDRED), ANDRA sees a potential application of NAGRA's work results for the future plugging of the access drifts of its underground storage at time of closure operations.

5.1.2.2 Modules

For ANDRA, the main link identified is with Module 3. This point is discussed in more detail in Chapter 7.1.2.2. It is also illustrated in the diagram of operations shown below, depicting the sequence of emplacement of the sets of rings into the perforated liner thanks to the air cushion system developed in Module3.

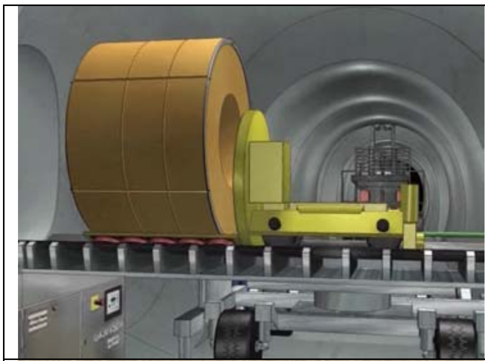
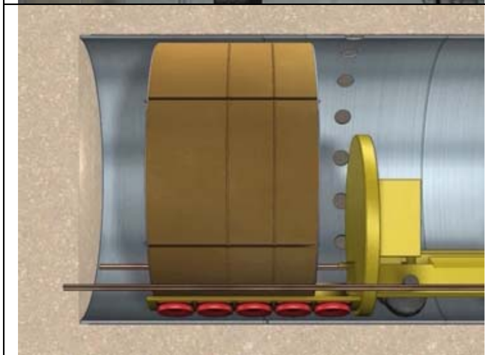
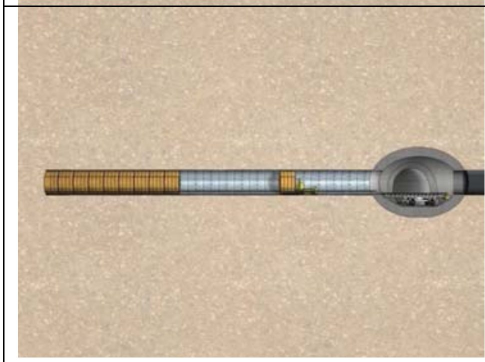
	A first series of rings is installed on the cushion pallet in the access gallery, in front of the disposal cell; cushions are inflated with compressed air, lifting the pallet and its load. *Note: the device for tying the 4 rings together during the emplacement phase is still under design. The concept shown here will have to be updated.*
	The air cushion pallet carrying its load (set of rings) is pushed into the cell. The pushing trolley is guided by 2 rails. Cushions are deflated when the final position is reached. The set of rings rests on the 2 rails and the air cushion pallet is free to move backwards.
	A second set of rings is emplaced.
	Operations are repeated until the cell is fully equipped with buffer rings. Note: the same method is then used for concrete rings forming the plug. The inner steel tube (metal sleeve) is inserted when all the rings are in place. This sleeve comes as segments of 2 to 3 m long, welded together at the cell mouth.

Figure 4: Buffer ring emplacement – Sequence of operations

5.1.2.3 Work Packages

There is no noteworthy direct link per se to another work package. However the regular exchange of information resulted in the Module partners identifying at least one commonality. MX80 is the type of bentonite used by ANDRA, NAGRA and GRS.

5.1.3 Discussion

Within the implementation of the contract between ANDRA and GME, an indirect help from SKB can be pointed out as an act of effective contribution to Integration. SKB has developed a specific know-how (in house and with the assistance of a Swedish company called "Clay-Technology") on the characterization of buffer (bentonite) material, mould design and ring fabrication. This fact being known by ANDRA, it was decided to get the technical assistance of SKB-IC (subsidiary of SKB), for assessing the technical work made by GME. Their relevant remarks have been integrated by the Contractor in the process of design.

5.2 ONDRAF/NIRAS – ANNULAR GAP FILLING

5.2.1 Description of the design

The reference disposal is the Super-Container for the disposal of vitrified HLW (high level waste). With the Super-Container, the waste canisters are placed within a carbon steel overpack, which is surrounded by a high pH concrete buffer, of which OPC (Ordinary Portland Cement) is the predominant component. The thickness of the concrete layer is designed to provide sufficient radiological protection to eliminate the need for a shielding cask, thus enhancing operational safety and facilitating the underground handling of the waste packages. A high pH material was chosen for the buffer with the aim to create a sustained strongly corrosion-protective environment for the overpack. The basic corrosion objective of the design is to ensure a watertight integrity of the overpack for a given time period (i.e. 500 years for vitrified HLW, and 2000 years for spent fuel).

The buffer material is enveloped by a stainless steel liner. The functions of this liner are:

1. to enhance the structural integrity of the Super-Container during transportation and emplacement,
2. to serve as a first barrier against corrosive chemical substances residing in the host rock. It is the current O/N position that it is not required that the liner be watertight to perform this function. However this position remains to be confirmed.

A radial cross-section of the disposal cell with the Super-Container for vitrified HLW is given in **Figure 5**. An axial cross-section is given in **Figure 6**. The figures also indicate reference materials and dimensions.

Based on the Super-Container for vitrified HLW, the Belgian engineering office BELGATOM have elaborated a detailed architectural design of the associated disposal gallery, shown in **Figure 7.** The figure portrays one axial cross-section (view from above) and two radial cross-sections of the disposal gallery (one section going through the Super-Container and the air cushion trolley and one section in front of the Super-Container). The nominal gallery inner diameter is 3.0 m. Given the fact that the 1.928 m diameter Super-Container is eccentrically located within the gallery, the envisaged dimensions of the gap are in the range between 20 cm (at the top of the Super-Container) and 70 cm (at the side).

One may notice the shape of the gallery floor. The step in the floor constitutes a groove, in which an air cushion trolley, loaded with a Super-Container, can travel to the furthest possible location in the gallery, deflate its air cushions and dispose the Super-Container, and then return to the main gallery to pick up a new Super-Container. The step thus also functions as the mechanical support for the Super-Container in its final resting position. The figure also shows the ventilation ducts. The air is extracted from the back end of the disposal gallery. The air duct is mounted on the upper level of the floor, except for the entrance section of the gallery, where the duct is embedded in the floor. The gallery lighting is not shown on the figure. The air duct and the lighting will be gradually dismantled at the same pace as the filling of the gallery.

Figure 8 gives a sketch of the Belgian integral repository for HLW and LILW-LL (long-lived low and intermediate level waste). It is a snapshot of the repository at the time of HLW disposal, which is planned to occur several decades after the disposal of the LILW-LL. This artistic view illustrates how the Super-Container will descend into the repository via a large central shaft, which is the waste shaft. Mounted on an air cushion trolley, each Super-Container will travel through the large access gallery and into its destined disposal gallery. Note that the disposal galleries are much longer than might appear on the figure; the distance between the waste shaft and the construction shaft is in the order of a few hundred meters, whereas the length of a disposal gallery is generally about one thousand meters.

In principle, the length of the section to be backfilled can vary between 4.2 m (the length of one Super-Container) and 1000 m (the length of a disposal gallery). However, for technological reasons, it is considered unlikely that the whole gallery will be backfilled at once. A maximum section length of 300 m has been postulated for this. In addition, the length of the backfill section will play an important role in the planning of operations. To limit the total duration of waste disposal and backfill operations, a minimum section length should be respected. This minimum value could be 30 m, but this is not confirmed yet. Hence, the length of the section to be backfilled in the repository is assumed to be in the range between 4.2 and 300 m.

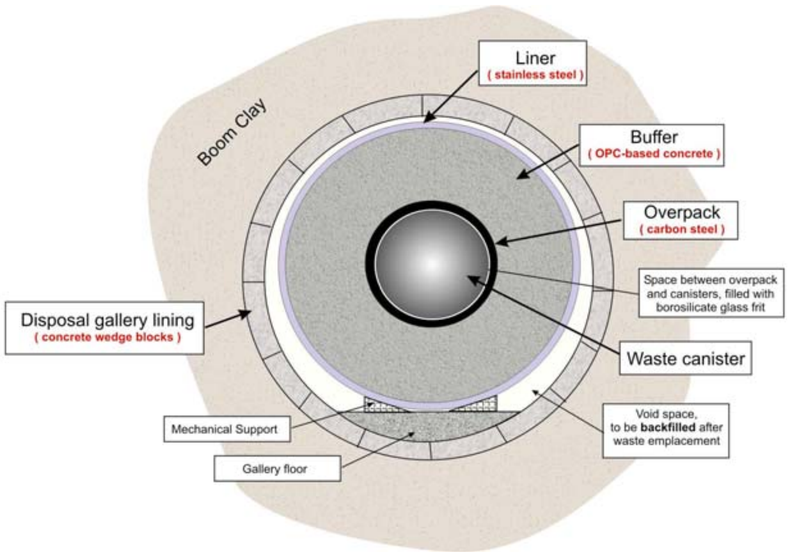


Figure 5: Radial cross-section of the reference Super-Container

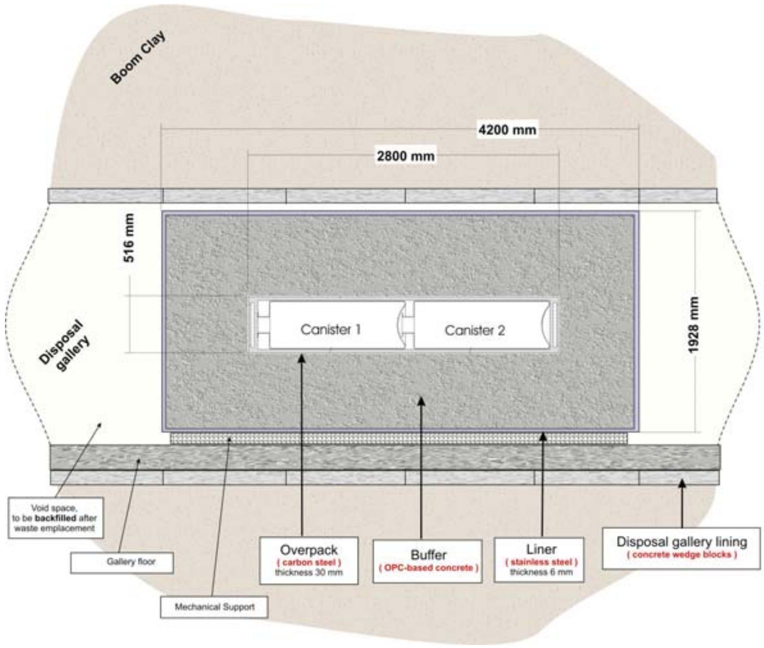


Figure 6: Axial cross-section of the reference Super-Container

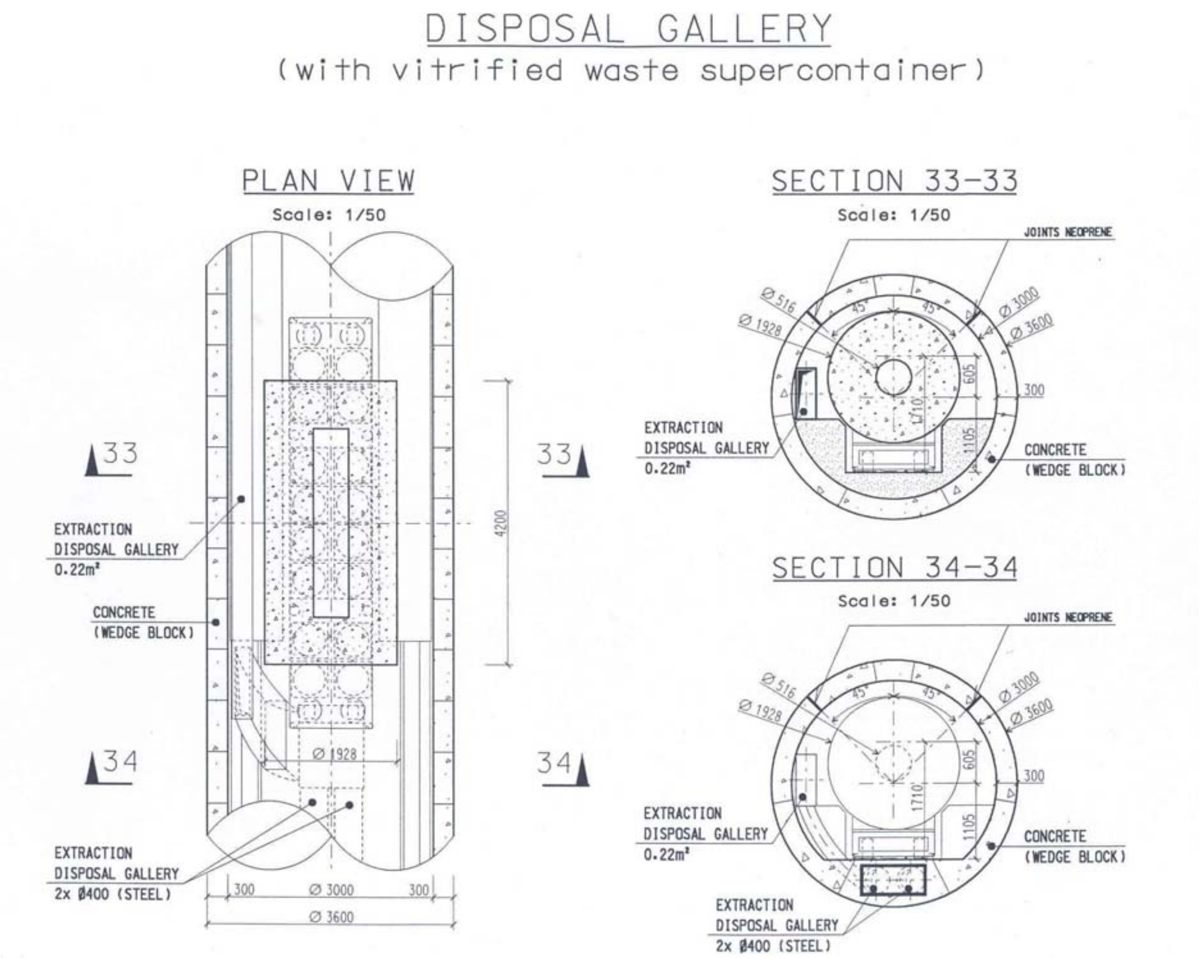


Figure 7: Disposal gallery architectural design for the Super-Container with vitrified HLW

