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# Äspö Hard Rock Laboratory

## Project description
## Cluster Repository Project

## A basis for evaluating and development concepts of final repositories for high level radioactive waste

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August 2001

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# ABSTRACT

The Cluster Repository Project (CROP) is an international Thematic Network funded by the European Commission (EC) within the 5th EURATOM framework programme (1998-2002), specific research and training programme: “Key action Nuclear Fission” under contract FIR-CT2000-20023. The project objectives’ are to evaluate and compare results from investigations of engineered barriers in underground laboratories for development and improvement of present and future concepts for disposal of highl level radioactive waste.

The aim of the cluster project is to create a forum for exchange of information on repository design, construction and operation. The expected improved knowledge will give better insight in the performance of repositories and yield improved concepts, particularly with respect to safety margins, and it can facilitate the description of the performance of repositories to the public. The work is focused on design, construction and modelling of engineered barrier systems, and on experimental procedures. Major issues are: Assessment of the function of EBS, Understanding of and capability to model important processes, and System optimisation and development of practically applicable concepts.

The different geological media has led to different problems in designing, construction modelling and operation of underground laboratories (URL). The individual experience gained herein is believed to be of great value to the organisations and serve as catalyst in future development of safer national repository concepts.

# SAMMANFATTNING

Cluster Repository Project (CROP) är ett internationellt och EC-stött arbete med syfte att utvärdera och jämföra resultat från undersökningar av ingenjörsbarriärer i underjordiska laboratorier för utveckling och förbättring av nuvarande koncept för slutförvaring av högaktivt avfall.

Iden med projektet är att åstadkomma ett forum för utbyte av information rörande design, byggande och handhavande av slutförvar med ändamålet att optimera det vetenskapliga nätverket av nyckelexperter i de medverkande länderna. Den förväntade ökade kunskapen, kommer att ge djupare insikt i förvarsfunktionerna och leda till förbättrade koncept, särskilt avseende säkerhetsmarginalerna, och den bör kunna underlätta beskrivningen av funktionen hos slutförvar för allmänheten.

Arbetet fokuseras på utformningen av ingenjörsbarriärerna (EBS) och rör materialval, byggande och modellering och också provningsförfarandena i respektive underjordlaboratorium. Viktiga frågor är: Värdering av EBS, Förståelse av fysikalisk/kemisk/biologiska processer och möjligheter till teoretisk modellering av dem, samt Systemoptimering och utveckling av förbättrade, praktiska och säkra koncept.

De skilda geologiska medierna har inneburit olika problem vid design, byggande, modellering och användning av underjordslaboratorier (URL). De vunna erfarenheterna förväntas bli av stort värde för de berörda inom alla organisationer och verka som katalysator vid den framtida utvecklingen av säkrare nationella slutförvarskoncept.

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# 1 BACKGROUND

Several national underground laboratories for studying the possibility of safe deep disposal of radioactive waste have been in operation for different periods of time. They represent different geological media, such as crystalline rock in Sweden (AEspoe), Finland (Olkiluoto), Switzerland (Grimsel), and Canada (Pinawa), bedded salt and salt domes in the US (WIPP) and Germany (Asse and Gorleben), respectively, and dense clay beds in Belgium (Mol)and Mont Terry. The different host materials imply different problems in the respective countries, which has led to different design and instrumentation of the underground laboratories (Figure 1). However, many of the engineered barriers have a similar function and despite obvious differences in various respects many of the solutions and techniques are believed to be applicable also to other concepts. The results from the testing of a number of components, primarily clays and near-field rock, are hence assumed to be valuable to all the organisations. It is probable that improved technical concepts will evolve from joint analyses of the present ones.

The aim of the cluster project is to create a forum for exchange of information on repository design, construction and operation with the purpose of promoting scientific networking among key organisations in the involved countries. The expected improved knowledge, particularly with respect to safety margins, will resolve a number of problems involved in selecting accurate theoretical models for performance assessment and in describing the function of repositories to the scientific society and the public. The work is focused on design, construction and modelling of engineered barrier systems, and on experimental procedures.

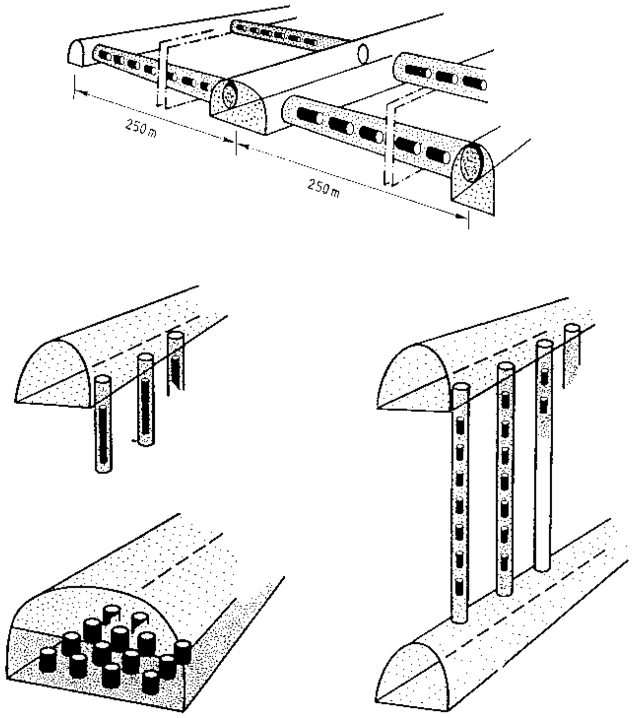



***Figure 1.*** *Examples of design principles of HLW repositories [1].*

# 2 OBJECTIVES

The aim is to engage implementors and organisations responsible for handling and disposal of high level radioactive waste in synthesising experience from underground laboratories (URL) with respect to:

- Design and construction of repositories in different geological media considering feasibility and short- and long-term performance with respect to isolation of radioactive waste products

- Characterisation and quantification of rock structure and physical properties as a basis of modelling and calculation of heat transport, groundwater flow, and physical and chemical interaction of the host medium and engineered barriers systems (EBS)

- Composition and design of EBS, including selection, preparation and application of canisters, buffers and backfills, and quality designation

- Modelling of the performance of EBS (determination and modelling of thermal and wetting/drying processes, gas evolution and migration, stress and strain, and chemical processes including microbial activities, and longevity) for getting a basis of calculating dose rates and safety factors

- Optimisation of EBS composition and dimensions, development of alternative systems and configurations

# 3 RATIONALE

## 3.1 Relevance to repository performance

The performance of the engineered barriers largely determines the net isolating potential of repositories in any geological environment, and the study is hence focusing on the EBS. Selection and design of suitable barriers are naturally of fundamental importance to the project, for which adequate conceptual physico/chemical models and relevant numerical models are required. The state of knowledge in these respects is believed to be raised considerably by the exchange of information and assessment of models in the project.

