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ESDRED

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DELIVERABLE 1 OF MODULE 6
WORK PACKAGE 1.1
COMMON INPUT DATA & FUNCTIONAL REQUIREMENTS

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1 - EXECUTIVE SUMMARY

This report is intended to provide a "Compilation of Input Data and Functional Requirements Common to all Modules". The approach actually used by the authors to provide the backbone to this document was to identify the main similarities and the main differences between the REFERENCE NATIONAL OR ESDRED (variation of National concept used within ESDRED) REPOSITORY CONCEPTS, as they relate to the major participants within ESDRED, and then to discuss the most relevant issues affecting input data and functional requirements. Where the repository concept used in ESDRED is different from the National Concept the authors have used the ESDRED concept as the reference. The main themes used for comparison include:

- National Concepts
- Dimensional Characteristics
- Radiological Protection Criteria
- Engineered Barriers
- Low pH Cement
- Reversibility and Retrievability issues

The main source of information has been the final Deliverable D1's produced by the 4 technical Module Leaders. This has been augmented through direct involvement by some of the ESDRED partners in completing the tables. The results of this work are presented in Tables 1 to 8. The Authors have tried to make these "Tables" as simple and as clear as possible in spite of the many differences between the concepts considered, as well as the variations within the concepts themselves. The down side of trying to keep things simple is that it precludes a full recording and discussion of all the possible options and variations within a disposal concept, of which there are always many.

Notwithstanding that the authors have made every reasonable effort to be as accurate as possible in the information presented in the "Tables", it must be remembered that all of the National Concepts are very dynamic and constantly evolving. The primary purpose of the "Tables" is therefore to provide information that can be used to understand and to compare the different disposal concepts. However the information provided only represents a snapshot at a single moment in time. For the latest up to date information and/or for a full understanding of options, alternatives and variations, relevant and reliable data can only be obtained from official national representatives.

Within the "Tables" the authors have tried, as much as possible, to use vocabulary that is clear and precise and have in some instances added additional comments for clarity in the "Comments" column at the extreme right of the "Tables". In addition a Glossary and a List of Abbreviations and Acronyms have been included in Appendices 3and 4 at the back of the report.

Seven National and ESDRED disposal concepts have been compared, of which 2 are essentially identical. Although there are many similarities between them the comparison shows that there are 3 very different host rocks, the maximum allowable temperature at the skin of the disposal packages varies by a full order of magnitude and the design life of the overpack varies by a factor of 1000. Also everyone is concerned with minimizing and/or filling the annular gap between the excavation and the disposal package but the means and the materials proposed for doing so are

quite different from one concept to another. Finally the notion of leaving a space between consecutive packages is unresolved for many and will no doubt result in a variety of layouts.

Six of the 7 concepts presented in the "Tables" involve horizontal disposal and only one is vertical. On the other hand 2 other National Concepts, not considered herein because there exists a separate and different ESDRED concept, are also vertical. If one excludes the vertical concept the geometrical dimensions (with 2 exceptions) for the excavations and for the disposal packages are quite similar. However the weights of the disposal packages vary tremendously so the emplacement methods and the emplacement equipment also vary significantly. This is an area where the ESDRED program will demonstrate a number of alternatives. Obviously there is a high probability that the most successful options may get incorporated in one or another of the National Concepts during future concept development and optimisation.

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 the almost without exception "remote control" is the operating mode selected for emplacement.

Engineered barriers 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. The methods of placement are as varied as the materials themselves.

Use of the shotcrete method, to replace cast in place concrete, for plug construction is an option retained by many National Concepts. The shotcrete construction method for plugs will be demonstrated using low pH cements. If successful one could imagine similar shotcrete plug construction tests using OPC in place of 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. An in depth understanding is only possible by looking at the complete system and the characteristics of all components, particularly the host rock. 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.

Finally the "Tables" 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 permanent 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.

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. It has become quite clear that most of the integration will occur subtly and/or over the long term, potentially 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 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 currently are 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 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 reinforcing 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:

- Aspö in Sweden,
- Bure in France,
- 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 Programs and therein lies one of the main challenges of the project. Integration involves extensive and comprehensive sharing of information between the partners, always looking for consistency of Input Data and Functional Requirements. 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, 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 most 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 represented and sometimes as many as six. The ESDRED programme therefore provides an opportunity for radioactive waste management organisations to work together efficiently to generate solutions, systems and technologies which can be shared.

Two reports, to be prepared by the Integration Project Coordinator (IPC), are intended to deal specifically with tangible integration. The objective of the first document (this report) is to summarize the common Input Data and Functional Requirements across the spectrum of the four technical Modules. A second report will deal with the common features of the design studies. Both reports will be submitted to an Experts Committee who will report independently to the ESDRED Governing Board.

2.2 *Overview of Module 6, Deliverable 1*

The Conceptual approach to the Integration Module is described in Annex 1 to the Contract ("Description of Work") 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 first deliverable of Module 6, (i.e. Mod6 – WP1.1 - D1), which is this report, is intended to be a summary of the common Input Data and Functional Requirements developed by the four technical Modules (Module 1 to Module 4) as documented in the D1 produced by each of them.

In a second step, a selected panel of technical experts, covering the fields of expertise relevant to ESDRED and called the "Experts Committee", will undertake a review of this D1 document which has been compiled by the IPC. Their review will aim to confirm the soundness and relevancy of these Input Data and Functional Requirements. The Experts Committee will formally report in detail to the Governing Board.

The main identified links to integration are between Modules 1 & 2, 2 & 3, 1 & 3, 1 & 4 (see Chapter 4, Figures 3 and 4).

2.2.1 INPUT

The input to this report, with only a few exceptions comes primarily from the four D1 deliverables produced by the four technical Module leaders as follows:

- Module 1 – O/N – FINAL report – December 23, 2004,
- Module 2 – DBE-TECHNOLOGY – FINAL report – October 13, 2004,
- Module 3 – SKB – FINAL Report – September 14, 2004,
- Module 4 – ENRESA – FINAL Report – November 08, 2004.

All or part of the introductory chapter of each of the four finalized technical Module D1 reports is reproduced below. Depending on the Module, this chapter has been called “Introduction” or “Executive Summary”. For obvious reasons any paragraphs that dealt only with an overview of the ESDRED project have been omitted.

2.2.2 Module 1 *(taken from Mod1-WP1-D1)*

“This Module aims to develop or refine technologies related to the construction and/or emplacement of the buffer/backfill associated with the waste package. This Module also aims to investigate and further develop the use of non-intrusive or “wireless” monitoring techniques in deep repository conditions. Non-intrusive techniques offer the advantage that no physical penetration of any of the engineered barriers is required.”

“The contracting parties in Module 1 are:

- ONDRAF/NIRAS
- ANDRA
- NAGRA
- GRS
- ENRESA
- EURIDICE
- NIREX (for the monitoring aspects)

For the work within Module 1, the following three geometrical configurations are envisaged:

1. filling of an annular gap in a horizontal drift with a granular material;
2. filling of a circular horizontal drift with prefabricated rings;

3. filling of a circular horizontal drift with a combination of prefabricated blocks (waste package resting on a “cradle” formed by these blocks) and a granular material.

The efforts within Module 1 should result in the establishment of three different buffer/backfill solutions that result from sharing of information and a common approach to tackling technological challenges.

Module 1 should also establish a number of non-intrusive measurement techniques to monitor the performance of the Engineered Barrier System (EBS) and the adjacent host rock. These techniques should consider the presence of High Level Waste (HLW) and be applicable in the envisaged geometrical configurations.

In its turn, Module 1 is divided over a number of Work Packages. In a chronological, but overlapping sequence, these are:

1. Input Data and Functional Requirements,
2. Basic design of several buffer/backfill configurations,
3. In-workshop demonstration tests,
4. In-situ demonstration tests,
5. Non-intrusive monitoring techniques demonstration tests,
6. Final evaluation.”

“The basic objective of Work Package 1 is to come to a description of the Input Data and consequent Functional Requirements for the buffer/backfill component. These Functional Requirements will then be used for the development of test designs for the different buffer/backfill configurations and their associated monitoring equipment.

The contracting parties involved in Module 1 all have a specific role to play and therefore a specific contribution to make. Each of the three envisaged geometrical configurations is representative of the conceptual design currently supported by a certain waste management organization. For *the* filling *of an* annular gap in a horizontal drift with a granular material, this is ONDRAF/NIRAS. For the circular horizontal drift with prefabricated rings, this is ANDRA. For the circular horizontal drift with a combination of prefabricated blocks and a granular material, this is NAGRA. These organizations will clearly provide the bulk of the inputs related to the design that they are supporting. The contribution of the GRS and ENRESA exists in providing their specific expertise on buffer/backfill materials. EURIDICE is the organization that will physically implement the in-situ test design based on the annular configuration. The contribution of NIREX is related to the definition and design of the monitoring equipment.”

“Within a commonly shared format, each participant first explains the specific situation of his organization with respect to the work in Module 1. To this extent, each participant provides a brief description of the historical background of his country’s national waste disposal program and the development of the applicable conceptual design(s). Then the participant clearly defines the component(s) which will be his object of study for Module 1. Only then, the Input Data and Functional Requirements are given. This is done according to a well-specified list of items, which is in line with Annex 1 of the ESDRED Contract. The lists of Input Data and Functional Requirements present this information in a specific and structured way.”

2.2.3 Module 2 *(taken from Mod2-WP1-D1)*

"DBE TECHNOLOGY GmbH is responsible for the successful management of Module 2: Waste canister transfer and emplacement technology. The contracting partners in Module 2 are ANDRA (France), DBE TECHNOLOGY (Germany) and NRG (Netherlands).

The detailed objectives of this Module are:

- Identification of a clear set of shielding cask requirements based on European nuclear regulations and safety objectives of the implementers,
- Demonstration of the technical feasibility at an industrial scale of the transportation and emplacement of remote handled waste canisters in horizontal cells and vertical boreholes,
- Demonstration of the compliance of the development equipment with reversibility requirements.

This report summarises the Input Data and the Functional Requirements, which have been elaborated for Module 2.

According to some of the national waste management programmes, the feasibility of a reliable and safe transportation/emplacement technology for remote handled waste canisters has to be developed and demonstrated prior to repository implementation. Module 2 considers the emplacement of small canisters for vitrified waste and small to medium size canisters for spent fuel in specially prepared horizontal emplacement cells (French case) or into deep vertical boreholes (German case).

The report starts with a brief description of the German and French repository concepts for high level waste.

In Germany a salt dome close to the village of Gorleben, in the federal state of Lower-Saxony, is being evaluated as to its suitability to host all kinds of radioactive waste. A reference emplacement concept has been developed in the past, which consists of the emplacement of spent fuel elements in shielded POLLUX® casks in horizontal drifts (cells). The appropriate transport and emplacement components have been developed and tested on surface in a 1:1 scale. The cask and a pilot conditioning plant have been realized. In comparison, the newly studied concept of canister (containing fuel rods from spent fuel assemblies) disposal in deep vertical boreholes is still lagging behind, development wise.

As an alternative to the disposal of POLLUX® casks in horizontal drifts, this new concept has been examined on the basis of safety/technical and economic optimization for vertical disposal of canisters in salt, through the disposal in a common borehole of the following type of canisters:

- complete fuel rods from spent fuel assemblies,
- vitrified high level wastes from reprocessing,

- compressed interim level wastes (cut cladding and structural parts arising from reprocessing).

These 3 types of waste packages considered have identical outer diameters and grapple heads, but different lengths, depending on the types of waste to be disposed of.

In France a repository concept for the emplacement of high level waste in argillites is subject to conceptual studies and underground research activities. The repository concept considers three main parts:

- The surface installations which cover an area between 500 and 1000 ha,
- The works connecting the surface with the underground which provide access to the underground facilities,
- The underground installations, located 490m below surface, which cover an area of between 1500 and 3000 ha.

The connection between the surface and the underground is provided by 4 large diameter shafts (8 to 12 m) and one ramp. The waste canisters will be disposed of in horizontal emplacement cells, which have been equipped in advance with a steel tube (also called inner sleeve), surrounded or not by prefabricated bentonite buffer rings. The disposal package (canister) is transferred underground, inside a metal radiation shielding cask via a waste shaft and horizontal drifts to the disposal zone.

The waste packages are specific to the national emplacement concepts.

Within Module 2, the waste canisters of concern will have diameters from 40 to 60 cm, lengths from 1.3 to 4.9 meters and weigh up to 8.3 t.

