R-04-60

Deep repository
Underground design premises

Edition D1/1

Svensk Kärnbränslehantering AB

September 2004

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ISSN 1402-3091
SKB Rapport R-04-60

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Keywords: Deep repository, Underground design, Risk analysis, Rock mechanics, Hydrogeology.

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Preface

This report proposes design premises and methodology for application in the preliminary design of underground excavations within the framework of SKB's site investigations.

The design premises and supporting instructions for rock mechanical and hydrogeological analyses are a result of planning work carried out between the autumn of 2002 and the spring of 2003. Other overall planning has also been done at the same time for the Deep Repository Project. The first draft underwent revision following a seminar on 30 June 2003 primarily with respect to structure and coordination aspects within the project, as well as certain factual questions. That version served as a basis for an application exercise based on site descriptive model version 1.1 Forsmark. The purpose of the application exercise was to:

- Test relevant portions of the proposed methodology for rock engineering for the initial site investigations (ISI).
- Evaluate the application of preliminary design requirements.
- Identify and develop proposals for collaboration between design and site and site modelling units for the best possible feedback in future work, especially iterations for meeting the needs of design.
- Identify and develop proposals for collaboration between safety assessment and design for realistic proposals for site adaptation.

The design application exercise was evaluated at the end of 2003 and its results serve as an important basis for revisions. The update was commenced with a workshop in February 2004, where the goals were established.

The present work has been continuously discussed and reviewed by a reference group consisting of Lena Morén, Ann Emmelin, Stig Petterson, Eva Widing, all SKB, Håkan Stille, KTH, Johan Andersson, KTH/Streamflow AB, and Derek Martin, Univ. of Alberta. The working group has consisted of Lars Rosengren, Rosengren Bergkonsult AB, Anders Fredriksson, Golder Associates AB, Mats Holmberg, Tunnel Engineering AB, and the undersigned. Extra resources were used for Appendix 2. They were Åsa Fransson and Magnus Liedholm, Sweco, Magnus Eriksson, KTH and Nils Outters, Golders. Ingvar Rhén, Sweco and Jan-Olov Selroos, SKB, supported the reference group in the hydrogeological issues.

Stockholm, 10 May 2004

Rolf Christiansson

Contents

1 Introduction

1.1 Deep repository programme

The process of siting, building and operating a deep repository is divided into the following phases: feasibility study phase, site investigation phase, construction and detailed characterization phase, initial operating phase and regular operating phase. The work leading up to the submission of an application for siting of the deep repository is pursued in project form: the Deep Repository Project. The site investigation phase (SI) lasts until a siting permit is obtained.

Site investigations have been conducted since the beginning of 2002 at two sites in Sweden: 1) The Simpevarp and Laxemar areas in the municipality of Oskarshamn and 2) the Forsmark area in the municipality of Östhammar.

1.2 Site investigation phase

The generic programmes for the site investigations, SKB 2001a and SKB 2000a, describe the main features of the planning for the site investigations, including what will or can be measured and what methods will be used.

The site investigation phase provides the broad knowledge base that is required for evaluating the suitability of potential site for a deep repository. The material must be comprehensive enough to:

- show whether the selected site satisfies fundamental safety and civil engineering requirements,
- permit comparisons among sites, and
- serve as a basis for adaptation of the deep repository to the properties and characteristics of the site with an acceptable impact on society and the environment.

The site investigation phase (SI) is divided into two main stages: initial site investigation (ISI) and complete site investigation (CSI). The main purpose of the initial stage is:

- To identify and select the site within a specified candidate area that is deemed to be most suitable for a deep repository and thereby also the part of the area to which further investigations will be concentrated, and
- To determine, with limited efforts, whether the feasibility assessment of the suitability of the candidate area is confirmed by data from depth.

The purpose of the complete site investigations is to gather the material that is required to select a site and apply for a permit for the deep repository. This means that knowledge of the rock and its properties needs to be increased so that:

- a scientific understanding of the site is obtained as regards current conditions (states) and naturally ongoing processes,

- a site-adapted repository layout can be arrived at,
- an analysis of the feasibility and consequences of the construction of the repository can be done, and
- a safety assessment can be carried out to determine whether long-term safety of the site can be assured.

When site investigations, design work and safety assessment have been completed and the results evaluated from a holistic perspective, SKB will submit an application for the siting of the deep repository on one of the investigated sites. An environmental impact statement prepared in consultation with all concerned parties will be appended to the application, along with other supporting material.

1.3 Activities and products of the site investigation phase

The main activities of the site investigation phase are (1) investigation, (2) site modelling, (3) design, (4) safety assessment and (5) EIA/Communications.

When the site investigations are completed, the activity investigation/site modelling shall have:

- determined the necessary data for the site to enable a site-adapted configuration of the deep repository and assessment of the deep repository's long-term radiological safety to be carried out,
- achieved a fundamental geoscientific understanding of the site, i.e. have analyzed the reliability and assessed the reasonableness of the assumptions made with respect to the current states of the site and ongoing natural processes,
- identified any potential environmental cause that require special considerations during the construction and detailed characterization phase and the operation of the deep repository.

The main product of the investigations/site modelling is a site description. It consists of (a) a document that presents an integrated description of the site (geosphere and biosphere) and (b) digital models for different disciplines (see also section 4.2). After the initial site investigation, a preliminary site description is presented, model version 1.2, which comprises part of the supporting material on which design in accordance with this document is to be based (see section 4.1).

The activities safety assessment and design are the primary beneficiaries of the resulting site descriptions. Design will use the site description to prepare a site-specific layout as a partial basis for a facility description. The prospects for and consequences of the civil engineering work are assessed. When the site investigations are finished, the activity design shall have:

- presented one site-adapted deep repository facility among several analyzed and proven its feasibility,
- identified facility-specific technical risks, and
- developed detailed design premises for the construction and detailed characterization phase.

The main product of the design process is a facility description (see section 4.3). The product of the work described in this document is a presentation of different layout proposals based on site specific conditions and completed analyses. It also presents premises for the different rock works to be carried out, such as assessed requirements on rock support and grouting. A technical risk assessment will be carried out, describing e.g. the uncertainty in the preliminary design. The proposed techniques of the methods for rock excavation, support and grouting as well as a description of the underground set-up are presented as a basis for the facility description. The facility description is developed stepwise. When the initial site investigations have been completed, a preliminary facility description will be presented – Layout D1.

Safety assessment in this report refers to the analyses that are required for evaluation of the long-term safety of the proposed facility design on the site in question. The main product of the safety assessment is a safety report. The safety report presents analyses and assessments of whether long-term safety is ensured for the planned deep repository based on reported investigation results and the proposed repository layout. The safety assessment includes analyses of technical, hydraulic, mechanical and chemical processes around the deep repository as well as calculations of radionuclide transport and environmental impact (with respect to radiation doses and risks).

When the site investigations are completed, the activity safety assessment shall have:

- evaluated the long-term radiological safety of the planned deep repository based on reported investigation results and prepared layouts for the underground facility.

The safety assessment will consist of:

- a thorough description of the appearance or state of the repository system at an initial point in time, e.g. just after construction and closure,
- a survey of what changes the repository could conceivably undergo in time as a consequence of both internal processes and external forces, and
- an evaluation of the consequences of the changes for long-term safety.

1.4 Design process during the Deep Repository Project

During the site investigation phase (SI) the design process is divided into a number of design steps, which are linked to the stages of the site investigation and result in supporting material for various versions of facility descriptions. An overview is provided in Table 1-1. The design work in each new design step is based on the products of preceding design steps and the updated site description based on new information that is generated from the investigations within the framework of the ongoing design step. The different design steps are named D0, D1 and D2. The results of design step D0 (Layout D0) pertain solely to the surface facility and have been completed. The rock engineering within design step D1 (Layout D1) will be carried out based on the present document. The results of the rock engineering comprise a part of the supporting material for a preliminary facility description. The facility description Layout D2 will be based on information from the complete site investigation (CSI).

Design step D1 that is carried out during ISI will present as its main product a preliminary facility description, possibly with alternative layouts for the underground facility for which configuration, constructability and costs are reported.

Table 1-1. Deep Repository Project during the site investigation phase – relationships between different stages, design steps etc. in the Deep Repository Project.

Deep Repository Project during the site investigation phase (SI)				
Stage in SI	**Initial site investigation (ISI)**		**Complete site investigation (CSI)**	
Step in SI	1.1	1.2	2.1	2.2
Model version	1.1	1.2	2.1	2.2
Design step	D0	D1	D2	
Product of the design work in the Deep Repository Project	Sketches of the surface facility (internal study material)	Preliminary facility description, Layout D1	Facility description, Layout D2	

The main product of the design work after CSI is a site-specific facility description with repository layout and assessment of the prospects for and consequences of the civil engineering work for each of the investigated sites. For the chosen site, this site description comprises the supporting material for an application of siting the repository.

When ISI has been completed, an integrated evaluation is made of the results of all main activities by the Project Manager of the Deep Repository Project. Based on this evaluation, the Project Manager issues recommendations and directives for CSI and the design step D2 included in it.

1.5 This document

1.5.1 Contents and validity

Rock engineering comprises a part of the design activities during the site investigations. The present document "Underground Design Premises" (for the deep repository's hard rock facility) contains the preliminary requirements for the design work in design step D1 during ISI. The document is hereinafter called "UDP".

The purpose of the document is to guide the rock engineering work in design step D1 during ISI towards the established goals (see Chapter 2) so that there is a uniformity in the rock engineering work between the sites with respect to content, degree of detail and quality.

The document applies to the rock engineering of a deep repository facility with vertical deposition holes, KBS-3V. Design premises for installations, furnishings, non-structural elements and other systems that are to be built or installed in the hard rock facility are not included in this document.

The premises for the rock engineering work in design step D1 are gathered in UDP, which contains the following chapters:

1 Introduction

2 Goals

3 Organization and quality

4 Design basis

5 Design requirements

6 References

UDP includes two design instructions, which describe in greater detail how certain design steps are to be carried out, see Figure 1-1. Where necessary, UDP refers to these instructions, which can be found in Appendices 1 and 2.

UDP will be revised prior to the complete site investigations, i.e. before design step D2 is begun. This version will be called edition D2/1. Additional updates may be issued within a given design step. Furthermore, UDP may need to be updated prior to the construction and detailed characterization phase.

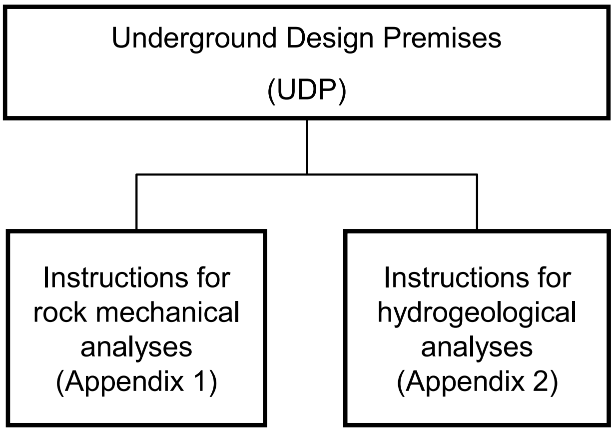


Figure 1-1. *UDP with relevant instructions.*

1.5.2 Reading instructions

The document is divided into requirements, and advice and comments on the requirements. Advice and comments are written with indented and italicized text. Exceptions from this rule are, however, made in sections 1.1–1.6, in which descriptive text is written with normal formatting.

The document is divided into chapters and sections. References within the document follow this principle.

References to other documents are made as follows:

- *Publications of public agencies: Document name and issuer, e.g. BV Tunnel (Banverket)*
- *National Board of Housing, Building and Planning's regulations and handbooks: Document designation, e.g. BBK, BKR, etc.*
- *Reports: Author and year.*

Requirements on one and the same function, design element, etc. may be presented in several chapters and sections. For example, regarding the function stability, requirements on materials, execution and inspection during construction are presented in section 4.5, while requirements on calculations are presented in Chapter 5.

1.6 Definitions and abbreviations

1.6.1 Abbreviations

Abbreviations used are explained below.

BBK	BBK, Boverkets handbok om betongkonstruktioner (Handbook on concrete structures, in Swedish only)
BBR	BBR, Boverkets byggregler (English version: Building Regulations)
BKR	BKR, Boverkets konstruktionsregler (English version: Design regulations)
BSK	BSK, Boverkets handbok om stålkonstruktioner (English version: Swedish Regulations for Steel Structures)
CSI	Complete site investigation. CSI is a stage during the site investigation phase.
ISI	Initial site investigation. ISI is a stage during the site investigation phase.
SI	Site investigation phase. The site investigation lasts until the construction and detailed characterization phase and includes the time taken by the authorities to process the siting application with respect to the Environmental Code and the Law of Nuclear Activities.
UDP	The document "Underground Design Premises, Edition D1/1"

1.6.2 General

Definitions for general terms are given below.

Candidate area	Area within a municipality which has been judged in the feasibility studies to contain possible site(s) for a deep repository.
Client	The Client referred to in this document is the design Client, who is the Project Manager for the Deep Repository Project. The purchaser of the Deep Repository Project is SKB's president.
Deep Repository Project	The project that embraces the site investigation phase, up to submission of a siting application.
Design	All the work of preparing system and building documents and a facility description.
Design coordinator	Unit within SKB that is responsible for execution and coordination of the design of the deep repository facility, its furnishing and required equipment for operation. The design coordinator is unit TU.
Designer	Resource that executes a defined design assignment.
Independent reviewer	Resource contracted by the design coordinator for independent review of the project results.

Investigations	Measurements, surveys, samplings and tests aimed at determining properties and mechanisms. *In SI, this refers to the measurements, surveys, samplings and tests that are carried out in the field and that comprise a basis for the site description.*
Layout	The spatial disposition of the constituent parts. The layout can be visualized in a drawing or the like.
Safety assessment	Assessment whose purpose is to evaluate long-term post-closure safety.
Site	A prioritized part of a candidate area, i.e. the area required to accommodate with good margin a deep repository and its immediate environs, roughly 5–10 km^2 (see SKB, 2001a).
Stage	A clearly defined part of a phase. *The site investigation phase includes the stages ISI, CSI and Application Review.*

1.6.3 Parts

Different parts are defined below (see also Figure 1-2).

Backfill	Backfill refers to the material that is placed in deposition tunnels and the rock caverns in the central area as deposition proceeds.
Backfilling	Backfilling refers to the activity.
Buffer	Diffusion barrier of bentonite surrounding the canister.
Canister	Load bearing steel container with copper shell in which spent nuclear fuel is placed for deposition.
Central area	The part of the hard rock facility in which caverns for operation and maintenance are located, e.g. storage and workshop hall, elevator hall, ventilation hall and connecting tunnels.
Deep repository	Final repository for spent nuclear fuel designed according to the KBS-3 concept. *The reference design is KBS-3V, with vertical deposition beneath the tunnel floor*.
Deep repository facility	The deep repository and the facility parts that are required to build, operate and seal the deep repository. *Can be roughly subdivided into a surface part and an underground part*.
Deposition area	The part of the hard rock facility in which canister deposition will take place. The deposition area includes main tunnels, deposition tunnels, deposition holes, and the rock mass immediately surrounding these openings.
Facility part	Delimited part of the deep repository facility.
Hard rock facility	The excavations for the deep repository and its accesses.

Hard rock part of deep repository facility	The hard rock part comprises rock caverns, shafts and deposition holes with rock support, grouting, drainage, etc., that is required for the openings.
Loadbearing main system	The part of the hard rock facility, including rock mass and rock support, that is used to ensure its loadbearing capacity and durability.
Permanent plug	Facility part that is used to permanently separate or seal various underground openings in the hard rock facility.
Repository area	Central area and deposition areas plus transport tunnels between them, including the immediately surrounding rock mass.
Surface part of deep repository facility	The surface part comprises facility parts above ground for the construction and operation of the deep repository.
Temporary plug	Facility part that is used during the construction and operating phases to temporarily separate or seal various underground openings in the hard rock facility. *Temporary plugs normally consist of reinforced concrete structures.*
Underground part of deep repository facility	Synonymous with the hard rock facility. The underground part comprises ramp – shafts – transport tunnels; central area, deposition areas; technical systems and furnishings under ground.