## 3.2 Current state of knowledge

### 3.2.1 Near-field rock

The performance of the near-field geological host medium gives the boundary conditions for the EBS, and relevant characterisation of the respective media - rock, salt, clay - is required for practical assessment of the applicability of various construction techniques as well as for modelling and calculating the hydraulic and mechanical performances of the EBS.

Different current approaches to model the host medium with respect to structural build-up, groundwater flow paths, stress/strain, thermal conductivity, and chemical performance will be defined, discussed and tested in the project.

### 3.2.2 Buffers and backfills (EBS)

The various national studies have led to certain degrees of understanding, conceptualisation and mathematical modelling of the processes that determine the performance of the barrier components, i.e. canister, buffer and backfill, taking the interaction with the surrounding rock into consideration. For a Swedish repository concept located in crystalline rock, comprehensive laboratory tests and field experiments in the Stripa Mine and AEspoe Hard Rock Laboratory have yielded both practical experience and opportunities to test conceptual and theoretical EBS models [1,2,3,4,5]. Similar tests have been conducted by organisations that have the responsibility for handling and final disposal of high-level radioactive waste in other countries with the same geological conditions or where salt or dense clay are considered as host media.. The processes of interest are commonly referred to as thermal/hydraulical/mechanical/chemical/ biological (THMCB).

The domestic projects have covered a number of major topics but coupled processes (THM) have only been investigated and modelled to a small extent due to limited access to suitable field test sites and budget restrictions. Close international co-operation is hence a possibility for development and assessment of numerical tools for predicting and evaluating the integrated performance of the engineered barriers and the confining host medium. This concerns modelling of water saturation of the buffer under actual thermal gradients (TH) and rock structure conditions, considering also the associated chemical processes (C), and mechanical (M), i.e. rheological, functions like consolidation and expansion of the buffer and backfill. Many of the coupled processes are known to be very complex and it will be required to make additional conceptual descriptions and suggest upgrading of already developed codes. For some processes it may be necessary to identify and define models both for simple practical use and for scientific purposes. The ultimate evaluation of the validity of the various conceptual and numerical models describing several major processes will be made by comparing predictions and measured results of past, planned and ongoing full scale experiments (Stripa Project, Prototype Repository Project, FEBEX, etc).

A number of practical issues like preparation and handling of buffer blocks, application of backfills, and construction of tight plugs, have been studied in separate large scale experiments but the knowledge and experience are limited. The present project will give opportunities to improve the practicality of several activities and to give training in planning and logistics. Quality designation will be in focus of all parts of the project.

Attempts will be made to identify and define current THMCB models for explaining and predicting the maturation and performance of EBS components in short- and long-term perspectives, as well as to investigate how accurate the models are .

# 4 WORK PLAN ISSUES

## 4.1 Near-field host medium

The structural constitution of the near-field host medium controls the advective flow along and around holes or tunnels that contain embedded canisters with radioactive waste, and it also determines the inflow into and flow through the buffer and backfills. It further determines how tectonically induced movements will affect holes and tunnels with EBS in the form of buffer and backfills. Different current methods for structural characterisation and visualisation of the rock, primarily the near-field rock, will be applied to the different URL rock masses for identifying differences and to find out if the methods can be optimised and generalised for making comparisons possible. The current models of interest are those describing:

- General and detailed structure with respect to the presence and nature of discontinuities in the host medium
- Geological constitution
- Hydraulic characterisation
- Mechanical constitution, properties and behaviour of the test site (stress/strain properties, failure by fracturing and fracture propagation)
- Thermal characterisation
- Chemical characterisation (groundwater composition, redox conditions)

## 4.2 EBS components

### 4.2.1 Canisters

The canisters need to have sufficient mechanical strength and to interact mechanically and chemically with the buffer and rock in a predictive manner. The project work will comprise description of the philosophy behind proposing the various canister concepts, and the canister prototypes selected and manufactured for the respective URL experiments.

The heat production of the waste in URLs is simulated by use of electrical heaters and models for calculating the heat production and temperature evolution in the near-field and far-field will be examined and evaluated.

### 4.2.2 Buffer

**General**

The buffer study is of key importance to the understanding of the detailed performance of the various repository concepts and URLs. The work will comprise description of the philosophy behind proposing the respective buffer concepts and the buffer prototypes selected and manufactured for the respective URL experiments.

**Orientation of work**

The work is focused on practical as well as theoretical issues. The first-mentioned deal with selection, preparation, handling and application of buffers as well as determination of their properties, while the latter concern prediction and evaluation of experimentally recorded thermally affected water saturation and permeation, and strain (expansion, consolidation, creep), as well as of chemical changes and gas and microbial processes.

**Modelling**

Thermally controlled processes involving hydration/desiccation, strain (expansion, consolidation, creep) and homogenisation, and transport processes (flow, diffusion), as well as chemical processes (ion exchange, dissolution/precipitation, mineral alteration) in the buffers have all been modelled in most of the national programmes and comparison of the models and of theoretically and recorded experimental data is believed to illustrate their validity.

### 4.2.3 Backfill

Backfilling will be made of deposition and transport tunnels and of shafts in all sorts of repositories. The backfill material must be compatible with the buffer and the host medium, like clay-based soil in repositories in crystalline rock and salt in repositories in salt formations. The criteria are, firstly, that it must have an acceptable hydraulic conductivity with respect to the surrounding medium, secondly that it remains physically and mineralogically stable, and thirdly that it provides mechanical support to the surrounding geological medium. Like for the buffer, the physical properties must be defined for which the national studies are expected to serve as a database. The techniques for application of the backfill will naturally be considered and evaluated.

An inventory will be made of models that can describe the mechanical behaviour, particularly with respect to the interaction with the buffer and the host medium. For repositories of KBS-3 type, consolidation under the swelling pressure exerted by the buffer is a typical issue, while interaction with a converging surrounding is a major issue for repositories in salt and clay. Their applicability will be investigated by comparing predictions and actual recordings.