In Germany the development of a new, relatively thin walled cask (Fuel Rod Canister BSK 3) – suitable for the interim storage and final disposal of spent fuel assemblies in vertical boreholes – was carried out by GNB. This canister has been designed for receiving fuel rods from a maximum of 3 PWR or 9 BWR fuel assemblies. The interim storage of the BSK 3 takes place in transport and storage casks. Details of the canister layout criteria and design specifications are provided.

In France the primary waste packages considered *within ESDRED* consist of a metal container that holds the radioactive waste. There are many different containers depending on the nature of the waste held within. These primary waste packages are transported by road and/or rail from the production centers to the repository. Road casks are used for this transport.

Upon arrival at the repository the waste packages are removed from the transport casks and “over-packed” into disposal canisters. A disposal package (a canister) essentially consists of a metal envelope that holds one or more primary packages of the same type. Two types of waste packages (CU for Spent Fuel and C for vitrified waste) are considered and described in detail in the present report. Details of the canister layout criteria and design specifications are also provided.

The report continues by describing the state of the art in drilling technology / tunnel boring technology and provides an appreciation of the room needed for vertical borehole / horizontal cell waste canister emplacement. In addition, the state of the art in disposing of waste canisters in horizontal cells and vertical boreholes has been analysed and the results are presented. Finally the emplacement concepts which have been selected for further investigations are briefly described.

The report ends with a section on the methodology for deriving Functional Requirements. The methodological approach to developing a set of Functional Requirements is described. This approach has been applied for the two emplacement concepts which are the subject of demonstration tests. Consequently the applicable norms and technical rules were derived and the safety requirements for the entire system were compiled. Finally the boundary conditions as well as the external requirements and constraints / interfaces between external and internal equipment were defined."

"The common interest of the participating organisations is to develop, manufacture and demonstrate appropriate shielding transportation casks and emplacement technologies matching the European nuclear regulations as well as the specific nuclear safety objectives of the implementers. The development of this technology will also address the retrievability issues."

2.2.4 Module 3 *(taken from Mod3-WP1-D1)*

"The purpose of this document is to present the Deliverable D1 of WP1 ("Input Data and Functional Requirements") for Module 3. In order to get a clear understanding of the two different disposal concepts which are covered by this Module, they are briefly presented in the first part of this document.

The partners within Module 3 are SKB (Svensk Kärnbränslehantering AB), acting as the Module Leader, POSIVA and ANDRA (Agence Nationale pour la Gestion des Déchets Radioactifs)."

"Module 3 consists of the three following different heavy load emplacement concepts:

- Deposition machine with ancillary equipment for disposal of Super-Container, with a weight of about 45 tons in horizontal drifts with a diameter of 1.85 m. This disposal concept for spent nuclear fuel is called KBS-3H in SKB's and POSIVA's programs. The general layout is shown in **Figure 1.**

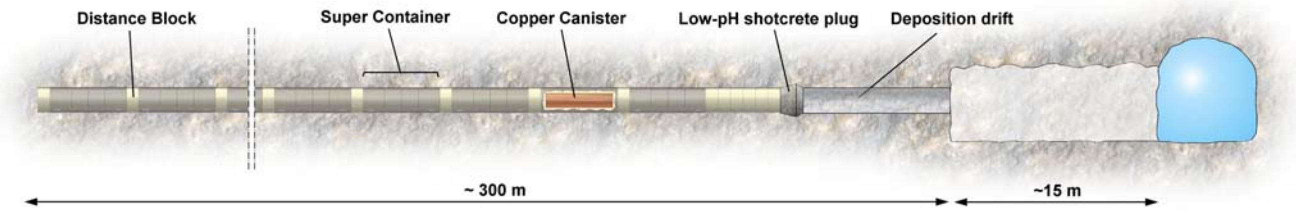


Figure 1. *The arrangement of Super-Containers and distance blocks (spacers) in SKB's and POSIVA's KBS-3H concept.*

- Deposition machine with ancillary equipment for emplacement of sets of bentonite rings into the liner of a disposal cell (in ANDRA's concept), in order to build the engineered barrier system. The load is about 15 tons, with a length of about 2 m and an outside diameter of either about 2.45 m or about 3.10 m (OD varies with the type of waste canister). This general layout is shown in **Figure 2**.
- Deposition machine with ancillary equipment for disposal of spent fuel canisters into the inner tube of the disposal cell (in ANDRA's concept). The load is about 43 tons, with a length of about 5 390 mm and a diameter of 1 255 mm. This layout is also shown in **Figure 2.**

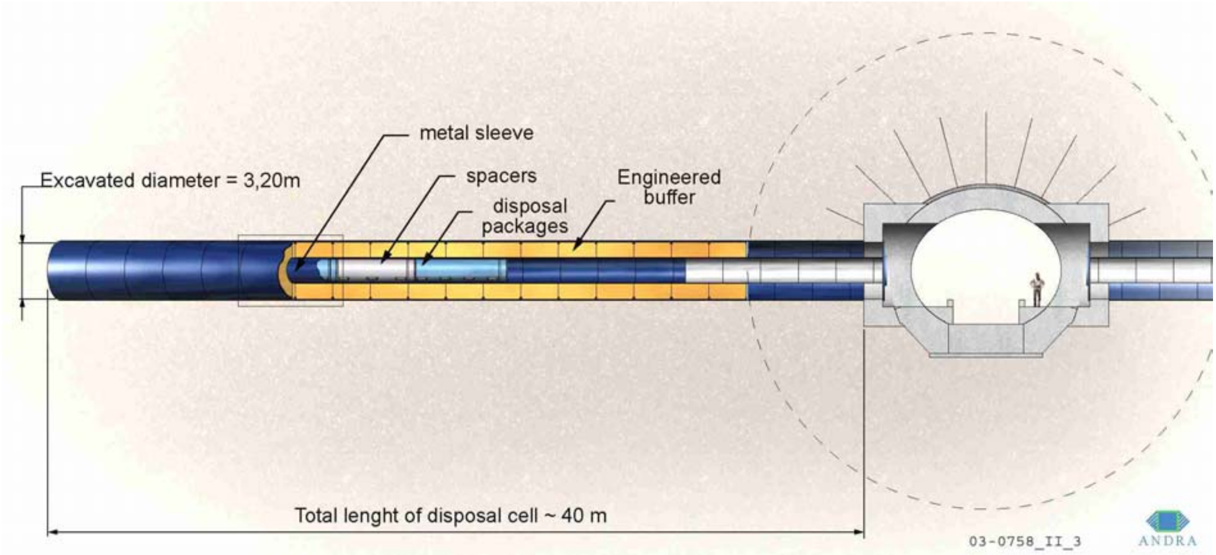


Figure 2. *The arrangement of the Engineered Buffer & of the Spent Fuel package, in a horizontal disposal cell, as per ANDRA's disposal concept.*

a) In the KBS-3H concept the SF canister will be transported down to the repository level in a transport cask (an IAEA BU-container). The assembly of the Super-Container will be done in a reloading station with a shielded handling cell. The transfer of the SF canister from the transport cask into the Super-Container will be done in the shielded handling cell. The transport tube for the Super-Container will be closed inside the cell before being transported to the chamber where the deposition equipment is located. The shielded handling cell, the assembly of the Super-Container and the transfer of the SF canister into the handling cell from the transport cask are not part of Module 3.

Note: *For the demonstration, a mock-up of the Super-Container will be used. This mock-up will have the correct physical dimensions and weight but the SF canister will not contain spent fuel. Furthermore, during the demonstrations, the buffer material will be substituted with concrete rings and blocks with the correct dimensions and weight similar to bentonite buffer.*

b) In ANDRA 's concept, a set of 4 pre-assembled bentonite rings is transported from the surface (via a shaft) down to the intersection of the access drift and the disposal cell by an appropriate means (truck or wagon). Then, it is loaded onto an air cushion pallet (cradle) for lifting and final emplacement inside a steel lined drift with an inner diameter (ID) of about 2.5 m (this last dimension relates to a disposal cell for C type (vitrified waste) canisters, not for CU1 type (Spent Fuel) canisters as shown in Figure 2).

Note: *For the demonstration, a steel drift liner mock-up of about 12 m long will be used as well as a few set of bentonite ring assemblies (or light concrete rings acting as dummies).*

c) In ANDRA's concept, a Spent Fuel Canister is loaded onto an air cushion cradle (moved by an electrical cart acting as a pusher) and positioned inside a shielding cask until docking in a final launching position onto the radiation protection gate of the disposal cell. Following opening of the shielding cask gate and of the cell gamma gate, the electrical cart and the air cushion cradle move forward into the steel inner sleeve, until the Spent Fuel Canister reaches its final position at the blind end of the disposal cell.

Note: *For the demonstration, a steel sleeve mock-up of about 12 m long, a dummy shielding cask and a dummy canister will be used."*

2.2.5 Module 4 *(taken from Mod4-WP1-D1)*

"The basic objectives of this research activity are:

- Development and validation of low-pH cementitious materials for industrial application in repository construction,
- Development of low-pH shotcreting techniques for construction of repository plugs and rock support,
- Full scale demonstration of a low-pH shotcrete plug and rock support.

Six organizations participate in this Module:

- AITEMIN (Spain)
- CSIC-IETCC (Spain)
- ENRESA (Spain)
- NAGRA (Switzerland)
- POSIVA (Finland)
- SKB (Sweden)"

"This report deals with the research work formulated for demonstrating the feasibility of using low-pH shotcrete in underground repositories. Besides the framework described in the previous paragraph, Chapter 1 describes the packages in which the research work is divided and provides the project schedule. The organizations involved in this project are also listed *above*.

Chapter 2 presents a synthesized description of the different uses of cementitious materials conceived in the deep geological disposal concepts for the different type of host rocks, with emphasis in the application of shotcrete for rock wall support and plug construction. Technical reasons for justifying the need of using low-pH cements in the formulation of said materials are also presented.

Chapter 3 contains an itemized formulation of the criteria that the waste management agencies involved in this research project impose for the utilization of shotcrete in underground repositories. The Functional Requirements that the shotcrete should comply with when used as rock wall support or in the construction of plugs, according to the specifications of each of the waste management agencies involved in the project, are also tabulated and discussed."

3 - METHODOLOGY

Since the beginning of the project, the execution of Module 6 and thus the preparations for assembling this deliverable D1 have consisted mainly of ensuring that there is a common understanding of the meaning and objective of INTEGRATION, that the Contractors communicate effectively and that the components of the ESDRED puzzle fit together to the extent that they are both practical and possible. Only 2 of the 4 technical D1 deliverables were scheduled for completion ahead of this Module 6 D1. Fortunately Module 3 produced its report ahead of schedule and the participants in Module 1 produced the final version in December 2004 according to the project plan.

The final ESDRED integration concept, as currently understood by the Contractors and put in practice by them, has a practical focus. There is clearly no effort to force changes in anyone's national program. Instead the focus is on information sharing, on working together and on UNDERSTANDING the similarities and differences between the various national concepts. Nevertheless, such a close cooperation will provide the Contractors with a common background on various subjects and could thus lead to the modification of national concept programs during future optimisation work.

The Contractors involved in any given Module, of necessity work very closely together, developing good synergies, and generating a sort of effortless integration.

Between Modules, the situation is a bit different. It works best where a given Contractor is also a major participant in more than one technical Module. For example ANDRA will very definitely integrate the engineered barrier products it develops in Module 1 with the heavy load emplacement technology fabricated in Module 3 and with the horizontal emplacement demonstration it will execute within Module 2. For other participants in ESDRED there does not exist the same obvious opportunities for practical integration. For them, in the end, the controlling factors are typically the constraints imposed by their national programs and the constraints related to the URL sites available to carry out their demonstrations.

On the other hand it is important to keep in mind that the most important results of this "Integrated Project" may in fact occur towards the end of the ESDRED Project or even later. In fact the different concepts tested within ESDRED program can serve as alternative options or fall-back positions for one or another of the national concepts. With the full benefit of knowledge of everything that went on with a different concept (also being tested within ESDRED) it is then reasonable to assume that less successful concepts may be abandoned or modified to come closer to successful ones, hence producing the Real Integration.

Finally the project Experts Committee contributes to Integration by reviewing the two (2) deliverables produced by the IPC within this Module and by witnessing at least one of the demonstrations.

4 - 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".

Although only the first bullet point relates directly to this report, 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.

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.