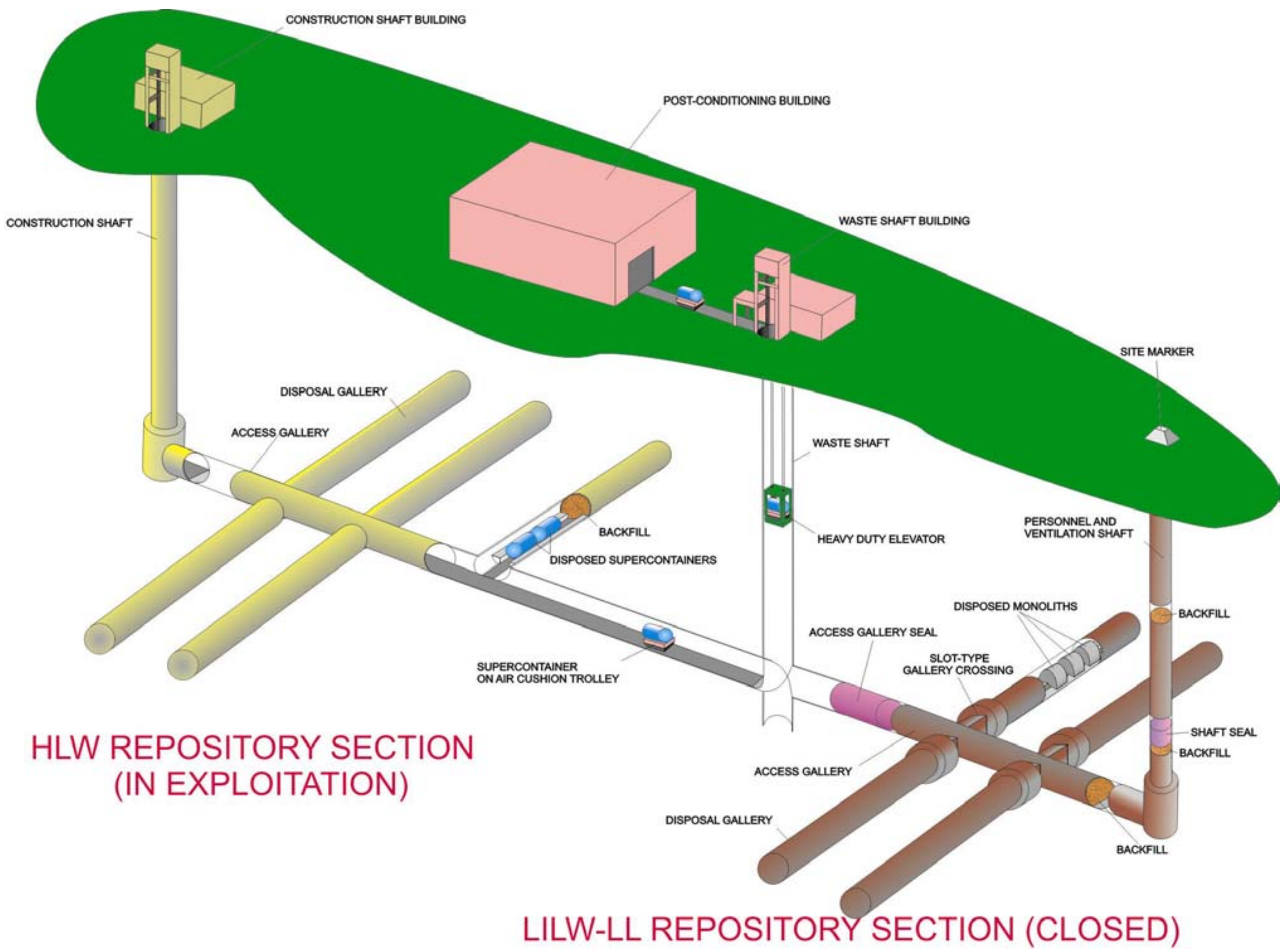


Figure 8: Schematic drawing of the Belgian integrated repository for HLW and LILW-LL

5.2.2 Links with other elements of ESDRED

5.2.2.1 Partners

EURIDICE is responsible for the field work of the O/N tests under WP3 and WP4.1.

5.2.2.2 Modules

No links between Modules have been identified

5.2.2.3 Work Packages

In WP1, a first schematic representation of the requirements was established. In WP2, this was further elaborated and brought to a first frozen set of requirements, although for many of the requirements, no specific criterion value was attributed. WP3 aims to test the technological feasibility of emplacement of a backfill in agreement with the disposal concept and as much as possible in line with the requirements. A range of materials and two different techniques are tested. For O/N, the grout technique is the preferred one since it fits best within the disposal concept. In WP4.1, the backfill emplacement is tested at an industrial scale. In parallel with the latter test, there is also the test to demonstrate the emplacement of a seal material in an annular configuration, under actual underground conditions.

5.2.3 Discussion

Although the backfill emplacement according to these techniques seems deviant, because of the use of other materials besides bentonite, their development and testing is fully in line with the ESDRED philosophy of the development of a range of "off-the-shelf" solutions. As discussed and pointed out already within WP1, the use the type of material to fill up the void around the HLW is the result of specific blend of host rock geology, regulatory framework and waste management strategic decisions.

5.3 NAGRA – BLOCKS AND GRANULAR BUFFER

5.3.1 Description of the design

Nagra's concept of buffer construction is based on the simultaneous use of bentonite blocks as support of the waste canister and highly compacted granular buffer material to provide a maximum of flexibility and easy operation. The feasibility of the concept was shown in principle in the EB experiment at the Mont Terri underground laboratory in 2002 which was supported by the EC as part of the 5th Framework Programme.

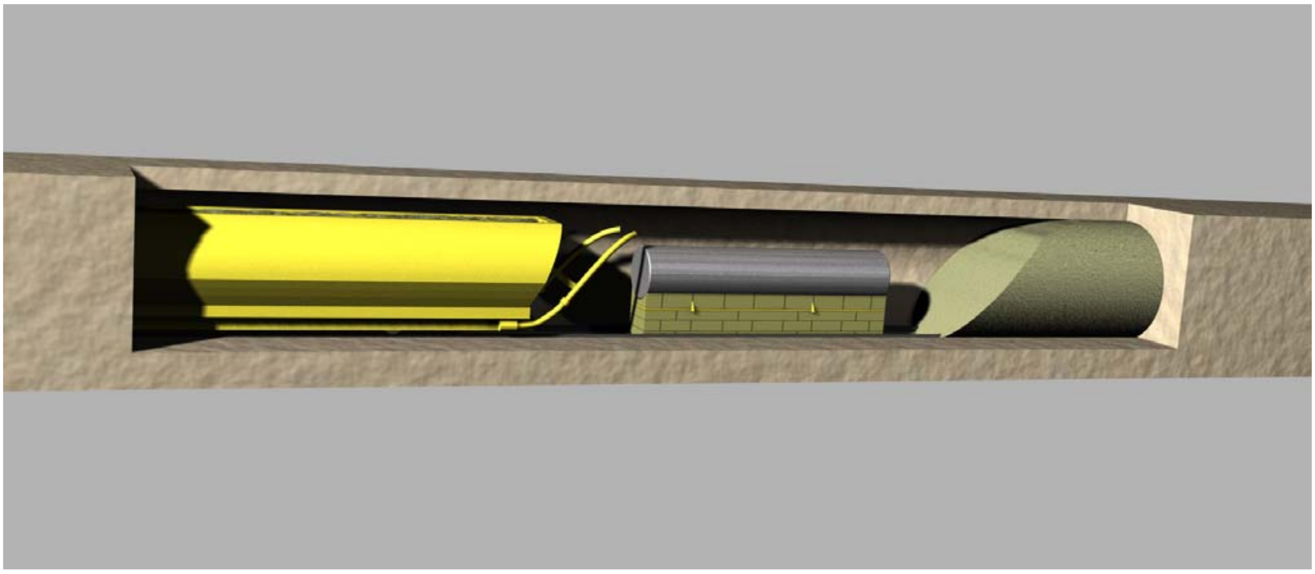
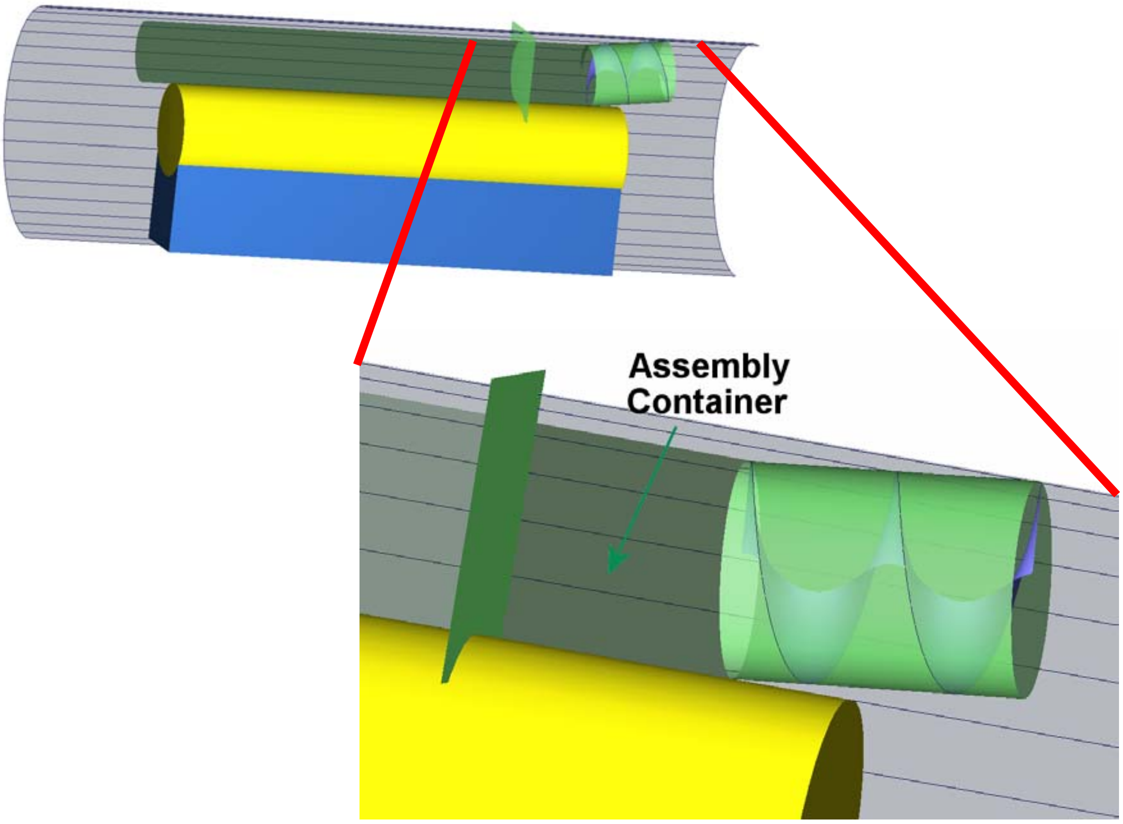


Figure 9: Nagra Concept Emplacement of SF canister

Within the last year the work concentrated on:

- Finalisation of the numerical studies (PFC-code; ITASCA) to optimise the emplacement of the granular bentonite (**Figure 10**)
- Assessment of potential suppliers of MX80 bentonite. Chosen sub-contractor: AMCOL SPECIALITY MINERALS, GB.
- Selection of sub-contractor (OYMA GmbH, Germany) for bentonite drying under given conditions (temperature below 80°C, final water content about 4%
- Selection of sub-contractor for production of the granular bentonite (RETTENMAIER & SÖHNE GmbH, Germany) and definition of processing parameters (e.g. particle size) and processing scheme
- Construction of steel model (**Figure 11)** by GASSER FELSTECHNIK AG, Switzerland
- Planning and construction of auger emplacement system.(**Figure 12**) by ROWA TUNNELING LOGISTICS AG, Switzerland



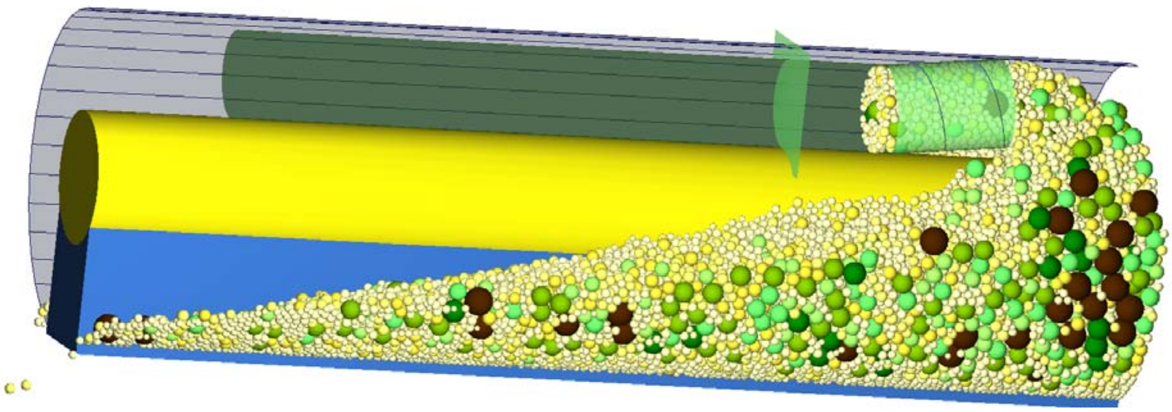


Figure 10: 3D numerical modelling of the emplacement of the granular bentonite. Upper part: model realization. Lower part: snapshot of the backfilling procedure