### 4.2.4 Plugs

Plugs are required in all types of repositories for temporary and permanent sealing. The two major requirements are: 1) The plugs have to resist high piezometric pressures in addition to the effective pressure exerted by the backfill, 2) The plugs must remain physically stable during the prescribed lifetime, and 3) The plug material must not cause significant degradation of the buffer and backfill by chemical attack. The latter problem may be significant for the case of permanent concrete plugs contacting smectitic backfills. Solid salt interacting with such backfills may have an impact on the stability of the smectite crystallites and even if they are preserved, there will be changes in the performance of the backfill because of possible dehydration and cation exchange processes, yielding an increase in hydraulic conductivity and a loss in swelling pressure. A possible concept of a permanent plug in rock, salt or clay is a masonry of precompacted blocks of smectitic clay (Figure 2).

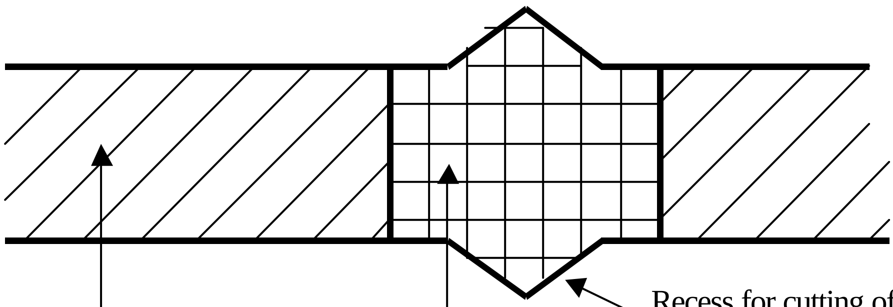



***Figure 2.*** *Principle for construction of permanent plug consisting of a masonry of precompacted blocks of smectite-rich clay like certain bentonites.*

For temporary plugs there is a need for finding alternatives to the rigid concrete plugs that have been constructed in the Swedish URLs primarily because of the long construction time and high cost but also with respect to longevity. This is an example of problems that may well be solved through the international co-operation in the project.

## 4.3 Construction of underground laboratories

### 4.3.1 Experience

Significant parts of a complete repository have only been simulated in a few underground laboratories and the experience from repository construction is hence very limited. However, with the know-how gained from the larger URLs it should be possible to predict difficulties and suggest the most suitable ways of constructing complete repositories according to the various concepts. As to activities on a smaller scale, the construction of representative parts of the national concepts, i.e. short segments of a deposition tunnel or one or a few deposition holes, has been implemented in all underground laboratories and yielded much information, like in the laboratories at Pinawa, Mol, Grimsel, WIPP, Kamaishi and Olkiluoto. Comparison of such information will increase knowledge on deep excavation for URLs as well as for the design and construction of forthcoming repositories for final storage of HLW.

### 4.3.2 Major issues

The reaction of the rock to excavation of deposition tunnels and large holes is of primary importance for the excavation-induced disturbance (EDZ, cf. Figure 2) and such information will be provided by SKB:s acoustic emission data from the Aespoe experiments and by strain measurement in holes close to and extending from the deposition holes. Similar information is available from underground laboratories in other crystalline rock masses, like in the URLs of Finland and Canada, as well as in salt and in dense clay. Results from measurements of the hydraulic conductivity of the disturbed zone are available from large-diameter holes in Swedish and Finnish crystalline rock and they will be examined and correlated with rock structure models and rock mechanical data.

## 4.4 Instrumentation

The host medium, backfill and buffer have been instrumented for recording important processes in all URLs and much information has been gained with respect to performance and lifetime. Collection and evaluation of such information will be of value in interpreting and assessing recorded data and in planning and instrumentation of future URLs as well as in monitoring of real repositories. There is a particular interest in the experience from the performance of gauges and sensors used for recording the following properties and processes:

- Hydraulic conductivity of the host medium
- Stresses and displacement in the host medium
- Wetting of buffer and backfill
- Temperature evolution in canister, buffer, backfill and host medium
- Evolution of pore pressure in buffer, backfill and host medium
- Evolution of swelling pressure and displacement in buffer and backfill
- Deformation and settlement of canisters
- Gas accumulation and composition in the buffer
- Chemical composition of the buffer and backfill porewaters and of the water in the host medium
- Salt accumulation in the buffer
- Mineral alteration in the buffer
- Bacterial growth and migration in the buffer and backfill

Much effort has been put in selecting adequate instrumentation for the URLs, and the experience from the choice, assessment, and monitoring, representing different temperatures and chemical ground water compositions in the various URLs, will be of value in the design and construction of future underground laboratories as well as in monitoring future high level waste repositories.

## 4.5 Emplacement techniques and sequence

This study makes it possible to investigate the practicality of the planned procedures for application of buffer components and canisters with high level radioactive waste and to develop alternative, improved techniques. Particularly valuable information will be obtained from the various full scale experiments with emplacement of EBS components (clay buffer blocks, canisters, backfill and plugs.

## 4.6 Expected outcome

The prospects of the project will be of primary use for the design and performance assessment of future high level waste repositories. It is believed to yield numerous technological and economical improvements of the EBS, respecting material choice, manufacturing, design and construction. The major ones are believed to be development, preparation, handling and application of clay materials for embedding waste containers and backfilling of tunnels and shafts, development of cement and concrete materials of high chemical integrity with respect to EBS interaction, development of rock sealing methods and grouts and equipments for cost-effective drilling of large-diameter boreholes for waste containers, and development of equipment and techniques for homogeneous backfilling of tunnels and shafts.

Major expectations are firstly that the technical feasibility and practicality of geological disposal will be demonstrated, and secondly that an improved basis for safety assessment will be achieved by the deepened understanding of the integrated EBS/rock performance through evaluation of the comprehensive conceptual and theoretical modellings that have been made.

A further expected outcome of the project concerns is cost reduction due to optimisation of the repository design with due respect to safety criteria. This has to be based on an improved understanding of the integrated performance of the EBS and the surrounding rock, which is the primary objective of the project.

## 4.7 Problem areas

The most essential components of the test arrangements in URLs are the heaters used for simulating the temperature rise that is associated with radioactive decay. This is because breakdown and malfunctioning or loss of electric power, will ruin major parts of the expensive tests. Redundancy and back-up of the heating units and the instruments need to be considered in future projects, for which the experience gained in the individual national laboratories will be indispensable.