EXAMPLES OF INTEGRATION

The main links to 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 Figures 3 and 4 and are described in (a) below. Some additional examples of possible integration are described in (b) to (f) below.

(a) Figure 3 shows the link between Modules 1, 2 and 3 as regards the integration of Design, Construction and Demonstration. Clearly the intent is that the buffer rings fabricated in Module 1 will be sized to fit the air cushion 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.

(b) Input Data (source terms) related to Spent Fuel and/or vitrified waste as regards dose rates, thermal power and the number of assemblies are linked for Modules 1, 2 and 3. Differences may/will exist and need to be understood and explained.

(c) Modules 2, 3 and to some extent Module1 have a Functional Requirements link as regards radiological shielding that is required during the emplacement procedures. The system of interlocking doors in Module 2 and the launch tube in Module 3 are all designed to limit the maximum dose rate to which operators may be exposed. The link to Module 1 would be in regard to remote controlled placement of a granular barrier which needs to be carried out in an environment with controlled and acceptable dose rates.

(d) Another Functional Requirement linking Modules 2 and 3 has to do with the remote controlled emplacement procedures. Specifically, and especially in case of malfunction the operator must at all times know the exact location of the package. The logical extension of this requirement has to do with the associated corrective measures and possibly retrieval.

(e) Another Functional Requirement that could link Modules 1 and 4 has to do with the ability of a plug built with low pH cement designed in Module 4, to resist the expansion forces exerted by the seal in front of it built with swelling bentonite characterised in Module 1. This is actually a bit outside the ESDRED project as Module 4 focuses on the construction rather than the design of the plug itself and Module 1 focuses on the buffer/backfill next to the disposal packages rather than on plugs and seals.

(f) A further example could be the link between the QA/QC procedures and certain measurements related to the materials used in the construction of plugs, seals, and other engineered barrier systems as per Modules 1, 2 and 3. Again this is marginally outside the scope of ESDRED.

(g) A final example, which remains to be determined, relates to the Partners' long term non intrusive monitoring needs which are presently being inventoried and collated by NIREX.

Although much of the above appears to be somewhat outside the scope of ESDRED, a subtle type of Integration will occur 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. However, the work conducted under this Module 6 (Integration) provides a basis for the partners to review the position of integration and to provide appropriate challenge to enhance the opportunity for integration. It is further envisaged that the close co-operation within the four modules will increase the potential for integrated development as the work programmes progress and the results of the demonstrations are known.

FIGURE 3 Links between Modules 1, 2 and 3
Integration of Design, Construction & Demonstration

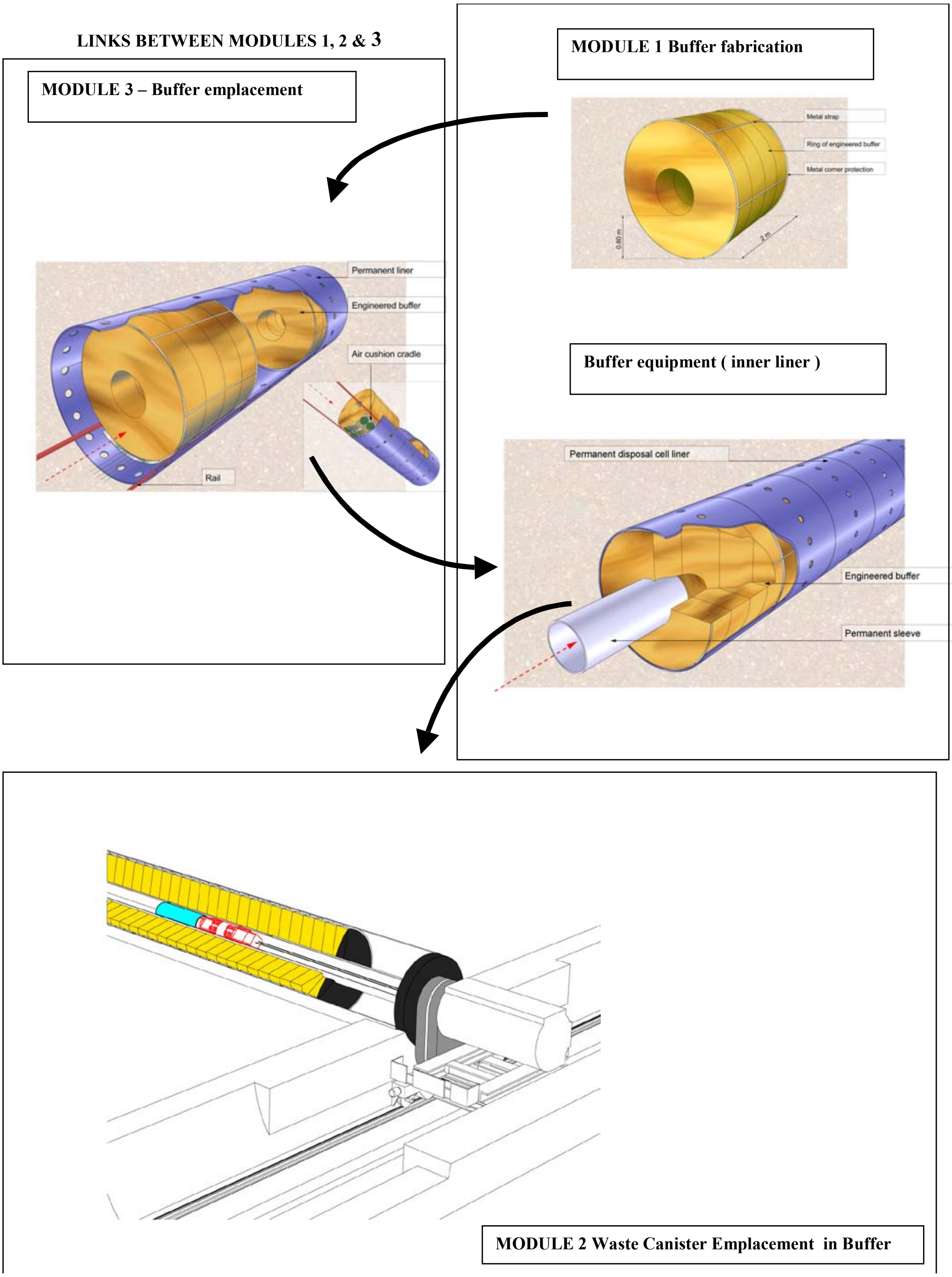
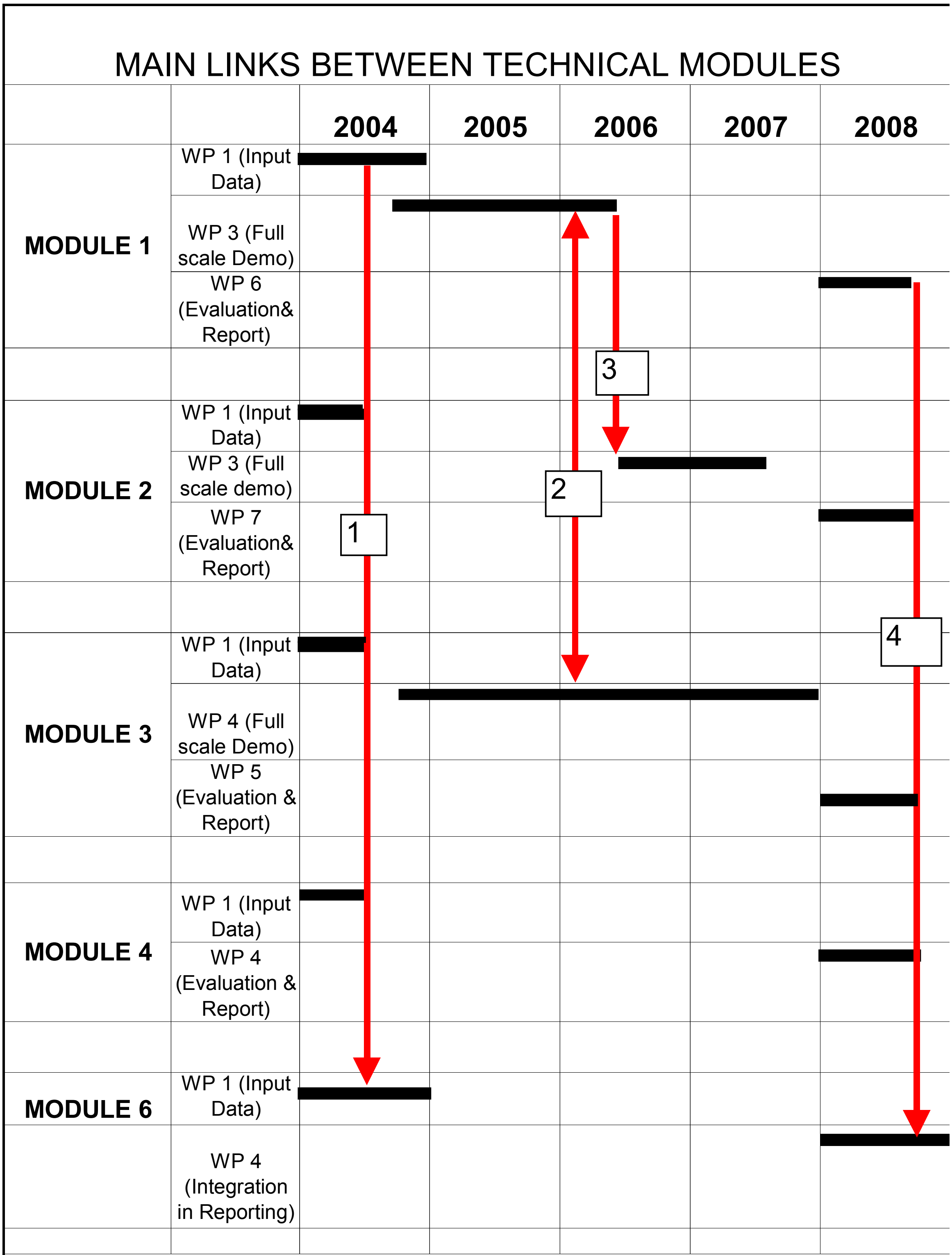


FIGURE 4 – Main Links between Technical Modules



LINK 1: Relevancy & Consistency of input data & functional requirements
LINK 2: Operational compatibility (planning and physical features)
LINK 3: Link End/Beginning
LINK 4: Homonegeity of modules reports & final global report and evaluation

5 - ESDRED INTEGRATION

It became very clear early on in the progress of the technical work that, with the exception of the subtle integration that was happening daily at the technical Module level, the next most probable area of success would likely be in documenting and understanding the similarities and the differences between the different National Concepts. For this purpose either the National Concept or a variation thereof, also sometimes referred to herein as the ESDRED Concept, have been considered in this report. In the case of DBE-Technology, of SKB and POSIVA the ESDRED Concept is different from the current National Concept. It is important to understand that the parameters used for comparison generally relate to issues that fall within the scope covered by the four ESDRED technical Modules but often are not of themselves an issue within ESDRED.

In addition to a broad brush overview of 7 National or ESDRED Concepts (Tables 1, 2 and 3 below), four main topics have been selected for comparison. To the extent that information has been provided in the D1 reports, or separately by the Contractors, parameters defining these issues have been summarized in Tables 4 to 8 which are presented in the sub-sections that follow. The selected topics are:

- Dimensioning
- Radiological Protection
- Engineered Barriers
- Low pH Cements

5.1 *NATIONAL CONCEPTS*

Seven National or ESDRED concepts are considered within the context of this report. Tables 1 to 3 below provide a summary of the main parameters that were used for comparison purposes. This is by no means an exhaustive list nor does it pretend to necessarily have considered all of the most important parameters. With a couple of exceptions, the parameters considered in these tables, and in the 5 tables that follow, are those considered most relevant within the context of the ESDRED Project.

For the sake of clarity it should be noted that both SKB and POSIVA use KBS-3V (vertical disposal) as their national concept but that within ESDRED both are using the KBS-3H (horizontal disposal with Super-Container) alternative. None of the ESDRED participants are using a concept that is neither the National Concept nor a variation thereof.