1.6.4 Underground openings

The various openings in the hard rock facility are defined below (see also Figure 1-2).

Access route	Link between repository area and ground surface, used for transporting material and/or personnel.
Central area's rock caverns	Chambers necessary for operation of the deep repository.
Deposition hole	Chamber for deposition of canisters containing spent nuclear fuel. Besides canisters, deposition holes also contain buffer.
Deposition tunnel	Tunnel from which deposition holes are bored.
Evacuation route	Protected passageway for evacuation in the event of an accident (e.g. fire).
Installation tunnel	Tunnel for technical systems.
Main tunnel	Tunnel leading directly to deposition tunnel and connecting deposition tunnels with other underground openings.

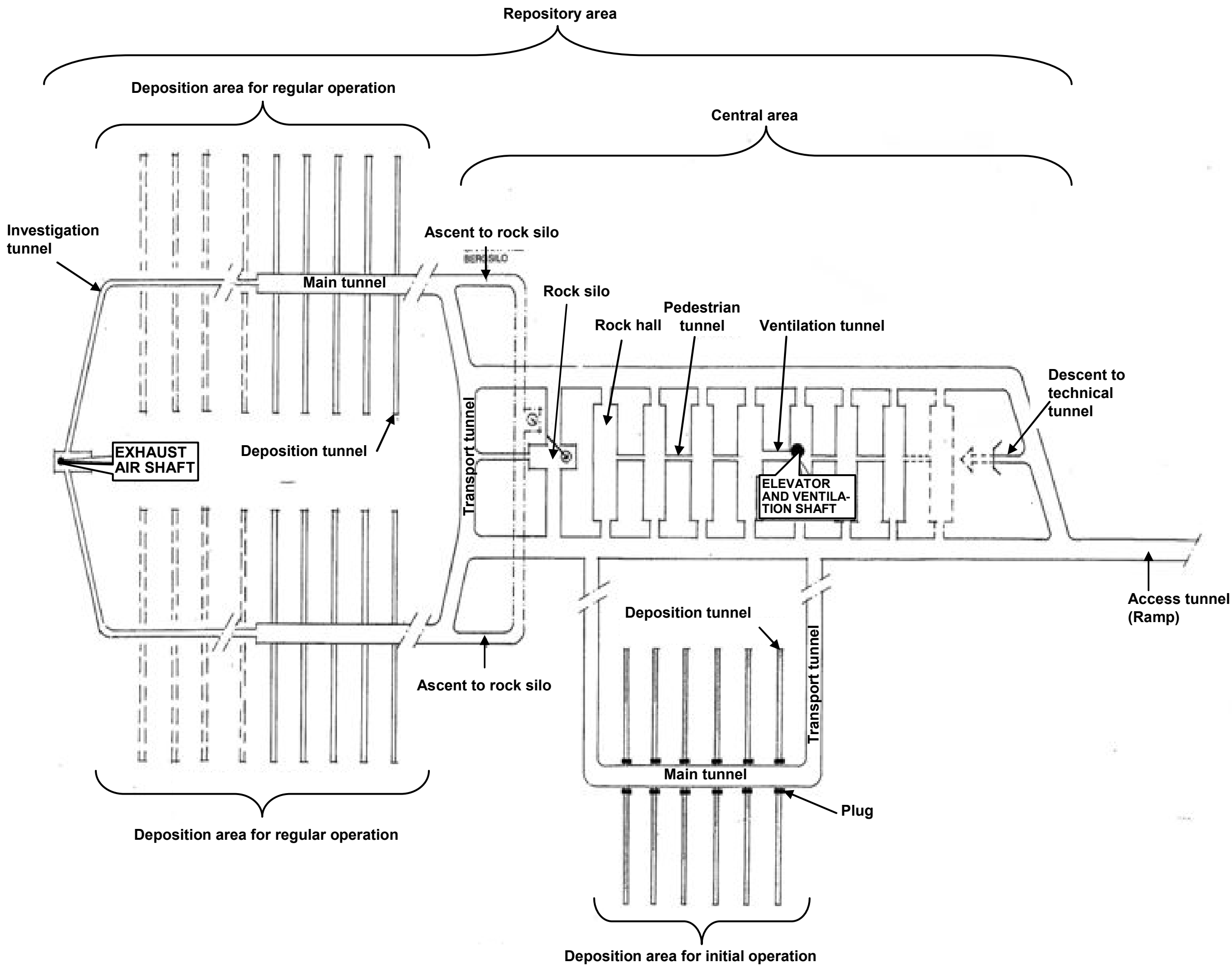


Figure 1-2. *Schematic plan showing certain parts and underground openings.*

Other rock excavation	Excavation that is not deposition tunnel or deposition hole.
Pedestrian tunnel	Connecting passageway between the rock caverns in the central area.
Ramp	Inclined transport tunnel providing access for vehicle.
Rock cavern	Underground opening intended to contain chambers for personnel and visitors, technical systems, other equipment or for loading/unloading that is required for construction and operation.
Rock silo	Chamber for interim storage of rock spoil from blasting.
Shaft	Vertical or steeply inclined connecting passageway.
Tunnel	Underground transport route (personnel, vehicles, material) and/or distribution route (supply, ventilation).
Ventilation tunnel	Installation tunnel specially designed for supply and exhaust air ducts between shafts and ventilation hall.

1.6.5 Documents

Different documents are defined below.

Facility description	The facility description presents the layout of the deep repository facility, the sequential build-out of the facility, systems for construction and operation, and activities. Included in supporting materials for application.
Safety report	The safety report describes analyses and assessments of the post-closure radiological safety of the deep repository. Included in supporting materials for application.
Site description	The site description is an integral description of a site (geosphere and biosphere) and its regional surroundings with respect to current state and naturally ongoing processes. Included in supporting materials for application. *Consists of a site model + written descriptions.*

1.6.6 Other definitions

Other definitions are given below.

Aggressive water	Water which, when analyzed according to the method description "Determination of corrosive properties of water" (National Road Administration), exhibits one or more of the following properties: – pH < 6.5, – hardness < 20 mg Ca/l (total hardness), – alkalinity < 1 meq/l, – conductivity > 100 mS/m.
Design working life	The assumed period for which a structure is to be used for its intended purpose with anticipated maintenance but without major repair.
Internal contour	Actual envelope surrounding the free space in a tunnel, rock cavern, shaft, etc., i.e. inside concrete structure, support, drains, etc.
Rock contour	Actual rock surface surrounding a tunnel, rock cavern, shaft, etc., i.e. outside support, drains, etc.
Rock domain	A region of rock containing rock domains whose properties can be considered to be statistically uniform (see Andersson, 2003).
Theoretical internal contour	Theoretical envelope surrounding the free space in a tunnel, rock cavern, shaft, etc., i.e. inside concrete structure, support, drains, etc.
Theoretical rock contour	Theoretical rock surface surrounding a tunnel, rock cavern, shaft, etc., i.e. outside support, drains, etc.

2 Goals

2.1 Design goals in design step D

The goals of the design work during the site investigations shall be to:

- Present a facility description for the chosen site with a proposed layout for the deep repository facility's surface and underground parts as a part of the supporting material for an application. The description shall present constructability, technical risks, costs, environmental impact and reliability/effectiveness. The underground layout shall be based on information from the CSI phase and serves as a basis for the safety assessment.
- Provide a basis for EIA and consultation regarding the site of the deep repository facility's surface and underground parts with proposed final locations of ramp and shafts, plus the environmental impact of construction and operation.
- Have carried the design work for the entire deep repository facility to the point that it is possible to plan for the construction phase.

SKB shall also show/explain which technical solutions do not need to be engineered in detail in this phase.

Based on these project goals for design, the goals of rock engineering for design step D2 shall be formulated, which is done after design step D1.

2.2 Rock engineering goals in design step D1

The goals of rock engineering during design step D1 shall be to:

- test and evaluate the design methodology described in this document
- determine whether the deep repository can be accommodated within the studied site
- identify site-specific facility-critical issues and provide feedback to:
  - design organisation regarding additional studies that needs to be done,
  - the site investigation organization regarding further investigations,
  - safety assessment regarding which factors control the extent of the repository.
- provide material for consultations according to Chapter 6 of the Environmental Code regarding:
  - the location of the surface facility,
  - the location and extent of the underground facility,
  - theoretical impact (e.g. groundwater draw down).
- provide supporting material for Preliminary Safety Evaluation (PSE) regarding:
  - theoretical extent of deposition areas,
  - estimation of the quantity of injection grout and other "foreign" materials.

  For information regarding PSE, see Andersson et al. (2002).
- present supporting documentation for preliminary facility description.

3 Organization and quality

3.1 Overall project organization

Design comprises one of the Deep Repository Project's main activities, see Figure 3-1 and is ordered as a project from unit TU by the Project Manager. A more detailed description of the Deep Repository Project, its organization and the division of roles between the main activities is provided in the project plan for the project. Rock engineering comprises a part of the subproject Design, as is evident from the project plan prepared for the subproject Design.

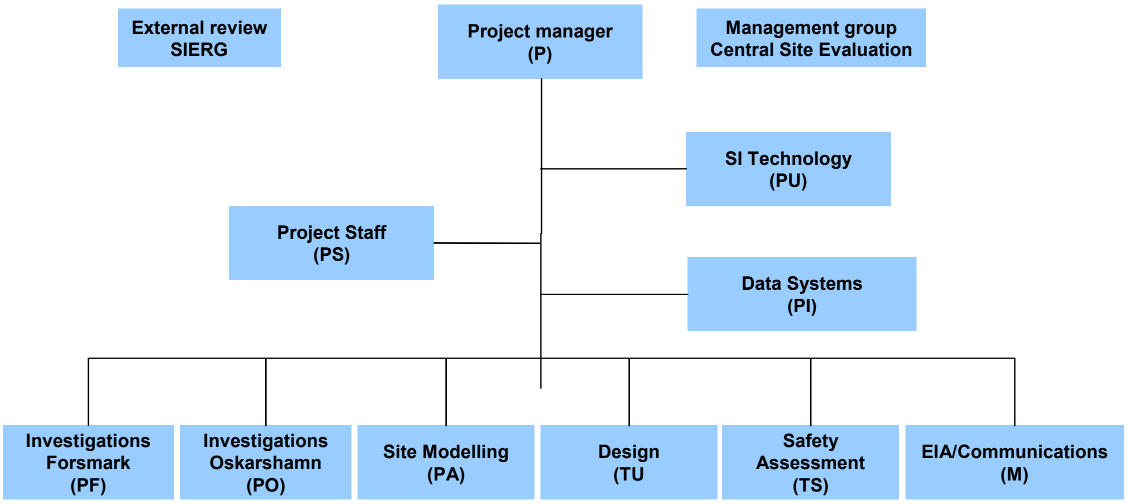


Figure 3-1. *Overall project organization for Deep Repository Project – supporting material for application and construction. The unit/department in SKB's line organization that is primarily responsible for executing the activity is given in parentheses.*

3.2 Roles and responsibilities

The goal of the Deep Repository Project is to produce supporting reports for an application for a siting permit for a deep repository located at Forsmark or Oskarshamn. The project's different activities are led by resources from SKB's department P for project management, investigations and site analyses, resources from department T for design and safety assessment, and resources from department M for EIA and consultation. The project manager for the Deep Repository Project is the Client of the activity design.

Design and its interaction with other activities and products during the initial site investigation phase are shown in Figure 3-2. What constitutes a design basis in design step D1 is explained in Chapter 4.

Design shall collaborate and coordinate its work with investigations/site modelling, EIA and safety assessment, see Figure 3-2. This means, for example, that design should take into account the feedback that it receives.

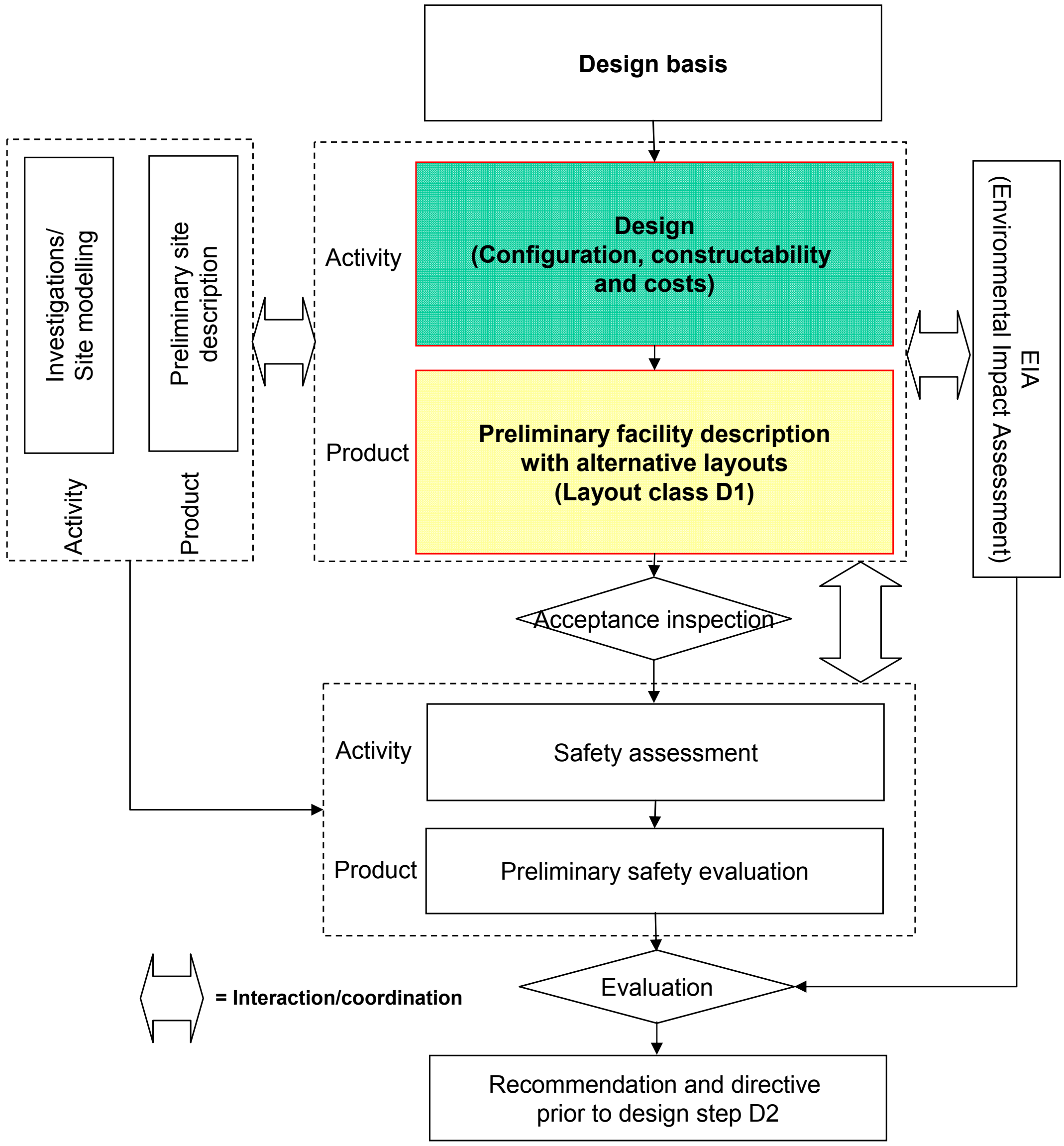


Figure 3-2. *Interaction between rock engineering and other activities and products during the initial site investigation phase.*

> *A systematic feedback from the longterm safety point of view can however not be achieved until a Preliminary Safety Evaluation (PSE) has been carried out based on a proposed layout (design step E, section 5.6).*

A "design coordination" within SKB's unit TU shall take responsibility for design vis-à-vis the Client. The design coordinator shall engage internal or external resources, hereinafter called "Designers", to carry out design, as well as other independent resources, hereinafter called "Reviewers", to review the results of design.

> *The overall organization and interfaces with respect to division of responsibilities and information flow within design and between design and the Client in design step D1 are illustrated in Figure 3-3.*

The design coordinator is responsible for ensuring that the necessary internal and/or external resources are available for design and for review of the results. The design coordinator is also responsible for coordination with other technical areas and disciplines in matters with a bearing on design, see Figure 3-2.