In URLs difficulties may arise in the practical construction and instrumentation activities and in the development and application of theoretical models but there is room for adjustments and significant changes in many respects in contrast to what will be possible in a real repository. Thus, problems may appear in the handling and application of buffer components without jeopardizing the tests since manual operations and use of various auxiliary techniques can be employed. In real repositories, however, serious problems, like difficulties in accurate positioning of the buffer may appear and make accurate and safe emplacement of radioactive waste containers impossible. Hence, all phases in emplacing buffer and canisters must be carefully examined before the techniques can be accepted for use under real conditions. The Prototype Repository Project is therefore believed to be of great importance to all involved parts as are ongoing and preceding projects like FEBEX, Big Ben, and the Stripa BMT experiment.

As to difficulties in describing and modelling the performance of the EBS, already available coupled THM models are believed to be sufficiently useful for predicting and evaluating thermally induced water saturation/desaturation processes and mechanical strain, while the setting of boundary conditions is still a problem.  Information from the various URLs, like the Stripa experiments and ongoing as well as forthcoming supplementary studies, are expected to be helpful in this respect. Chemical and biological modellings are believed to be much more difficult and a primary aim is to develop conceptual models that can later be put in mathematical form, at least with respect to THMC.

# 5 SCOPE

## 5.1 Main project tasks

In addition to the information on practical issues like manufacturing and monitoring of EBS, evaluation and assessment of the integrated performance of EBS and the host medium is of profound interest. Both practical and theoretical issues depend on the characterisation and constitutive structural modelling of the host medium, which is hence a major task. Most important to the project are the properties and behaviour of the EBS, which puts calculation of the integrated performance of the host medium and EBS and comparison of predictions and recordings in focus for assessing the repository concepts. It implies access to relevant ways of describing the performance of individual and interacting EBS components and host medium, for which modelling of coupled processes will be needed. Identification and assessment of the various sorts of conceptual and numerical models that have been used in the URL activities will be made. The following issues will hence be dealt with in the project:

- Modelling
- Predictive calculations
- Data collection, visualisation
- Evaluation of processes from recordings, visualisation
- Comparison of predictions and actual data

## 5.2 Inventory of models and modelling methods

### 5.2.1 Host medium

The regional host medium has to be described and modelled with respect to the geological features, structural constitution, stress state and groundwater conditions, for which various numerical tools have been worked out and applied. They will be examined and assessed in the present project.

### 5.2.2 EBS in host medium

Prediction of various important processes has been made by application of Simple models for scoping calculations, and of more or less Complete coupled thermo-hydro-mechanical (THMC) models of the near-field host medium and buffer and backfill for predicting heat and water transport with respect to changes in mechanical stresses and transient chemical processes. Modelling of long-term chemical and microbiological processes in the buffer, backfill and contacting host medium must also be made in future planning and construction of repositories. The present project will comprise examination and assessment of available models for all these purposes.

## 5.3 Scoping calculations

Scoping calculations are made for preliminary prediction of the thermal evolution and for selection of required initial properties of the EBS, like density and degree of water saturation of buffers and backfills, as well as for selecting suitable instruments for URLs. The codes and ways of predicting the evolution of EBS in the various URLs will be examined and assessed.

### 5.4 Data collection

The very comprehensive number of raw data that were obtained in most URLs makes it difficult to overview the experiments and identify trends, and great effort should therefore be put in identifying and assessing available suitable numerical codes for visualisation of individual and coupled processes. Major processes should be plotted with short time intervals so that the responsible scientific staff can currently overview and evaluate them.

The project comprises examination of the following processes and properties recorded in the field tests with the intention to evaluate and assess the experience gained in the various URLs and to compare predicted and recorded data.

**Maturation**

For repository concepts adapted to crystalline rock and clay host media, the rate of water uptake of initially incompletely saturated buffer and backfill is essential since it controls the temperature evolution and the internal strain generated in the course of moistering, as well as chemical processes like salt accumulation. Several techniques have been used for recording the wetting process like RH-sensors, psychrometers or resistivity gauges and evaluation of their performance will be an important issue in the project

For repositories in salt, maturation is strongly related to time-dependent strain, which has been recorded, particularly in caverns in Germany and the US and there will be good opportunities to evaluate the mechanical creep models.

**Temperature**

Temperature is the driving force of a number of physical and chemical processes in the buffer, backfill and near-field host medium. Comprehensive monitoring and recording have therefore been required in the URLs and a large number of thermal gauges will be installed in future URLs and high level waste repositories. Experience from the national URLs is expected to be of great common value for this purpose.

## Water pressure

The water pressure in buffers and backfills will increase gradually in repositories in rock and clay host media and the natural piezometric pressure conditions will be re-established after a long time. This state will usually not be reached in the testing period in a URL due to the draining function of a number of excavations and interacting geological features. The spatial variation in hydration of buffer and backfills is of great practical importance for their performance and calls for a considerable number of piezometers in the buffer, backfill and host medium. Experience in this respect is expected to deepen the understanding of water flow in geological media very substantially.

## Gas accumulation and composition

Pore gas representing trapped air or gas produced by biological or corrosion processes is of interest for understanding the hydration process and for modelling structural changes in buffers and backfills. Methods for gas sampling in the EBS are therefore of great interest, for which the FEBEX project at Grimsel and the Prototype Repository at AEspoe will provide examples.

## Total pressure

The total pressure, i.e. the sum of the effective (or swelling pressure) and the pore-water pressure in the buffer and backfill as well as at the contact between the host medium and the buffer, is of great value for validation of the THM models and should be frequently measured in field tests. Various methods have been applied in the URLs and evaluation of their accuracy and long term performance will be made in the project.

## Displacements and strain measurements

In the operation phase, wetting, heating and creep of the buffer and backfill will produce strain. The increase in temperature will exert thermo-mechanical loading of the host medium, buffer and canisters and thereby yield strain. Swelling pressure in the buffer, particularly uneven build-up of pressures, may displace the canisters and produce mechanical loading of the walls of deposition holes and tunnels. A major question is whether canisters will sink or rise and development of suitable, sufficiently accurate techniques for recording canister movements is therefore asked for. The matter will be discussed in the project on the basis of laboratory experiments and actual recording in the FEBEX Project at Grimsel and in the Prototype Repository project at AEspoe.

## Groundwater chemistry

Sampling of groundwater for chemical analysis of pore-water in buffers and backfills in situ would be of great value but there is still no well working technique for this purpose. The matter will be discussed in the project.