TABLE 1: National Concepts

	Current Reference National Concepts							
	ANDRA	**DBE-TEC[4]**	**ENRESA**	**NAGRA**	**O/N**	**POSIVA[1]**	**SKB[1]**	**COMMENTS**
Geological Formation	claystone	salt	granite/clay[11]	claystone	clay	gneiss	granite	[1]KBS-3H is variant of the national concept ie vertical emplacement
Disposal Products	Vw & SF	Vw & SF	Vw & SF	Vw & SF	Vw[2]	SF	SF	[2]Also SF but not within ESDRED
Canisters 2b stored	32 180	13 542	3617	2795	4000	3018	4500	[3]Vw & SF only; used most likely scenario if more than 1
Criteria for # Canisters[3]	existing plants to 40 year life	nuclear phase out scenario	existing plants to 40 year life	existing plants 60 yr life	existing plants to 40 year life	existing plants 60 yr life	existing plants to 40 yr life	
Supercontainer	no	no	no	no	yes	yes	yes	[4]Germany's Nat'l concept being revised. Tables reflect vert BH in salt concept as per ESDRED
Spacers	yes	undecided	yes	no[10]	no	yes	yes	
Disposal Unit	Cell	Borehole	Drifts	Drifts	Drifts	Drift	Drift	[5]based on existing NPPs till 2038
Length Each	40 m	300 m	500 m	800 m	1000 m	300 m	300 m	[6]during operational phase
Total Length	290 kms[5]	not defined yet	42 kms	22 kms	9 kms	30 kms	45 kms	[7]before final closure
Orientation	horiz	vert	horiz	horiz (6% grade)	horiz	horiz	horiz	[8]no legal requirement
Temporary Support	N/A	none	none	RB & mesh	N/A	none	none	[9]Post Closure
Permanent Lining	steel	none	no/yes	RB & mesh	concrete blocks	none	none	[10]3m space filled with bentonite
First Buffer Barrier	Bentonite/Sand EB rings	backfill annular gap with salt	Bentonite blocks	Bentonite block cradle & granular backfill	hi pH concrete inside Super container & cement grout backfill	bentonite blocks inside the supercontainer	bentonite blocks inside the supercontainer	[11] Spain retains 2 national concepts at this time
How placed?	air cushion or pushing robot emplacement machines	by pouring down the hole	undecided	cradle by rail granular material by auger	concrete buffer on surface during mfg,grout is pumped	in reloading station on repository level	in reloading station on repository level	
Retrievabilty req'd ?	yes	no	yes	yes[6]	yes[8]	yes	no	
LT Monitoring Req'd[9]	yes	no	undecided	yes[7]	yes	no	no	

Vw = Vitrified Waste
SF= spent fuel
EB = engineered barrier

Cell = short tunnel/gallery
Drift = long tunnel/gallery
RB = rockbolts

BH = borehole
ID = inside diameter
OD = outside diameter

N/A= not applicable
LT = long term

TABLE 2: Spent Fuel – Similarities and Differences between National Concepts

	Spent Fuel: Other Similarities & Differences Between National Concepts							
	ANDRA	DBE-TEC	ENRESA	NAGRA	O/N	POSIVA	SKB	COMMENTS
Overpack used [2]	yes	yes [1]	yes	yes	N/A	yes	yes	[1] BSK 3 Canister
Overpack Material	S 235 carbon steel	15 MnNi 6 3 steel	carbon steel	carbon steel	N/A	copper	copper	[2] SF rods are considered to be the primary package or canister
								[3] given as max temp in buffer
Overpack Wall Thickness	110mm	40mm	100mm	130 - 150mm	N/A	50mm	50mm	[4] O/N have SF program but not considered within ESDRED
Insert Material	cast iron	baskets but no additional fill	baskets & AL beads	steel plates	N/A	cast iron	cast iron	[5] given as max temp at host rock contact
								[6] after 60 years of surface storage
Overpack Design Life	10 000 yrs	not decided yet	1000 yrs	1000 yrs	2000 [4]	at least 100 000	at least 100 000	
								[7] Temperature in U/G environment
Supercontainer Skin Material	N/A	N/A	N/A	N/A	N/A	carbon steel	carbon steel	[8] Humidity in U/G environment
								[9] preliminary design value on the surface of supercontainer less than 1 mSv/h
Supercontainer Skin Thickness	N/A	N/A	N/A	N/A	N/A	8 mm	8mm	
Max dose rate @ skin of disposal package	10 mSv/h [6]	not available	not decided	not defined yet	N/A [4]	see [9]	0,5 mSv/h [10]	[10] after 40 years of surface storage
Max Temperature at Skin of Disposal Package °C	100	200 [5]	100 [3]	160	N/A	not defined yet	not defined yet	
Max Working Temp °C [7]	28	38	28	35	N/A	24	15	
Max Humidity [8]	90%	50%	variable	80%	N/A	100%	100%	

U/G = underground

TABLE 3: Vitrified Waste – Similarities and Differences between National Concepts

	Vitrified Waste: Other Similarities & Differences Between National Concepts							
	ANDRA	**DBE-TEC**	**ENRESA**	**NAGRA**	**O/N**	**POSIVA**	**SKB**	**COMMENTS**
Overpack used	yes	no	yes	yes	supercontainer	N/A	N/A	[1] after 60 years of surface storage
Overpack Material	S 235 carbon steel	N/A	carbon steel	carbon steel	2.25 Cr-1Mo Steel	N/A	N/A	[2] given as max contact temp host rock
								[3] Temperature in U/G environment
Overpack Wall Thickness	55mm	N/A	90mm	250mm	30mm	N/A	N/A	[4] Humidity in U/G environment
								[5] The given value of 25 micro-SV/h at 1 m is the design value. Numerical modeling results give a corresponding value of about 100 micro-SV/h at the skin of the disposal package. But this value is extremely specific to the assumed type of waste, the Supercontainer geometry and material composition. It is not a design value.
Overpack Design Life	1000 yrs	N/A	1000 yrs	1000 yrs	500	N/A	N/A	
Supercontainer Skin Material	N/A	N/A	N/A	N/A	AISI 316LStainless Steel	N/A	N/A	
Supercontainer Skin Thickness	N/A	N/A	N/A	N/A	6mm	N/A	N/A	
Primary Pkg Material	stainless steel	stainless steel	stainless steel	stainless steel	stainless steel	N/A	N/A	
Primary Pkg Wall Thickness	5mm	5mm	5mm	5mm	5mm	N/A	N/A	
Max Dose Rate @ Skin of Disposal Package	10 Sv/h [1]	1,4 x 10^4 Gray	not decided	not defined yet	25 µSV/h at 1 m [5]	N/A	N/A	
Max Temperature at Skin of Disposal Package °C	100	200[2]	100	150	100	N/A	N/A	
Max Working Temp °C [3]	28	38	28	35	undecided	N/A	N/A	
Max Humidity [4]	90%	50%	variable	80%	undecided	N/A	N/A	

5.1.1 Discussion

The conceptual design of a repository for radioactive waste depends strongly on given boundary conditions in a specific country such as available host rock, waste inventory and regulatory guidelines. In addition, the following geometrical parameters and physical properties of the host rock influence the layout of the repository:

- the thickness and the lateral extension of the host rock,
- the dip of the formation,
- the thermal conductivity of the host rock,
- the mechanical properties of the host rock.

Of the 7 national or ESDRED concepts considered, 3 are in clay, 1 is in granite, 1 is in gneiss, 1 includes both clay and granite and 1 is in salt. Six of the 7 concepts involve horizontal disposal and the other is vertical.

On the other hand, there is considerable communality between the different concepts compared in this report. For example:

- The multi-barrier system is found in each general design: a primary waste container that is over-packed (no overpack in German concept) in a metal canister, an engineered barrier and a host rock,
- With the exception of NAGRA and DBE TEC, the temperature limitation at the skin of the disposal package is equal to 100°C,
- The over-pack design life is in the range of 1 000 to about 10 000 years except for SKB/POSIVA who use a copper canister for encapsulation of the spent fuel with an expected lifetime of more than 100 000 years,
- All concepts are focused on bentonite as an important part of the buffer/backfill system (around the disposal packages) with the exception of O/N who makes extensive use of cement. In the case of DBE TEC's salt option, crushed salt is used as backfill and acts as a compacting buffer.

The most striking differences are:

- The disposal package skin temperature for NAGRA (160°C) and for DBE TEC (200°C max.);
- The absence of an overpack in the German concept;
- The choice of copper (versus carbon steel or alloy steel) as the overpack material, by SKB & POSIVA;
- The number of canisters to be stored; with ANDRA at 32 180 and ENRESA at the other end of the spectrum with only 3 617;
- The main final emplacement equipment includes rail mounted equipment, robots, as well as air and water cushion vehicles.

Nagra's concept of radioactive waste disposal is based on a robust multi-barrier approach where compartmentalisation on different levels is one of the key design criteria. This means that every canister is surrounded by a significant amount of buffer material, building its own separate compartment. The thickness of the buffer (radial thickness between canister surface and rock = 0.7 – 0.8 m; distance between canisters = 3 m) guarantees that even with comparably high canister surface temperatures a significant part of the buffer stays below 110°C. Therefore, the outer part of the bentonite does not experience major mineralogical and physical changes due to temperature. The important well-known and favourable properties and the predictable performance of this part of the buffer are thus conserved over the transient non-isothermal time period of the repository.

The rationale used by the German Nuclear Waste Management Authorities in their decision to forego the use of an overpack is as follows:

In the late 80s and 90s the direct disposal of spent fuel in salt formations has been developed and tested in a 1:1 scale in Germany. This concept considered the emplacement of large self shielding POLLUX® casks containing the fuel rods of 8 LWR spent fuel elements into horizontal drifts. In parallel it was planned to dispose vitrified waste canisters in deep (up to 300m) vertical boreholes.

Within the ESDRED program a concept of disposing unshielded canisters for spent fuel rods (BSK 3) into deep vertical boreholes will be developed. Thus, all heat producing waste canisters can be disposed of with one single emplacement technology. A transfer cask acts as shielding during the transport of the BSK 3 and the vitrified waste canister through the repository. The unshielded BSK 3 container will be lowered down through the transfer cask and a locking system into the borehole by means of a specific emplacement device.

The intention of this concept is to incorporate as much as possible, the encapsulation capability of rock salt. Salt is a host rock which is mechanically stable; thus no additional support for the drifts and openings in the mine are required. On the other hand the creep behavior of salt, which increases with increasing temperatures and pressure, ensures the entire encapsulation of the waste canisters by the host rock after a relatively short period of time. The top of the stack of containers and the annulus between borehole wall and container will be backfilled with pure crushed salt. Thermo mechanical calculations show that within a few years the backfill will be compacted. Thus no additional sealing is required and an overpack is dispensable.

The rationale used by SKB/Posiva in selecting the longer life copper canisters is that, when combined with the two additional barrier system i.e. bentonite buffer and granite host rock, they together ensure maximum safety and overall system integrity possibly for as much as 1 million years (officially more than 100 000 years). The selection of copper and bentonite for the engineered barriers is because they are both naturally stable materials that have existed for a very long time. Furthermore the lifetime of the copper canister can be modelled on natural analogues for copper in an environment similar to the deep repository. The final result will be a waste management system that will meet very stringent requirements regarding the long term safety of the repository.

It is also worth noting that the cross-sections of the disposal drifts (or cells) are quite consistent from one concept to the other and vary from about 1.85m up to 3.20m. The German concept consists of disposing of waste canisters into deep (up to 300m) vertical boreholes with an ID of 0.6 to 0.7 m.

On the other hand there is a really big difference as regards to the lengths of the disposal drifts (or cells), which vary from about 40m up to 1000m.

The main reasons for such differences are explained as follows:

- Long disposal tunnels in hydraulically low conductive rocks reduces the influence of buffer properties and excavation induced damage on the flow and transport properties along tunnels thus making the system more robust from PA point of view. The reason for this behaviour is the loss of radionuclides into the intact rock during the transport along the tunnel due to matrix diffusion,
- Short tunnels provide more flexibility in the layout and easier retrievability / reversibility,
- The relative importance attached to the retrievability requirement.

Depending on specific design criteria of a given country, long tunnels are more suited to the disposal problem than short ones and vice versa.

All concepts try to minimize the annular clearances between the various components of the disposal cavity (gap between the walls of the formation and the inner components, gap between the buffer and the canister). Each design aims at minimizing the excavated volume, as far as the long-term safety, the radioprotection factors and the handling means allow it.

Finally, the total cumulative length of emplacement cavities (drifts, cells or boreholes) varies with the national inventories (waste production scenarios) and the size of the nuclear power production in the various countries – present and future. However it is not always in direct proportion to the quantity of packages to be disposed as the thermal power of the disposal packages and the ability of the geological medium to transport the heat obviously also play an important role.