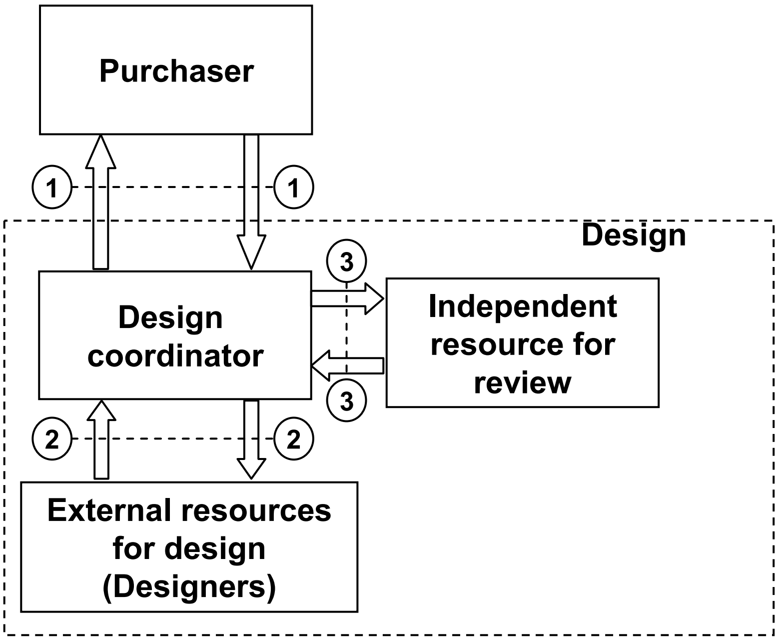


Figure 3-3. *Overall organization and interfaces with respect to division of responsibilities and information flow within design and between design and the Client in design step D1.*

Responsibility with respect to the information flow in the interfaces according to Figure 3-3 shall be divided as follows.

INTERFACE 1-1: Client − Design coordinator

The Client shall provide:

1-B1. Design basis according to Chapter 4

1-B2. Schedule including times for Client's delivery of site descriptions, site models and facility descriptions.

1-B3. Project plan for the Deep Repository Project, including schedule for the design coordinator's deliveries of documentation of interim results and final results from design.

1-B4. Overall operational control of Deep Repository Project.

The design coordinator shall deliver:

1-P1. Documentation of interim results from design according to sections 5.3.4, 5.6.4, 5.8.5, 5.10.4 and 5.12.3

The design coordinator and the Client shall jointly devise meeting procedures.

Interim and final results from design according to point 1-P1 shall be reviewed by an independent resource prior to delivery.

INTERFACE 2-2: Design coordinator − Designer

The division of responsibilities in interface 2-2 shall be defined in the project plan for design and in contract documents between the design coordinator and the external resources (designers).

The division of responsibilities with respect to the information flow in interface 2-2 is dependent on how the design coordinator divides the design work between internal and external resources.

The design coordinator shall be responsible for devising procedures for meetings with external design resources as well as the required schedules.

INTERFACE 3-3: Design coordinator −Reviewer

The design coordinator shall provide:

3-P1. Design basis according to Chapter 4.

3-P2. Guidelines and schedule for review.

3-P3. Documentation according to point 1-P1.

The independent resource for review shall deliver:

3-EG1. Review reports.

3.3 Quality assurance

Quality assurance in an SKB project has to do with both doing things "the right way" and doing "the right things". Furthermore, it is of vital importance that checking and review be performed systematically.

3.3.1 Doing the right things

The deep repository must meet the requirements made in applicable Swedish legislation and the international agreements to which Sweden has subscribed. The deep repository must also meet the owners' demands on efficient operation as well as wishes expressed by concerned municipalities and other stakeholders.

When the site investigations commenced, a compilation was made of those requirements in Swedish legislation and international agreements, as well as owners' wishes, that have a bearing on the design of the deep repository and its parts (SKB, 2002a). Based on these requirements and the KBS-3 concept, system requirements that express the desired function, performance and features of the deep repository and its parts have been formulated. With these system requirements in mind, processes that occur during the construction and detailed characterization phase, the operating phase, and the post-closure phase have been examined. The processes that influence the deep repository's ability to fulfil the system requirements have given rise to engineering requirements that express how the deep repository and its parts should be engineered. Together with the rest of the design basis, the engineering requirements comprise the basis for the design requirements described in Chapter 5 in this document.

Doing the right things in the design process shall be ensured by:

- regarding the deep repository system as a whole and the hard rock facility's part in this,
- conducting technical risk assessments with respect to design in accordance with section 5.11.

The design coordinator shall keep constant track of the design results by means of technology meetings and review, see section 3.3.3. Scope and procedures for meetings and review shall be documented in an assignment description.

In addition, SKB arranges for external review, see Figure 3-1.

Since the deep repository system is not yet fully developed, an overview is required of all development issues with a bearing on the system. Such an overview is available within the framework of SKB's planning of the design activities. An important part of the design process is to keep the designer informed of studies that might affect his work and to feed back design results to SKB's activity planning for development of the deep repository system. A decision-making structure is being defined by the management of the Deep Repository Project to identify and evaluate the need for feedback between the different participants in the project.

3.3.2 Doing things the right way

Design shall be carried out in accordance with SKB's management system. The Deep Repository Project shall be carried out in accordance with SDP-001 Activity Manual for Deep Repository Project – supporting material for application and construction.

Procurement of external resources shall be done according to SD-016 Purchasing in SKB's management system.

The designer shall work in accordance with a systematic management system, and shall prepare a quality plan for the design assignment. This shall ensure that the designer's responsibility for quality in his own work is fulfilled. Correct execution of design, i.e. fulfilment of the requirements in UDP, shall furthermore be ensured by review by an independent resource according to Figure 3-3.

SKB has procedures for the execution of audits to ensure that the executed work complies with the assignment specifications and is executed in accordance with an approved quality plan.

3.3.3 Checking and review of design results

A step-by-step decision-making process shall be applied in design step D1 (see section 5.1). The step-by-step decision-making process is controlled by "check/evaluation stations" ("milestones") at which the Client checks and evaluates the design result and makes a decision regarding the direction of the continued design work. All documentation delivered to the Client in conjunction with these check/evaluation stations shall be reviewed prior to delivery by an independent resource (see section 3.2).

After the conclusion of the design process, the Client performs acceptance inspection, see Figure 3-2.

The documentation prior to each decision point shall, in addition to the documentation stipulated in Chapter 5, also include documentation of at least the following checks/reviews:

- that all premises are documented and taken into account,
- that an up-to-date version of the site model has been used, and that uncertainties in the model have also been taken into account,
- that assumptions made for design are fully traceable, as well as what design results are affected by these assumptions,
- designer follow-up according to own quality plan.

3.3.4 Document management

Documentation of the design work – i.e. design results, on what grounds design has been carried out (design premises), what available site data have been utilized, etc., as well as what assumptions have been made in design – is fundamental in ensuring traceability through the design process.

The basis for decisions in the different steps according to the design methodology in section 5.1 shall be documented ongoingly. This documentation shall be named "Design Report" and comprise internal project material during a design step. These "Design Reports", together with minutes from meetings, any separate decision documents prepared after a check/evaluation point according to Figure 5-1 shall be managed and administered in accordance with SKB's document management system.

4 Design basis

4.1 General

The basis for rock engineering in design step D1 shall consist of:

- The present document.
- The site descriptions, model version 1.2.
- Facility descriptions from previous design steps (Layout E), SKB (2001b), SKB (2002b), SKB (2002c).
- Other study material that will be specified in conjunction with procurement of designers.

The rock engineering during design step D1 shall be based on the site description updated during design step D1, i.e. model version 1.2.

Sections 4.2 and 4.3 provide a general site description and facility description. Sections 4.4, 4.5 and 4.6 define requirements on durability during the construction and operating phases, requirements on construction and requirements on operation and maintenance.

4.2 Site description

The site description describes geometric units that have been assigned discipline-specific properties. In this manner, a three-dimensional, mainly geoscientific site descriptive model of rock and ground has been constructed. The relationship between investigation database and site descriptive model is illustrated in Figure 4-1. See SKB (2001a) and Andersson (2003) for a detailed account.

The geometric units have been chosen so that the spatial variation is limited, or can be described with relatively simple statistical measures, within the unit. For each geometric unit, the model describes geological conditions, mechanical, thermal, hydraulic and hydrogeochemical properties, and properties of importance for transport of solutes in the groundwater in the rock. In addition, it describes the surface ecosystems.

All information regarding the geometric subdivision and properties of the rock mass in the different units that is used during design must have been obtained from the relevant site description.

For one and the same version of the site model, there may be different alternative geometries with respect to location and orientation of the deterministically determined deformation zones. Alternative descriptions of properties may also occur. The Client specifies how the designer should take into account alternative interpretations of site conditions.

Model version 1.2 of the site description shall be used for design step D1.

For information on the content of site descriptions, see also SKB (2004 a and b).

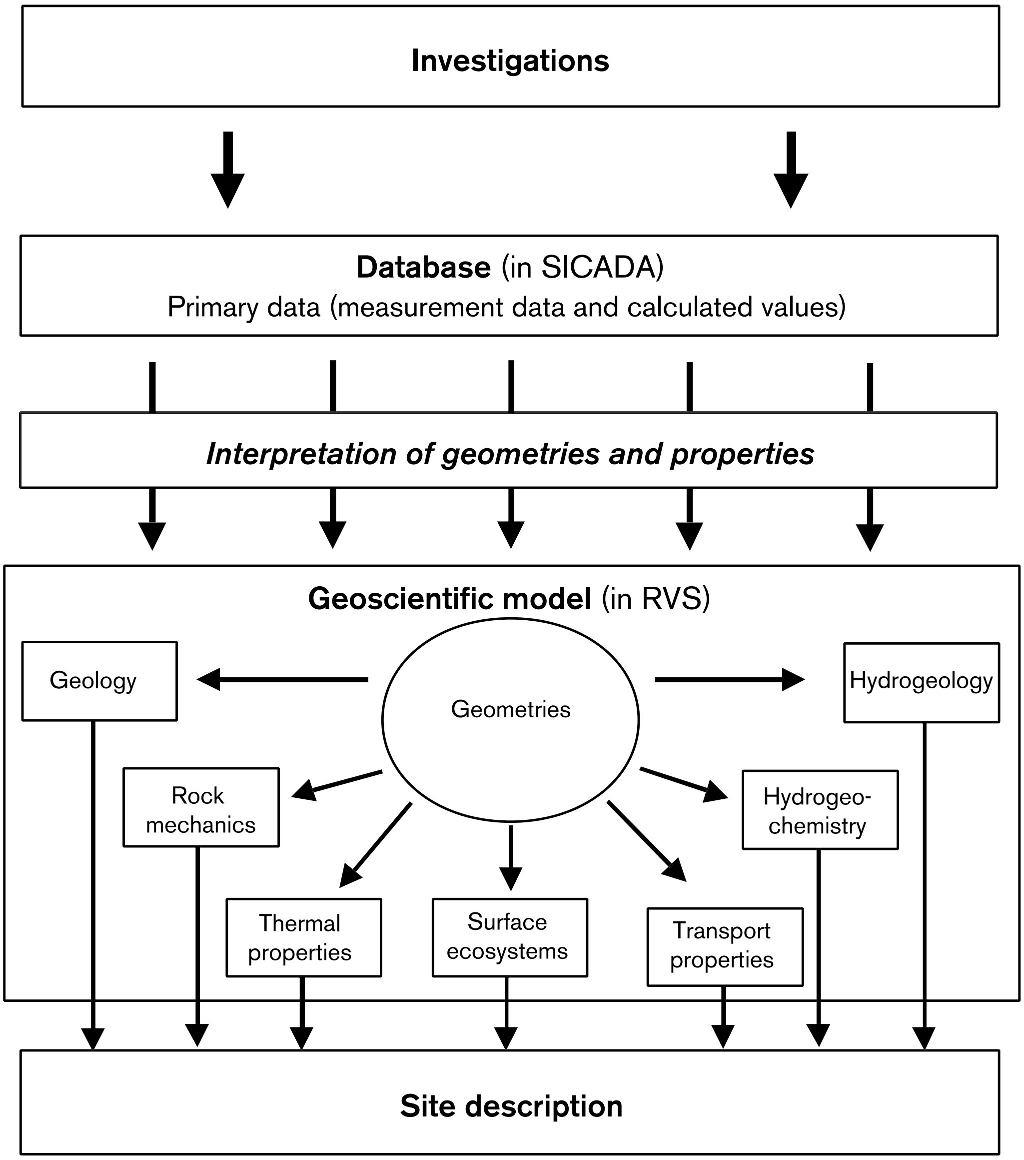


Figure 4-1. *The primary data from the investigations are collected in a database. Data are interpreted and presented in a site descriptive model, which describes the geometry and different properties of the site (SKB, 2001a).*

4.3 Facility description

The design of the deep repository is based on the KBS-3 method, which is described in SKB (2000b).

A facility description illustrates the deep repository as it can be expected to be configured with the knowledge level and the experience existing at the time of its preparation. The purpose of a facility description is:

- *To create a document that describes the entire deep repository facility with respect to design, function and mode of working, and which can constitute a common base for the continued work of facility design.*
- *To comprise a basis for devising site-specific facilities on actual repository sites.*
- *To comprise a point of departure for development of site-specific investigation programmes.*

- *To comprise a basis for cost calculation and scheduling.*
- *To comprise a basis for in-depth studies of activities, logistics, and machine and vehicle needs.*
- *To comprise a basis for estimating the personnel requirement during regular operation.*
- *To serve as an instrument for ascertaining the need for further studies of technical problems of importance for the final design.*
- *To comprise a basis for information to concerned regulatory authorities, municipali ties, landowners and other stakeholders.*

4.4 Durability during construction and operating phases

4.4.1 Design working life

The Design working life of the loadbearing main system in the different underground openings of the hard rock facility shall be as stipulated in Table 4-1.

Requirements on Design working life during construction and operation of disposal according to Table 4-1 apply only to the loadbearing main system, i.e. not to installations, furnishings, etc.

Table 4-1. Design working life of loadbearing main systems.

Underground opening in the hard rock facility	Design working life [years]
Deposition tunnels and deposition holes	≥ 5
Other excavations	≥ 100

Design working life requirements may be changed in later design steps.

4.4.2 Exposure and corrosivity classes

4.4.2.1 Classification

With respect to aggressiveness to the engineering materials, e.g. steel and concrete, the environment in an around the tunnels shall be divided into different exposure and corrosivity classes depending on use and location in relation to surroundings.

For design step D1, surrounding soil and rock shall be classified as marine environment, unless it can be shown otherwise.

The borderline between the different exposure and corrosivity classes for concrete and shotcrete structures without a special waterproof layer against soil, rock or water shall be assumed to be located in the class with the greatest aggressiveness of the environments on the inside and outside of the structure.

4.4.2.2 Concrete and steel structures

In the case of concrete and steel structures, at least the classes in the stipulated in Table 4-2 shall be used.

The table is based on exposure classes according to SS-EN 206-1 and corrosivity classes according to BSK.

Table 4-2. Exposure and corrosivity classes for structural parts of concrete and steel.

	Exposure class with respect to carbonatization/ chloride corrosion	Exposure class with respect to chemical attack	Corrosivity class for structural steel
Underground opening in hard rock facility			
Deposition tunnels and deposition holes	XC2	–	–
Other openings	XC2	2)	C3 or A2 3)
Surrounding soil and rock			
Marine environment	XS3	2)	R3 1), Im3
Other environment	XC4	2)	R2 1), Im3

1) In the case of a steel structural part in rock that does not contain aggressive water, corrosivity class R1 can be applied if systematic pre-grouting has been done in the rock formation or if the rock is sufficiently impermeable and special grouting measures are not required. In the case of embedded bolts in deposition tunnels, corrosivity class R1 is acceptable regardless of the environment in the surrounding rock.

2) Exposure class shall be chosen based on the chemical composition of the groundwater according to SS-EN 206-1 Table 2.