**Mineral alteration**

Sampling of buffer and backfill is required for determining whether mineral changes have taken place in URLs as illustrated by the Stripa BMT and the Buffer Container Experiment at Pinawa. And it will be made in the Backfill and Plug Test, and the Prototype Repository project at AEspoe and in the FEBEX experiment at Grimsel. The longterm test of buffer material (LOT) at AEespoe is specially dedicated for this task. Alterations will be identified by X-ray diffraction and transmission electron microscopy as well as by determining the caution exchange capacity after termination of field experiments. There is still no well working technique for this purpose in current hydrothermal experiments and the matter needs to be discussed in the project.

**Microbiology**

Microbiological processes in the form of survival, multiplication and migration of bacteria, requires sampling as for mineralogical analyses. Current testing appears to be very difficult and the matter will be discussed in the project.

**Canister conditions**

Surface conditions and corrosion products in the shallow part of canisters can be analysed after the termination of field tests by applying optical and scanning electron microscopy with element analysis. In-situ ultrasonic measurements appear to be possible as well.

## 5.5 Predictive calculations

**Stress/strain conditions, tectonics**

Stress/strain calculations for predicting strain in the near-field host medium can be made by use of 3D finite element codes like the Rocscience Examine3D and Unwedge, 3DEC and the boundary element code BEASY. Other codes will be discussed in the project as will the selection of representative scale-related material data.

**Hydraulic conditions**

Description and prediction of hydraulic conditions in test areas in URLs and in planned repositories can be made by use of a number of codes, like DFN modelling. This matter will be discussed in the project, for which the hydraulic conditions are of absolutely key importance.

**Integrated performance**

Prediction of the behaviour of complete URLs and future repositories, i.e. the integrated physical function of the near-field host medium, buffer and backfill, can be made by use of coupled THM numerical analyses employing e.g. the ABAQUS code and other programmes, which will all be discussed in the project. It is expected that much work will be required in working out accurate conceptual models as a basis for developing mathematical versions.

## 5.6 Evaluation of data and validation of models

The data representing the evolution of temperature and pressures are usually very accurate and current interpretation is a straightforward matter as concluded from the various URLs, while evaluation of processes like canister motion and displacements in the host medium, buffer and backfill is expected to be more difficult. This is also the case for physico/chemical processes in the buffer and backfill and for all of them the time required for evaluation and assessment may be considerable. In some cases upgrading of the theoretical models may have to be made parallel to the experiments and it is estimated that the accuracy in describing many of the mechanisms will be fairly low. Relevant modelling of the physical processes in the buffer close to the canisters can not be made unless supporting laboratory tests have been performed in order to define and describe the macro- and microstructural evolution in the initially drying part of the buffer. Hence, application of coupled THM models must be made with care and due respect to the structural constitution. The same is valid for chemical and microbial processes and complete THMCB models probably have to be relatively simple. These matters will be discussed in detail in the project.

## 5.7 Safety issues

Safety is related to risks for human beings, i.e. staffs in URLs and future repositories, and for possible mishaps in the preparative work on site or for malfunctioning of test components and of power and monitoring systems. The first-mentioned issue is of general character and considered by all the involved organisations. For the test and monitoring systems the following matters.

Despite careful planning of a repository or URL the conditions may turn out to be quite unexpected. This may be the case with respect to:

- The inflow of water into drifts or deposition holes may be substantially higher than can be accepted and may require drainage during the application of the buffer and backfill or sealing by grouting or casting of concrete seals. It might even be that drifts and holes have to be abandoned.

- In certain URLs the pore-water pressure in the backfill is expected to be high, which may cause leakage into the buffer along cable bundles, by which the boundary conditions set for calculation of water uptake of the buffer may not be valid.

- In certain URLs a high salt content of the groundwater will cause corrosion of ordinary gauges and sensors and corrosion-resistant materials like titanium are therefore required. It is necessary to make sure that there are no iron objects in the buffer and backfill because they will produce hydrogen gas that can have an effect on the water saturation and generate electric potentials. Similarly, great care must be taken to avoid damage and exposure of reinforcement bars in concrete plugs located in the test areas.

- In URLs, breakdown of the data acquisition system with loss of all or large parts of stored data may take place. Regular, frequent saving and storage of data will minimise the risk of loosing information.

- In URLs, heater elements in the canisters may fail requiring rearrangement of the power connections, which is possible if there is redundancy through a sufficient number of spare elements.

While these problems are foreseen and countermeasures can be taken, there are others that may be more problematic and have to be considered:

- In URLs, short circuit of the power system in test arrangements behind plugs may damage the project. This problem can be partly avoided by careful testing of the various transmission components before closure but unexpected large strain may cause breakage of cables for power supply and for transfer of output signals from the gauges. The design of the system must therefore include estimation of possible extreme buffer strain.

- In URLs and real repositories, large instantaneous rock deformations shortly after backfilling and plugging due to heat-generated stress accumulation in the rock may affect the buffer and canisters. It may cause changes in rock/buffer interaction and difficulties in interpreting the tests, and also power breakdown by cable damage. The stability conditions in the host medium in the construction and operating phases must hence be carefully considered.

- In URLs, early breakdown of gauges and sensors due to failing cable connections or malfunctioning may be disastrous. Back-up by installing parallel systems of different types of gauges can reduce this problem but it can still not be guaranteed that they survive long-term experiments. This means that safe information on the physical and chemical states of the buffer and backfill can only be obtained by examining samples after the termination of the test, while transient processes will not be known.

All the aforementioned risks of poor performance of instrumentation and EBS components identified in earlier and current underground projects will be discussed and evaluated in detail in the project with the aim of listing procedures and techniques for minimising them in future URLs and monitored forthcoming high level waste repositories.

## 5.8 Time schedule

The general time schedule for the main activities is as shown by Table 1.

**Table 1.** General time table

| Activity | Time after project start, month number |
|---|---|
| Definition of state-of-art and specification of work issues | 6 |
| Description of national repository concepts and the testing of their EBS | 12 |
| Description of conceptual and matehmatical models for predicting THMCB performance of the near-field (EBS in host medium) | 18 |
| Description of application of THMCB models to lab and field tests for verification/validation | 24 |
| Preliminary assessment of the performance of underground laboratories and repository concepts and suggestions for improvement of repository concepts. Outline of final report | 30 |
| Final report on comparison of concepts and recommendations for specific experiments, design and construction of future safe repositories | 36 |

# 6 PROJECT ORGANISATION

## 6.1 General

The Cluster Repository Project will be performed and reported following the guidelines given both in the SKB and AEspoe HRL Quality Handbooks and by the EC. This implies application of scientific principles and regular reporting at meetings on several levels and current documentation in various report series.

Participants in the thematic Network are as specified in Table 2.