For example in the French concept, the sensitivity curve (Figure 5 below) shows the impact, on the total excavated volume in a clay host rock, of installing some spacers between C type disposal packages of a given age. This curve shows that the excavated volume reaches very high values when spacer lengths are less than 1 m. If no spacer is used, the repository may even become unfeasible, unless canisters are cooled down at surface for much longer periods of time (>> 60 years).

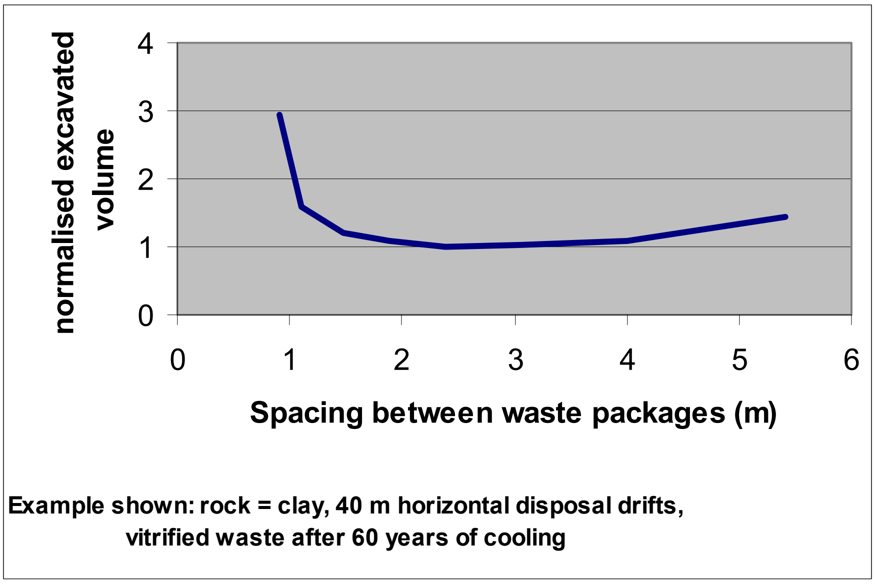


FIGURE 5 – Sensitivity of excavated volume on waste package spacing – French concept

5.2 *DIMENSIONING OF DISPOSAL PACKAGES*

ESDRED is only concerned with the emplacement of high-level long-lived waste. In particular the two types of waste considered within the four technical Modules are "Vitrified high-level waste" (Vw) and Spent Fuel (SF). Within ESDRED, the Contractors did not get into the numerous sub-categories of waste that exist in some of the national programs.

The geometrical and physical characteristics of the disposal packages are an input data to the project even though the design of the canisters, overpacks or Super-Containers is not within the scope of ESDRED.

The main dimensional parameters related to SF and Vw waste types are presented in Tables 4 and 5 below. Clearly not all national programs are intending to handle both types of waste. In the case of O/N, only the current Belgian vitrified waste disposal concept was considered within ESDRED, since the disposal concept for SF is still too premature.

TABLE 4: Spent Fuel Main Dimensional Characteristics

	SF National Concepts							
	ANDRA	DBE-TEC	ENRESA[7]	NAGRA	O/N	POSIVA	SKB	COMMENTS
Disposal Drift ID[1]	3200	N/A	2400	2500	N/A	1850	1850	[1] Inside the liner if any
Disposal BH ID	N/A	600-700	N/A	N/A	N/A	N/A	N/A	[2] Located Inside the supercontainer
								[3] space filled with granular bentonite
Buffer Rings								[4] in the disposal cell/drift or BH
Monolithic or Blocks	monolithic	N/A	blocks	N/A	N/A	N/A	N/A	[5] weight of package of spacers if more than one is bundled together
Outside Diameter	3071	N/A	≤2400	N/A	N/A	1721[2]	1721[2]	
Inside Diameter	1471	N/A	≥900	N/A	N/A	1057[2]	1057[2]	[6] Cu1 type
Axial Thickness	500	N/A	±500	N/A	N/A	1212	1212	[7] All dimensions are identical for SF and Vw
Inner Sleeve ID	1371	N/A	N/A	N/A	N/A	N/A	N/A	
Disposal Package								
Package OD	1255[6]	430-440	900	1050	N/A	1765	1765	
Package length	4640-5390[6]	4980	4700	4400-4931	N/A	5564	5564	
Weight of Package	43[6]	5.3	15	24-28.6	N/A	45	45	
Emplacement Method[4]	air cushion[6]	winch	undecided	rail	N/A	water cushion	water cushion	
Spacers								
Spacer OD	1252	not defined yet	2400	N/A	N/A	1765	1765	
Length between pkgs	4.5 - 8 m	not defined yet	2.5 m	3 m [3]	N/A	not defined yet	not defined yet	
Weight of Spacer[5]	18	not defined yet	11	N/A	N/A	not defined yet	not defined yet	

ID = inside diameter
OD = outside diameter

BH = borehole
Disposal Package = see glossary

All dimensions are in mm unless marked
All weights are in tons

TABLE 5: Vitrified HLW Main Dimensional Characteristics

	Vitrified HLW National Concepts							
	ANDRA	DBE-TEC	ENRESA[5]	NAGRA	O/N	POSIVA	SKB	COMMENTS
Disposal Drift/Cell ID[1]	2380	N/A	2400	2500	2.5 to 3m	N/A	N/A	[1] Inside the liner if any
Disposal BH ID	N/A	600-700	N/A	N/A	N/A	N/A	N/A	[2] Including sliding runners
								[3] space filled with granular bentonite
Buffer Rings								
Monolithic or blocks	monolithic	N/A	blocks	N/A[6]	N/A	N/A	N/A	[4] weight of emplacement package
Outside Diameter	2290	N/A	≤2400	N/A	N/A	N/A	N/A	[5] All dimensions are identical for SF and Vw
Inside Diameter	690	N/A	≥900	N/A	N/A	N/A	N/A	
Axial Thickness	500	N/A	±500	N/A	N/A	N/A	N/A	[6] Concept consists of solid bentonite cradle & granular bentonite pellets for filling
Inner Sleeve ID	620	N/A	N/A	N/A	N/A	N/A	N/A	
Disposal Package								
Canister OD	590[2]	430	900	940	1928	N/A	N/A	
Canister length	1607	1338	4700	2000	4200	N/A	N/A	
Weight of Canister	2.0	0.5	15	8.9	34.3	N/A	N/A	
Emplacement Method	pushing robot	winch	undecided	rail	air cushion	N/A	N/A	
Spacers								
Spacer OD	590	not defined yet	2400	N/A	N/A	N/A	N/A	
Length between pkgs	2.4m - 4.0m	not defined yet	2.5	3m [3]	nil	N/A	N/A	
Weight of Spacer[4]	1.8 - 3.5	not defined yet	11	N/A	N/A	N/A	N/A	

All dimensions are in mm unless marked
All weights are in tons

5.2.1 Discussion

The 2 previous tables show quite clearly that, except for the diameter of the disposal drift/cells, there is a wide range of values for all the other dimensions. Especially where the weights are concerned this immediately has an impact on the choice of emplacement method/equipment. For the heavier packages (ANDRA/SKB) the choice is to use fluid cushion technology and this will be demonstrated as part of the ESDRED project.

Only ANDRA use an "inner sleeve" as part of their design. This choice is integral to the decision to use monolithic prefabricated bentonite buffer rings as the second barrier and it also ensures the longest possible retrievability period. Again ANDRA, with the exception of SKB/Posiva's KBS-3V concept which is not considered in this report, is the only Contractor to select one piece rings and the design, fabrication and placement of these rings is very much a part of the ESDRED program. This combination of rings and inner sleeve ultimately impacts the available options for emplacement method and equipment.

As regards the SF disposal packages:

- The lengths vary from 4400 mm to 5550 mm,
- The OD's vary from 430 mm to 1765 mm,
- The weights vary from 5.3 to 45 tons

This extremely wide range of dimensions is very much the result of the designs selected by the different national concepts. At one extreme is the light weight canister for vitrified waste (German concept) without overpack, while at the other extreme is the very heavy SKB/Posiva "Super-Container" with integral engineered buffer blocks.

As regards the Vw disposal packages:

- The lengths vary from 1338 mm to 4700 mm,
- The OD's vary from 430 mm to 1928 mm,
- The weights vary from 0.5 to 34.3 tons.

As in the case of the SF's the extremely wide range of dimensions is very much the result of the designs selected by the different national or ESDRED concepts, as demonstrated in the examples above for the significantly different selection of canisters when comparing the German and Swedish concepts.

What communality exists, or is possible, is mostly related to the options for methodology of emplacement. The heaviest loads, 45t to 15t, are emplaced by means of air/water cushion technology (French, Belgian and Swedish/Finnish cases). For the intermediate loads (2t to 26t) "pushing robots" or "emplacement trolleys" and other types of specific emplacement devices are being considered. The smallest loads, (0,5t vitrified waste canister in the case of DBE-TEC) are being lowered down the boreholes with a winch and grapple system.

Finally, all national concepts consider some sort of spacing between the disposal packages within the disposal cells/drifts. This is an area, not directly within ESDRED, where the fewest number of participants have made firm commitments regarding the dimensions. This is very much a part of an optimisation exercise where the objective is to minimize the total length of excavation required, to maximize the number of packages per unit of excavation and at the same time to respect the geothermal constraints. This point is illustrated by the sensitivity curve in Figure 5 for the French concept, and is commented below. In the German concept there is no need for spacers due to thermal limitations but spacers may be used concerning canister stacking.

Finally it should be mentioned that, by having some spacing between consecutive disposal packages, a type of compartmentalisation is generated which makes the overall disposal system more robust especially with regard to intentional or unintentional human intrusion in the future.

One of the main objectives of the repository design is to come up with the lowest cost layout based on having the least amount of material to excavate while respecting all the criteria related to safety. From this point of view two types of excavation must be considered. The **active volume** is related to that part of the repository where the disposal packages are placed while the **non-active volume** is related to the rest of the underground infrastructures within the disposal zone, including the heads of the disposal cells/drifts. The intuitive configuration, which is to place the disposal packages in a "touch – touch" alignment, results in a big increase in the volume of the non-active part. In effect the small number of disposal packages per disposal cell/drift imposed by the touch – touch arrangement results in large dissymmetry between the active and the non-active part of a disposal cell/drift. This also means more disposal cells/drifts and more linear metres of handling drift. Therefore the total volume of material excavated is much higher when the disposal packages are close together in a disposal cell/drift because they are then thermally coupled. If the disposal packages are spaced further apart from one another it is possible to reach an "ultimate spacing value" (value of thermal decoupling) from which point on the thermal load per linear metre in the active part of the disposal cell/drift is such that it becomes possible to put an infinite number of disposal packages into a supposedly infinite disposal cell/drift. The longest possible disposal cell/drift can then be selected after giving due regard to the limitations imposed by technology, constructability and handling constraints.

As explained above thermal decoupling is not absolute or perfect, since this would require a very large separation distance between two adjacent waste packages. Thus, thermal decoupling should be seen as a relative decoupling more than as an absolute decoupling. Increasing the waste package separation distance improves the thermal decoupling, and it is then possible to reduce the distance between adjacent parallel disposal drifts (or disposal cells). This leads to cost savings. However, there is an optimum situation (minimum cost) beyond which increasing the waste package separation does not generate additional savings (thermal decoupling is already high, so that the distance between adjacent drifts cannot be significantly reduced, whereas the disposal drift construction costs continue to rise as the waste separation distance is increased). If the disposal drift length is fixed, as it is the case in various national concepts, then the optimum situation described above is reached at a much lower waste separation distance i.e. at a condition that is far from absolute decoupling.

5.3 *RADIOLOGICAL PROTECTION*

The presence of radioactive waste introduces exposure risks for workers and for the public. The risks are taken into account by the waste management implementers by applying either the EURATOM or the national directives, which fix maximum annual dose rates (Sv/year) that must not be exceeded. In the framework of ALARA (as low as reasonably achievable) the different repository operators establish annual dose rates which are even more restrictive than the EURATOM or national rates. These tougher rates once converted into equivalent dose emissions (µSv/hour) are used to size the thickness of radioprotection which must separate the personnel from the sources of radioactivity i.e. the radioactive waste. The overall layout and design of the radioprotection also takes into account the operating methods and procedures in the repository.