3) Environmental class according to BBK.

When bolt end in other underground openings are protected by a covering concrete layer (e.g. shotcrete) according to Table 4-2, a bolt end of untreated steel with a 30 mm covering concrete layer (water/cement ratio ≤ 0.5) is accepted.

Approved corrosion protection systems for embedded bolts in corrosivity classes R1–R3 are shown in Table 4-3.

Table 4-3. Approved corrosion protection systems for embedded bolt.

Corrosivity class according to Table 2-2		
R1	**R2**	**R3**
Untreated steel and grouting with cement mortar, water/cement ratio ≤ 0.32.	Hot-dip galvanized steel and grouting with cement mortar, water/cement ratio ≤ 0.32.	Hot-dip galvanized steel combined with surface protection of thermoset epoxy with layer thickness ≥ 80 mm and grouting with cement mortar, water/cement ratio ≤ 0.32.

Exposure and corrosivity classes for concrete and steel structures and approved corrosion protection systems for rock bolts may be changed in later design steps.

4.5 Requirements on construction

4.5.1 General

Design during design step D1 shall be general with regard to excavation methods, rock grouting and rock support. Detailed design of these construction activities will take place in later design steps. However, as a basis for costing, requirements on excavation methods, rock grouting and rock support in accordance with sections 4.5.2–4.5.4 shall be assumed.

Regarding requirements on materials, execution and inspection for rock support, the present document refers to trade practice. BV Tunnel (Banverket) and BV Bro ("BV Bridge") (Banverket) have for design step D1 been assumed to represent trade practice with regard to this question. The references to these documents are made to preliminarily indicate a level of ambition in the construction phase to permit a cost calculation. Requirements on excavation methods and materials, execution and inspections for rock support and rock grouting measures will be specified in a later edition of UDP.

Use of commercially available cement products shall be assumed.

Development work is being pursued within SKB on the use of low-alkaline cement products.

4.5.2 Excavation methods

For design step D1, it shall be assumed that all underground openings, with the exception of deposition holes and ventilation shafts, are excavated by drill and blast. Full-face boring shall be assumed for deposition holes and ventilation shafts.

Blasting shall be carried out with smooth blasting technicues using boreholes parallel to the contour to minimize damage in the rock. For design step D1, it shall be assumed in deposition tunnels that the section is taken out by top heading and bench.

For design step D1, horizontal drilling is assumed even for benches in rock halls in the central area. This may be changed for later design steps when the matter has been studied in greater detail.

Standard drilling can be assumed for pump sumps, pipe trenches, sedimentation basins, etc.

SKB is currently carrying out a general study of the suitability of different excavation methods for the different parts of the deep repository.

When necessary, for example for near-surface blasting of ramp and shafts, controlled blasting shall be assumed.

4.5.3 Grouting

4.5.3.1 General

The question of grouting is currently being studied by SKB as regards materials, execution and inspection. No detailed design of grouting measures will be done in design step D1.

To permit a cost estimate for design step D1 shall it be assumed that trade practice and currently commercially available grouts are employed.

4.5.3.2 Grouts

For design step D1, grouting with cement-based grouts shall be assumed.

The requirement that cement-based grouts are to be used may be changed in later editions of UDP.

More detailed material requirements on grouts will be made in a later edition of UDP.

4.5.3.3 Execution

Execution of grouting shall be adapted to existing conditions. In design step D1, assumptions of suitable grouting procedures with regard to screen lengths, look-out angle, grouting methodology, etc., shall be made for different grouting objects, see section 5.9.

> *Grouting procedures will be specified in conjunction with detailed design.*

4.5.3.4 Inspection

For design step D1, it shall be assumed that inspection will be carried out in accordance with trade practice as regards the properties of grouts and grouting procedure.

> *For design step D1, tests of grouts and grouting procedure comprise only one cost item in the cost calculation, see Figure 3-2.*
>
> *Tests of grout properties and grouting procedure will be specified in a later edition of UDP.*

4.5.4 Rock support

4.5.4.1 General

> *No detailed design of rock support is carried out in design step D1. The following requirements on materials, execution and tests are preliminary and are given to indicate a certain standard for the purpose of permitting a cost estimate. The requirements on rock support are determined in part by the rock mechanical environment in which it is applied, e.g. fracture types and size of deformations. The requirements will be specified in a later edition of UDP.*

Materials incorporated in loadbearing main systems, including soil and rock, shall have known and documented short- and long-term properties of importance for their use.

"Manufacturing class I" shall be assumed for all concrete.

Structural steel shall meet requirements according to BV Bro (Banverket), section 54.

Rock support shall conform to durability requirements according to section 4.4.

4.5.4.2 Concrete

Materials

Requirements on materials for concrete and cement mortar for bolt grouting according to BV Tunnel (Banverket), sections 3.3.3.3 and 3.3.4, shall be assumed.

Execution

Execution of concrete works shall be assumed to take place in accordance with requirements in BV Tunnel (Banverket), sections 3.3.4.7 and 3.4.5. Execution of formwork shall be assumed to take place in accordance with BV Tunnel (Banverket), section 3.3.4.5.

Inspection

Inspection of concrete and concrete works shall be assumed to take place in accordance with requirements in BV Tunnel (Banverket) section 3.4.6.

4.5.4.3 Shotcrete

Materials

Requirements on materials for shotcrete according to BV Tunnel (Banverket), section 3.3.3.4, shall be assumed.

Execution

Execution of shotcrete works shall be assumed to take place in accordance with requirements in BV Tunnel (Banverket), section 3.3.4.8.

Inspection

Inspection of shotcrete and shotcrete works shall be assumed to take place in accordance with requirements in BV Tunnel (Banverket), section 3.3.5.

4.5.4.4 Rock bolt

Materials

Requirements on materials for rock bolts according to BV Tunnel (Banverket), section 3.3.3.6, shall be assumed.

Execution

Execution of shotcrete works shall be assumed to take place in accordance with requirements in BV Tunnel (Banverket), section 3.3.4.4.

Inspection

Inspection of rock bolts shall be assumed to take place in accordance with requirements in BV Tunnel (Banverket), section 3.3.5.

4.5.4.5 Concrete reinforcement

Materials

Requirements on materials for concrete reinforcement according to BV Tunnel (Banverket), section 3.3.3.7, shall be assumed.

Execution

Execution of concrete reinforcement shall be assumed to take place in accordance with requirements in BV Tunnel (Banverket), section 3.3.4.6.

Inspection

Inspection of concrete reinforcement shall be assumed to take place in accordance with BV Tunnel (Banverket), section 3.4.6.

4.6 Operation and maintenance

4.6.1 General

Tunnels and rock caverns shall be designed and constructed so that operation and maintenance of all constituent parts is facilitated and so that these parts can be inspected.

All underground openings in the hard rock facility shall, with respect to safety and good radiation protection, be designed and executed so that their total energy consumption during operation is as low as possible.

4.6.2 Caverns for installations, operation and maintenance

Facility description Layout E describes the need for and requirements on caverns for installations, operation and maintenance, see section 4.1.

4.6.3 Accessibility for inspection

Loadbearing main systems shall normally be able to be inspected at close hand.

To permit such inspection, there should be at least 0.5 m of free space.

Inspection of the lining cast against the rock surface is considered to provide adequate information on the state of loadbearing main systems behind it.

Rock bolts behind prefabricated concrete elements or cast concrete lining with a special waterproof layer in the form of e.g. a membrane shall not be considered accessible for inspection and/or maintenance.

5 Design requirements

5.1 Design methodology

The goals of rock engineering according to Chapter 2 shall be met for design step D1 by applying for each site a design methodology aimed at answering a number of design tasks. These design tasks are:

A. What locations and depths within the site may be suitable for locating the deep repository in, with a view towards the properties and states of the site?

B. Is it reasonable that the repository can be accommodated, with a view towards preliminary respect distances to deformation zones and preliminary assumed loss of deposition holes?

C. How can the deposition areas be designed with a view towards sufficient space and long-term safety?
   - C1. How can deposition tunnels, deposition holes and main tunnels be designed with a view towards the equipment and the activities they are supposed to accommodate, stability and location of temporary plug?
   - C2. What distance may be required between deposition tunnels and between deposition holes with a view towards maximum permissible temperature on the canister surface?
   - C3. What orientation may be suitable for deposition tunnels with a view towards water seepage and stability in deposition tunnels and deposition holes?
   - C4. How large a proportion of the deposition holes may be unusable with a view towards the minimum permissible distance to stochastically determined fractures, excessive water inflow and instability? How is the loss affected by different criteria?
   - C5. At what depth or depth range may it be suitable to build the deep repository? Is there a site specific depth dependence?

D. How can other underground openings, especially the central area's rock caverns, be designed with a view towards stability and the equipment and activities they have to accommodate.

E. How can the layout of the entire hard rock facility be configured?

F. What deformation zones may be passed and what difficulties can be expected to arise?

G. How may the repository be affected by the hydrogeological situation around the repository with respect to: (1) upconing of saline water and (2) lowering of the water table?

I. How much grouting may be required?

J. How much rock support may be required?

K. What consequences can different design requirements, criteria and parameters be expected to have on the design of the hard rock facility with respect to enclosed utilized deposition area, utilization rate and excavated rock volume? What studies and investigations need to be done before or during the next design step?

L. Reporting of rock engineering.

For design step D1, the following design methodology shall be applied.

The design methodology is illustrated in Figure 5-1. Table 5-1 is a compilation of all design tasks to be handled by rock engineering in design step D1, with reference to the corresponding section in the present document.

A Identification of possible locations and depths within the site

Design shall begin with an identification of which locations (rock domains) within the site are possible (suitable) to use for placement of the hard rock facility and its various parts (see Figure 5-1). Identification shall be carried out according to the requirements in section 5.2 and by the design coordinator in cooperation with the Deep Repository Project's management group, CPU. Based on the results of the identification, rock domains and depths should be proposed on which the continued design process should focus.

B Preliminary assessment of the potential of the site to accommodate the repository

Based on proposed locations and depths within the site according to task A above, a preliminary assessment shall be made of the potential of the site to accommodate the repository, i.e. whether the required number of canisters can be deposited on the site. This assessment shall be carried out in accordance with the requirements in section 5.3. The results from design tasks A and B shall, after completion of task B, be delivered and presented to the Client.

The Client checks and evaluates the results and, after consultation with the unit for safety assessment, decides which rock domains and depths the continued design process should focus on or whether the design process should be stopped, see section 5.3.4.

C–E Design of deposition areas, design of other rock excavations and layout

If the Client has decided to proceed with the design process according to task B above, the design process shall continue with design tasks C–E and produce a first layout alternative for design step D1, Layout D1:1. Design tasks C–E shall be carried out according to the requirements in sections 5.4–5.6. After design according to task E has been concluded, the design results from design tasks C–E shall be delivered and presented to the Client.

The Client checks and evaluates the design results and then decides either to proceed with the design process or to supplement or stop the design process, see section 5.6.4. If design of the current layout is stopped, the Client decides whether further layout alternatives are to be studied.

F–G Identification of passages through deformation zones, seepage and hydrogeological situation around the repository

If the Client has decided to proceed with design according to task E, design shall continue according to design tasks F–G for Layout D1:1. Design tasks F–G shall be carried out according to the requirements in sections 5.7–5.8. After design according to task G has been concluded, the design results from design tasks F–G shall be delivered and presented to the Client.

The Client checks and evaluates the design results and then decides either to proceed with the design process or to supplement or stop the design process, see section 5.8.5. If design of the current layout is stopped, the Client decides whether additional layout alternatives are to be studied.

H–I Estimation of the required amount of grouting and rock support measures

If the Client has decided to proceed with the design process according to task G, design according to design task H and I for Layout D1:1 shall be carried out. Design tasks H–I shall be carried out according to the requirements in sections 5.9–5.10. After design according to task I has been concluded, the design results from design tasks H–I shall be delivered and presented to the Client.

The Client checks and evaluates the design results and then decides either to continue design of the layout in question or to supplement or stop the design process, see section 5.10.4. The Client also decides whether additional layout alternatives are to be studied.

If the Client decides that additional layout alternatives are to be studied, design tasks C–I shall be repeated to the necessary extent for alternative layouts (D1:2–D1:n).

K–L Technical risk assessment and rock engineering report

When layout alternative D1:n has been concluded, the completed design shall undergo technical risk assessment. In the final design task (L), the rock engineering for design step D1 as a whole shall be compiled and reported. Design tasks K–L shall be carried out according to the requirements in sections 5.11–5.12. The results from rock engineering as a whole according to design task L shall be delivered and presented to the Client along with all underlying study material.

The Client checks and evaluates the rock engineering and decides whether the rock engineering should be approved or whether supplementary work should be done, see section 5.12.3.

The results of rock engineering comprise only a portion of the supporting material for preparation of the preliminary facility description, Layout D1. Design carried out within other technical areas, such as backfill, installations, furnishings, ventilation, etc., also comprises supporting material for the preliminary facility description. This means that preparation of the preliminary facility description is not included in rock engineering.

After preparation of the preliminary facility description, the Client performs an acceptance inspection, see Figure 3-2.

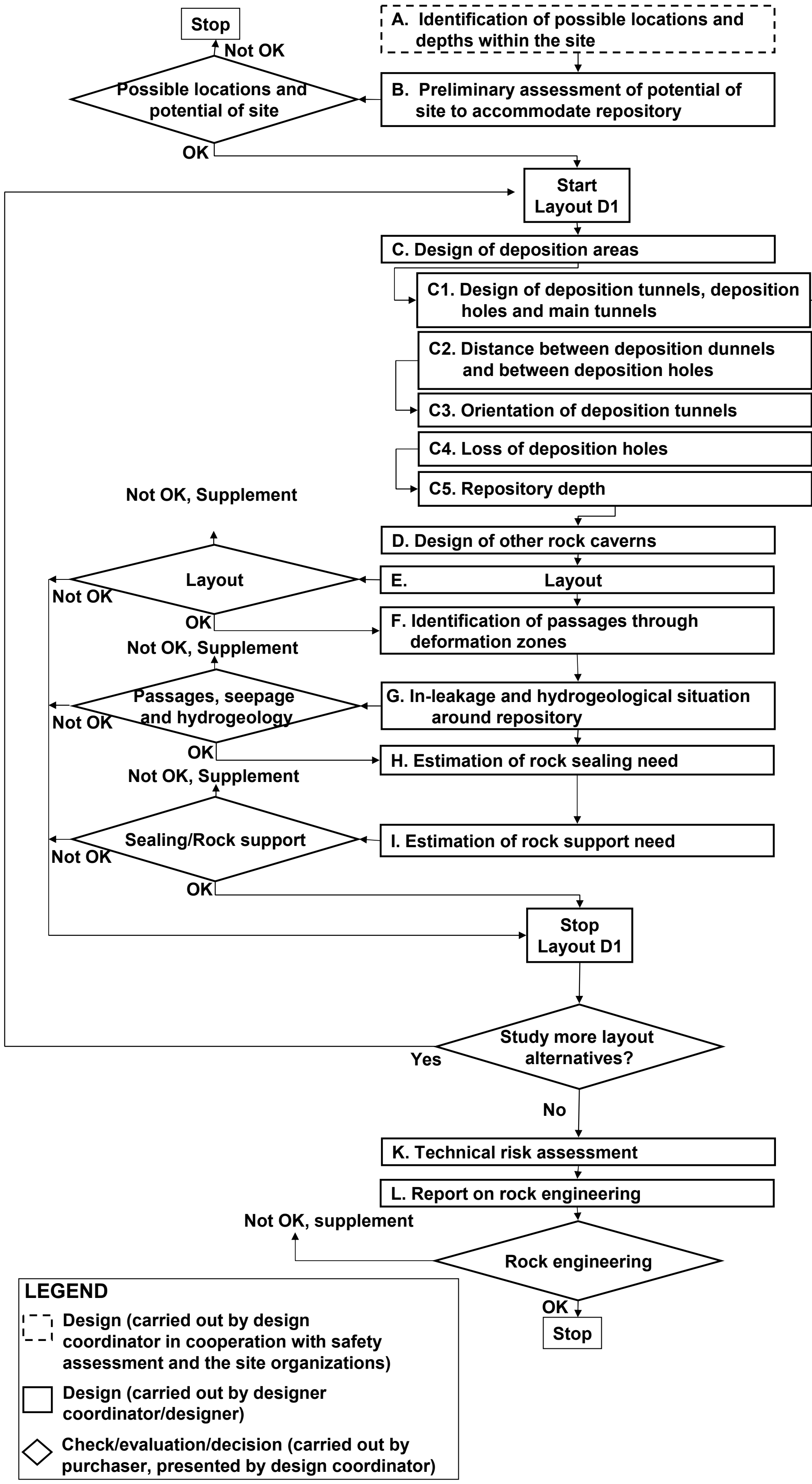


Figure 5-1. *Illustration of design methodology for rock engineering in design step D1.*

Table 5-1. Design tasks to be dealt with in rock engineering in design step D1 and corresponding sections in the present document.