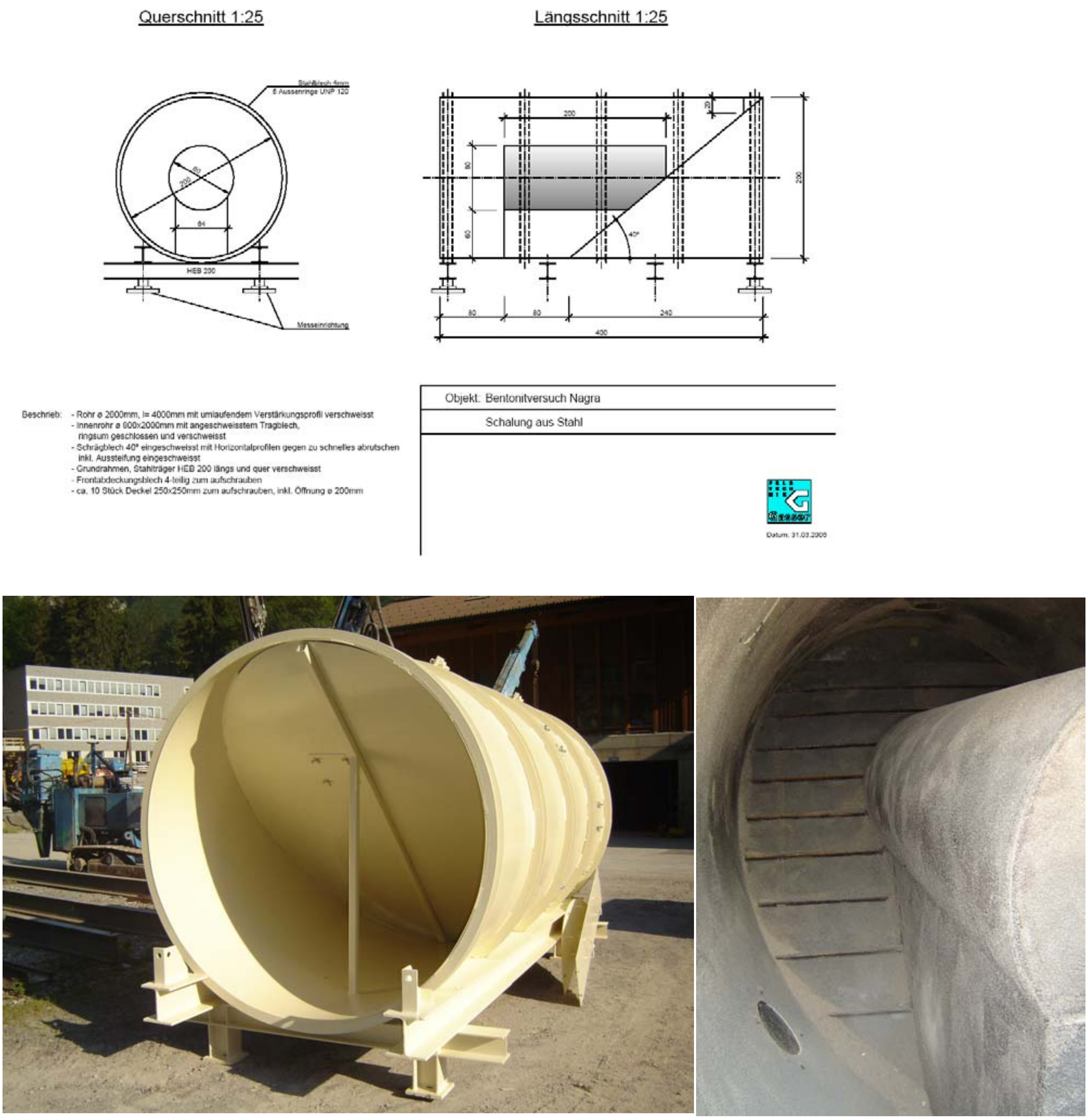


Figure 11: Technical drawing and photos of the steel model (Photos Nagra, June 2006)

Figure 12: Photo of the fabricated twin auger system (Photo Nagra, June 2006)

5.3.2 Links with other elements of ESDRED

5.3.2.1 Partners

Beside very fruitful discussions during various technical meetings, direct cooperation helped us during the preparation of the work. During the selection process for the bentonite supplier we could build on the experience from other partners (especially SKB and their sub-contractors). In addition, it was possible to use the characterisation work of our partners on the MX80 bentonite.

It was also possible to include the granular bentonite material into the test programme of GRS providing the possibility to directly compare the performance of sand/bentonite mixtures with pure granular bentonite material.

5.3.2.2 Modules

Because of the differences in the technologies there is no direct link to other modules (e.g. there are no heavy loads to transport). Nevertheless, the low-pH concrete plug investigated in Module 4 could provide a technology for temporary support structures for the granular bentonite (retaining walls).

5.3.2.3 Work Packages

As mentioned above there are direct links to Module 1 WP 4.2.

5.3.3 Discussion

NAGRA's part of the projects progresses according to the planning and it is envisaged that the emplacement tests will be completed by the end of 2006. The main results will already be available at mid-term of the project and could be used in other demonstrators in Module 1 (e.g. ONDRAF's demonstrator in WP 4.1 and the GRS demonstrator in WP 4.2). Further, the results will be an important source of information for NAGRA's on-going concept refinements.

6 MODULE 2 DESIGNS - (WASTE CANISTER TRANSFER & EMPLACEMENT)

6.1 ANDRA – PROTOTYPE PUSHING ROBOT

6.1.1 Description of the design

Within the framework of WP2.2 of Module2, between mid April 2005 and mid February 2006 ANDRA contracted “MUSTHANE” to design, fabricate and test a prototype pushing robot.

The main objectives established for the design, manufacturing and testing of a prototype are listed below:

- The primary objective was to demonstrate the technical feasibility of using a “Prototype Pushing Robot” for moving C type canisters into a horizontal disposal cell steel tube (inner steel sleeve). It included designing, fabricating and testing of a very basic version of an emplacement system, with a simplified shielding cask mock up and a short length (around 6m) of inner steel tube, to move a simplified mock-up of the C type canister (scale 1 for the OD and for the length, the actual weight and an external geometry identical to the real one).

- The second objective was to confirm the suitability of the material and shape selected for the ceramic sliding runners (a technical choice which was also questioned by the external Experts in December 2003) and to evaluate the extent of wear potentially induced on the sliding track by the back and forth movements of the C type canister.

- The third objective was to determine the main operational characteristics of the system and to assess their extrapolation to the future full scale industrial demonstrator.

- The fourth objective was to evaluate the performance and the various limitations of the system (vis-à-vis its environment and its failure potential) and to take them into account for the design & construction of the future full scale industrial demonstrator.

- The fifth and final objective was to identify potential improvements which would be taken into account in the future full scale industrial demonstrator.

This preliminary test campaign, to be run in a surface workshop facility, subsequently needed to be carried out early in the ESDRED Module 2 programme in order to confirm, as soon as possible, that the fundamental concept was feasible i.e. well in advance of fabricating a full scale emplacement demonstration equipment which was foreseen later in the Module (WP3, WP5 & WP6).

Note: The rationale of testing a prototype before moving to a full scale industrial demonstrator (WP 3, WP5 & WP6) is quite similar to the logic that was effectively implemented in Module 3 where the successful testing of a prototype air cushion lifting system (with the BERTIN company) paved the way to proceeding with the industrial scale demonstrator phase (now ongoing) with the MECACHIMIE company.
A general view of the test bench showing the dummy canister, the pushing robot, the control panel and the primary test bench structure is shown below in **Figure 13.**

Figure 13: General view of the test bench in MUSTHANE's premises (Willems, France)

A sketch of the operating principle of the pushing robot is presented below.

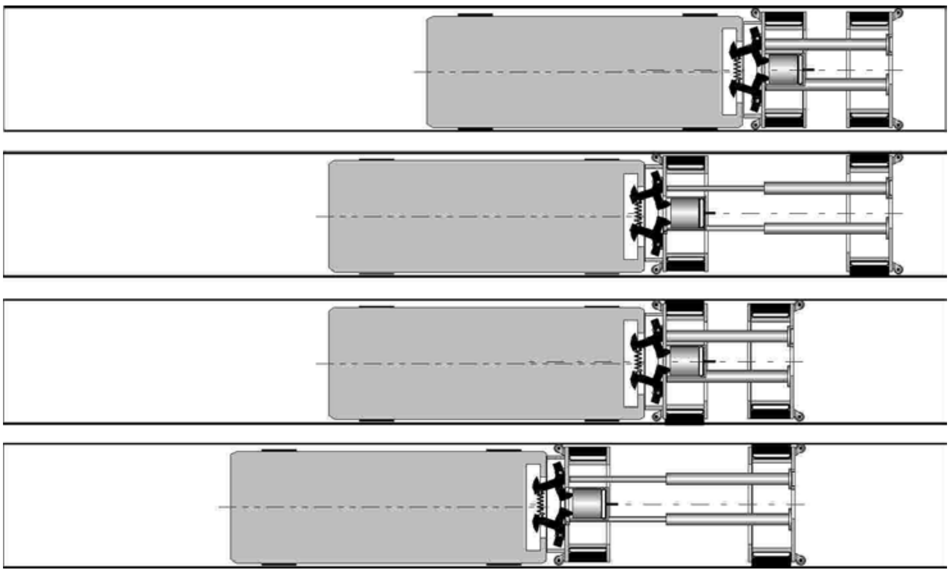


Figure 14: Illustration of the working principle of the pushing robot (Technical Variant)

6.1.2 Links with other elements of ESDRED

6.1.2.1 Partners

Within ESDRED, no other applications similar to this concept have been identified. The sharing of information was however important, since ANDRA convened on October 2005 all the ESDRED Partners to attend a demonstration run in MUSTHANE's premises (see photo below).

Figure 15: General view of the assembly (ESDRED Partners & EC Project Officers) convened to attend the preliminary tests on 25th October, 2005

Outside ESDRED, ANDRA was informed both by SKB and MUSTHANE of technical exchanges taking place for some very specific application (derived from the pushing robot operating concept). A business opportunity for a subcontractor from Module 2 with a Participant from Module 3 can be considered as an Integration achievement of its own!

6.1.2.2 Modules

No links between Modules have been identified.

6.1.2.3 Work packages

The main link for ANDRA, between the preliminary studies (conceptual design in WP2.1) and the studies for the Industrial Scale Demonstrator to come (WP3), is the "re-engineering" of the pushing robot itself and its successful demonstration, which provided a solid confidence in the future developments.

The major differences between the old and the new designs can be seen in **Figure 16** below and are further explained in the text underneath.

Major differences

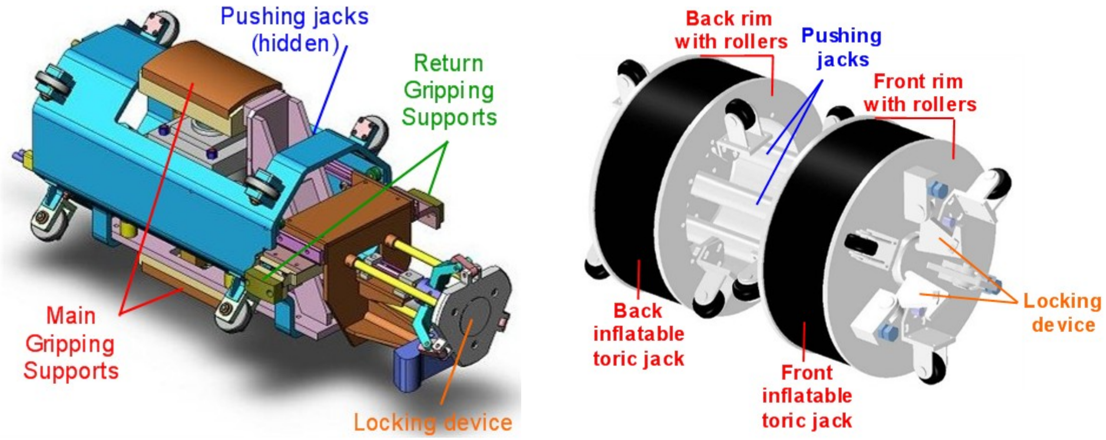


Figure 16: Initial and final robot designs

- Main gripping supports (mounted on radially actuated hydraulic jacks) and designed to resist the thrust on the canister are replaced by a unique "back inflatable toric jack" at the back of the robot.
- Return gripping supports (mounted on small radially actuated hydraulic jacks) are replaced by a unique "front inflatable toric jack" at the front of the robot.
- The canister retrieval system made up of 3 small longitudinal hydraulic jacks and a locking jack are replaced by a single central jack combined with 3 fingers (with return springs) actuated by an inflatable bag.

Motivations & advantages of design variations

The 3 main reasons for the replacement of radially actuated hydraulic jacks by inflatable toric jacks are the following:

1) substituting pneumatic jacks for hydraulic oil jacks reduces the risk of potential pollution,
2) thrust stresses are applied evenly on the full circumference of the disposal cell walls, therefore avoiding risks of out of round wear of the tube,
3) the mechanism is simplified, thereby making it more robust.

As for the canister retrieval system, the concept selected is also simpler and therefore more cost effective and more reliable. It too is pneumatic, therefore avoiding risks of pollution due to hydraulic oil leakage. Thus, the general principle of having an intrinsically safe ("fail safe") system is achieved.

6.1.3 Discussion

From ANDRA's point of view, Module 2 is probably the ESDRED Module with the lowest content of effective Integration, since:

a) The number of participants is very small, only 3 partners, and only 2 are building equipment,
b) the emplacement concepts (vertical borehole and horizontal cell) and the characteristics of the host rocks are very different,
c) the national waste management programmes are different (ANDRA's ESDRED activities are based on the French WM concept described in the "Dossier 2005", whereas DBE TECHNOLOGY is relying on the German RTD-programme)
d) the exchange of information and the continuous coordination between DBE TECHNOLOGY and ANDRA are limited essentially to Module meetings every 4 months and to providing each other with the input needed for the production of the various Deliverables ,
e) NRG is only concerned by a Desk Study on Reversibility,
f) the Partners work within a different time frame and with a different approach to the work in terms of organization (i.e. mostly in-house work for NRG and DBE TECHNOLOGY while ANDRA relies mainly on subcontracting),

It must however be pointed out that the convening of all the Partners for the demonstration of the Pushing Robot Prototype was an "Integration First", which paved the way for similar actions in other Modules. For example Module 4 - low pH shotcrete plug by ENRESA in Äspö on 28 March 2006; Module 3 - KBS-3H heavy load water cushion emplacement machine by SKB the same day; and most recently ANDRA's Module 3 demonstration of its air cushion heavy load emplacement machine in Cherbourg on June 7, 2006.

The point made in the previous paragraph is fully shared by DBE TECHNOLOGY as indicated in Section 6.2.3.

6.2 DBE TEC – VERTICAL EMPLACEMENT EQUIPMENT

6.2.1 Description of the design

From the very beginning of the project DBE TECHNOLOGY has decided to evolve the emplacement technology for spent fuel canisters in a standard manner. Thus, first input data and functional requirements were compiled followed by conceptual design and basic design work. Almost all this design work was done in-house.

The main result of the conceptual design - accomplished in the autumn of 2005 and described in detail in the Deliverable Mod2-WP2.1-D2 – was the selection of one of several different technical variants for the emplacement system. An assessment process corresponding to VDI guideline 2225 showed the emplacement device with transfer cask as the most advantageous one in terms of safety engineering, handling, technique and costs.

The emplacement device (see **Figure 17**) contains all the handling devices needed for the reception of the transfer cask from the transfer cart and for emplacement of the BSK 3 canister into the borehole. The emplacement device is stationary and firmly positioned above the borehole for the period of the filling of the borehole. Changes of position between the boreholes or emplacement lines are done by transfer cart and mining locomotive. These two components are also needed for the delivery and removal of the transfer casks.