The applicable legislation (EURATOM or national) is therefore one of the most important pieces of Input Data as it indirectly impacts everything that is done in the field of waste disposal. The first thing to be impacted is the selection of a Corporate or national exposure dose limit (ALARA based objective) for workers and for the public. This dose rate may be a fraction of the legal limit. This then becomes an important Functional Requirement.

Although radioprotection per se does not directly constitute a work package within any of the four ESDRED, technical Modules it is nevertheless a very important topic. For example, the selection of an exposure dose rate limit affects:

- The shielding requirements, which impact:
    - the thickness of the shielding metal (shielding cask or shielding gates),
    - the selection of the emplacement method and equipment,
- The maximum annual hours of worker exposure,
- The design and placement of the adjacent buffer material.

All of which impact the operating safety issues and the general architecture of the repository.

Finally it needs to be mentioned that many of the national agencies appear reluctant to firm up the essential dose rate corporate objectives. An important reason for this is that the national disposal concepts are still evolving as are the relevant national/European legislations.

TABLE 6: Radiological Protection

	Radiological Protection National Concepts							
	ANDRA	**DBE-TEC**	**ENRESA**	**NAGRA**	**O/N**	**POSIVA**	**SKB**	**COMMENTS**
ANNUAL DOSE RATES								
Worker Dose Rates (mSv/yr)								
Legislated max	20	20	50[1]	20	20	50[1]	50[1]	[1] Max 100/5 Yrs per Euratom regs
Corporate objective max[2]	5	5.5	4	5	10	not defined yet	not defined yet	[2]includes external & internal radiation
								[3]for workers ie not for public
PUBLIC DOSE RATES[9] (mSv/yr)								[4]placement of buffer & canister in one step
Legislated max	1	1	1	1	1	1	1	[5]some remote control used for Alara purposes
Corporate objective max	0.25	not defined yet	0.1	0.1	0.3	not defined yet	not defined yet	**[6]Eg:Max dose rate/hr = (10msv/year)/2000 hr/yr = 5 µSv/hour**
MAX ALLOWABLE RADIATION FOR FULL TIME EXPOSURE[3]								**[7]Eg:Max dose rate/hr = (10msv/year)/400 hr/yr = 25 µSv/hour**
Max Hours/Year Worked	1500	not defined yet	2000	2000	2000	1600	1600	**hours**
Corporate objective max dose rate	5	5.5	4	5	10	not defined yet	not defined yet	**mSv/year**
Calculated max design dose rate/hr to respect maximum annual corporate exposure level objective (µSv/hour)	3[10]	not defined yet	2	2.5	5[6]	not defined yet	not defined yet	**(µSv/hour)**
								[8]this handling cell is located underground in a reloading station
MAX ALLOWABLE RADIATION FOR PART TIME EXPOSURE[3]								**(µSv/hour)**
Assumed max hrs exposure/yr	300	not defined yet	undecided	not defined yet	400	not defined yet	not defined yet	**hours**
Corporate objective max dose rate	5	5.5	4	5	10	not defined yet	not defined yet	**mSv/year**
Distance to radiation source	0.3/1.0m[10]	not defined yet		not defined yet	1m	not defined yet	not defined yet	[9]also applies to workers exposed by exception
Calculated max design dose rate/hr to respect maximum annual corporate exposure level objective (µSv/hour)	15	not defined yet	undecided	not defined yet	25[7]	not defined yet	not defined yet	**(µSv/hour)**
								[10]measured @ 0.3m from fixed protection devices & 1.0m from moveable sources
OPERATING MODE								
1.Buffer Placement Mode	remote control	N/A	remote control	remote control[5]	undecided[5]	remote control	remote control	
What radioprotection?	not req'd	N/A	distance only	shielded area	undecided	radiation shielded handling cell[8]	radiation shielded handling cell[8]	
Where is operator?	in access drift	N/A	far enough away	in access drift	undecided	outside handling cell	outside handling cell	
2.Disposal Pkg Placement Mode	remote control	remote & direct control	remote control	remote control	undecided[5]	remote control	remote control	
What radioprotection?	transport cask gamma & neutron gates	transport cask gamma and neutron gates	not req'd	unloading of transport cask in shielded area	some local radioshielding eg on the air cushion trolly	transport cask gamma gate	transport cask gamma gate	
Where is operator?	nearby in access drift	on machine protected	far enough away	in access drift	in disposal drift	nearby in access drift	nearby in access drift	

5.3.1 Discussion

The EURATOM legislation is a common reference for all Contractors. However, all except 2 of the national concepts are based on similar but tougher national regulations which limit the total maximum annual worker dose to 20 mSv/year. By contrast the EURATOM regulations have a higher maximum annual exposure of 50 mSv/year but they limit the total exposure over a five year period to 100 mSv/year, i.e. an average of 20 mSv/year. Collectively this is certainly one area where there is a lot of communality between the national concepts. Also, as a result of the common acceptance of the ALARA principle, the emplacement methods generally call for remote control and for a shielded transport cask in most concepts. But that seems to be where the similarities end.

In all cases, national waste management agencies, when designing their radioprotection devices/installations, use annual radiation exposure limits which are much lower than those allowed by law. Generally speaking this translates into a dose rate of between 2 and 5 µSv/hour behind the radioprotection screens/devices put between the sources of radiation and full time worker operating positions. The hours of potential exposure of a worker in such a position varies between 1 500 and 2 000 hours per year.

For example, for a work station with a full time worker the following applies:

- The annual hours used to calculate the maximum allowable radiation exposure varies between 1500 and 2000 hours ,
- The maximum allowable dose rate in µSv/hour in such working areas, resulting from a calculation using the above, varies between 2 and 5 for the different national concepts.

For work stations with only occasional part time exposure such as for repair, maintenance or brief operation of equipment the exposure limits are generally 4 to 5 times higher as shown below:

- The corporate objectives vary between 4 and 10 mSv/year,
- The maximum hours of annual exposure, used in the calculations, is 300 and 400 and is mostly undecided,
- This distance from a radiation source at which the representative measurements are taken is also not constant being anywhere from 0.3 to 1.0 metre and is mostly not decided,
- And finally the maximum dose rate in µSv/hour emanating from a package is between 15 and 25 and is mostly not decided. See Tables 2, 3 and 6.

The corporate objectives for maximum dose rates for the public vary from 0.1 to 0.3 mSv/year.

Most national agencies include, in their current reference design, some dose rate values which are already being applied in their existing industrial operations (e.g. short lived low to medium activity waste storage). As such these are “already proven” corporate objectives as per the ALARA rule. There are also differences between some of the implementers in terms of dose rate measurement (as far as the distance from a source is concerned); between mobile shielding protections (like the casks) and fixed ones (like the cell/borehole gates/lids). For the others, the "design freeze" time is not ripe and flexibility is still needed.

5.4 *ENGINEERED BARRIERS INCLUDING PLUGS AND SEALS*

The term "Engineered Barriers" covers a whole host of topics most of which are not directly an issue within ESDRED. Our first concern here is with the buffer material placed next to an overpack as per Module 1. The term overpack is equally appropriate where the Super-Container is also the final waste disposal package. Our second concern is with the materials used to construct seals and plugs within a disposal cell or drift as per Module 1 in the case of seals and as per Module 4 for plugs. For the sake of completeness Table 7 below also includes some information regarding the annular gap filling.

This is the first thematic topic which relates directly to one or more technical Module hence a more elaborate discussion is possible.

TABLE 7: Engineered Barriers

	Engineered Buffer/Backfill/Seals/Plugs National Concepts							
	ANDRA	**DBE-TEC**	**ENRESA**	**NAGRA**	**O/N**	**POSIVA**	**SKB**	**COMMENTS**
BUFFER								
Type used	prefabricated bentonite/sand rings	none	prefabricated bentonite blocks	bentonite cradle blocks & pure granular bentonite	OPC Concrete[1]	bentonite[1]	bentonite[1]	[1]integral to Super-Container
ANNULAR GAP FILLING[2]								[2]between the disposal package & the next barrier
Type used	N/A	Salt gravel	N/A	N/A	cement based grout[8]	N/A	N/A	
BACKFILL[3]								[3]behind plugs/seals & in access drifts
Type used	excavated waste rock	salt gravel	rock & bentonite	bentonite/sand	undecided	rock & bentonite	rock & bentonite	
SEALS[4]								[4]in disposal cells/drifts/boreholes
material	bentonite/sand	not defined yet	bentonite	bentonite[5]	undecided	bentonite blocks	bentonite blocks	[5] bentonite without sand added
length	3	not defined yet	6	12-40	undecided	1.5 - 2.5	1.5 - 2.5	[6]wedge shaped to retain backfill in disposal drift & to withstand hi pressures
PLUGS[7]								
material	OPC concrete	not defined yet	concrete	frictional material eg gravel	undecided	low pH concrete	low pH concrete	[7]to support (backstop) the seal
length	4 - 7	not defined yet	3	8 to 22	undecided	2.5	2.5	[8]reference option with OPC grout

BH = borehole

Dimensions are in metres

5.4.1 Input Data

The following list of items was developed by the participants in Module 1 for the Input Data related to buffer/backfill:

1. functions to be fulfilled by the buffer/backfill,
2. composition and origin of the buffer/backfill,
3. density and moisture content of the buffer/backfill,
4. geometrical shape of the buffer/backfill, with gap dimensions and tolerances,
5. involved waste types and potential impact on the buffer/backfill,
6. specifications regarding monitoring techniques,
7. parameters to be monitored.

5.4.2 Functional Requirements

The following list of items was developed by the participants in Module 1 for the Functional Requirements related to buffer/backfill component:

1. thermal conductivity of the buffer/backfill,
2. hydraulic conductivity of the buffer/backfill,
3. gas permeability and diffusivity of the buffer/backfill,
4. swelling characteristics of the buffer/backfill,
5. fracture toughness or mechanical rigidity of the buffer/backfill,
6. chemical compatibility of the buffer/backfill with other materials,
7. other Functional Requirements of the buffer/backfill,
8. specific Functional Requirements regarding monitoring techniques

Table 11, in Appendix 2, provides a comparative summary of the "Buffer Backfill Functional Requirements" prepared within D1 of Module 1.

5.4.3 Discussion

Table 7 presents a limited amount of information regarding 5 applications of "Engineered Barriers" i.e. Buffer, Annular Gap Filling, Backfill, Seals and Plugs. Some explanatory comments are required. The first 2 categories are covered within Module 1 although it would be correct to say that Annular Gap Filling and Buffer are in fact one and the same. The distinction made in the table is intended only to differentiate between some relatively large amounts of buffer (rings, blocks or granular) as compared to some rather small amounts of annular gap filling. In both cases ESDRED is only concerned with what happens inside a disposal cell or drift and not with the other repository access openings which may also be filled at a later stage. Because the partners in ESDRED come from different national concepts, which in some cases include "Super-Containers", there is a further variation regarding the buffer. For most partners, the buffer is installed to surround the disposal package, which also happens to be the overpack. Hence the buffer in blocks, monolithic rings or in granular form is located between the exterior surface of the disposal package and the disposal cell/drift lining, if any. In the case of the Super-Containers the buffer is still installed to surround the overpack but now it is located between the overpack and the outer skin of the Super-Container, which may or may not be perforated.

The term ***buffer/backfill*** is used within Module 1. This too can be the source of confusion and demands an explanation. The IAEA Glossary, Version 2003, defines ***backfill*** as shown below:

- "The material used to refill excavated portions of a repository (*drifts,* disposal rooms or *boreholes)* during and after *waste* has been emplaced."

On the other hand the IAEA defines ***buffer*** as:

- "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*."

These definitions in effect confirm that all buffer is a backfill but not all backfill is a buffer. Since ESDRED only concerns itself with the material placed in front of a disposal cell/drift seal, the use of term ***buffer/backfill*** is not incorrect. Moreover, at least in the NAGRA case, the method of placement could be very close to the method one might use to place backfill, as defined by the IAEA above, so that the term ***buffer/backfill*** might signify both the function and the method of placement.

Backfill as intended in the Table 7, i.e. outside of the disposal drift, is not a part of ESDRED and is included in Table 7 only for completeness and to further confirm the differences between the various national concepts.

The fourth item on the table i.e. the ***"Seals"*** is not specifically a part of ESDRED except in the context of Module 1 which deals with materials which are typically used to construct seals and in the context of Module 4 where the main related issues are a) the use of low pH cements next to clay-based seals and b) the use of the shotcreting method for construction of the plug which acts as a backstop for the seal.