Table 2. Contractors in the thematic Network.

| No | Name of organisation | Acronym | Country |
|---|---|---|---|
| 1 | Swedish Nuclear Fuel and Waste Management Co | SKB | Sweden |
| 2 | Studiecentrum voor Kernenergie/Centre d'étude de l'Energie Nucléaire | SCK-CEN | Belgium |
| 3 | POSIVA OY | POSIVA | Finland |
| 4 | Gesellschaft fuer Anlagen- und Reaktorsicherheit | GRS | Germany |
| 5 | Empresa Nacional de Residuos radiactivos S.A. | ENRESA | Spain |
| 6 | Agence National pour la gestion des Déchets Radioactifs | ANDRA | France |
| 7 | Nationale Genossenschaft zur Lagerung radoaktiver Abfälle | NAGRA | Switzerland |
| 8 | USDOE Carlsbad Area Office | USDOE CBFO | US |
| 9 | Ontario Power Generation | OPG | Canada |
| 10 | Geodevelopment AB | GEO | Sweden |

## 6.2 Organisation

### 6.2.1 General

A Project Manager is in charge of the project being assisted by a Technical Co-ordinator. A Steering Committee and two Task Groups are established for governing the work, which will be headed and co-ordinated by SKB. The Parties will have to review their own work in the respective work packages and put together and report relevant material in the prescribed way. The Steering Committee summons meetings and seminars and reviews draft reports.

Major decisions that concern the work and the reports are taken by the Steering Committee, which is also responsible for taking necessary quality and environmental management measures. The Project Manager assisted by the Technical Co-ordinator is jointly responsible for the preparation of documents for reviewing by the Steering Committe and for the information flow throughout the project. Quarterly reports will be prepared by the Project Manager and the assistant Technical Co-ordinator and they are also responsible for the distribution of all reports. Financial statements will be given in accordance with the needs and recommendations of the EC.

### 6.2.2 Project staff

The project will be organised in accordance with the guidelines given in the SKB QA procedures (ISO 9001). The Project Manager for the CROP project (co-ordination against the European Commission in the EC-project) is SKB. Activities in the Cluster Repository Project will be co-ordinated and organised by personnel at AEspoe HRL and Task force leaders. Geodevelopment will assist as Technical Co-ordinator.

### 6.2.3 Organisation of work

The work will be conducted under four headings representing different work packages:

1. Description and function of repositories of different design and located in different types of geological media. Design, construction, application and predicted performance of the near-field in general and engineered barrier systems (EBS) in particular. This part, which will put the EBS concepts and performances in a form that makes them comparable, refers both to the concepts and to the underground laboratory tests.

2. Description of the background for selecting experimental procedures, instrumentation, recording and documentation of data for the respective underground laboratories. Evaluation of the performance and comparison of the experience from the underground laboratory tests.

3. Description of the function of EBS as evaluated from the tests in underground laboratories and accessory bench- and laboratory-scaled experiments. Specification of conceptual and theoretical models and assessment of the capability to accurately predict important THMCB processes. General estimation of the applicability of specific models to other concepts.

4. Optimisation of design of the near-field including the EBS (package form, composition, manufacturing, thickness and density) and spacing and size of deposition holes or tunnels with respect to the structure, hydraulic, mechanical and chemical properties as well as stress conditions in the host medium. Selection and conceptual adaptation of most suitable techniques for repository construction including temporary drainage, sealing, application of waste packages, and plug construction.

Focus will be on the behaviour of and processes in the EBS, primarily the buffer materials used for embedding waste containers, and backfill materials in tunnels and shafts. The work includes examination and interpretation of information and experience from the national URLs and comparison of different design principles and construction techniques. Comparison of theoretical predictions with the outcome of performed experiments is expected to demonstrate the validity of the THMCB models, and to indicate optimum design principles with respect to safety criteria, practicality and cost. Thus, it is believed that, at present, the EBS designs are not optimised with regard to performance, operational practicality (mode of emplacement and quality assurance), safety or costs. Improved EBS design may have advantages including:

1. Increased robustness with respect to short- as well as long-term performance considering both chemically induced degradation and tectonically generated disturbance (THMCB)

2. Improved transparency of the safety case, involving optimisation of EBS dimensions and use of models for coupled processes (THMC)

3. Improved practicality and quality assurance of manufacturing and emplacement operations

4. Reduced cost without compromising safety

The function of EBS is strongly dependent on the physical properties of the surrounding host medium: the hydraulic conductivity of the excavation-disturbed zone, the rheological behaviour of the near-field host medium, and the groundwater chemistry. Hence, the integrated function of the entire near-field, consisting of EBS as well as of the rock around deposition holes or tunnels, are basic to the project. The comprehensive experience from the large-scale underground experiments, providing a large amount of recordings, is believed to form a solid basis for synthesis of the overall function of proposed and improved repository concepts.

### 6.2.4 Work packages

The activities are grouped to form four work packages:

**WP1.** Design and construction of engineered barrier systems (EBS)

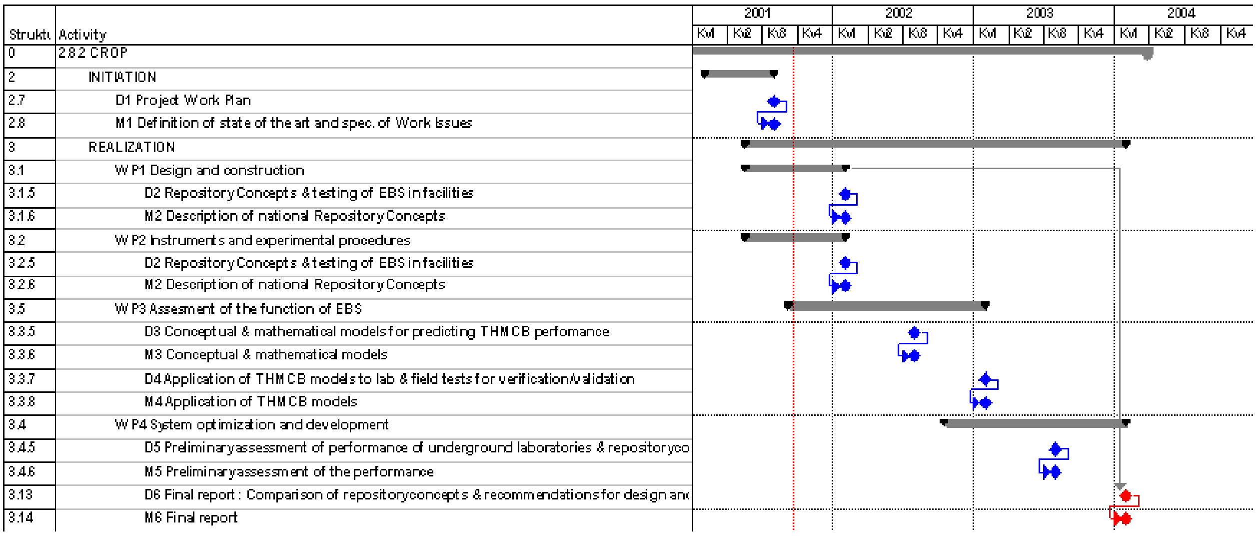
**WP2.** Instruments in the near-field rock and EBS, and experimental procedures