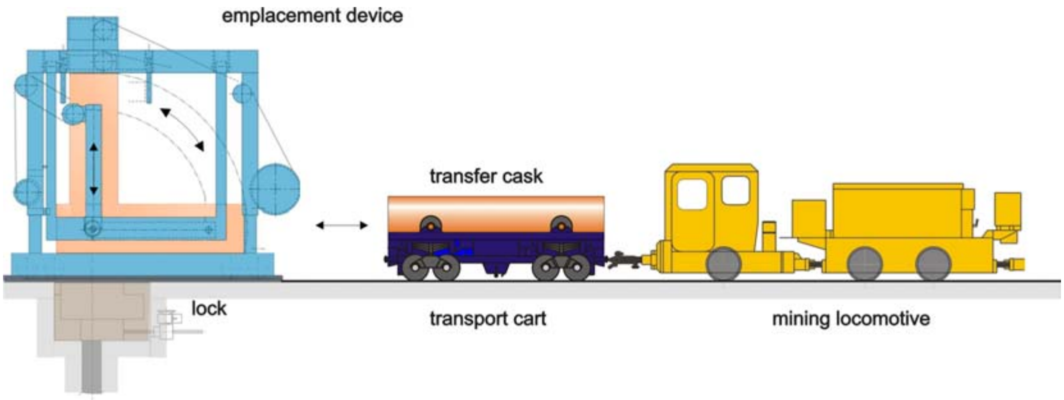


Figure 17: Emplacement device with transfer cask

The emplacement device with transfer bushing (**Figure 18)** differs from the previous variant in that the transfer cask is not used for the direct emplacement process of the canister. It is unloaded into the transfer bushing in the delivery position - prone on the transfer cart.

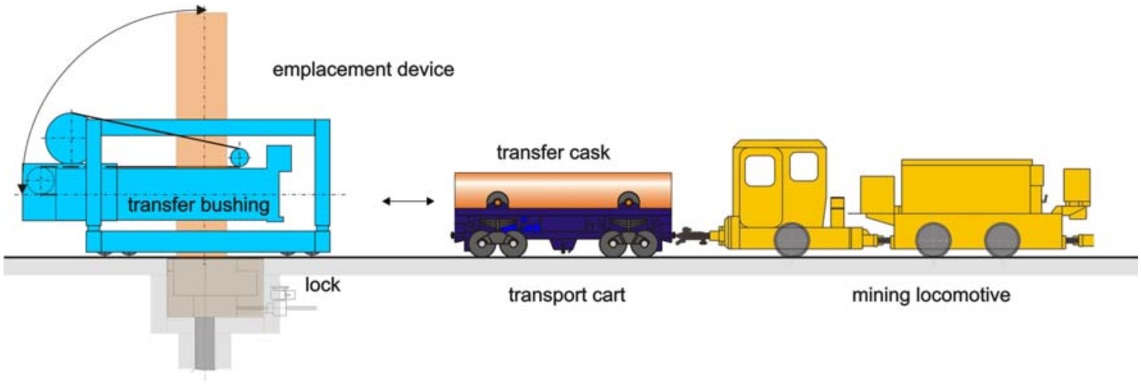


Figure 18: Emplacement device with transfer bushing

On basis of the conceptual design results the basic design for the various components was performed from the summer of 2005 to January 2006. The results are described in detail in a report, Mod2-WP3-D3.1. The following figures provide an overview of the entire emplacement system (**Figure 19**), the transfer cask (**Figure 20**), the emplacement device (**Figure 21**) and the borehole lock (**Figure 22**).

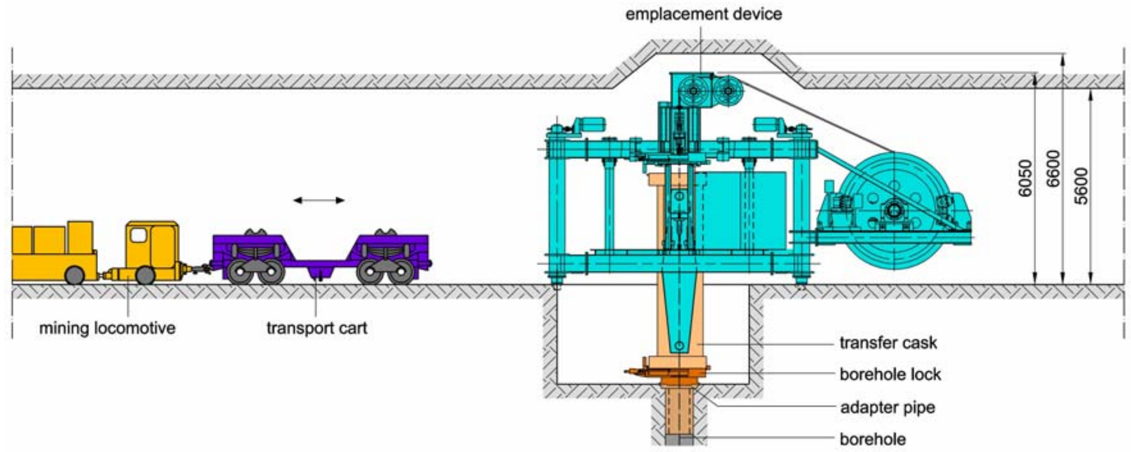


Figure 19: Emplacement system at the disposal position

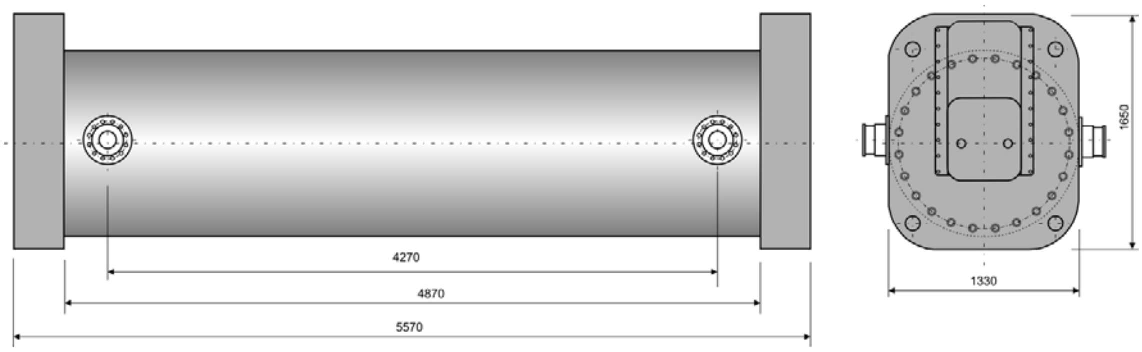


Figure 20: Transfer cask containing one single BSK3 canister

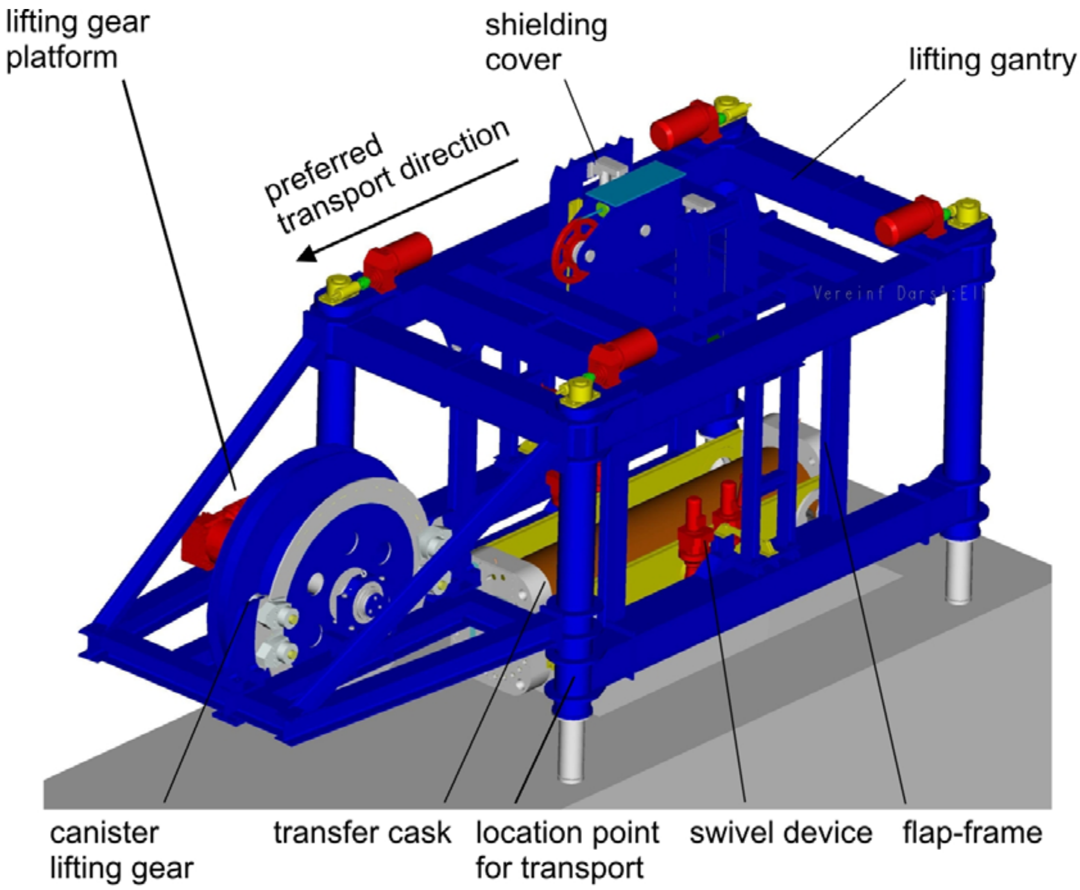


Figure 21: Emplacement device with transfer cask

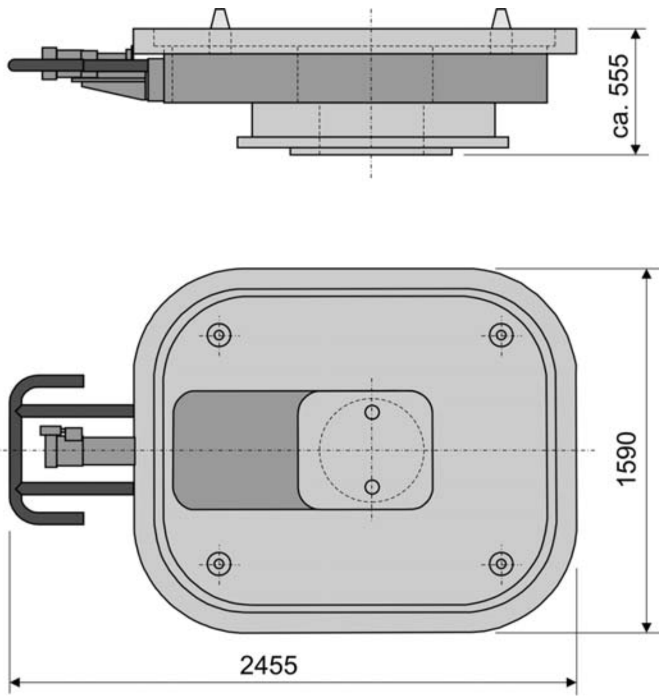


Figure 22: Borehole lock

The next design step in DBE TECHNOLOGY's approach is the detailed design for the various components. This will be subcontracted to German companies in conjunction with the manufacturing. The appropriate RFP's were launched during the spring 2006.

6.2.2 Links with other elements of ESDRED

6.2.2.1 Partners

The vertical emplacement of spent fuel canisters into deep boreholes in rock salt seems to be a unique concept within ESDRED. The only other country in Western Europe which is considering salt as a host rock for high level waste and spent fuel is the Netherlands. Consequently the Dutch ESDRED partner, NRG, is involved in evaluating one specific issue – reversibility and retrievabilty – which in the Netherlands is a legal requirement for repository design. As this issue is also a legal requirement in France, NRG (in a separate work package) is critiquing the provisions for retrievability and the consequences of this requirement on both the emplacement concepts and the technologies, for the French horizontal concept and the German vertical concept.

6.2.2.2 Modules

Due to the specific nature of Module #2 there is no direct link to other Modules. However, the information exchanged, in particular with SKB, regarding the experiences during the manufacturing and during the in situ implementation of a 1:1 industrial demonstrator will be of benefit when these tasks are implemented within Module #2 in the not too distant future.

6.2.2.3 Work Packages

At the end of Work Package 1 – "Input data and Functional Requirements" – it appeared obvious that the two main partners in Module #2, ANDRA and DBE TECHNOLOGY, will according to company specific procedures apply completely different strategies concerning subcontracting and in-house work.

As described earlier DBE TECHNOLOGY's approach for developing an emplacement system which fulfils the requirements of both the German Mining and Atomic Law is a step wise approach. Consequently, from one design phase to the other – and in this sense from one Work Package to the next – the level of detail for the different components increases and subsequently the confidence in the system to be manufactured and tested in a 1:1 scale surface demonstrator also increases.

However, the information exchange that takes place within Module #2, either during Module meetings or by other means, improves on the one hand the understanding of the different design strategies and allows on the other hand a detailed insight in the development of the different technical components.

6.2.3 Discussion

See Section 6.1.3 for a joint discussion with ANDRA.

7 MODULE 3 DESIGNS - (HEAVY LOAD EMPLACEMENT TECHNOLOGY)

7.1 ANDRA – PROTOTYPE AIR CUSHION EMPLACEMENT MACHINE (WP2)

7.1.1 Description of the design

Between mid July 2004 and December 2005 ANDRA contracted “Bertin Technologies” to design, fabricate and test a prototype air cushion emplacement machine.

The primary objective of this work was to demonstrate the technical feasibility of using a PROTOTYPE AIR CUSHION SYSTEM for lifting and moving a CU1 Spent Fuel canister into a horizontal disposal cell. It included designing, fabricating and testing of a very basic version of a PROTOTYPE AIR CUSHION CRADLE intended to lift and move a simplified mock-up of the canister (scale 1/1 for the OD and scale 1/3 for the length, hence 1/3 of the actual weight, i.e. 14 tons instead of 43 tons).

The second objective was to determine the main operational characteristics of the system and to assess their extrapolation to the future full scale industrial demonstrator.

The third objective was to evaluate the various limitations of the system (vis-à-vis its environment and its failure potential) and to take them into account for the design & construction of the future full scale industrial demonstrator (WP3).

This preliminary test campaign, to be run in a surface workshop facility, subsequently needed to be carried out early in the ESDRED programme in order to confirm, as soon as possible, that the fundamental concept was feasible i.e. well in advance of fabricating a full scale emplacement demonstration equipment which was foreseen later in the ESDRED programme (WP3 and following).

Unlike the full scale demonstrator (in WP 3 & 4), which was to focus also on the mock up of the inner steel sleeve, on the shielding cask and on the gamma gates, the test carried out in WP 2 only needed to validate the relevancy of using air cushions (selected amongst off the shelf products) for lifting a heavy payload with a relatively small radius of curvature (the diameter of the canister is 1255 mm).