A ***Seal*** is defined by the IAEA as:

- "Engineered *barriers* placed in passages within and leading to a *repository* to isolate the *waste* and to prevent seepage leakage if water into or *radionuclide migration* from the *repository* area. Sealing is performed as part of *repository closure*."

Finally the last unit on the table is the "***Plug***". Construction of a plug using low pH cement and utilising the shotcrete (sprayed concrete) method for construction is one of the demonstrations within Module 4. The Plug does not really fulfil a barrier function in the classical sense (except very briefly) and should therefore not be included except for completeness. On the other hand it does fulfil an important mechanical function insofar as it supports the Seal constructed in front of it and it does have characteristics which support the function of the seal.

A Plug is not specifically defined by the IAEA.

In Module 1 three different geometrical configurations are considered for the buffer/backfill:

1. annular horizontal drift, to be filled with granular material,
2. circular horizontal drift, to be filled with prefabricated rings,
3. circular horizontal drift, to be filled with a combination of prefabricated blocks and granular material.

A review of the Functional Requirements developed within Module 1 (see **Table 11,** Appendix 2) indicates that the contracting parties sometimes have a somewhat different view regarding the role and function of the buffer/backfill. The Module 1 partners have identified the following main reasons for these differences:

- 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.

Nevertheless, even though the conceptual designs are different, a number of technical and non-technical problems are the same. For a buffer or a seal made of bentonitic material, the main challenges are:

- *The buffer composition and characterization*: Should the material be made of "pure bentonite" or include some sand? The first solution favours the swelling (expansion) of the clay, while the second is prone to a better thermal diffusion and could also improve the mechanical performance of the prefabricated blocks or rings (a quality much needed in the case of the emplacement of the buffer rings by means of the air cushion technology). The compaction of the material (of pellets once emplaced in the drift or of rings when moulded) also has a major impact on the swelling properties of the buffer (swelling pressure is related to the dry density of swelling material). Initial water content will impact on initial thermal conductivity of the buffer (and this initial conductivity is of paramount importance since the thermal peak occurs rather rapidly after emplacement) and on other aspects such as compaction method, resaturation duration, and bacteria growth control.
- *The gas permeability*: After swelling, the bentonitic material should have a low hydraulic conductivity but should allow the release of gas. Possible cracking induced by gas pressure build-up should self-seal. The development of channelling which would negatively impact its barrier performance should be avoided. The relative water/gas permeability must consequently be properly assessed.
- *The emplacement method*: Due to radioprotection considerations, a remote (or at distance) emplacement method is envisaged in all cases, even by the Swedes and Belgians who plan to use Super-Containers. When surrounding the waste canister with buffer, there is no choice but to find out a way to deal with the radiation phenomena. In the French concept the buffer rings are put in place **before** the emplacement of the waste disposal packages. On the other hand the Swiss concept consists of a 2 sequence approach: a) pre-positioning of bentonite blocks (to be used as a cradle) in the disposal

drift, together with the remote emplacement of the disposal package by rail (emplacement trolley) and b) remote emplacement of bentonite pellets each time a package is positioned on the cradle working from the back towards the mouth of the disposal drift.

For a buffer or a seal made of a high pH cementitious material, the main challenge is:

- *The construction feasibility*: How can the cementitious buffer be constructed around the radiation and heat-emitting waste, in such a way that the creation of large voids due to radiolysis or major fissuring due to thermal stresses is avoided? The existence of wall-through fissures or large pockets in the vicinity of the steel overpack would have an adverse effect on the corrosion-protection capacity of the high pH buffer.

Gas permeability is normally not a problem in cementitious materials. Emplacement is not considered to be a major challenge either since the thickness of the cementitious buffer is designed to provide a sufficient extent of biological shielding.

The selection by O/N of normal (high pH) concrete as a buffer material around the waste comes from the strategic decision to emphasize the performance of the overpack barrier. By surrounding the overpack with a stable high pH cementitious environment, instead of a clay environment, the corrosion resistance and integrity of the steel overpack can be increased by several multiples of the values applicable to clay environments. Inseeping 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 of a clayey buffer.

This strategic decision to use a normal concrete buffer has the following important operational advantages:

- It offers an opportunity to apply a permanent biological shielding around the waste;
- It greatly improves quality assurance and quality control of the waste package fabrication process, since the buffer can then be constructed on the surface and be made of a material with a broad industrial knowledge basis.

5.5 *LOW pH CEMENTS*

This is the only technical issue to which an entire technical Module is dedicated. This is also an area where real integration on a European level is likely to occur. There is serious interest on the part of most, if not all, Contractors regarding the potential use of low pH cements. In most cases this means that the use of low pH cement has been retained as an option within the national concepts. A positive result with the work and demonstrations to be carried out within this Module 4 would enhance the probability that some national concepts adopt the option of using low pH cements next to bentonitic buffers and seals, and for temporary rock support shotcrete. This new approach may also include the use of the shotcreting method for the construction of plugs.

TABLE 8: Low pH Cements

	Low pH Cements: Retained as an Option by National Concepts?							
	ANDRA	**DBE-TEC**	**ENRESA**	**NAGRA**	**O/N**	**POSIVA**	**SKB**	**COMMENTS**
Applications								
In Shotcrete	yes	no	yes	yes[1]	no	yes	yes	[1] shotcrete used by exception only
In Drift Lining Concrete	yes	no	yes	no	no	yes occasionally	yes[2]	[2] for occasional rock support only
In Buffer Mixtures	no	no	N/A	no	yes	no	no	
In Gap Filler Grout	N/A	no	N/A	no	no	no	no	
In Plug Constr Concrete	yes	no	yes	yes	no	yes	yes	
Shotcrete Method for Plug Construction	yes	no	yes	no	no	yes	yes	
Plug = concrete structure used to support a bentonite based seal; also referred to as a seal backstop								

5.5.1 Input Data

The following Input Data was considered relevant by all the participants in Module 4:

- Shotcrete as emplacement method,
- pH equal or below 11,
- Mechanical properties of host rock,
- Hydraulic conductivity of host rock,
- Ground water composition.

5.5.2 Functional Requirements

The Functional Requirements developed by the Module 4 participants are shown in the list below. A summary of the specific technical data is provided in APPENDIX 1, **Tables 9 and 10.**

- Hydraulic conductivity (site specific – same order of magnitude as that of the EDZ),
- Mechanical properties of concrete,
- Durability (concept specific – linked to the operational life of the repository),
- Workability,
- Pumpability,
- Slump (as per NAGRA),
- Peak hydration temperature,
- Thermal conductivity (concept specific – not below that of the bentonite barrier),
- Construction rate (for plug),
- Use of organic components (fibres or admixtures),
- Steel fibres (as per NAGRA),
- Maximum total pressure or pressure at the plug/buffer interface(for plug),
- Length of plug (as per SKB),
- Gallery dimensions or diameter,
- Time between start of construction and full function of plug (as per SKB),
- Use of other products (as per SKB),
- Drainage (as per SKB).

5.5.3 Discussion

There is more discrepancy than communality regarding the role played by concrete (or of a cementitious material) for the various applications considered in a repository:

NAGRA does not plan to use concrete plugs for HLW and SF. The Swiss concept for the construction of the seals foresees the use of frictional non-cementitious materials for embankments. Concrete plugs will only be used to protect the seals from accidental flooding during the operational phase. The distance between such concrete plugs and waste packages will be large enough (metres) to rule out any influence of a potential pH-plume in a diffusion dominated system (bentonite and Opalinus Clay). Regular (not low-pH) concrete is therefore planned to be used.

ANDRA, ENRESA and NAGRA, and to a certain extent SKB and POSIVA, share the same concerns regarding the deleterious effect (plume effect) of the high pH OPC cements on the swelling capacity of the bentonite (and also on the host rock characteristic when this rock is a clay material). These concerns may not extend into the more marginal applications such as annular gap filling. The latter however is well outside the Scope of the present ESDRED work. As mentioned earlier the real probability for integration of low pH applications throughout the European national concepts will occur after the ESDRED project has been completed if the demonstrations have been successful. It is at that point that low pH cements and shotcreting construction methods may start to be incorporated into future engineering studies by many of the implementers.

The "pure OPC approach" contemplated by ONDRAF/NIRAS is obviously out of scope with the concepts currently endorsed by the other Contractors' however it is fully consistent with the Belgian concept of a "fully alkaline medium" between the package and the host rock.

The consideration of a high pH cementitious buffer within ESDRED is not in conflict with the main objectives of the EC support to research projects on the geological disposal of radioactive waste. These objectives are:

1. development of a "common understanding" of scientific and technical issues,
2. development of "shared technical solutions".

The consideration of a high pH cementitious buffer within ESDRED is not in contradiction with the development of a "*common understanding of scientific and technical issues*", because the main objective of testing and optimizing a number of solutions to the technical problem of backfilling an annular gap with a granular material will not change. It is not the objective to rule out the use of clay as a material for backfilling an annular gap, nor to degrade the testing of the emplacement of a clay backfill.

The consideration of a high pH cementitious buffer within ESDRED is also not in contradiction with the goal of *"working towards the development of shared technical solutions*", because the results of the O/N work will evidently be shared with all the members of the consortium. The technical solution(s) that should be recommended at the end of the integrated project will be based on a larger spectrum of studied materials and emplacement methods. These recommendations will therefore be more conclusive than an a priori choice for a clay-based technical solution. Adding other materials, including the cement grout option, to the number of potential solutions being studied takes nothing away from the clay-based solutions. The use of clay-based prefabricated blocks/rings and clay-based granular materials will continue to be studied within Module 1. The expansion of candidate materials should not be seen as a disadvantage, but rather as an opportunity for all ESDRED partners to further develop and adjust their disposal concepts, not only for High Level Waste (HLW) but also for Medium Level Waste (MLW). In the case of MLW, the use of cement is an important design feature, shared by all partners. Hence, in the end, any of these solutions could be of value to the other ESDRED partners.

5.6 *REVERSIBILITY AND RETRIEVABILITY*

This is not a topic for which "Input Data and Functional Requirements" have been, or will be, developed within ESDRED.

Nevertheless it is a topic which is incorporated within Module 2 and for which a desk study will be produced within the coming months. A discussion of the subject has been included within this report because the different national requirements do have an important impact on the development of the various national concepts.

5.6.1 Discussion regarding the different Reversibility approaches

A comparison of the disposal concepts relevant to ESDRED shows that there exists a wide range of national requirements concerning the extent to which the development of a waste disposal facility should be reversible prior to closure. For example, France has a policy requirement that each step of a repository development process, up to emplacement of the waste, is easily reversible. In contrast, Germany currently has no requirement concerning reversibility or waste retrievability in the context of any future geological disposal. Within this spectrum, most national disposal concepts aim to show that waste could be retrieved during the operational period of a repository, if so desired in future for whatever reason, though only limited provisions are intentionally incorporated in the design to facilitate easy retrieval of the waste.

Potential retrievability enhancing measures may include design and operational measures, together with monitoring activities associated with the three basic conditions that determine the extent of retrievability provided by a particular disposal concept. These are:

- Accessibility of the packages;
- Confinement of the waste in the packages following emplacement; and
- Technical feasibility of retrieving the packages.

Potential design measures that enhance retrievability of waste prior to repository closure are primarily aimed at providing easier accessibility to the waste packages, particularly in clay and salt host environments, and/or providing an improved capability to retrieve the waste packages. Potential design measures in the first category include enhancing the stability of openings (e.g. by incorporating concrete or steel liners) and, in the second category, provision of easily removable buffer materials (e.g. in the form of pre-fabricated bentonite blocks). It is worth noting also that the use of copper waste canisters, as envisaged by the Swedish and Finnish disposal concepts, ensures a high level of waste confinement for perhaps thousands of years, i.e. far beyond the operational period of a repository.

In most disposal concepts relevant to ESDRED these issues are still under consideration and definite positions may not be reached until countries are much closer to starting the development phase. Likewise, operational and monitoring strategies are still under development. For some disposal concepts, this may mean that access ways will remain open for perhaps several decades whilst greater levels of confidence in the disposal concept are achieved, e.g. as a result of ongoing monitoring of the disposal system. For other concepts, it is likely that intensive monitoring activities will be focussed on a special facility, e.g. as envisaged for the Swiss concept, with closure of accesses to the main facility taking place relatively sooner, on the basis that the risk of neglect or even from deliberate intrusion is thereby significantly reduced.

6 - SUMMARY AND CONCLUSIONS

The various contexts (waste nature and inventory, geological, political and legal) in which the different national Contractors are implementing their research programs 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.