Design task	Section in UDP
A. Identification of possible locations and depths within the site.	5.2
B. Preliminary assessment of potential of site to accommodate repository.	5.3
C. Design of deposition areas.	5.4
C1. Design of deposition tunnels, deposition holes and main tunnels.	5.4.1
C2. Distance between deposition tunnels and between deposition holes.	5.4.2
C3. Orientation of deposition tunnels.	5.4.3
C4. Loss of deposition holes.	5.4.4
C5. Repository depth.	5.4.5
D. Design of other rock excavations.	5.5
E. Layout.	5.6
F. Identification of passages through deformation zones.	5.7
G. Seepage and hydrogeological situation around repository.	5.8
H. Estimation of grouting need.	5.9
I. Estimation of rock support need.	5.10
K. Technical risk assessment.	5.11
L. Report on rock engineering.	5.12

5.2 Identification of possible locations and depths within the site (A)

5.2.1 General

Identification of possible locations and depths for deposition areas and other parts of the hard rock facility (mainly the central area and access roads to the hard rock facility) shall be done to a suitable extent in design step D1 taking into account:

1. extractable natural resources,
2. thermal properties of the rock,
3. hydrogeological properties of the rock,
4. mechanical properties of the rock and initial (in-situ) stresses,
5. groundwater composition,
6. planning and environmental conditions on the surface.

Identification provides preliminary information on which rock domains and depths are suitable for placement of the hard rock facility and its various parts and can thereby be recommended for the continued design process in design step D1.

The Client stipulates how alternatives in the site description, model version 1.2, are to be handled in the continued design process.

5.2.2 Execution

Identification of possible locations for deposition areas and other parts of the hard rock facility shall in design step D1 be carried out by SKB's project coordinator in consultation with the Deep Repository Project's management group, CPU. Identification shall be carried out by comparing the properties and states of rock domains with requirements and preferences according to Andersson, et al. (2000).

The comparison shall be performed for depths of 400, 500, 600 and 700 m in each rock domain that may constitute a potential volume for placement of deposition areas or other parts of the hard rock facility.

Information on the properties and states of the site shall be taken from the site description with associated site models, version 1.2.

Rock domains proposed for placement of the different parts of the hard rock facility (deposition areas, central area, etc.) shall be specified.

In order for a rock domain to be utilized as a deposition area, the following two conditions shall be met for design step D1:

- length of deposition tunnels shall be ≥ 100 m,
- number of deposition tunnels shall be ≥ 5.

5.2.3 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Identification of properties and states for which requirements and preferences are not fulfilled, and assessment of how they influence the continued design process.
5. Any calculations carried out.
6. Results of comparison of properties and states of rock domains with requirements and preferences.
7. Plan maps, one for each proposed depth, showing proposed rock domains.
8. Conclusions and proposals regarding which rock domains and depths the continued design process should focus on, and what each unit should be used for (deposition area, central area, etc.), including any alternative descriptions in the site model.
9. References.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made.

5.3 Preliminary assessment of potential of site to accommodate repository (B)

5.3.1 General

Assessment of the potential of the site to accommodate the repository shall be done taking into account:

1. loss of deposition area due to preliminary respect distances to deterministically determined fracture zones,
2. preliminarily assumed loss of deposition holes.

5.3.2 Execution

Based on the results from design in section 5.2, a preliminary assessment shall be made for each proposed depth of the potential of the site to accommodate the required number of canisters by:

1. marking of preliminary respect distances on plan maps,
2. preliminary calculation of potential to accommodate the required number of canisters.

1. Marking of preliminary respect distances on plan maps

Deposition areas (deposition tunnels) shall be located at a minimum distance (respect distance) from deterministically determined deformation zones.

In design step D1, deformation zones with associated respect distances specified by the Client shall be taken into account.

Deterministically determined deformation zones shall, together with preliminary respect distances, be marked on plan maps for the depths proposed by the Client according to section 5.2. Available deposition area, A_T, shall be stipulated for each depth.

The respect distances applied in design step D1 are preliminary and will be evaluated within the framework of safety assessment, see Figure 3-2. This means that the respect distances may be revised as a result of further investigations and/or the safety assessment.

Respect distances between deposition areas (deposition tunnels) and deterministically determined deformation zones result in the fact that a certain area within a possible deposition area cannot be used for deposition, which reduces the available deposition area in the particular deposition area.

For definition of available deposition area, A_T, see Equation 1 below.

2. Preliminary calculation of potential to accommodate the required number of canisters

In design step D1, the preliminary potential that the required number of canisters can be accommodated according to Equation (1) shall be calculated for each proposed depth according to section 5.2.

$$P = (1 - \frac{K}{100}) \cdot \frac{A_T}{N \cdot A_S} \quad (1)$$

where

K = Assumed preliminary percentage loss of deposition holes.

N = Preliminary number of canisters to be deposited.

A_T = Available deposition area, i.e. sum of areas for rock domains at a given depth that have, according to section 5.2, been proposed to be utilized as deposition areas after reduction for respect distance.

A_S = Preliminary required specific area per deposition hole.

For design task B within design step D1:

- the assumed preliminary percentage loss of deposition holes, K, shall be assumed to be 25%,
- the preliminary number of canisters to be deposited, N, shall be assumed to be 4500,
- the preliminary required specific area per deposition hole, A_s, shall be assumed to be 240 m^2 (6x40 m^2).

  A P-value<1 indicates preliminarily that there may be a shortage of space.

  A P-value>1 indicates the site's preliminary overcapacity, i.e. is a preliminary measure of how much space there is for depositing more canisters than assumed.

5.3.3 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Calculations carried out.
5. Plan maps, one for each depth, showing:
   - proposed rock domains and how they are utilized with regard to deposition area, central area, etc. (obtained from report according to section 5.2.3),
   - deterministically determined deformation zones with associated respect distance (marked by e.g. shading),
   - deterministically determined deformation zones that are allowed to be passed by main and transport tunnels,
   - available deposition area, A_T, and how it is broken down among proposed rock domains according to section 5.2,
   - preliminary potential, P, to accommodate the required number of canisters.
6. Table and/or bar chart showing available deposition area, A_T, as a function of the depth.
7. Table and/or bar chart showing the potential of the site, P, to accommodate the required number of canisters as a function of the depth.

8. Conclusions and recommendation regarding which rock domains and depths the continued design process should focus on for the different parts of the hard rock facility.

9. References.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made. Reasons shall be given for recommendations.

5.3.4 Checking and evaluation

The design coordinator shall deliver to the Client documentation according to sections 5.2.3 and 5.3.3 and give an account of the work and its results.

The documentation shall, according to section 3.3.3, be reviewed by an independent resource prior to delivery to the Client.

> *The Client checks and evaluates the design results and decides which rock domains and depths the continued design process should focus on for the different parts of hard rock facility, or whether the design process should be stopped. The Client also decides which deterministically determined deformation zones main tunnels and transport tunnels are allowed to pass.*

5.4 Design of deposition areas (C)

Design of deposition areas shall be carried out in design step D1, taking into account:

1. design of main tunnels, deposition tunnels and deposition holes,
2. distance between deposition tunnels and between deposition holes,
3. orientation of deposition tunnels,
4. loss of deposition holes,
5. repository depth.

5.4.1 Design of deposition tunnels, deposition holes and main tunnels (C1)

5.4.1.1 General

Design of deposition tunnels shall be carried out in design step D1, taking into account:

1. the required space for the equipment and installations required for ventilation, transport of rock spoil, investigation of the rock, preparation and cleaning of deposition holes, deposition of buffer and canisters, backfilling and temporary plugging,
2. the possibility of canister retrieval,
3. the minimum required distance between deposition holes and main tunnel with a view towards:

- the stress state around the first deposition hole due to stress redistribution around the main tunnel.
- The position of the concrete plug with a view towards fracturing in the rock mass due to unilateral water pressure on the concrete plug,

4. minimum required distance between deposition holes and tunnel end,
5. stability.

Points 3 and 4 provide information on how much of the deposition tunnels cannot be utilized for deposition holes due to the location of the temporary plug and space requirements for the deposition equipment.

Design of deposition holes shall be carried out taking into account:

6. the required space for deposition of buffer and canisters,
7. the possibility of canister retrieval.

Design of main tunnels shall be carried out taking into account:

8. the required space for the equipment and installations required for ventilation, transport of rock spoil, investigation of the rock, preparation and cleaning of deposition holes, deposition of buffer and canisters, backfilling and temporary plugging,
9. stability.

5.4.1.2 Execution

In design step D1, the requirements on space and retrieval of canisters according to points 1, 2, 6, 7 and 8 in section 5.4.1.1 shall be considered to be met if the theoretical rock contour conforms to cross-sectional dimensions and form of deposition tunnels, deposition holes and main tunnels according to facility description, Layout E (see section 4.1).

Length of main tunnels and deposition tunnels is determined in conjunction with preparation of layout according to section 5.6. Requirements regarding maximum length of deposition tunnels are given in section 5.6.1.

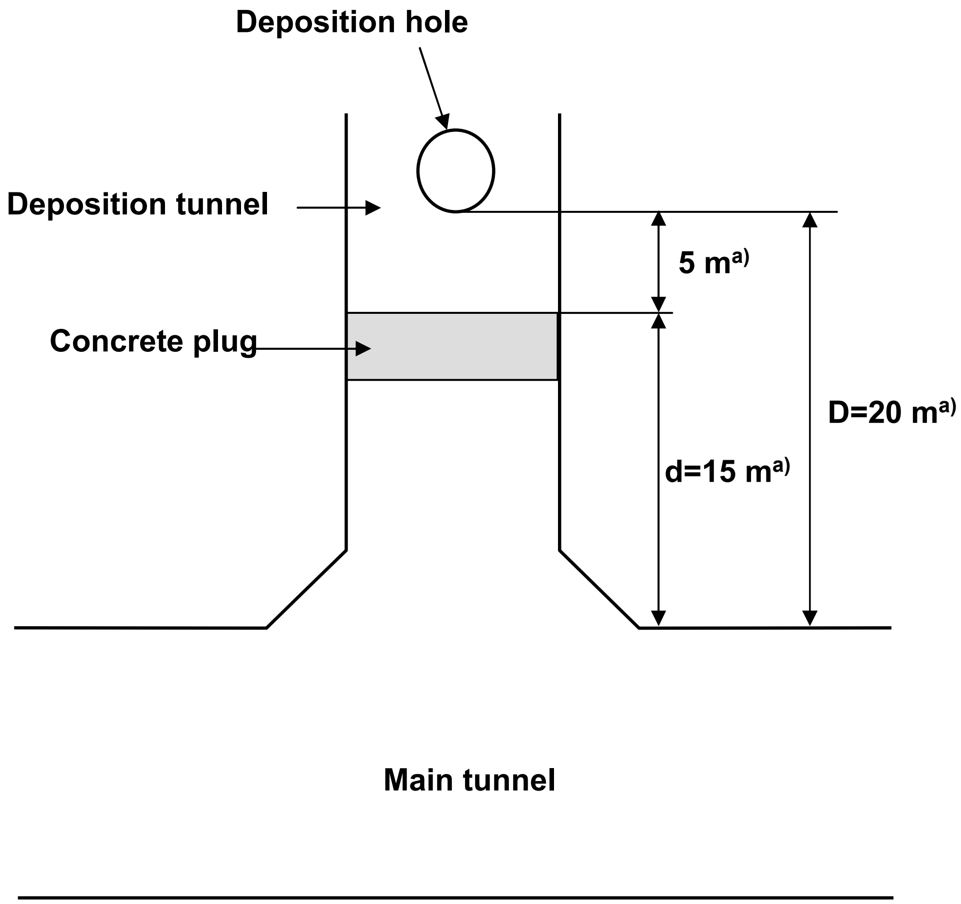
Requirements on minimum requisite distance between deposition tunnel and main tunnel according to point 3 in section 5.4.1.1 shall in design step D1 be assumed to be met if the minimum distance, D, according to Figure 5-2 is 20 m.

Requirements on minimum requisite distance between deposition holes and tunnel end according to point 4 in section 5.4.1.1 shall for design step D1 be assumed to be met if the distance between the periphery of the deposition hole and the tunnel end is at least 8 m, see Figure 5-3.

Requirements on stability according to points 5 and 9 in section 5.4.1.1 shall in design step D1 be assumed to be met if the form and cross-sectional dimensions of the tunnels according to facility description Layout E (see section 4.1) are applied, orientation and depth according to sections 5.4.3 and 5.4.5 are chosen and rock support according to section 5.10 is installed.

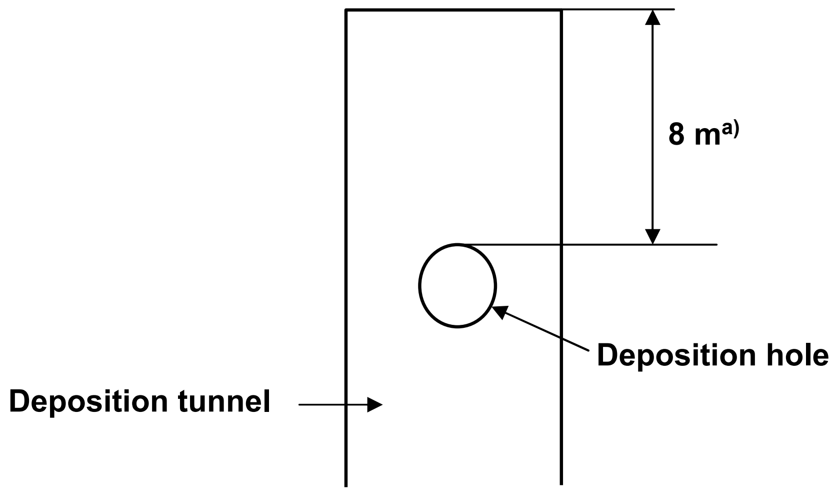
More detailed design of the configuration of the tunnels taking into account the requirements in section 5.4.1.1 will be carried out in later design steps.

Design of the concrete plug is not included in the rock engineering in design step D1.



a) Distance assumed for design step D1

Figure 5-2. *Schematic plan drawing of main tunnel, deposition tunnel and deposition holes.*



a) Distance assumed for design step D1

Figure 5-3. *Distance between deposition holes and tunnel end assumed for design step D1.*

5.4.1.3 Documentation

For design step D1, no requirements are made on specific documentation of the design of tunnels and deposition holes in deposition areas, since they are configured essentially in accordance with Layout E. The documentation of the design of these facility parts takes place instead in conjunction with the documentation of the supporting material for the preliminary facility description according to section 5.12.

5.4.2 Distance between deposition tunnels and between deposition holes (C2)

5.4.2.1 General

The minimum distance between deposition tunnels and between deposition holes shall in design step D1 be determined with respect to the highest permissible temperature on the canister surface.

The highest permissible temperature on the canister surface shall be set to 100° C.

5.4.2.2 Execution

In determining the minimum distance between deposition tunnels and between deposition holes according to the requirement in section 5.4.2.1, the following shall be taken into account:

- the rock mass and its thermal properties,
- the initial temperature at repository depth,
- the canister effect,
- the buffer and its thermal properties.

In design step D1, a distance (s/s) between deposition tunnels of 40 m shall be assumed.

In design step D1, the distance (s/s) between deposition holes, taking into account the highest permissible temperature on the canister surface according to section 5.4.2.1, shall be verified according to section 5.4.2.3.