A cross section of the test bench showing the dummy canister, the ballast plates and the primary test bench structure is shown below in **Figure 23.**

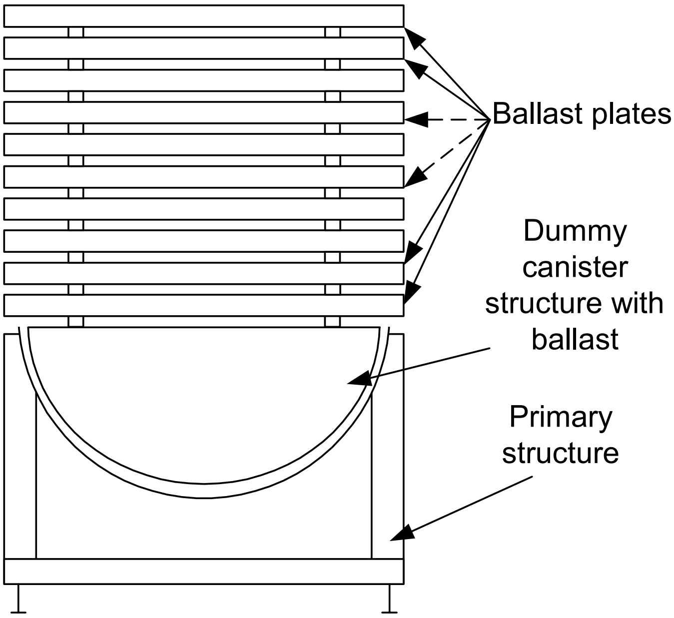


Figure 23: Cross-section of test bench arrangement

Photographs of the cradle and air cushion arrangement and of the complete test bench are shown below in **Figure 24.**

View from bottom to top showing the slide plate, 2 rails, cradle, dummy canister and the ballast plates

View of the lower face of the air cushion supports

Figure 24: Photos of the prototype demonstrator

7.1.2 Links with other elements of ESDRED

7.1.2.1 Partners

The evolution of the Scope of Work for this first RFP (Request for Proposal) borrowed heavily from the work which had previously been carried out by SKB outside of, and prior to, the ESDRED Project. In 2003 SKB had operated a small demonstrator incorporating a sliding plate, a cradle for lifting the heavy load and air/water cushions designed and manufactured by Solving, a Finnish company. Solving was invited to bid on the design and fabrication of ANDRA's one third scale prototype demonstrator but was unsuccessful.

The most relevant things learned, and used, from the SKB's experience were:

- A confirmation that the air cushion configuration deemed the most appropriate was the one with an "air flow downwards" and not the one with an "air flow upwards" as recommended at the end of ANDRA's conceptual studies on the subject (undertaken prior to ESDRED),
- A confirmation of the validity of the emplacement technology for heavy loads such as the sets of 4 pre-assembled pre-fabricated bentonite rings (cf. Module 1) constituting the engineered barrier around the waste canister (since the mass/linear metre and the radius of curvature of the SKB's dummy load were of the same order of magnitude as the load constituted by a set of bentonite rings),
- The existence of a least 2 valuable providers of air/water technology solutions (Bertin & Solving), likely to be consulted again by SKB or ANDRA in their RFP's to come (WP 2 &WP 3 of Module 3).

7.1.2.2 Modules

The design and fabrication of ANDRA's prototype heavy load emplacement machine (WP2 of Module 3) did not impact any of the other Modules directly. However it did impact the design and fabrication of ANDRA's full scale demonstrator within this Module 3 as described below.

SKB's heavy load emplacement demonstrator was also impacted, as it was being implemented at about the same time as ANDRA's, and because there was regular communication between the SKB and the ANDRA representatives (including a sharing of tender documents, common bid evaluation, etc).

7.1.2.3 Work Packages

Work Package 3 followed on the heels of WP 2 described above. It involved the "Detailed design and manufacturing" of the full scale equipment to be used not only for the emplacement of 43 ton spent fuel canisters (CU1) but also for the emplacement of sets of 4 pre-assembled "donut shaped" rings of bentonite.

The strong link between the work done in WP2 and the design phase in WP3, which followed, was in proving that the concept of using air cushions in a small diameter circular disposal tunnel did indeed work, and subsequently the road was paved for a real scale demonstrator.

The design work in WP3 was also impacted in the following ways:

- MECACHIMIE, the company contracted by ANDRA for its Industrial Demonstrator made a repeat test with the BERTIN's prototype, to check the performance range and identify the improvements to be incorporated into the system in the new design,
- BERTIN also successfully ran a test of its prototype (at the request of CNIM, the company contracted by SKB for its Industrial Demonstrator) using water as a lifting fluid (instead or air as in the ANDRA's case).
- BERTIN was selected both by MECACHIMIE & by CNIM as the sole provider of air/water cushion cradles for the Industrial Demonstrators.

7.1.3 Discussion

Overall the work in this WP 2 was not only necessary but also extremely helpful before moving forward with the design of the full scale heavy load emplacement machine complete with all its paraphernalia.

In the end the prototype designed, built and tested is conceptually very similar to the one used by SKB in its earlier prototype demonstrator and to the final ones of both SKB's and ANDRA's full scale demonstrators.

Probably the biggest impact regarding commonality of designs has to do with the fact that very early in the ESDRED Project SKB and ANDRA learned to work together towards a common goal and in the process they developed a trust and respect which enabled them to easily share designs, documents and information.

7.2 ANDRA –INDUSTRIAL SCALE AIR CUSHION EMPLACEMENT EQUIPMENT (WP3)

7.2.1 Description of the design

On 06 January 2005, ANDRA contracted MECACHIMIE for the design, fabrication and testing of the following systems:

- a) An air cushion emplacement machine with ancillary equipment for deposition of Spent Fuel canisters (CU1 packages) into the inner metal sleeve of the Disposal Cell. The load is about 43 tons, with a length of about 5.390 m and a diameter of 1.255 m;

- b) An air cushion emplacement machine with ancillary equipment for emplacement of sets of 4 pre-assembled bentonite Rings into the perforated steel liner of a Disposal Cell, in order to build the engineered barrier system. The load is about 17 tons, with a length of about 2 m and a diameter of about 2.25 m.

These 2 real scale Industrial Demonstrators are planned to be built consecutively with the CU1 test bench being fabricated first and then adapted for the sets of bentonite rings. The corresponding layouts are illustrated in the figures below.

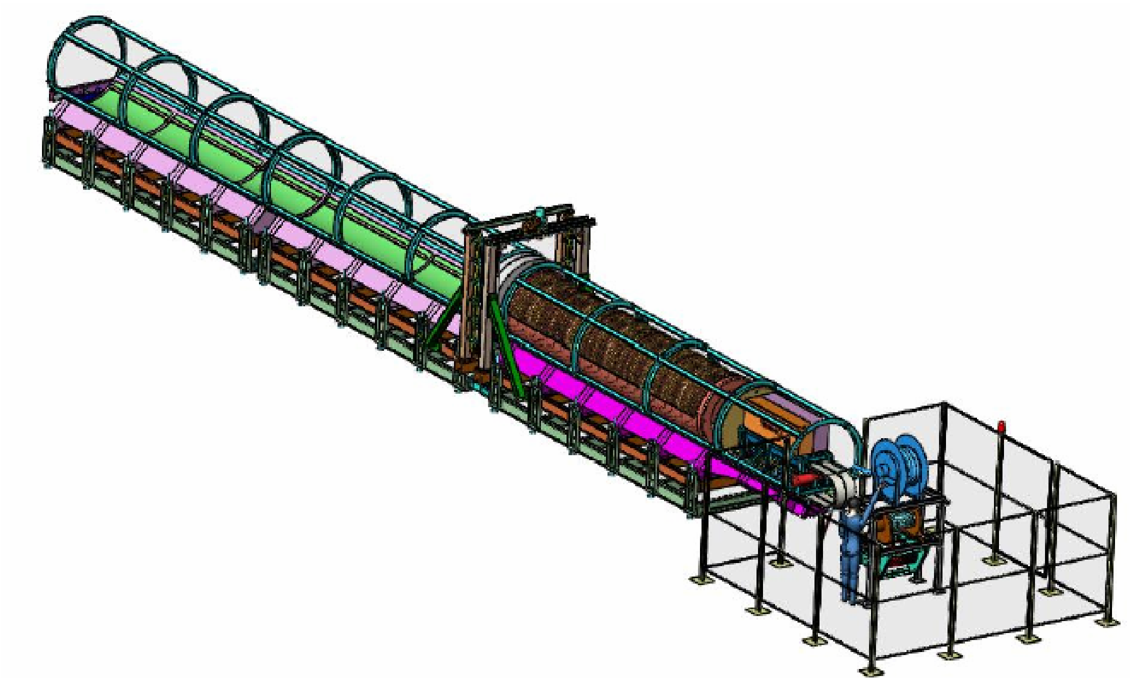


Figure 25: General layout of the test equipment for CU1 package emplacement into a Disposal Cell inner steel sleeve

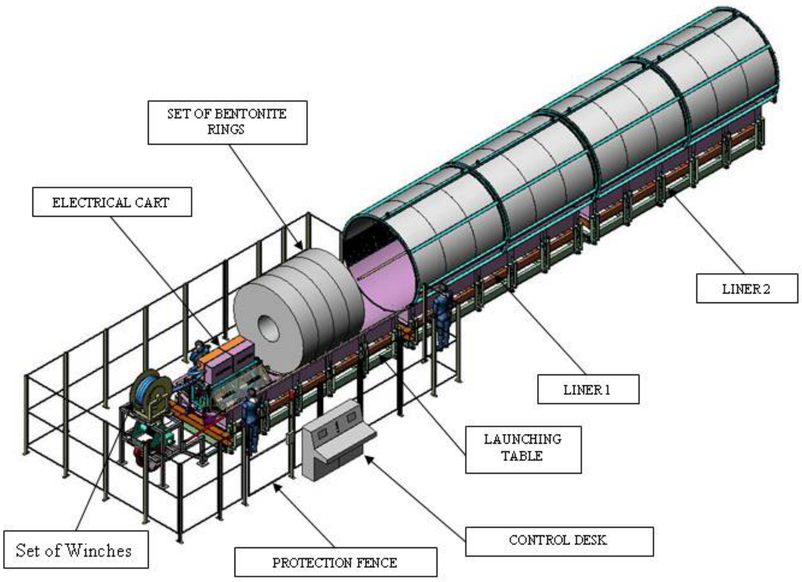


Figure 26: General layout of the test equipment for Bentonite Rings emplacement into the perforated steel liner of a Disposal Cell

7.2.2 Links with other elements of ESDRED

7.2.2.1 Partners

As with the prototype demonstrator mentioned in Section 7.1.2.1, the main link again was with SKB. In this case ANDRA and SKB cooperated in the preparation and launching, in a coordinated way, of their RFP's for their respective Industrial Scale Demonstrators. This RFP process was an Integration Process of its own, since the 2 Partners shared all the information throughout the period, from the preparation of the Call for Tenders until the final awarding of the Contracts which, for various reasons, could not be allocated to the same company.

The end result, in terms of engineering documents obtained from the Contractors, demonstrates much similarity in terms of design solutions, simplifications, control and monitoring. The most outstanding particular point is that the "basic component", i.e. the air/water cushion units, are an "off-the-shelf" product common to the 3 applications (the 2 ANDRA machines and the 1 from SKB), independent of the load and of the nature of the lifting fluid. The only adaptation of this product was:

a) the number of cushions to deal with the effective payload,
b) the radius of curvature of the cushion (also of the cradle & the payload),
c) the fluid pressure and fluid flow at cushion inlet.

These points are evidenced in Deliverable D 3 of Module 3.

7.2.2.2 Modules

There is a clear link between Module 3 and Module 1 but this relates to ANDRA only. In this case ANDRA, within Module 1, designs and fabricates Bentonite Rings and pre-assembles them into 3 sets of 4 rings each and then subsequently emplaces them into the perforated liner of the Disposal Cell in using the equipment designed and fabricated within Module3.

This need for coordinated design compatibility is illustrated in the sketch below.

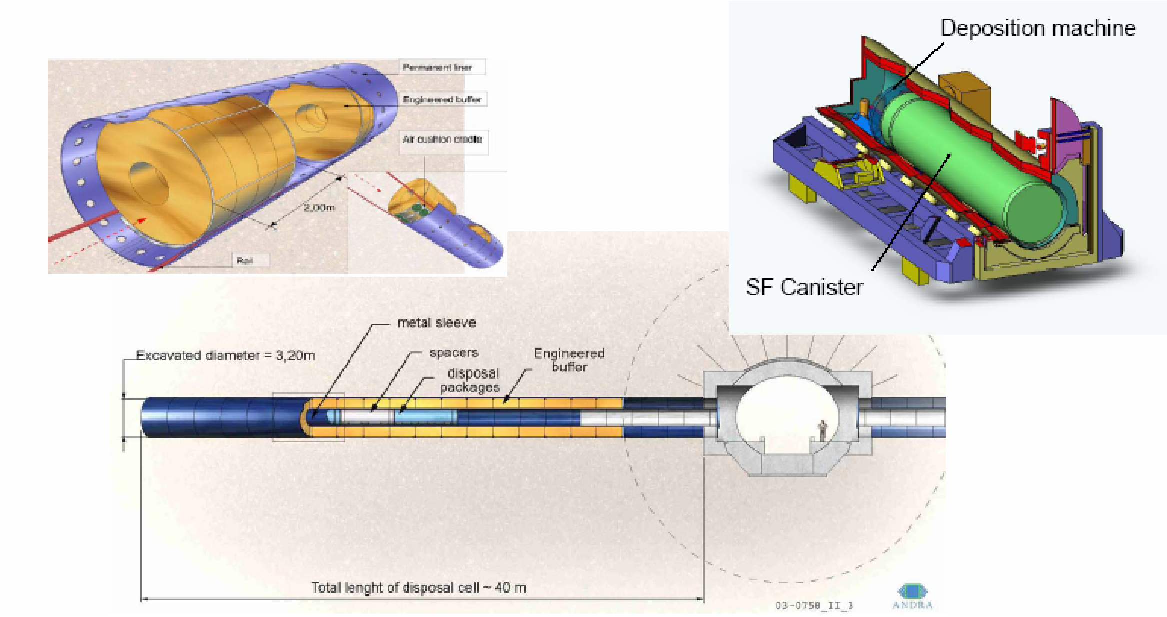


Figure 27: Bentonite Rings and SF Canister Emplacement

Top left: Components of the ANDRA conceptual design for emplacement of sets of pre-assembled Bentonite Rings using an air cushion pallet

Top right: The emplacement machine for the SF canister using the same technique

Bottom: Overview of the ANDRA Disposal Cell

From a practical point of view, the Contractors selected by ANDRA (i.e. MECACHIMIE for Module 3 and the GME for Module 1) had to work closely together to establish a common interface for installing the set of rings onto the "launch table" i.e. the "loading sequence" This particular point is depicted below. Such a coordination effort implied for the Contractors to get together, giving them an opportunity for joint-ventures, at a later stage, for national waste management implementers' future projects.