6.1 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.

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

Example from Module 4:

The potential applications of low pH cement shotcrete; 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.

6.3 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 organization, 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, inseeping 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.

Example from Module 2: No overpack required in repository in rock salt

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 nearfield. 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.

6.4 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.

7 - APPENDICES

7.1 *APPENDIX 1 - Low pH Cement Functional Requirements*

TABLE 9: Module 4 Functional Requirements for Concrete Plugs

Ítem	ENRESA	SKB	ANDRA	POSIVA
Hydraulic conductivity	k ≤ 10^{-10} m·s^{-1}	k ≤ 10^{-10} m·s^{-1}	Depends on length L: k / L ≤ 10^{-12} s^{-1}	k ≤ 10^{-10} m·s^{-1}
Final mechanical properties: • **Young modulus** • **Poisson's ratio** • **Tensile strength** • **Friction angle** • **Cohesion** • **Compressive strength**	›20000MPa 0,2 – 0,3 > 1 MPa ≥ 37º ≥ 2 MPa ≥ 10 MPa	›20000MPa 0,2 – 0,3 > 1 MPa ≥ 37º ≥ 2 MPa ≥ 10 MPa	High strength is not required as such, but the requirements on durability lead to prescribe mix compositions corresponding to high performance concrete (≈ 60 MPa at 90 days)	›20000MPa 0,2 – 0,3 > 1 MPa ≥ 37º ≥ 2 MPa ≥ 10 MPa
Durability	≥ 100 years	≥ 100 years	as high as possible (and sulphate resistant)	≥ 100 years
Workability	≥ 2 hours	≥ 2 hours	≥ 2 hours	≥ 2 hours
Pump ability	250m	250 m	> 100 m	250 m
Peak hydration temperature	≤ 40ºC	≤ 40ºC	≤ 30ºC	≤ 40ºC
Thermal conductivity	1,2 W/mºC	1,2 W/mºC	Access drift plugs: not specified Disposal cell plugs: 1,75 W/mºC	1,2 W/mºC
Construction rate	1 m/day	Not specified	Not specified	Not specified
Use of organic components (fibres or admixtures)	To be studied	Not at all but if this is not possible, quantities and types of organic material must be described	Not at all but if this is not possible, quantities and types of organic material must be described	Not at all but if this is not possible, quantities and types of organic material must be described
Estimated pressure at the plug/buffer interface	7 MPa	15 MPa	Access drift plugs: 3 MPa Disposal cell plugs: 4.5 MPa	15 MPa
Length of plug	≈≈3 meters	As short as possible but it must be able to withstand the estimated pressure with a safety factor	Access drift plugs: not defined Disposal cell plugs: 4 to 6 m	As short as possible but it must be able to withstand the estimated pressure with a safety factor
Rock surface	Full face tunnel bored	No slot shall be necessary	No slot shall be necessary	No slot shall be necessary
Diameter	2.5 m	1860 mm-1840 mm	Access drift plugs: 7 m Disposal cell plugs: 0.7 to 3.5 m	1860 mm-1840 mm
Ground water conditions	Site specific	Saline (3.5%)	Not very saline (5 g/l)	Saline (3.5%)
Time between start of construction and full function of plug	Not specified	To be studied	Not specified	To be studied
Rest products	It must be possible to describe and quantify the rest products after degradation of the plug	It must be possible to describe and quantify the rest products after degradation of the plug	It must be possible to describe and quantify	It must be possible to describe and quantify the rest products after degradation of the plug
Drainage	Not considered an issue in local conditions	It must be possible to drain water through the plug during construction (including curing time). It must be possible to seal the drainage hole after the construction of the plug.	Not specified. However, piping might be needed for artificial water supply to buffer (to be eventually grouted)	It must be possible to drain water through the plug during construction (including curing time). It must be possible to seal the drainage hole after the construction of the plug.

NAGRA does not specify requirements for concrete plugs. The Swiss concept for the construction of the seals foresees the use of frictional non-cementitious materials for embankments. Concrete plugs will only be used to protect the seals from accidental flooding during the operational phase. The distance between such concrete plugs and waste packages will be large enough (metres) to rule out any influence of a potential pH-plume in a diffusion dominated system (bentonite and Opalinus Clay). Regular (not low-pH) concrete is therefore planned to be used. NOTE: Includes some info not in original table.

TABLE 10: Functional Requirements for Rock Support

Ítem	NAGRA	SKB	ANDRA	POSIVA
Hydraulic conductivity	$k \leq 10^{-10}\ m \cdot s^{-1}$	Not relevant	none	Not relevant
Mechanical properties: • **Compressive Strength** • **Young modulus** • **Bonding**	≈ 10 MPa (8 hours) ≈ 25 MPa (7 days) ≈ 35 MPa (28 days) ≈ 0.5 MPa (28 days) ≈ 1.0 MPa (28 days) As high as possible	≈ 10 MPa (8 hours) ≈ 25 MPa (7 days) ≈ 35 MPa (28 days) ≈ 15 GPa (7 days) ≈ 20 GPa (28 days) ≈ 0.9 MPa (7 days) ≈ 1.5 MPa (28 days)	≈ 10 MPa (8 hours) ≈ 25 MPa (7 days) ≈ 35 MPa (28 days) Not very important As high as possible	≈ 10 MPa (8 hours) ≈ 25 MPa (7 days) ≈ 35 MPa (28 days) ≈ 15 GPa (7 days) ≈ 20 GPa (28 days) ≈ 0.9 MPa (7 days) ≈ 1.5 MPa (28 days)
Durability	≥ 2 years (sulphate resistant)	≥2 years (sulphate resistant)	Sulphate resistant	≥2 years (sulphate resistant)
Workability	≥ 2 hours	> 2 hours	> 2 hours	> 2 hours
Pump ability	> 100m	~ 15m	> 100m	~ 15m
Slump	15 – 20 cm	15 – 20 cm	5 – 20 cm (15 – 20 cm if fibres)	15 – 20 cm
Peak hydration temperature	Not relevant (< 100°C)	~ 40ºC-	Not relevant	~ 40ºC-
Thermal conductivity	Dry: > 0.5 W/m°C Saturated: >1.2 W/m°C	Not applicable-	Not relevant	Not applicable-
Use of organic components (fibres or admixtures)	Compatible with PA, needs to be studied	Compatible with PA, needs to be studied	To be studied	Compatible with PA, needs to be studied
Steel fibres	Steel (or plastic) fibres compatible with PA, needs to be studied	No steel fibres	To be studied	No steel fibres

NOTE: Includes some info not in original table.

7.2 *APPENDIX 2 - Buffer Backfill Functional Requirements*

TABLE 11: BUFFER/BACKFILL COMPARISON OF FUNCTIONAL REQUIREMENTS 1/2

		ONDRAF/NIRAS and EURIDICE	**ANDRA**	**NAGRA**	**GRS**	**ENRESA (*)**
MATERIAL		**Not specified** (but preferably cement-based)	**Clay-based (compacted rings)**	**Clay-based (granular)**	**Clay-Sand mixture for SB experiment**	**Clay-based (compacted cylinders)**
thermal conductivity	objective	Overpack surface < 100°C	Buffer surface < 90°C.	Canister surface < 160°C Buffer outer surface < 95°C	Conductivity similar to host rock	Buffer < 100°C
	value	> **1.0 W/m°C** (generic low value for concrete)	> **1.2 W/m°C** before resaturation > **1.5 W/m°C** after resaturation	> **0.4 W/m°C**	**≈ 1.6 W/m°C**	≈ 0.55 W/m°C before resaturation ≈ 1.3 W/m°C after resaturation
hydraulic conductivity	objective	No requirements	As low as possible	Similar to EDZ conditions	As low as possible	Sufficiently low
	value		< 10^{-12} m/s after resaturation	< 10^{-12} m/s	< 10^{-11} m/s initially	≈ 10^{-13} m/s
gas permeability and diffusivity (clay-based materials)	objective	Sufficiently high (no pressure build-up)	As high as possible	No significant water expulsion and limited gas entry pressure	Sufficiently high	No requirements
	value	Diffusivity > **5. 10^{-10} m^2/s** (host rock diffusivity)	No value specified	Dry density needs to be: **1.0 < ρ_{dry} < 1.6** 10^3 **kg/m^3**	• Initial permeability > 10^{-13} to 10^{-15} m^2 • Gas break-trough pressure < **5 MPa**	
swelling charact. (clay-based materials)	objective	No structural instability of gallery wall	• Keep low hydraulic conductivity • No damage on rock or canister	Tunnel convergence should be limited	No damage on rock	Void sealing and low hydraulic conductivity
	value	Swelling pressure **< 3.5 MPa** (expected lithostatic pressure)	**(0.5..1.5)<** swelling press. **<7 MPa**	Dry density needs to be: **1.35 < ρ_{dry} < 1.60** 10^3 **kg/m^3**	swelling pressure **< 2 MPa**	swelling pressure 5 MPa
Fracture toughness or mechanical rigidity	objective	Retrievability	No damage during handling, assembling, or when resting on rails	Blocks must be able to support the canister	No requirements	No requirements
	value	Fracture toughness **< 30 MPa** (weaker than light concrete)	• UCS > **9 MPa** • Tensile strength > **1 MPa**	Dry density of the blocks needs to be: ρ_{dry} ≈ 1.7 to 1.8 10^3 kg/m^3		

NOTE: Contains some info not in original table.

TABLE 11: BUFFER/BACKFILL COMPARISON OF FUNCTIONAL REQUIREMENTS 2/2

		ONDRAF/NIRAS and EURIDICE	ANDRA	NAGRA	GRS	ENRESA (*)
Chemical compatibility	objective	Protection of steel waste pack liner (main objective) against chemical interaction with backfill	Protection of buffer and glass waste matrix	Protection of buffer and host rock	Protection of buffer	Protection of the host rock
	value	Backfill material concentration **Cl^- and S^{-2} ≈ 0**	• No high pH cement in the vicinity of the buffer. Use concrete only for seals and then with **pH < 10** • No graphite in buffer allowed	No high pH cement in the vicinity of the buffer	No high pH cement in the vicinity of the buffer	No value specified
Macroscopic void contents	objective	Protect waste package in case of gallery collapse; Disable escape of spent fuel filing material.	Void index approx 0.5 Limit porosity to max 30%	Limit expulsion of water resulting from heavy loading	• Limit expulsion of water resulting from heavy loading • Avoid high gas pressure build-up	The total void volume has been estimated in about 10% of the annular volume between the canister and the rock surface
	value	• Average void ratio < **20%** (waste acceptance criterion) • No large individual voids in vicinity of waste package		No value specified (to be further investigated)	From dry (state of delivery) to full water saturation (on the long term)	
Plasticity	objective	No objective has been set	Fill the voids	Protect canister in case of deformation (e.g. displacement during earthquake)	allow compaction and avoid fracturing	As high as possible
	value		Plasticity index **> 90**	Value not decided yet	highly plastic	
Sorption	objective	No objective has been set	As high as possible	As high as possible	As high as possible	As high as possible
	value		No value specified	No value specified	No value specified	
Specific heat		No objective has been set	To be determined	To be determined	To be determined	1.38 x T + 732.5 J/kg°C
Microbial activity	objective	No objective has been set	Protection of canister	Protection of canister	Not considered	Protection of canister
	value		To be determined	To limit microbial activity, dry density should be: • $\rho_{dry} > 1.26\ 10^3$ kg/m^3 initially • $\rho_{dry} > 1.57\ 10^3$ kg/m^3 finally	Not applicable	Not decided
Setting time (cementitious materials)	objective	Limit the total duration of HLW waste disposal and backfill operations < 10 years	Not applicable	Not applicable	Not applicable	Not applicable
	value	Removal of casing < **4 days**				

(*) given values are for a reference case corresponding with a 1.6 10^3 kg/m^3 dry density NOTE: Includes some info not found in original table.

7.3 *APPENDIX 3 - Glossary*

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	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
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
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
Long Term		Generally intended to mean extending in time beyond the final closure of a repository
Overpack	yes	A secondary (or additional) outer container for one or more *waste packages* , used for handling,

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 abutement to resist the pressures eventually exerted on a seal by
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.
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
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
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

7.4 *APPENDIX 4 - 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
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
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
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
SF	Spent Fuel
Sv	Sievert
U/G	Underground
UCS	Unconfined Compressive Strength
URL	Underground Research Laboratory
Vw	Vitrified High Level Waste
WP1	Work Package 1