**WP3**. Assessment of the function of EBS and the understanding of and capability to model the most important processes

**WP4.** System optimisation and development of practically applicable concepts

For maximum practicality the work will be divided into sub-packages related to WP1-WP4, in which all participants shall be involved. Two Task Groups (TG) will be established for heading, evaluating, discussing and reporting of the work performed in the four WPs.

The work is proposed to be scheduled in the following fashion:




## WP1. Design and construction of engineered barrier systems (EBS)

*Work plan and Sub-packages of item WP1*

The work will commence with the compilation of "country annexes" which include summation of main data and conclusions from relevant technical reports describing national radioactive waste programmes and results from tests in underground laboratories. The annexes should describe and comment the various items specified under headings I, II, and III listed below. Documents should be compatible with the corresponding documents prepared by the other participants and consist of no more than 15 pages (single line spacing), i.e. about 5 pages per heading. The co-ordinator will assure the consistency of the annexes.

A summary report (part of Deliverable #2) will be compiled by the co-ordinator highlighting the principal technical solutions. The report will be prepared in close co-operation with the other participants.

*I. Detailed description of the respective repository concepts.*

- Waste types and amounts
- Principles of waste isolation
- Host medium (geology, seismicity, rock stress conditions, rock mechanics, hydrology and geochemistry)
- Design criteria (Flow through repository, long term requirements, release of radionuclides)
- Geometry (depth, size, 1D, 2D, 3D)
- Thermal loading

*II. Principles for design of deposition holes and tunnels with special respect to the EBS performance*

- Geometry of deposition holes and tunnels and EBS
- Plugs, temporary and permanent
- Petrology, soil composition
- Piezometric conditions
- Chemical characterisation
- Host medium stability and deformation in a short and long perspective
- Heat evolution
- Boundary conditions for the EBS

*III. Positioning, construction and manufacturing of holes, tunnels, plugs, heaters and EBS. Stabilisation of host medium. Arrangements for creating suitable conditions in different phases*

<u>Host formation (rock, salt and clay)</u>

- Geologic medium (petrology, structure, and hydrology)
- Positioning of holes, tunnels, and shafts
- Excavation of shafts and tunnels
- Boring of deposition holes
- Boring and sealing of holes for characterisation
- Stabilisation of host formation, temporary and permanent
- Positioning, design and construction of plugs
- Means of creating suitable conditions in different phases (drainage, irrigation)

<u>Buffer and backfill</u>

- Selection of materials
- Quality designation and control
- Preparation and application of buffers and backfills

<u>Power and auxiliary systems</u>

- Main and back-up electric power and water systems
- Transmission, cables, pipes, pumps, lead-through arrangements
- Control, maintenance

<u>Plugs</u>

- Selection of material in temporary and permanent plugs
- Construction of plugs

## WP2. Instruments and experimental procedures.

*Work plan and Sub-packages of item WP2*

The work will commence with the compilation of "country annexes" which include summation of main data and conclusions from relevant technical reports describing test set-ups, experimental procedures, and results from tests in underground laboratories. The annexes should describe and comment the various items specified under headings I, and II listed below. Documents should be compatible with the corresponding documents prepared by the other participants and consist of no more than 15 pages (single line spacing), i.e. about 5 pages per heading. The co-ordinator will assure the consistency of the annexes.

A summary report (part of Deliverable #2) will be compiled by the co-ordinator highlighting the principal technical solutions and main conclusions from the performed tests. The report will be prepared in close co-operation with the other participants.

*I. Test of repository concepts in underground laboratories*

Experimental procedures

- Experimental set-up for testing specific processes
- Design and manufacturing of heaters
- Sampling in the course of the testing
- Sampling in the course of excavation at the termination of field experiments

*II. Selection and application of instruments for recording of major processes in field tests and in the operative phase of repositories*

- Thermal evolution
- Pressure in host medium
- Effective pressure
- Water pressure in host formation
- Water pressure in buffers and backfills
- Water flow in the host formation including de-/resaturation
- Water flow in the buffer and backfill including de-/resaturation
- Gas flow in the buffer and backfill
- Displacements in the near-field host formation
- Displacements in the buffer (movement of canisters)
- Chemical element distribution
- Data acquisition (frequency, storage, accessibility, processing)

## WP3. Assessment of the function of EBS and the understanding of and capability to model important processes

*Work plan and Sub-packages of item WP3*

The work will commence with the compilation of "country annexes" which include summation of main data and conclusions from relevant technical reports describing tests of mathematical models, the parameters needed for calculations, and results from application of these models to tests in underground laboratories (Deliverable #3). The annexes should also describe and comment the various items specified under headings I, II, and III listed below. Documents should be compatible with the corresponding documents prepared by the other participants and consist of no more than 15 pages (single line spacing), i.e. about 5 pages per heading. The co-ordinator will assure the consistency of the annexes.

A summary report on items I, II, and III will be compiled by the co-ordinator giving condensed and stringent descriptions of conceptual and theoretical models, verification/validation of them through field data, and drawing main conclusions from the performed modelling work (Deliverable #4). The report will be prepared in close co-operation with the other participants.