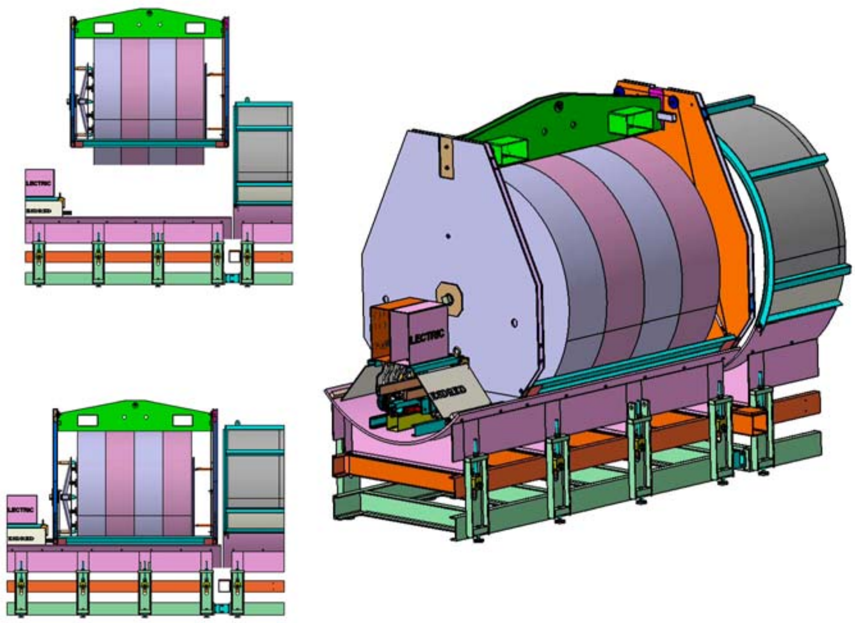


Figure 28: A set of Bentonite Rings is loaded onto the Launch Table of the Test Bench

7.2.2.3 Work Packages

The free and open exchange of information between SKB and ANDRA and the cross review of the respective results obtained at the end of the design phases, where the commonalities were evidenced, comforted the 2 Partners and enabled them to proceed with confidence into the fabrication and testing phases, implemented within Work Package 4 to come.

7.2.3 Discussion

From ANDRA's point of view (we believe shared also by SKB), this Module 3 is probably the best Module within all of ESDRED in terms of effective Integration. For example:

a) the emplacement concepts and the characteristics of the payloads are very similar,
b) the exchange of information and the continuous coordination between SKB and ANDRA were intense and rewarding,
c) the Partners and their Contractors worked within the same time frame and with a similar approach in terms of Contract management,
d) the inter-Module coordination was also effective between ANDRA's Subcontractors (GME & MECACHIMIE).

7.3 SKB-INDUSTRIAL SCALE WATER CUSHION EMPLACEMENT EQUIPMENT (WP3)

7.3.1 Description of the design

On 20th December 2004, SKB signed the contract with CNIM for the design; fabrication and testing of a water cushion emplacement machine with ancillary equipment for deposition of Super-Container with buffer material and a Spent Fuel (SF) canister. The main part included in the contract with CNIM is the Transport Tube, Launch Tube with supporting frames and the emplacement machine was included in the contract with CNIM. The different components of the emplacement system can be seen on **Figure 29.**

The Super-Container with buffer and SF canister and the perforated shell was not part of the contract with CNIM and has been designed and manufactured by SKB. The Super-Container has weight of about 45 tonnes, a length of 5.55 m and a diameter of 1.765 m.

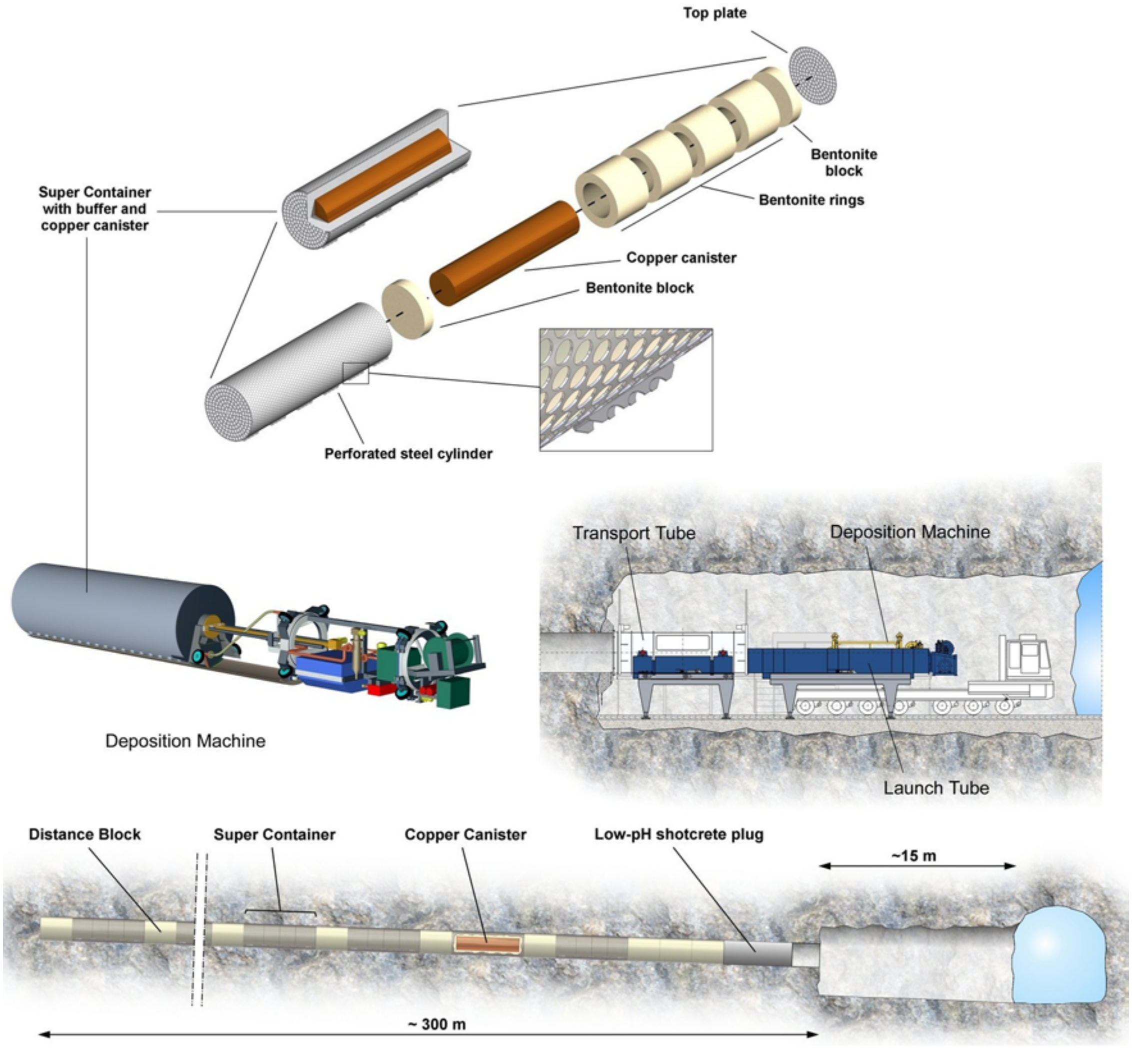


Figure 29: Main parts of the emplacement system with Super-Container, Deposition machine, arrangement of the equipment at Äspö HRL and the arrangement of the drift in future repository.

The manufacturing of the emplacement machine with ancillary equipment was completed during December 2005 has the equipment was tested in CNIM´s factory during February 2006. The equipment arrived to Äspö HRL early March 2006 and the preparation for the site acceptance tests is ongoing.

The factory acceptance test was performed in two steps. The first test was performed end January 2006 and resulted in a need to do some modification of the equipment that was considered better to do in the workshop at CNIM before transporting to Äspö HRL. The major modification was machining of the shield plate in front of the machine to the same diameter as the Super-Container, install new actuators with increased rod diameter, modification of the water supply to the cushions, etc. Due to the extent of the modifications it was agreed to redo some of the test and that was done 21 and 22 of February. These tests showed the modification was satisfactory and the equipment was prepared for the transport to Äspö HRL in Sweden. Some details of the deposition machine are shown in **Figure 30.**

Figure 30: Photo of the deposition machine, left and right side and the transport tube in the background during the factory testing at CNIM´s workshop during January and February 2006.

The emplacement equipment is now installed in a niche 220 m below ground level at Äspö HRL and the **Figure 31** shows the arrangement.

Figure 31: Photo of the installation of the emplacement equipment in the test niche at Äspö HRL end March 2006. In front you can see the emplacement machine (yellow parts) and the two gamma gates open and the end of the Super-Container.

7.3.2 Links with other elements of ESDRED

7.3.2.1 Partners

The emplacement system is part of KBS-3H concept and is a joint SKB-Posiva project. SKB and Posiva are therefore working very close with each other in this module and the third partner is ANDRA. As the principal of transferring the heavy waste package in the drift are identical except for the fact that water is used in the KBS-3H and air for the ANDRA application the links are very strong and a good exchange of information has taken place throughout the project.

7.3.2.2 Modules

SKB has no link to the other technical modules.

7.3.2.3 Work Packages

The first three work packages were completed ahead of the original time schedule. Next work package will describe the commissioning of the emplacement systems. The same principal with closed cooperation and exchange of information and experiences will continue.

7.3.3 Discussion

All members of Module 3 (ANDRA, POSIVA and naturally SKB) visited CNIM during the factory tests as well a representative from DBE for Module 2.

From SKB's point of view Module 3 has an effective Integration between the three partners. The arguments for the effective Integration are already stated in Section 7.2.3 written by ANDRA.

8 MODULE 4 DESIGNS - (TEMPORARY SEALING)

8.1 ENRESA – SHOTCRETE CONSTRUCTION OF LOW PH PLUGS

8.1.1 Description of the design

Within the frame of WP3.2 of Module 4 AITEMIN performed, during the first half of 2005, the design for the construction and testing of a shotcrete plug, in compliance with the recommendations derived from the results of the preliminary mechanical scoping calculations elaborated by DM Iberia using the code FLAC and the input of the functional requirements established early in the project.

The main objective of the shotcrete plug test is to demonstrate the construction feasibility and to check its bearing capacity in compliance with the established functional requirements [Deliverable: Mod4-WP1-D1]. The test is designed as a parallel 1 meter long shotcrete plug (without keys in the rock) constructed in a horizontal drift measuring 1,85 m in diameter, excavated by full face push boring technique in the ÄSPÖ URL. A mechanical pressure will be applied on one end of the plug, by injecting and pressurizing water in a hydraulically sealed water chamber. The high-pressure water injection system will have to provide sufficient loading capacity to bring the plug to failure (i.e. movement). The test location and layout are shown in **Figure 32** and **Figure 33.**

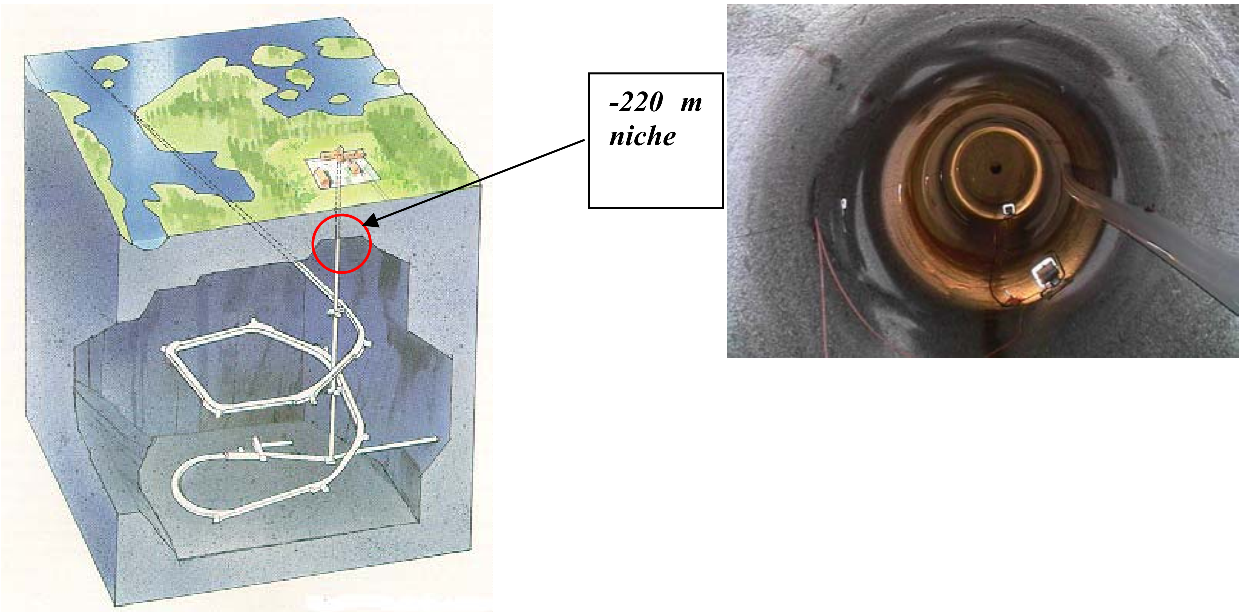


Figure 32: Test location at the Äspö HRL

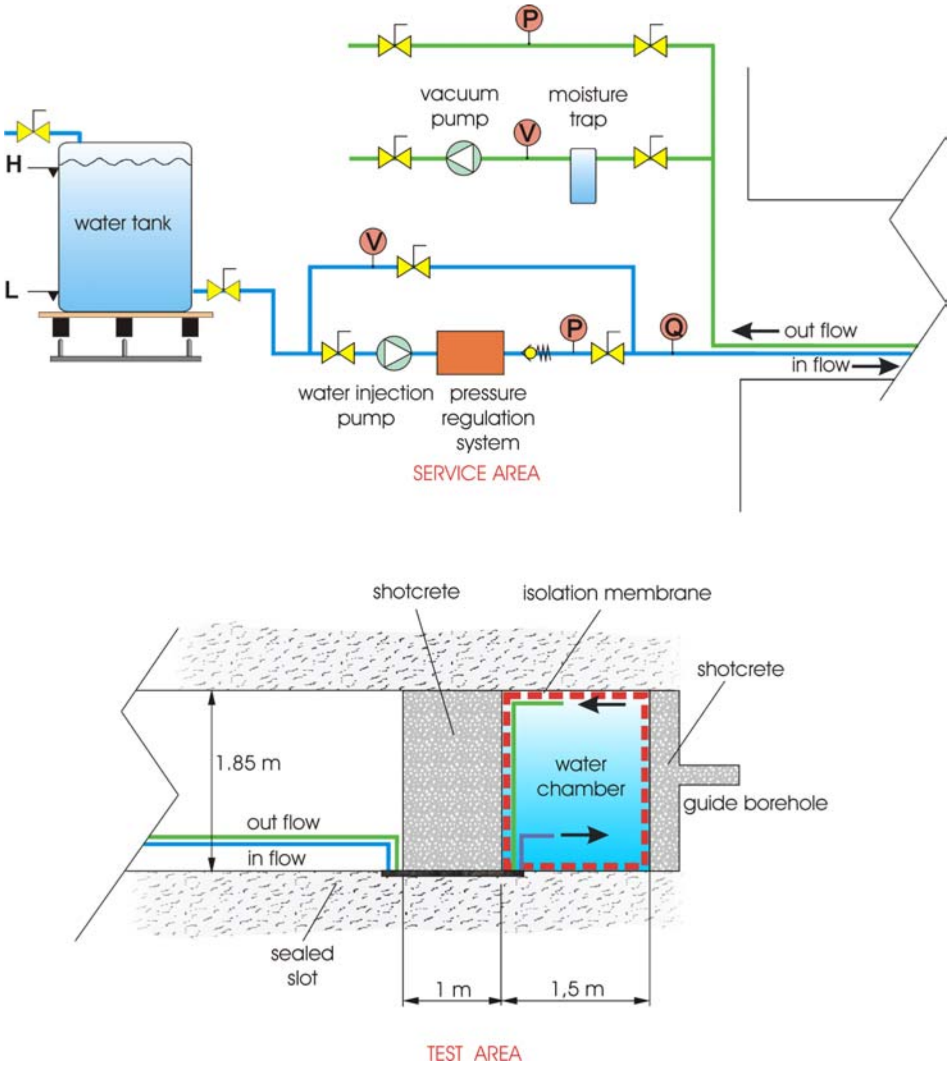


Figure 33: General layout of the plug test

8.1.2 Links with other elements of ESDRED

8.1.2.1 Partners

The integration of Module 4 with the Partners of the ESDRED IP comes from the fact that this repository component could be applicable to any disposal concept regardless the host rock. The results of this experimental and demonstration work, which are being shared with all the partners, can be easily adapted to other scenarios including a wide range of disposal vault geometries and pressure demands.