5.4.2.3 Verification

Verification of the minimum distance between deposition holes taking into account the highest permissible temperature on the canister surface shall be carried out.

In design step D1, this verification shall be based on an initial canister heat output of 1700 W/canister, a thermal conductivity in the buffer of 1.0 W/mK, a heat capacity in the rock of 2.08 MJ/m^3 K and the site specific initial temperature of the rock mass.

The rock's heat capacity has relatively little influence on the maximum temperature on the canister surface.

The verification shall be carried out in design step D1 by application of the graph in Figure 5-4 for the rock domains and depths within the range 400–700 m decided on by the Client according to section 5.3.4.

In design step D1, the limit value temperature taking into account the air gap between buffer and canister and uncertainties in input data (thermal conductivity of the rock, heat capacity of the rock and thermal conductivity of the buffer) shall be assumed to be 80° C.

In applying Figure 5-4, the limit value temperature shall be adjusted linearly with respect to the initial temperature of the rock.

This means that if the initial temperature in the rock differs from the initial temperature which Figure 5-4 is based on, the limit value temperature in the graph is parallel-shifted accordingly. Example: If the temperature of the rock is 13° C (instead of 15° C) at repository level, the limit value temperature is 82° C.

The thermal conductivity and initial temperature of the rock mass shall, for a given rock domain and depth, be in accordance with the site description, model version 1.2. Mean values for the thermal conductivity and initial temperature of the rock shall be used at actual depth.

The graph in Figure 5-4 is based on an initial canister heat output of 1700 W/canister, a thermal conductivity in the buffer of 1.0 W/mK, an initial rock temperature of 15° C and a heat capacity in the rock of 2.08 MJ/m³K. The thermal conductivity in the buffer (MX 80 bentonite) corresponds to a degree of water saturation of about 0.6 (Börgesson et al., 1994).

To shed light on the sensitivity due to variation in the mean value of the thermal conductivity of the rock, the minimum distance between deposition holes shall also be analyzed and reported when the mean value deviates ±5% from the mean values given by the site description.

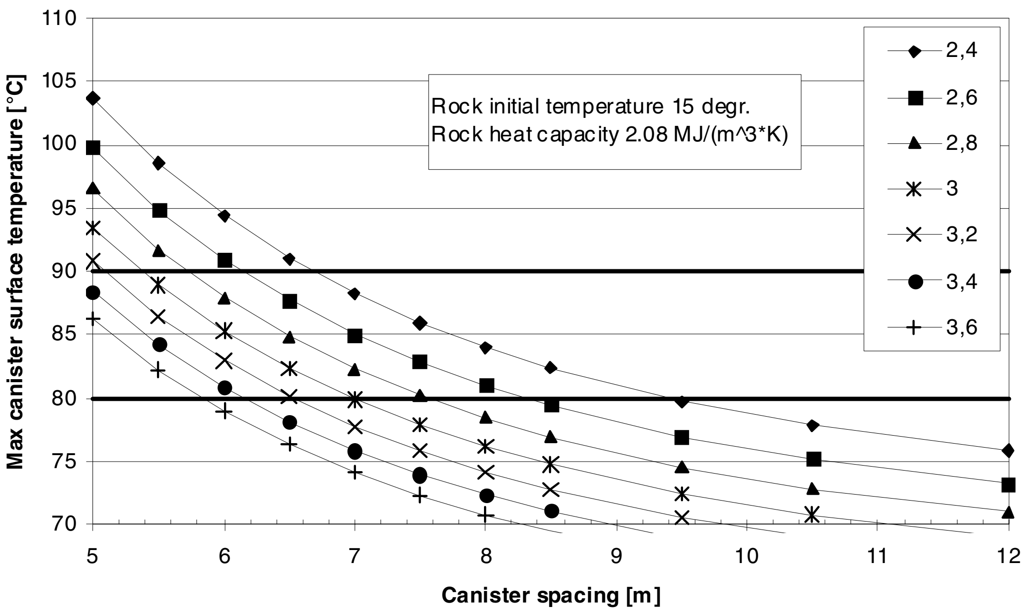


Figure 5-4. *Maximum temperature on canister surface as a function of the distance (c/c) between deposition holes and different thermal conductivities (W/mK) in the rock (Hökmark and Fält, 2003).*

5.4.2.4 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Table which for each rock domain gives the minimum distance between deposition holes as a function of the depth. Sensitivity due to variation in the mean value of the thermal conductivity of the rock shall be shown.
5. Conclusions.
6. References.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made.

5.4.3 Orientation of deposition tunnels (C3)

5.4.3.1 General

Orientation of deposition tunnels shall be chosen in design step D1 with a view towards minimizing:

1. the quantity of water leaking into deposition tunnels and deposition holes,
2. the risk of spalling in deposition tunnels,
3. the volume of potentially unstable wedges in deposition tunnels and deposition holes.

5.4.3.2 Execution

The orientation of the deposition tunnels shall in design step D1 be chosen primarily so that the requirements in points 1–3 in section 5.4.3.1 are met in the mentioned order. If the chosen tunnel orientation according to point 1 is judged to lead to unmanageable spalling problems according to point 2 and/or a large volume of potentially unstable wedges according to point 3, a compromise shall be sought so that the problems are manageable from a stability point of view as well. A small volume of potentially unstable wedges in deposition holes shall be given priority over a small volume of potentially unstable wedges in deposition tunnels. Low water seepage into deposition tunnels shall be given priority over minimum water seepage into deposition holes.

The requirements for choice of orientation of deposition tunnels according to point 1–3 in section 5.4.3.1 shall be verified according to section 5.4.3.3.

5.4.3.3 Verification

Verification of choice of orientation of deposition tunnels against requirements according to points 1–3 in section 5.4.3.1 shall be done by means of analyses as described below.

1. Quantity of water leaking into deposition tunnels and deposition holes

Choice of tunnel orientation with a view towards the quantity of water leaking into deposition tunnels and deposition holes according to point 1 in section 5.4.3.1 shall in design step D1 be verified by means of hydrogeological analysis in accordance with sections 4.2 and 4.3 in Appendix 2. The analyses shall include the rock domains and depths within the range 400–700 m decided on by the Client according to section 5.3.4.

The analyses shall in design step D1 be carried out for the construction phase and shall for each rock domain and depth at least include the orientations 0°, 30°, 60°, 90°, 120° and 150° angle between the deposition tunnel's longitudinal direction and the mean value of the orientation of the major horizontal principal stress at the depth in question.

2. Risk of spalling in deposition tunnels

Choice of tunnel orientation with a view towards the risk of spalling in deposition tunnels according to point 2 in section 5.4.3.1 shall in design step D1 be verified by means of stress analyses in accordance with section 4.2 in Appendix 1. The analyses shall be carried out for the rock domains and depths within the range 400–700 m decided on by the Client according to section 5.3.4.

The analyses shall in design step D1 be carried out for the construction phase and shall for each rock domain and depth at least include the orientations 0°, 30°, 60° and 90° angle between the deposition tunnel's longitudinal direction and the mean value of the orientation of the major horizontal principal stress at the depth in question.

The risk of spalling shall in design step D1 be defined as the ratio of the greatest tangential stress on the tunnel periphery to the uniaxial compressive strength of the intact rock.

3. Volume of potentially unstable wedges in deposition tunnels and deposition holes

Choice of tunnel orientation with a view towards the volume of potentially unstable wedges in deposition tunnels and deposition holes according to point 3 in section 5.4.3.1 shall in design step D1 be verified by means of kinematic block analyses in accordance with sections 4.3 and 4.4 in Appendix 1. The analyses shall be carried out for the rock domains and depths within the range 400–700 m decided on by the Client according to section 5.3.4.

The analyses shall in design step D1 be carried out for the construction phase and shall for each rock domain and depth at least include the orientations 0°, 30°, 60°, 90°, 120° and 150° angle between the deposition tunnel's longitudinal direction and the mean value of the orientation of the major horizontal principal stress at the depth in question.

5.4.3.4 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.

4. Three-dimensional graphs which for each rock domain show the dependent variable (inflow, spalling risk and volume of unstable blocks in deposition tunnels and deposition holes) as a function of tunnel orientation and depth.
5. Table which for each rock domain shows the chosen orientation at a given depth.
6. Conclusions.
7. References.
8. Appendix with calculations carried out according to reporting and documentation requirements in section 4.2 in Appendix 2.
9. Appendix with calculations carried out according to reporting and documentation requirements in section 4.3 in Appendix 2.
10. Appendix with calculations carried out according to reporting and documentation requirements in section 4.2 in Appendix 1.
11. Appendix with calculations carried out according to reporting and documentation requirements in section 4.3 in Appendix 1.
12. Appendix with calculations carried out according to reporting and documentation requirements in section 4.4 in Appendix 1.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made. Reasons shall be given for chosen tunnel orientations. Formulas used shall be explained, and references shall be given for those that cannot be considered to be generally known.

5.4.4 Loss of deposition holes (C4)

5.4.4.1 General

Loss of deposition holes shall in design step D1 be estimated taking into account:

1. the minimum permissible distance between deposition holes and stochastically determined fractures/fracture zones with radius R>100 m,
2. the quantity of water leaking into deposition holes,
3. wedge breakout in deposition holes,
4. the risk of spalling in deposition holes.

5.4.4.2 Execution

Estimation of loss of deposition holes shall in design step D1 be based on chosen tunnel orientations according to section 5.4.3, distance between deposition tunnels and between deposition holes according to section 5.4.2, and on the cross-sectional geometry of deposition tunnels and deposition holes (theoretical rock contour) according to section 5.4.1.

The requirements on estimation of loss of deposition holes according to points 1–4 in section 5.4.4.1 shall be verified according to section 5.4.4.3.

5.4.4.3 Verification

Verification of estimated loss against requirements according to points 1–4 in section 5.4.4.1 shall be done by means of analyses as described below.

All analyses shall for design step D1 pertain to the construction phase and shall be carried out for the rock units and depths within the range 400–700 m decided on by the Client according to section 5.3.4.

Calculation of loss of deposition holes according to points 1–3 shall be based on stochastic fracture networks. These analyses shall be performed on at least 20 realizations of the fracture network. The same realizations shall be used for all analyses. For each realization, the three analyses shall be carried out in the sequence 1–3. Calculation of loss of deposition holes according to point 4 shall be carried out by “Monte Carlo simulation” or the “Point-Estimate Method”.

If there are separate DFN models in the site description for hydraulically active fractures, open fractures and healed fractures, the model or combination of models that are relevant to the problem to be analyzed shall be used.

The size of the volume within which the stochastic fracture network is to be generated is governed by the flow calculation in the fracture network. The boundaries must be far enough away not to affect the calculated inflow. The rock mechanical analyses only require data on the stochastic fracture network in a zone around the actual tunnel or deposition hole. A volume of width 300 m, height 400 m and length 500 m is judged to be large enough for the flow calculation as well. The 300 m long tunnel is located centrally in the rock volume.

In calculating the total number of deposition holes that may be lost, the calculation shall be carried out in the sequence 1–4. The total percentage loss of deposition holes, p_n, shall be calculated based on the number of holes remaining after previous steps.

1. Minimum permissible distance between deposition holes and stochastically determined fractures/fracture zones with radius R>100m

The loss of deposition holes due to minimum permissible distance between deposition holes and stochastically determined fractures or fracture zones with radius R>100 m according to point 1 in section 5.4.4.1 shall in design step D1 be verified by means of statistical analyses in accordance with section 4.5 in Appendix 1.

The minimum permissible distance between the periphery of a deposition hole and stochastically determined fractures or fracture zones shall for design step D1 be assumed to be:

- 2 m for fractures or fracture zones when $100 < R \leq 200$ m
- 0.01 R for fractures or fracture zones when R>200 m

The minimum permissible distance between a deposition hole and stochastically determined fractures or fracture zones with a radius of R>100 m may, however, be changed in later design steps. The identification of such structures will be based on site-specific geological markers.

The percentage loss of deposition holes due to the minimum permissible distance between deposition holes and stochastically determined fractures/fracture zones with a radius >100 m, p_1, shall be calculated as

$p_1=(N_{TOT}-N_G)/N_{TOT}$.

Where N_{TOT} is the theoretically possible number of deposition holes along a 300 m long tunnel without taking loss into account and N_G is the number of approved deposition holes according to point 1 along the same tunnel.

2. Quantity of water leaking into deposition holes

The loss of deposition holes due to the quantity of water leaking into deposition holes according to point 2 in section 5.4.4.1 shall in design step D1 be verified by means of hydrogeological statistical analyses in accordance with section 4.4 in Appendix 2.

Calculation according to point 2 shall be carried out for the deposition holes that have been approved according to point 1.

Deposition holes with a seepage of q>10 l/min shall for design step D1 be assumed to be lost.

The criterion for loss due to seepage into deposition holes as described above may be changed in later design steps.

The percentage loss of deposition holes due to seepage, p_2, shall be calculated as

$P_2=N_F/N_G$

where N_F is the number of deposition holes where the inflow exceeds the critical value and where N_G is the number of approved deposition holes along a 300 m long deposition tunnel according to point 1.

To shed light on the sensitivity of the above in-seepage criterion, the loss shall also be calculated and reported at a loss of deposition holes with an in-seepage of q>1 l/min.

3. Potential wedge breakout in deposition holes

The loss of deposition holes due to potential wedge breakout in deposition holes according to point 3 in section 5.4.4.1 shall in design step D1 be verified by means of statistical block analyses (kinematic) in accordance with section 4.6 in Appendix 1.

Calculation according to 3 shall be carried out for the deposition holes that have been approved according to point 1, N_G, minus the number of deposition holes, N_F, where the in-leakage is greater than the critical value according to point 2.

Deposition holes with potential wedge breakout corresponding to a volume $V \geq 0.15 m^3$/ deposition hole shall be assumed to be lost.

The criterion for loss due to individual wedge breakout in deposition holes as described above may be changed in later design steps.

The percentage loss of deposition holes due to potential wedge breakout, p_3, shall be calculated as

$P_3=N_B/(N_G-N_F)$

where NB is the number of deposition holes with unstable wedges that have a volume in excess of the critical volume.

To shed light on the sensitivity of the above volume criterion, the omission shall also be calculated and reported at a volume $V \geq 0.1 m^3$ and $V \geq 0.2 m^3$.

4. Risk of spalling in deposition holes

The loss of deposition holes due to the risk of spalling in deposition holes according to point 4 in section 5.4.4.1 shall in design step D1 be verified by means of statistical analyses of the stress distribution around deposition holes in accordance with section 4.7 in Appendix 1.

The analysis shall be carried out for a deposition hole located centrally in a deposition tunnel.

Deposition holes that do not meet the criterion according to Equation (2) shall for design step D1 be assumed to be lost.

$$\sigma_\theta/\sigma_{ci}<D \qquad (2)$$

where

σ_θ = tangential stress on the periphery of the deposition hole over the part of the hole where the canister is placed, see Appendix 1, section 4.7.

σ_{ci} = uniaxial compressive strength of intact rock

D = onset of dilation determined from uniaxial compressive tests, expressed as a ratio to σ_{ci}.

The criterion for loss due to spalling as described above may be changed in later design steps.

The range of variation in the size and direction of initial stresses as well as in the uniaxial compressive strength of intact rock shall be taken into account.

The percentage loss of deposition holes due to the risk of spalling, p_4, shall be calculated as

$$p_4=N_S/N_C$$

where N_S is the number of holes where the greatest tangential stress exceeds the criterion when the distributions of the size and direction of the initial stresses and the variation in the uniaxial compressive strength of the intact rock are taken into account, and N_C is the total number of simulations.

To shed light on the sensitivity of the above spalling criterion, the loss shall also be calculated and reported for a 95% confidence interval of D.

5.4.4.4 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Table and/or graph showing the loss of deposition holes as a function of the depth of the particular rock domain decided on by the Client according to section 5.3.4. The breakdown of the causes of this loss shall be shown.
5. Graph showing the variation in the different loss components for each rock domain due to variation in criteria.