*I. Modelling and assessing the physical function of EBS*

- Evolution of heating
- Evolution of wetting/drying
- Evolution of swelling pressure
- Evolution of water pressure in the near-field host formation, buffer and backfill
- Evolution of internal movements in the buffer and backfill

*II. Description of the interaction of EBS and surrounding rock*

- Characterisation of the near-field host formation (type, structure, porosity, hydraulic conductivity, stress/strain properties)
- Groundwater movement in the near-field host formation
- Ion diffusive interaction of EBS and near-field host formation
- Blasting- and boring disturbance
- Buffer migration into fractures
- Convergence of tunnels, shafts and deposition holes
- Tectonically induced movements in the host formation

*III. Modelling and assessing chemical and biological processes in the EBS*

- Evolution of chemical environment in the buffer (pH, redox conditions)
- Carbonate chemistry
- Precipitation/cementation
- Impact of corrosion products of iron
- Assessment of the capability of coupled hydro/geochemical and diffusion/exclusion codes to describe ion and colloid transport and bacterial migration and multiplication

**WP4. System optimisation and development of practically applicable concepts**

*Work plan and Sub-packages of item WP4*

The work is planned to have the form of seminars and preparation of syntheses for presentation in preliminary assessment reports and in a final document. In the final report each participant will have a separate chapter ("country annex") and a common section forming a synthesis of the respective views will be included as well. This synthesis will be prepared by the co-ordinator in close co-operation with the other participants. The documents represent Deliverables #5 and #6, respectively. Like for the other WPs the work will refer to various issues – I, II, and III - as listed below.

*I. Overall comparative assessment of different concepts*

- Assessment of the EBS performance with respect to the type, repository location, and structure of the host formation as a function of time
- EBS performance under normal and extreme conditions
- EBS performance with buffer and backfill components of different type and quality

Table 4 is a compilation of the Work Package titles, responsible lead, time plan, and deliverables.

| **No**[1] | **Title** | **Lead contractor No**[2] | **Start month**[3] | **End month**[4] | **Deliverable No**[5] **(ch.6.4)** |
|---|---|---|---|---|---|
| WP1 | Design & Construction of engineered barrier systems (EBS) | 1 | 0 | 12 | D2 |
| WP2 | Instruments & experimental procedures | 1 | 0 | 12 | D2 |
| WP3 | Assessment of the function of EBS and the understanding of and capability to model important processes | 1 | 7 | 24 | D3/D4 |
| WP4 | System optimisation and development of practically applicable concepts | 1 | 13 | 36 | D5/D6 |

[1] Work-Package number: WP1 – WP n
[2] Number of the contractor leading the work in this work-package.
[3] Relative start date for the work in the specific work-packages, month 0 marking the start of the project, and all other start dates being relative to this start date.
[4] Relative end date, month 0 marking the start of the project, and all end dates beeing relative to this start date
[5] Deliverable number: Number for the deliverable(s) / results(s) mentioned in the work package: D1-Dn.

*II. System optimisation and development of improved practically applicable concepts*

- EBS performance in repository concepts of other types than the investigated ones (other deposition modes, other buffer materials etc)

Optimisation and outlining of practically applicable concepts

*III. Compilation of Final Project Report*

- Compilation of experience, data, syntheses
- Discussions and conclusions
- Formulation of recommendations

### 6.2.5 Task Groups

Two task groups are planned for heading, evaluating, discussing and reporting of the work:

Task Group 1 – The work comprises the subjects Design and Construction of engineered barrier systems (EBS), and Instruments and experimental procedures (WP1 and WP2).

Task Group 2 – The work comprises the subjects Assessment of the function of EBS and the understanding of and capability to model important processes and System optimisation and development of practically applicable concepts (WP3 and WP4).

A meeting frequency of once per half year for each Task Group is planned. Additional meetings between the co-ordinator and the Parties may be required.

## 6.3 Data management

Data that are collected in the CROP Project are filed by each organisation collecting them. The data should be accompanied with a description of their origin and they will be stored in a commonly accessible format. The Project Manager is responsible for administration of handling and quality assurance systems of all data.

## 6.4 Reporting

Reporting will regularly be made in:

- Six months reports (MPR)
- Annual scientific/technical reports (STPR)
- Mid-term report on scientific and technical achievements

Documentation will be made in the following classes, in SKB:s report series:

- International Technical Documents (ITD)
- International Progress Reports (IPR)
- Technical Reports (TR)

Technical documents including a detailed activity plan and a quality plan will be prepared for each main task before the execution of work. The Project Manager is responsible for production and quality of the technical documents.

Six months reports will be prepared by the Chair of the Task Groups and Annual Reports by the Project Manager. Specific technical reports termed “deliverables” are the ones specified in Tables 3 and 4.

The final report will be prepared under the leadership of the Project Manager but in close co-operation with the parties. It has the following preliminary organisation:

1. General, description of national URLs
2. Description of test programmes in the respective URLs
3. Description of construction, instrumentation and test procedures
4. Predictions of THMCB processes, description of models
5. Results of THMCB measurements
6. Evaluation of results with conclusions on the relevance, validity and accuracy of conceptual and theoretical models
7. Applicability of national models and design features to other repository concepts
8. Outline of improved repository concepts
9. Discussion and conclusions. Practical value of the project
10. Recommendations for further work
11. Summary.

**Table 4.** Deliverables

| **Deliverable No** | **Deliverable title** | **Delivery date** | **Nature** | **Dissemination level** |
|---|---|---|---|---|
| D1 | Project Work Plan | 6 | Re | PU |
| D2 | Repository Concepts & Testing of EBS in facilities | 12 | Re | RE |
| D3 | Conceptual & mathematical models for predicting THMCB performance | 18 | Re | RE |
| D4 | Application of THMCB models to lab & field tests for verification /validation | 24 | Re | RE |
| D5 | Preliminary assessment of performance of underground laboratories & repository concepts | 30 | Re | RE |
| D6 | Final report: Comparison of repository concepts & recommendations for design & construction of future safe repositories | 36 | Re | PU |

# 7 REFERENCES

The present list contains only SKBs references. It will be extended later to comprise also references to other sources.

1. **Pusch R, 1994**. Waste Disposal in Rock.. Developments in Geotechnical Engineering, 76. Elsevier Publ. Co (ISBN: 0-444-89449-7).

2. **Pusch R, Nilsson J, Ramqvist G, 1985**. Final Report of the Buffer Mass Test – Volume I: scope, preparative field work, and test arrangement. Stripa Project Technical Report 85-11. SKB, Stockholm.

3. **Pusch R, Börgesson L, Ramqvist G, 1985**. Final Report of the Buffer Mass Test – Volume II:test results. Stripa Project Technical Report 85-12. SKB, Stockholm.

4. **Börgesson L, Hernelind J, 1999**. Coupled thermo-hydro-mechanical calculations of the water saturation phase of a KBS-3 deposition hole. SKB Technical Report TR-99-41, SKB, Stockholm.

5. **Dahlström L-O, 1998**. Test Plan for the Prototype Repository. Äspö Hard Rock Laboratory Progress Report HRL-98-24, SKB, Stockholm.