On the other hand there was in fact a kind of physical integration insofar as the plug construction and testing took place at SKB's Äspö HRL.

8.1.2.2 Modules

There are no specific links with the other IP Modules since these are basically devoted to waste handling and emplacement.

8.1.2.3 Work Packages

No links with other Work Packages unless one considers that WP3 actually consists of 2 parts i.e. the plug and the rock support which are linked in their dependence on Work Package 2 to provide the basic design of the low pH cement.

8.1.3 Discussion

From ENRESA's point of view Module 4 is a good exercise of integration because is not linked to disposal concept specificities or site specific characteristics. Therefore, if proven to be efficient, it could be a universal basic disposal component.

8.2 SKB – LOW PH ROCK SUPPORT SHOTCRETE

8.2.1 Description of the design

The purpose of this part of Module 4 was to show that low-pH concrete also could be used for rock support. The base for the design of the recipe was to start from the work done with the recipe for the shotcrete for the construction of the shotcrete plug. However, as the specification for the plus and rock support differ additional laboratory work and also separate pilot and field test had to be done.

In order to get pH below 11 the binder is a mix with 60% sulphate resistant cement and 40% silica fume. As the compressive strength for the shotcrete for rock support must be higher then for the plug the amount of binder must be increased and the binder/water ration decreased. In order to make the shotcrete easier to pump, a mixture of natural sand and crushed rock from Äspö was used. In the recipe for the plug only crushed rock was used.

The laboratory work with the design of the shotcrete for rock support started after that the pilot testing of the recipe for the plug was done. In that way all experiences from the plug recipe could be used. The filed test at Äspö HRL was performed end April 2006 and **Figure 34** shows the shotcreting of the roof. The shotcrete was done on walls as well in the roof with different thickness, 50 mm single layer, two layers 50 mm + 50 mm each and one 100 mm thick layer.

Figure 34: Field test with low-pH shotcreting of walls and roof at Äspö HRL, April 06

8.2.2 Links with other elements of ESDRED

8.2.2.1 Partners

Partners for this part of Module 4 are SKB, POSIVA and NAGRA with SKB as leader and in cooperation with ENRESA who are the leaders of Module 4.

8.2.2.2 Modules

There is no direct link to any of the other Technical Modules within ESDRED. There are of course links between the two parts of Module 4 i.e. the low-pH shotcrete for construction of the drift plug and the low pH shotcrete used for rock support.

8.2.2.3 Work Packages

The reporting related to the first three work packages covering the specifications, the laboratory work and the project plan for the pilot and field tests was in a combined report (Deliverables D2.2, D3.2 and D4.2) presented on 15 March 2006. The selection of the recipe based on the laboratory work has been done as well as the pilot tests test. The field test at Äspö was performed at the end of April 2006.

The work done in Sweden with the low-pH shotcrete recipe for rock support will now be the basis for similar work by NAGRA in Switzerland and but with recipes adjusted for the type of host rock in their future repository for spent nuclear fuel. They will also perform some pilot tests with a modified recipe.

8.2.3 Discussion

The integration of the two parts of the Module has been useful and the same contractor has been used for the construction of the plug as for the field tests of the rock support.

9 CLASSIC INTEGRATION

The INTEGRATION OBJECTIVES are summarised in **Annex 1 - Description of Work**, approximately as follows:

- "*Ensure the relevancy and maximum coherence of Input Data and Functional Requirements between the four technical Modules,*
- *Ensure the relevancy & coherence of the design studies developed within the different Modules,*
- *Ensure coherence and compatibility of fabrication and demonstration techniques (including the associated planning) employed by the four technical Modules*".

The first bullet point relates directly to the first report D1 whereas the second bullet refers more specifically to this report D3. Nevertheless the intent of all three bullet points can be expressed another way by saying that the **INTEGRATED** ESDRED Project must be anchored on the 3 big "C's" **COMMONALITY, COHERENCE** and **COMPATIBILITY**. This applies to the planning, the Input Data, the Functional Requirements, the designs, the fabrication and finally to the demonstrations and the final evaluation reports.

To be truly successful, there are two other "C's" that must be brought into play i.e. **COMMUNICATION** and **COORDINATION**. Together the 5 "C's" underpin the Project as much at the Module level as at the Project Level.

Throughout the entire ESDRED Project, the challenge is to avoid the pitfall of trying to INTEGRATE those elements which cannot or should not be integrated, while staying focused on those elements which must be integrated or on information sharing.

The main examples of classic Integration, identified in Annex 1 – "Description of Work", are between Modules 1 & 2, 2 & 3, 1 & 3, 1 & 4. These all involve ANDRA and are shown schematically in **Figure 35** and **Figure 36** and are described in (a) below.

(a) **Figure 35** shows the link between Modules 1, 2 and 3 as regards the Integration of Design, Construction and Demonstration. Clearly the intent is that the set of 4 bentonite rings fabricated and pre-assembled in Module 1 will be sized to fit the air cushion emplacement system fabricated and demonstrated as part of Module 3 and finally placed in a disposal cell in Module 2. From a purely practical perspective this Integration essentially only involves ANDRA and it is happening. Unfortunately not all Integration is that simple.

In addition to the Integration described above a more subtle type of Integration also goes on because the partners are sharing information and their experiences openly. Obviously, ESDRED or similar multinational Projects cannot force any changes in national concepts because these are based on higher level requirements, including availability of host rocks, differences in waste inventory and differences in national regulatory guidelines. But the fact that all national concepts are dynamic and in a continuous state of evolution means that Integration may occur when there is a need and when the time is right.

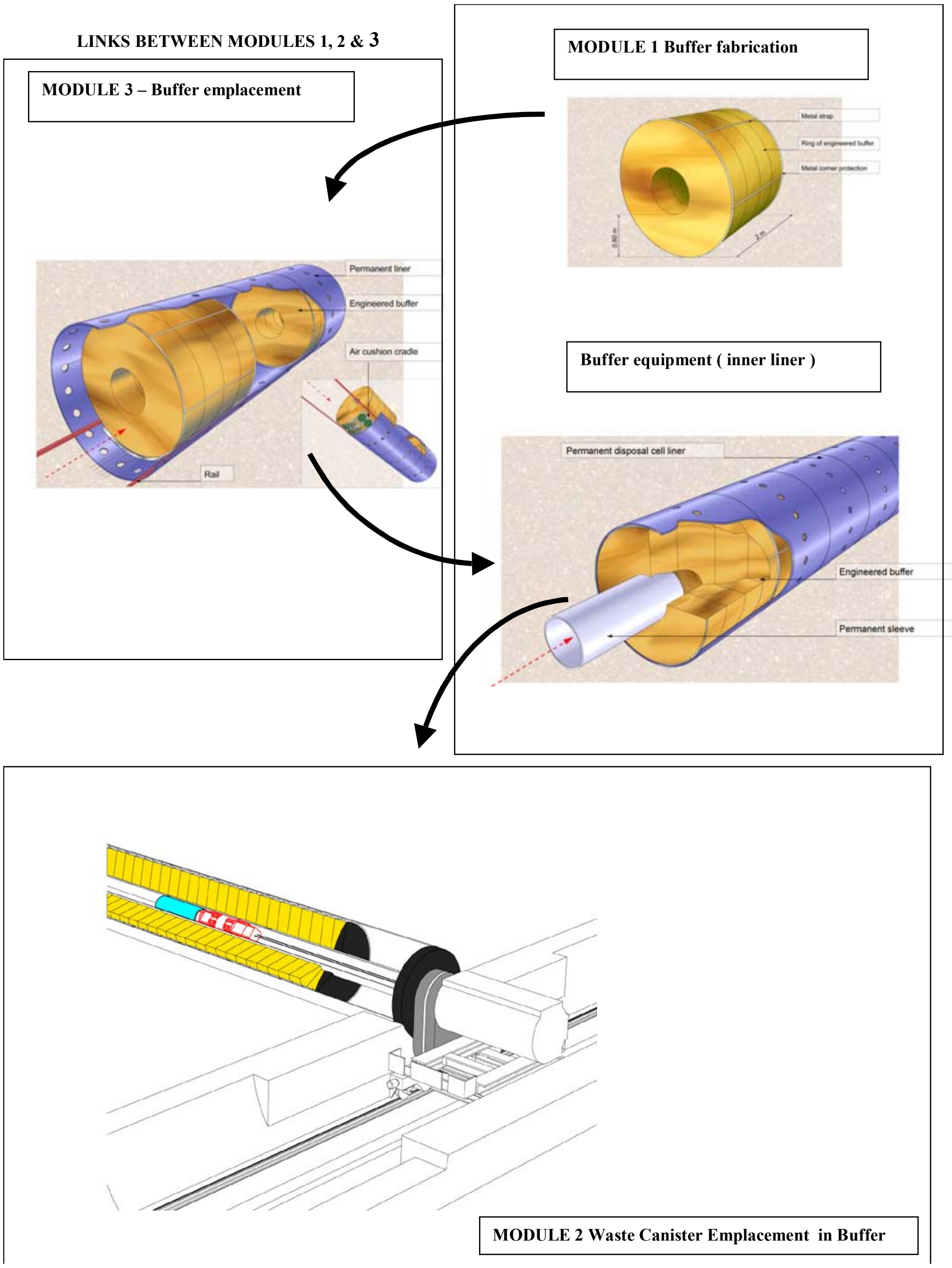


Figure 35: Links between Modules 1, 2 & 3 (Integration of Design, Construction & Demo.)

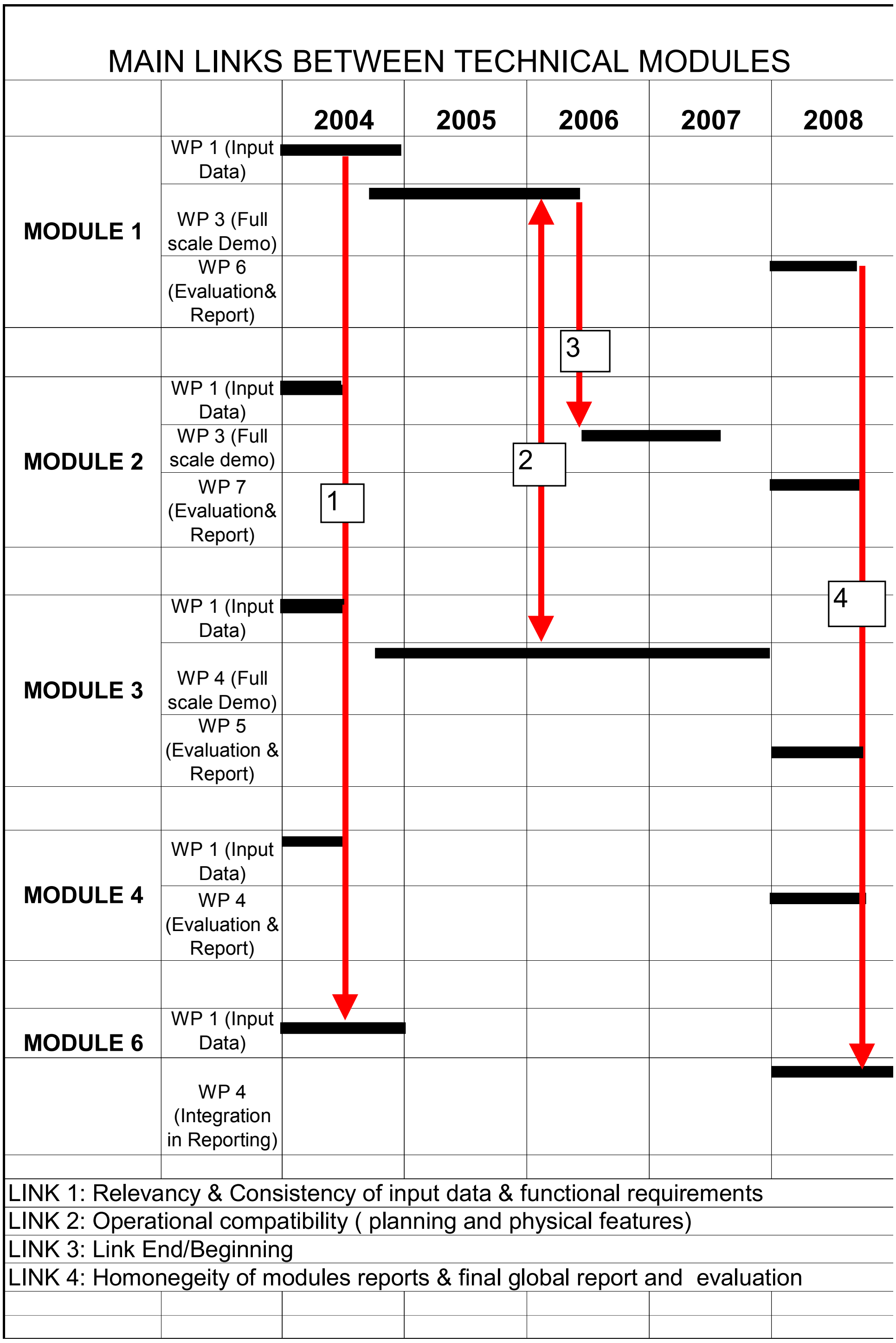


Figure 36: Main Links between Technical Modules

10 INTER-MODULE DESIGN INTEGRATION (WP2)

It became very clear early on in the progress of the technical work that classical Integration, as defined in the dictionary, would not have much application within ESDRED, except for ANDRA's part where its products from Modules 1, 2 and 3 were meant to be integral pieces of a whole. It was expected that between the ESDRED Contractors any Integration would be much more subtle and essentially limited to sharing of information.