6. Conclusions and assessment of reasonability of results.
7. Appendix with calculations carried out according to reporting and documentation requirements in section 4.5 in Appendix 1.
8. Appendix with calculations carried out according to reporting and documentation requirements in section 4.4 in Appendix 2.
9. Appendix with calculations carried out according to reporting and documentation requirements in section 4.6 in Appendix 1.
10. Appendix with calculations carried out according to reporting and documentation requirements in section 4.7 in Appendix 1.
11. References.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made. Reasons shall be given for chosen tunnel orientations. Formulas used shall be explained, and references shall be given for those that cannot be considered to be generally known.

5.4.5 Repository depth (C5)

5.4.5.1 General

The repository shall be located within the depth range 400–700 m under ground.

The repository depth shall in design step D1 be chosen so that:

1. the requirement on the number of canisters to be deposited according to section 5.3 is met,
2. as favourable conditions as possible are obtained with respect to stability,
3. an efficient and flexible facility is obtained.

5.4.5.2 Execution

Repository depth shall in design step D1 be chosen by a weighing-together of the design results as regards:

- respect distance to deterministically determined deformation zones and decided-on rock domains and depths according to section 5.3,
- design of deposition tunnels, deposition holes and main tunnels according to section 5.4.1,
- distance between deposition tunnels and between deposition holes according to section 5.4.2,
- orientation of deposition tunnels according to section 5.4.3,
- loss of deposition holes according to section 5.4.4.

5.4.5.3 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Compilation of experience from design in sections 5.3–5.4
5. Maps which, for each potential deposition area and depth decided on by the Client according to section 5.3.4 , show:
   a. respect distance to deterministically determined deformation zones,
   b. distance between main tunnel and first deposition hole, and between deposition holes and tunnel end,
   c. distance between deposition tunnels and between deposition holes,
   d. orientation of deposition tunnels,
   e. loss of deposition holes including estimated uncertainties.
6. Conclusions and recommendation of depth including reasons.
7. Possible references.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made. Reasons shall be given for the chosen repository depth.

5.5 Design of other rock excavations (D)

5.5.1 General

Design of other underground openings (caverns in central area, shaft, ramp and transport tunnels) shall be carried out in design step D1, taking into account:

1. the required space for the activities to be pursued,
2. stability.

5.5.2 Execution

In design step D1, requirements according to point 1 in section 5.5.1 shall be considered to be met if the design of caverns in the central area, shafts, ramp and transport tunnels takes place in accordance with facility description Layout E (see section 4.1) with respect to:

- layout of central area,
- dimensions and form regarding cross-section (theoretical rock contour) of rock halls and tunnels in central area,
- length of rock halls,
- distance between rock halls,
- dimensions and form regarding cross-section (theoretical rock contour) of shafts, ramp and transport tunnels.

Note that tunnels Type B according to facility description Layout E (SKB, 2002b) shall have a cross-sectional area of about 49 m^2 and not 30 m^2 as incorrectly stated.

The length of transport tunnels is determined in conjunction with preparation of the layout according to section 5.6.

Requirements according to point 2 in section 5.5.1 shall in design step D1 be assumed to be met if the form and cross-sectional dimensions of other rock caverns according to facility description Layout E (see section 4.1) are applied and rock support according to section 5.10 is installed.

More detailed design of the configuration of other rock caverns taking into account the requirements in section 5.5.1 will be carried out in later design steps.

5.5.3 Documentation

For design step D1, no requirements are made on specific documentation of the design of other rock caverns, since this is largely done in accordance with Layout E. Documentation of the design of other rock caverns instead takes place in conjunction with the documentation of the layout of the entire hard rock facility according to section 5.6.

5.6 Layout (E)

5.6.1 General

Based on the design process carried out in sections 5.2–5.5 and requirements as described below, a complete layout for the hard rock facility shall be prepared.

Deposition areas shall be placed in rock domains decided on by the Client according to section 5.3.4.

Deposition areas shall be placed at the chosen depth according to section 5.4.5.

In preparing subsequent layouts (D1:2, etc.), another depth may be chosen if it can be shown to be advantageous with respect to the efficiency and flexibility of the facility. Choice of other depth is done in consultation with the design coordinator.

In placing deposition areas, it shall be assumed that deposition tunnels, deposition holes and main tunnels are designed according to section 5.4.1.

The distance between deposition tunnels and between deposition holes shall be assumed to be according to section 5.4.2.

The orientation of deposition tunnels shall be chosen according to section 5.4.3.

If the chosen tunnel orientation leads to an unreasonably low utilization of an available rock domain, another orientation may be chosen, resulting in a greater need for grouting and support and a larger loss of deposition holes. In this case, choice of another tunnel orientation shall be carried out after renewed analysis of loss according to section 5.4.4 for the alternative orientation and in consultation with the design coordinator.

The placement of deposition areas shall take into account the respect distance of deposition tunnels to deterministically determined deformation zones according to section 5.3.

Deposition areas shall hold 6000 canisters. Account shall be taken to the loss of deposition holes according to section 5.4.4 and the loss of deposition area due to the distance between the first deposition hole and the main tunnel and the distance between the last deposition hole and the tunnel end according to section 5.4.1.

> *6000 canisters include margins and also the possibiliy for a longer operational time of the power units in Sweden than in the current reference.*

In design step D1, at least two deposition areas shall be assumed, one for initial operation with deposition of 200–400 canisters, and one for regular operation with deposition of 5600–5800 canisters.

In initial operation, deposition of 100 canisters/year shall be assumed in design step D1. In regular operation, deposition of 200 canisters/year shall be assumed in design step D1.

The angle between main tunnels and deposition tunnels shall be chosen with a view towards stability and the efficiency of the facility from a constructional and operational point of view.

Deposition tunnels shall in design step D1 be assumed to have a maximum length of 300 m.

The minimum distance between the deposition area for initial operation and deposition areas for regular operation for design step D1 is assumed to be at least 80 m.

Other rock caverns (central area etc.) shall be placed in rock domains decided on by the Client according to section 5.3.4.

> *In design step D1, the central area may be placed in the same rock domain as a deposition area, space allowing.*

The minimum distance between deposition tunnels and caverns in the central area, shafts, ramp and transport tunnels shall for design step D1 be assumed to be 50 m.

In placing caverns in the central area, shafts, ramp and other transport tunnels, it shall be assumed that these are designed according to section 5.5.

Connections with the ground surface (shaft and ramp) shall be placed so that nuisances for neighbours and nearby residents, impact on ecologically valuable environments, and impact on land use are minimized.

This shall be done in consultation with the site unit and EIA/Communications, who are responsible for the environmental studies.

In placing caverns in the central area, a minimum distance to deterministically determined deformation zones equal to the respect distance according to section 5.3 shall be assumed.

> *It may be assumed that deterministically determined deformation zones (regardless of length) are allowed to intersect ramp and shafts.*
>
> *Which deterministically determined deformation zones may be assumed to intersect main tunnels and transport tunnels is decided on by the Client according to section 5.3.4.*

Central area, shafts, ramp and transport tunnels shall be placed with respect to water-bearing zones so that sepage is minimized wherever possible.

In placing the different parts of the hard rock facility, allowance shall be made as far as possible for post-closure flow patterns so that transport of contaminated water into deposition areas is minimized.

The layout shall permit build-out of the hard rock facility in parallel with investigations, deposition, backfilling and temporary plugging.

The longitudinal slope of ramp and tunnels shall be steep enough not to complicate run-off of in-leaking water, but not so steep that transportation cannot be carried out safely and efficiently. The normal longitudinal slope of tunnels shall in design step D1 be assumed to be 1:100. The maximum permissible slope of the ramp shall in design step D1 be assumed to be 1:10.

The minimum curve radius shall in design step D1 be assumed to be 15 m.

The layout shall, with a view towards gradual build-out and deposition as well as fire and other accidents, be designed so that evacuation can take place in two directions in transport and main tunnels.

5.6.2 Sensitivity study

The sensitivity of the layout with respect to total mined rock volume, V, enclosed utilized deposition area, A_u, and degree of utilization, U, for the site shall be studied for:

1. changed premises with respect to the occurrence of deterministically determined zones (confidence level that they exist),
2. changed premises with respect to the orientation of deterministically determined zones (strike and dip),
3. changed premises with respect to the respect distance of deterministically determined zones,
4. changed premises with respect to the mean value of the thermal conductivity of the rock in conjunction with the choice of distance between deposition holes according to section 5.4.2.3,
5. changed premises with respect to the criterion for calculation of loss of deposition holes according to section 5.4.4,
6. changed premise with respect to the maximum length of deposition tunnels, assuming that it can be 600 m.

Determination of the limit values within which the sensitivity study shall be carried out with respect to points 1–3 above shall take place in consultation between the design coordinator, safety assessment and site modelling.

The degree of utilization shall be calculated according to Equation (3).

$$U = \frac{6000}{N_T} \qquad (3)$$

where

N_T = total number of available deposition hole positions for rock domains at the depth in question that have been decided on by the Client according to section 5.3.4 after reduction with respect to the loss of deposition holes.

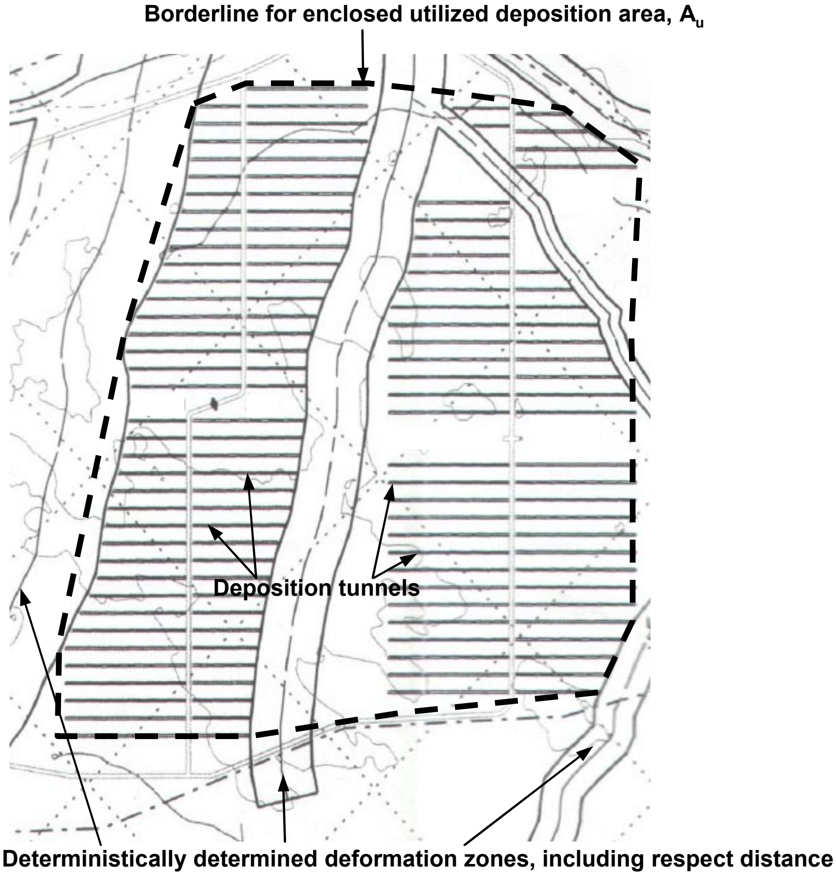


Figure 5-5. *Example of enclosed utilized deposition area, A_u.*

Enclosed utilized deposition area, A_u, is defined as the area obtained inside a closed borderline drawn between breakpoints and enclosing all requisite areas for deposition tunnels in a layout.

An example of an enclosed utilized deposition area, A_u, is given in Figure 5-5.

Absolute and relative changes in V, A_u and U shall be calculated separately for each changed premise in the sensitivity study.

5.6.3 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Drawings with requisite number of sections showing:
   a. deterministically determined deformation zones with associated respect distances.
   b. placement of deposition areas with indication of,
      – dimensions for distances between deposition tunnels and between deposition holes within each deposition area,
      – orientation of deposition tunnels within each deposition area,

   – number and length of deposition tunnels (dimension),
   – number of deposition holes within each deposition area.
c. placement of other rock caverns with indication of,
   – other rock caverns (central area, ramp, shafts, transport tunnels, main tunnels, etc.),
   – minimum distance between deposition tunnels and other rock caverns (dimension).

5. Account of principles for build-out of hard rock facility.

6. Total volume of mined rock, V (tfm^3), and broken down into tunnel types A–F according to facility description Layout E (see section 4.1), rock halls, vertical shafts and other underground openings according to completed design.

7. Deposition area (m^2) which exceeds requirement for number of canisters to be deposited and estimation of how many canisters this area can accommodate, taking the loss factor into account.

8. Sensitivity study with account of absolute and relative changes in total mined volume of rock, V, enclosed deposition area A_u and degree of utilization, U, plus associated layout drawings.

9. Conclusions.

10. References.

The report shall be prepared in A4 format. Drawings shall be prepared in A3 format which is folded to A4. The report shall contain information concerning what assumptions and interpretations have been made. Reasons shall be given for the chosen layout.

5.6.4 Checking and evaluation

The design coordinator shall deliver to the Client documentation according to sections 5.4.1.3, 5.4.2.4, 5.4.3.4, 5.4.4.6, 5.4.5.3, 5.5.2 and 5.6.3 and give an account of the work and its results.

The documentation shall, according to section 3.3.3 be reviewed by an independent resource prior to delivery to the Client.

The Client checks and evaluates the design results and then decides either to proceed with the design process or to supplement or stop the design process. If design of the current layout is stopped, the Client decides whether further layout alternatives are to be studied.

5.7 Identification of passages through deformation zones (F)

5.7.1 General

Identification of passages through deformation zones shall be carried out.

The purpose of identifying passages through deformation zones is to create a basis for determining measures with respect to excavation, grouting and rock support in these tunnel sections, and to permit comparisons between different layouts by relating the number of passages and the total length of the passages to the rock quality.

5.7.2 Execution

Identification of passages through deformation zone shall for design step D1 be done in the following steps:

1. Identification of passages through deterministically determined deformation zones to provide access routes between different parts of the hard rock facility and
2. Classification of each passage with respect to rock quality
3. Estimation of the length, L (m), of each passage.
4. Estimation of anticipated difficulties for each passage with respect to excavation, rock support and grouting based on empirical knowledge, and how these difficulties can be overcome.

The identification shall be based on a layout prepared according to section 5.6 and the site description, model version 1.2.

5.7.3 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Drawing/map with visualization of all passages with deterministically determined deformation zones.
5. Bar graph which shows for the layout:
   a. number of passages, N, as a function of estimated rock quality,
   b. the total length, ΣL, of the passages as a function of rock quality.
6. Description of anticipated difficulties for each passage and how they can be overcome.
7. Conclusions.
8. References.

The report shall be prepared in A4 format. The drawing/map shall be prepared in A3 format which is folded to A4. The report shall contain information concerning what assumptions and interpretations have been made.

5.8 Seepage and hydrogeological situation around repository (G)

5.8.1 General

Seepage into the repository and the hydrogeological situation around the repository with respect to salinity (TDS) and lowering of the groundwater table shall be assessed with a view towards assumed grouting levels.

The purpose of the assessments is to serve as a basis for:

- *the preliminary safety evaluation, see Figure 3-2,*
- *environmental impact assessment (EIA), see Figure 3-2,*
- *assessment of the need for pumping and water treatment for cost calculation, see Figure 3-2 .*

5.8.2 Execution

Seepage into the repository and the hydrogeological situation around the repository depend on how much rock grouting is done. Since no specific requirements on seepage are formulated for design step D1, the grouting need cannot be assessed on the basis of seepage requirements. Seepage and the hydrogeological situation around the repository are instead assessed on the basis of various assumptions of achieved grouting results(resulting permeability) at different points in time (phases/degrees of excavation).

Assessment of seepage into the repository and the hydrogeological situation around the repository shall be based on the layout produced in section 5.6 and the site description, model version 1.2, and shall be carried out as follows:

1. Definition of points in time (phases/degrees of mining) at which the assessments shall be carried out.

   Examples of points in time may be:

   a) when access roads and all caverns in the central area have been mined,

   b) when it can be assumed that most of the deposition tunnels are open.