The good news is that after two years into the Project there is evidence that the sharing of information type of Integration is having a more significant effect than originally assumed. For example:

- In Module 3 SKB and ANDRA have chosen the same fluid cushion type and supplier and in both cases their sub-contractors are working with BERTIN who built ANDRA's one third scale prototype air cushion demonstrator.

- In Module 2 where DBE-TEC and ANDRA are 90° apart in their concept (vertical vs. horizontal disposal, overpack vs. no overpack, retrievability vs. no retrievability) the two partners intend to share transport cask design knowledge that goes even beyond the limits of the ESDRED Project.

- In Module 4 ENRESA/AITEMIN/CSIC have built their test plug at Äspö a few metres from where SKB are erecting and testing their Module 3 "Heavy Load Emplacement" demonstrator. The formulation developed by ENRESA/AITEMIN/CSIC for low pH plug shotcrete was then exploited by SKB to derive its own recipe for the low pH rock support shotcrete.

- Although ANDRA (technical Participant in Modules 1, 2 and 3) is not directly involved with Module 4, it has taken an interest in the low pH work, has commented reports, participated in the low pH Workshop in Madrid and will witness the testing of the plug.

11 SUMMARY AND CONCLUSIONS

MODULE 1:

For Module 1, the summer of 2006 is a critical time. Three of the partners will then execute the WP3 tests that they have been preparing for since the beginning of the project;

- O/N+EURIDICE will perform the backfill testing on two 2/3 scale mock-ups of a disposal cell; one with a special grout and one with a range of dry materials of specific granule sizes,
- ANDRA will fabricate the prototype bentonite rings using the Aubert & Duval press at Issoire (France),
- NAGRA will emplace its selected granular buffer material in a 4/5 scale steel mock-up of a disposal cell.

In parallel with this, GRS have made a successful start-up of the pilot phase of the in-situ SB experiment and will now install the equipment for the tests in the other three boreholes and also start up these experiments.

NIREX, together with the other partners, have selected micro seismic measuring as the non-intrusive monitoring technology to be developed further and, together with NAGRA and the Technical University of Zürich, have set up an experiment in the Mont Terri URL. The first of four measurement campaigns has been successfully completed.

To conclude, the Module 1 work has overall been successful so far. No major delays or technical setbacks have been reported or are currently anticipated for the future. The partners have worked well together sharing experience and knowledge on a regular and informal basis

MODULE 2:

From DBE TECHNOLOGY's perspective the design phase – Work Package 2 and the subsequent Work Packages – has shown very clearly that DBE Technology and NRG have a very different approach from ANDRA (and most of the other ESDRED partners as well) concerning the way that the work is handled. DBE Technology performs most of the design work with its own staff whereas the majority of the ESDRED partners involve subcontractors. This difference is due to company specific work strategies and should not have any impact on the project results. However, this difference highlights the fact that there is also another kind of integration in the sense that partners learn how the different European WM agencies/organisations deal with the development of technical solutions.

From ANDRA's point of view the main integration factor is the sharing of information and the understanding of each Partner's rationale within the Module. For example NRG's desk study on "Reversibility", wherein they review both the French and the German approach, is a good example of how two different concepts can be critiqued by a common reviewer within the same Module.

MODULE 3:

Air cushion technology for handling heavy loads has been implemented in the industry for a very long time and for many different applications. The modification of this technology for the handling of heavy waste packages in drifts with curved surfaces (large diameter horizontal boreholes) was investigated and carried out by SKB/POSIVA outside and before the ESDRED project in 2003. The experiences from the initial tests were promising and became the basis for the development of the technology for handling heavy loads in drifts for the KBS-3H Super-Container in the Swedish case and the pre-compacted buffer and spent fuel canister in the French case. Furthermore ONDRAF/NIRAS participated in the initial testing phase (before ESDRED) but they decided later not to be a partner in Module 3 and to concentrate all their efforts on Module 1 only.

The three partners within Module 3 have had close contact, with an open exchange of information, throughout the ESDRED project. The integration and the exchange of information within the Module 3 was further enhanced by the fact that the subcontractor selected by SKB/POSIVA (the French company CNIM), and the subcontractor selected by ANDRA, (the French company MECHCHIMIE), for the design and fabrication of their respective demonstrators both used the same subcontractor for the design and supply of the air / water cushions i.e. the French company BERTIN.

The SKB and ANDRA deposition machines produced within Module 3 have many similarities but the development and design of the deposition machines has not been a subject for integration as each of the Industrial Demonstrators had to meet different functional requirements. Hence the machines are similar but different. However, as an example, the HMI for both deposition machines have many common features.

Module 4

The last demonstrator of the ESDRED integrated project, Module 4, has as its objective the development and validation of low-pH cementitious materials for industrial applications in repository construction utilizing the shotcrete technique. Specifically low-Ph shotcrete suitable for rock wall support and for the construction of disposal drift plugs was to be designed. There is almost no experience in either the workability or the performance of shotcrete formulated to obtain a final low-pH product and, therefore, testing of this specific material under realistic conditions is needed. A full scale demonstration test using low pH cements in the shotcrete formulation, was therefore proposed, as part of the ESDRED IP, to check this type of plug construction feasibility and to evaluate the performance under realistic conditions.

The main concern with the use of concrete in radioactive waste repositories comes from the potential chemical interaction with the disposal components. Depending on the use, concrete has different chemical compositions and is normally far from in a state of equilibrium with the natural media. Thus the concrete will be gradually altered by the ground water which releases into solution significant quantities of ions creating a pore water with pH higher than 12. The propagation of this alkaline fluid into the bentonite barriers or into the geological medium (clay or granite host rocks) can last for a very long time, up to thousands of years. This phenomenon, called the hyper-alkaline plume or high-pH plume effect, can cause physicochemical transformations and changes in the radionuclide confinement properties of the disposal components. Therefore, the reduction of the pore water pH is a long-term safety issue since cement based materials will be used in a repository construction.

In both cases, i.e. low-pH shotcrete for rock support and for plug construction, the demonstrator has been developed starting from a common root of basic components (low-pH binders) and which had been satisfactorily tested. The products obtained from the test work resulted in concrete formulas that were susceptible of being used in repository construction, and which were shown to comply with the main requisite of maintaining at all times the pH of the concrete pore water equal to or below 11. Once the recipes had been developed in the laboratory a very comprehensive field programme of pilot tests was conducted first in Spain and then in Sweden before the construction of the plug at Äspö HRL.

In addition to the test designed to confirm the feasibility of constructing a shotcrete plug in natural conditions a further test for evaluating the performance of the plug under load, was also designed. As a result of the preliminary design work for the plug, carried out during the initial stages of Module 4, it was decided that some parts of the plug development work should be modified in order to ensure a complete understanding of the plug mechanical performance under realistic conditions. The modifications introduced, with respect to the initial proposal, were:

- To shorten the plug length, to facilitate the failure under a reasonable loading pressure.
- To simulate only the mechanical functions of the plug, by hydraulic loading.

The plug was constructed late 2005 and the load testing was done in March 2006. The investigation and dismantling of the plug was carried out from mid May to mid June. The evaluation of the results and the documentation of the experiences of the plug work are ongoing.

With regard to the shotcrete formulated for rock support, the recipe selected for the plug had to be modified as the requirements for compressive strength are much higher than for the plug. Therefore the amount of binder had to be increased and the water/binder relation decreased. However, the work with the modified recipe could be based on the work done in Spain for the low-pH plug shotcrete and the experiences in Sweden regarding the use of Äspö crushed rock as aggregate in concrete. In the final recipe for the rock support, the fine fraction of the crushed rock was replaced with natural sand and filler material, which improved the pumping and spraying of the shotcrete. This resulted in quite a bit of integration within the Module itself as the partners interested in the plug, with 2 exceptions, (there are 6 participants in this Module) where not the same as the partners interested in the rock support. What they all had to share was the basic development of the low pH cement which was then to be used in the formulation of different shotcrete materials.

After completion of the initial laboratory tests at the end of 2005 the final low-pH recipe for rock support was completed in early 2006. Pilot tests were performed at the end of February and the field tests at Äspö HRL were carried out at the end of April. The evaluation of the results and documentation of the experiences related to the low pH rock support shotcrete is ongoing. Furthermore, the work done in Sweden with the low-pH shotcrete recipe for rock support will now be the basis for similar work by NAGRA in Switzerland adjusted for the type of host rock in their future repository for spent nuclear fuel.

12 APPENDICES

12.1 APPENDIX 1 - GLOSSARY

WORD	Per IAEA	DEFINITION
Backfill	yes	The material used to refill excavated portions of a *repository* (*drifts,* disposal rooms or *boreholes*) during and after *waste* has been emplaced
Behind		away from the dead end of a disposal cell/drift
Bentonite	yes	A soft light coloured *clay* formed by chemical alteration of volcanic ash. It is composed essentially of montmorillonite and related minerals of the smectite group. Bentonite is used as *backfill* and *buffer* material in repositories.
Buffer	yes	Any substance placed around a *waste package* in a *repository* to serve as an additional *barrier* to: stabilize the surrounding environment; restrict the access of *groundwater* to the *waste package*; and reduce by *sorption* the rate of eventual radionuclide *migration* from the *waste*
Clay		Within ESDRED this refers to indurated clay in the form of claystones and argillites. Clays differ greatly mineralogically and chemically but ordinarily their base is hydrous aluminum silicate.
Disposal Cell		Typically a short tunnel/drift/borehole excavated in an underground repository for the purpose of disposing packages of radioactive waste
Disposal Drift		Typically a long tunnel/drift excavated in an underground repository for the purpose of disposing packages of radioactive waste
Disposal Package		The final Waste Package which is placed into a repository without further conditioning ie the Super-Container, the Primary Package with Overpack or the Primary Package without Overpack
ESDRED Concept		This is a variation of the reference National Concept which is used within the ESDRED Project. Example: Sweden's national concept is "Vertical" however SKB's concept within ESDRED is horizontal
Front, in front of		towards the dead end of a disposal cell/drift
Functional Req'mts		Within ESDRED, similar to flexible design critereria or flexible input data; generally refers to criteria or elements that are open to discussion and/or negotiation
Input Data		Within ESDRED, similar to fixed design criteria; generally refers to criteria or elements that are unavoidable and not open to discussion and/or negotiation

WORD	Per IAEA	DEFINITION
Plug		Sometimes used interchangeably with *SEAL* but not within ESDRED where it refers to a concrete mass that serves as a backstop or abutment to resist the pressures eventually exerted on a seal by the swelling buffers
Primary Package		A package of radioactive material as delivered by the producer; before conditioning, for disposal
Retrievability		The ability to remove radioactive waste from the underground location at which the waste has been previously emplaced for disposal.
Reversibility		Implies a step wise disposal process and in particular refers to the ability of a repository system, for whatever reason, to reverse the steps that have been executed so far in its development.
Seal	yes	Engineered *barriers* placed in passages within and leading to a *repository* to isolate the *waste* and to prevent seepage leakage of water into or *radionuclide migration* from the *repository* area. Sealing is performed as part of *repository closure.*
Shotcrete		Mortar or concrete pneumatically projected onto a surface at high velocity
Super-Container		Generally seen as a disposal package that, unlike other disposal packages also incorporates bentonitic or cementatious buffer material
Waste Container	yes	The vessel into which the *waste form* is placed for handling, transport, *storage* and/or eventual *disposal*; also the outer *barrier* protecting the waste from external intrusions. The waste container is a component of the *waste package*. For example, molten *HLW* glass would be poured into a specially designed container (canister) where it would cool and solidify. NOTE: One or more waste packages can be put inside an overpack to become a Disposal Package.
Waste Package	yes	The product of *conditioning* that includes the *waste form* and any container(s) and internal *barriers* (e.g. absorbing materials and *liners*), prepared in accordance with the *requirements* for handling, transport, *storage* and/or *disposal*.
Wireless Monitoring		System for monitoring phenomonology in front of a seal or plug without installing cables or wires through any of the barriers intended to isolate one or more disposal packages

12.2 APPENDIX 2 - LIST OF ABBREVIATIONS & ACRONYMS

ABBREVIATION	MEANING
µSv	Micro-sievert
ALARA	As Low As Reasonably Achievable
BH	Borehole
BSK 3	German thin walled fuel rod canister (Brennstabkokille 3)
C	Waste Canister Containing High Level Vitrified Waste
CIDFR	Common Input Data and Functional Requirements Report Module 6 D1
CU	Spent Fuel Canister (ANDRA)
CU1	SF Waste Canister Containing 4 Spent Fuel Rods (ANDRA)
CU2	SF Waste Canister Containing 1 Spent Fuel Rod (ANDRA)
D1	Deliverable 1
D.O.W.	Description of Work - Annex 1 to the Contract with the EC
EB	Engineered Barrier
EBS	Engineered Barrier System
ESDRED	Engineering Studies and Demonstrations of Repository Designs
GNB	Gesellschaft für Nuklearbehälter mbH now part of GNS - Company for Nuclear Service Ltd.
HLW	High Level Waste
HMI	Human Machine Interface
ID	Inside Diameter
IPC	Integrated Project Coordinator
KBS-3H	SKB/POSIVA Horizontal Disposal Concept (ESDRED Reference)
KBS-3V	SKB/POSIVA Vertical Disposal Concept (National Reference)
LT	Long Term
LWR	German equivalent of PWR or Pressurized Water Reactor
MLW	Medium Level Waste
Mod1	Module 1
mSv	Milli-sievert
N/A	Not Applicable
NPP	Nuclear Power Plant
O/N	ONDRAF/NIRAS
OD	Outside Diameter
OPC	Ordinary Portland Cement
pH	Unit of measure for acidity and alkalinity of a material
Pkg	Package
QA	Quality Assurance
QC	Quality Control
RB	Rock Bolt
RFP	Request for Proposal
SF	Spent Fuel
Sv	Sievert
U/G	Underground
UCS	Unconfined Compressive Strength