2. Definition of assumed grouting levels at which the assessments shall be carried out.

   Examples of grouting levels may be:

   Level 0: No grouting.

   Level 1: Rock mass is sealed to resulting permeability $K=10^{-7}$ *m/s out to certain distance from tunnel periphery.*

   Level 2: Rock mass is sealed to resulting permeability $K=10^{-9}$ *m/s out to certain distance from tunnel periphery.*

3. Assessment of:
   - quantity of water leaking into the repository at the different points in time defined in point 1 for the different grouting levels defined in point 2,
   - distribution of salinity (TDS) in the near-field rock (i.e. in the area around the depo sited canisters) at the different points in time defined in point 1 for the different grouting levels defined in point 2,
   - lowering of groundwater table at the different points in time defined in point 1 for the different grouting levels defined in point 2.

Definition of points in time (phases/degrees of mining) at which the calculations shall be carried out according to point 1 and grouting levels according to point 2 shall be done by the project coordinator in consultation with the units for site modelling, safety assessment and EIA.

Assessment of seepage and the hydrogeological situation shall be verified according to section 5.8.3.

5.8.3 Verification

Assessment of seepage and the hydrogeological situation shall be verified by means of hydrogeological analyses in accordance with section 4.5 in Appendix 2.

5.8.4 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Tables, graphs and plots showing the estimated quantity of in-leaking water as well as the distribution of salinity (TDS) and lowering of the groundwater table as a function of point in time (phase/degree of mining) and grouting level.
5. Conclusions.
6. References.
7. Appendix with calculations carried out according to reporting and documentation requirements in section 4.5 in Appendix 2.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made.

5.8.5 Checking and evaluation

The design coordinator shall deliver to the Client documentation according to sections 5.7.3 and 5.8.4 and give an account of the work and its results.

The documentation shall, according to section 3.3.3 be reviewed by an independent resource prior to delivery to the Client.

> *The Client checks and evaluates the design results and then decides either to proceed with the design process or to supplement or stop the design process. If design of the current layout is stopped, the Client decides whether further layout alternatives are to be studied.*

5.9 Estimation of rock grouting need (H)

5.9.1 General

Estimation of rock grouting need shall for design step D1 be done for the different points in time and for the different grouting levels defined during the execution of design according to section 5.8.

Estimation of rock grouting need constitutes a basis for analysis of groundwater composition carried out by safety assessment, as well as a basis for cost calculation, see Figure 3-2.

5.9.2 Execution

Estimation of rock grouting work shall in design step D1 be carried out in the following two steps:

1. estimation (assessment/assumption) of suitable grouting procedures for the grouting levels defined during the execution of design according to section 5.8.
2. estimation of quantity of grout for the grouting levels and points in time (phases/degrees of mining) defined during the execution of design according to section 5.8.

1. Estimation of suitable grouting procedures

Estimation of suitable grouting procedures shall be done for each grouting object and include at least assessment of:

- number of holes and hole length in grouting screens,
- borehole diameter,
- look-out angle,
- number of grouting screens,
- mortar mixtures including additives,
- grouting method,
- total number of drilling metres for grouting object.

By "grouting object" is meant the tunnel section in a given tunnel type according to facility description Layout E (see section 4.1) for which grouting is to be done to obtain a certain resulting permeability (K value), out to a certain distance from the tunnel periphery, see section 5.8.

2. Estimation of quantity of grout

The quantity of grout shall be estimated for each grouting object. The quantities shall be broken down among the following facility parts:

- deposition tunnels,
- main tunnels,
- ramp,
- vertical shafts,
- rock halls and tunnels in central area with cross-sections according to Layout E (see section 4.1),
- transport tunnels outside the central area, i.e. tunnels with cross-section Type B according to Layout E (see section 4.1).

Estimation of quantity of grout shall be verified according to section 5.9.3.

Quantity of grout shall be given both as volume (m^3) and as weight of cement (tonnes). Any additives shall be given as volume (litres or m^3) and as weight (kg or tonnes) for each constituent additive component.

5.9.3 Verification

Estimation of quantity of grout shall in design step D1 be verified by means of analyses in accordance with section 4.6 in Appendix 2.

5.9.4 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Description and illustration of suitable grouting procedures
5. Tables showing estimated grouting need (grouting procedures and quantities) for defined grouting levels. Minimum and maximum quantities shall be specified.
6. Conclusions.
7. References.
8. Appendix with calculations carried out according to reporting and documentation requirements in section 4.6 in Appendix 2.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made.

5.10 Estimation of rock support need (I)

5.10.1 General

Estimation of rock support need shall in design step D1 be done for all underground openings in the layout prepared according to section 5.6.

> *Estimation of rock support need constitutes a basis for analysis of groundwater composition carried out by safety assessment, as well as a basis for cost calculation, see Figure 3-2.*

Rock support shall in design step D1 primarily be assumed to be done with conventional support elements such as rock bolts, shotcrete and wire mesh.

> *If necessary, e.g. on passage of zones with poor quality rock, in-situ-cast concrete structures may be used.*

Support of the contour in deposition tunnels shall primarily be assumed to take the form of wire mesh. Shotcreting in deposition tunnels shall be kept to a minimum if possible.

Requirements on durability as well as materials, execution and inspection are given in sections 4.4 and 4.5.4.

5.10.2 Execution

Estimation of rock support need shall in design step D1 be carried out by means of empirical methods, for example the Q-system (Barton, 2002).

> *No requirement is made in design step D1 that proposed rock support solutions be verified in any other way than by empirical methods. Other requirements on verification will be made in later design steps.*

Quantities for all rock support elements shall be calculated. The quantities shall be broken down among the following facility parts:

- deposition tunnels,
- main tunnels,
- ramp,
- vertical shafts,
- rock halls and tunnels in central area with cross-sections according to Layout E (see section 4.1),
- transport tunnels outside the central area, i.e. tunnels with cross-section Type B according to Layout E (see section 4.1).

In addition to quantities for rock support elements as per the above, the quantity of concrete and reinforcement for temporary plugging shall be estimated.

> *The design coordinator provides supporting material for calculation of the quantity of concrete and reinforcement in the temporary plug.*

Bolt quantities for each facility part shall be broken down among different bolt lengths and diameters. The quantities shall be stipulated both as number and weight of steel (tonnes). Corrosivity classes for bolts shall be specified.

Grouting material for embedded bolts shall be specified for each facility part both as volume (m^3) and as weight of cement (tonnes).

Shotcrete quantities for each facility part shall be broken down among different thicknesses. The quantities shall be specified as shotcreted area (m^2) and volume (m^3), as well as weight (tonnes). Quantity of steel fibres shall be specified as weight (tonnes). Exposure classes shall be specified.

For concrete structures, quantities shall be specified for concrete and reinforcement. Concrete shall be specified both as volume (m^3) and as weight of cement (tonnes). Concrete reinforcement shall be specified as weight (tonnes). Exposure classes shall be specified.

Any additives to grouting material, shotcrete and concrete shall for each facility part be specified as volume (litres or m^3) and as weight (kg or tonnes) for each constituent additive component. Quantity of additives shall be specified for each facility part.

5.10.3 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises.
3. Description of the execution of the particular design task.
4. Calculations.
5. Illustration of chosen rock support solutions
6. Drawings (plans) showing the distribution of different rock support solutions.
7. Tables showing estimated rock support need (quantities) for different facility parts. Minimum and maximum quantities shall be specified.
8. Conclusions.
9. References.

The report shall be prepared in A4 format. Drawings shall be prepared in A3 format which is folded to A4. The report shall contain information concerning what assumptions and interpretations have been made.

5.10.4 Checking and evaluation

The design coordinator shall deliver to the Client documentation according to sections 5.9.4 and 5.10.3 and give an account of the work and its results.

The documentation shall, according to section 3.3.3 be reviewed by an independent resource prior to delivery to the Client.

The Client checks and evaluates the design results and then decides either to proceed with the design process or to supplement or stop the design process. The Client also decides whether additional layout alternatives are to be studied.

5.11 Technical risk assessment (K)

5.11.1 General

Based on the premises underlying design step D1 according to section 4.1, and completed design according to sections 5.2–5.10, a technical risk assessment shall be carried out.

The technical risk assessment is performed to establish a feedback between the design results and the goals of rock engineering in design step D1 according to section 2.4. The purpose of the feedback is to ensure that the premises comprising the design basis are illuminated from several aspects with a view towards the aforementioned goals. Technical risk analyses will be carried out in later design steps.

The technical risk assessment shall be limited to completed design in design step D1 and shall include providing proposals for measures aimed at preventing the occurrence of undesirable events. The technical risk assessment shall not include events that are associated with the construction and operating phases or the post-closure phase.

Proposals for preventive measures may consist of recommendations for further studies and investigations.

The technical risk assessment shall be carried out so that every alternative layout is included and shall at least contribute towards meeting the following goals according to section 2.4:

1. "Test and evaluate the design methodology"
2. "Determine whether the deep repository can be accommodated within the studied site"
3. "Identify site-specific facility-critical issues and provide feedback to:
   - design regarding continued study work,
   - the site organization regarding further investigations,
   - safety assessment regarding which factors control the extent of the repository".

Point 1 above shall contain at least the following risk objects:

- applied design methodology,
- completed analyses,
- specified criteria and requirements,
- the design basis according to section 4.1.

Points 2 and 3 above shall contain at least the following objects:

- enclosed utilized deposition area, A_u
- volume of mined rock, V,
- degree of utilization, U.

For definition of A_u, V and U, see section 5.6.2.

Objects consist of numerical values, analyses, posed criteria and requirements or other design basis used to fulfil and describe the goals of rock engineering in design step D1.

5.11.2 Execution

The methodology and structure for the technical risk assessment shall be devised in consultation with the design coordinator and shall be carried out in accordance with the following guidelines. The input data to the risk assessment are derived from the designer's experience from the completed design work in design step D1.

Events and possible damage associated with the objects shall be described with a view towards the requirements made in the design basis and given premises, as well as completed analyses under the design tasks A–I.

The term "event" refers to an altered premise of a desirable or undesirable nature that leads to a change in a previously judged consequence. The term "consequence" refers to an increase or loss of values, goodwill, function or quality, and describes how altered premises influence studied objects with respect to persons, property or environment in an ongoing activity.

The technical risk assessment of a realized event shall be classified on a qualitative or quantitative scale. Reasons shall be given for chosen classifications, chosen numerical value and proposals for preventive measures, and they shall include a description of the feedback to the goals of the design work in design step D1.

Proposals of how the technical risk assessment can be structured are presented below for a selection of events.

Goal: Repository is accommodated on studied site

Object:	*Enclosed utilized deposition area* *Volume of mined rock*
Event:	*Addition of deformation zone* *Change in respect distance* *Change in size or direction of rock stresses* *Change in opinion regarding rock transmissivity or permeability requirements*
Damage:	*Environmental impact in the form of increased rock volumes, haulage, etc.*
Consequence:	*Quantitative numerical values, e.g. relative or actual change in enclosed utilized area* *Qualitative numerical values, e.g. negligible/little/moderate/great/probably unacceptable*
Preventive measures:	*Further investigations, study criteria and requirements, etc.* *Adapt quantity of rock support, quantity of grouting*

5.11.3 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of premises and execution.
3. Tables or other format showing structure and content for the technical risk assessment.
4. Ranking of events with respect to the magnitude of the consequence for each analyzed object.
5. Description of measures for preventing the occurrence of undesirable events with reasons and feedback to the goals in design step D1.
6. Proposal for prioritization of measured aimed at preventing the occurrence of undesirable events and damage.

7. Conclusions.
8. References.

The report shall be prepared in A4 format. The report shall contain information concerning what assumptions and interpretations have been made.

5.12 Report rock engineering (L)

5.12.1 General

The rock engineering carried out in design step D1 shall be described in a summarizing report. The scope of the report shall be according to section 5.12.2.

5.12.2 Documentation

The documentation shall comprise a design report including at least:

1. Summary.
2. Description of the design premises.
3. Summary of the rock engineering including all design tasks in sections 5.2–5.11 for all designed layouts.
4. Supporting material for preliminary facility description and cost calculation including: (a) alternative layouts (b) general description of production methods with respect to excavation, rock grouting and rock support, (c) compilation of quantities regarding excavation, rock grouting, rock support and water inflow (pumping), (d) description of build-out sequence, and (e) degree of utilization and total mined volume of rock.
5. Compilation of supporting material for early EIA consultation including: (a) location of the surface facility, (b) location and extent of the hard rock facility and (c) lowering and extent of the groundwater table.
6. Compilation of supporting material for preliminary safety evaluation including: (a) preliminary deposition areas, (b) estimated quantities and distribution of foreign materials, and (c) estimation of distribution of salinity (TDS) in the repository area.
7. Identification of site-specific facility-critical factors that influence the total volume of mined rock and the degree of utilization.
8. Recommendations for: (a) study work that needs to be done and (b) further investigations.
9. Evaluation of applied design methodology.
10. References.

5.12.3 Checking and evaluation

The design coordinator shall deliver to the Client documentation according to section 5.12.2, and all underlying documentation according to sections 5.3.4, 5.6.4, 5.8.5, 5.10.4 and 5.11.3 for checking and evaluation, and give an account of the work and its results.

> *The Client checks the documentation and decides whether it needs to be supplemented or whether the rock engineering can be approved and stopped.*
>
> *The documentation according to sections 5.3.4, 5.6.4, 5.8.5 and 5.10.4 has previously been checked and evaluated according to these sections. These checks can therefore be regarded as a subset of the checks according to this section. This means that this documentation can be considered to be checked but not formally approved. Formal approval can only take place when all documentation is available.*

The documentation shall, according to section 3.3.3 be reviewed by an independent resource prior to delivery to the Client.

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Instructions for rock mechanical analyses

1 Introduction

1.1 Contents and validity

The present appendix contains instructions for rock mechanical analyses to be carried out during design step D1. The appendix is a subdocument to “Underground Design Premises”, called “UDP” (PFB in Swedish), see Figure 1-1 in UDP.

1.2 Abbreviations and definitions

For an overview of abbreviations used and definitions of different parts of the deep repository’s hard rock facility, see Chapter 1.6 in UDP.

2 Design basis

The design basis is presented in Chapter 4 of UDP.

3 Verification of used software

3.1 General

Only widely recognized and verified software may be used.

3.2 Software for elastic analyses

Examples of software acceptable for elastic analysis are ABAQUS, BEFE, EXAMINE3D, FLAC3D, 3DEC, UDEC, FLAC2D, PLAXIS and PHASE2D.

3.3 Software for generation of stochastic fracture networks

Examples of software acceptable for generating stochastic fracture networks are FracMan and NAPSAC.

3.4 Software for checking wedge stability

Examples of software acceptable for checking wedge stability are RockBlock and Unwedge.

4 Questions to be analyzed

4.1 General

For a detailed description of the design process and design questions in design step D1, see Chapter 5 in UDP.

The analyses described in sections 4.3 – 4.6 that are to be carried out with the aid of stochastically generated fracture networks shall be coordinated so that the same realizations of stochastic fracture networks are used for all analyses. They shall also be coordinated with the hydrogeological analyses that are carried out with stochastically generated fracture networks, see Appendix 2.

Analysis of loss of deposition holes according to sections 4.5 – 4.6 shall be coordinated with the hydrogeological analyses according to section 5.4.4.5 in UDP

4.2 Analysis of suitable orientation of deposition tunnels with a view towards the risk of spalling

4.2.1 General

According to UDP section 5.4.3.3 point 2, a suitable orientation of deposition tunnels with respect to the risk of spalling shall be analyzed.

4.2.2 Input data

The mechanical properties of the rock mass (E, ν), the strength of the intact rock (σ_{ci}) and the initial stresses (σ_1, σ_2, σ_3) in the rock mass for a given rock domain shall be taken from the site description, model version 1.2.

Form and diameter of deposition tunnels shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

4.2.3 Analysis method

Three-dimensional elastic finite element, boundary element or finite difference analysis shall be used. If the finite element or finite difference method is used, elastic boundaries shall be used on the model.

In the analysis, the direction of the deposition tunnels shall be varied in relation to the mean direction of the major horizontal stress and for different rock domains and depths, according to section 5.4.3.3 in UDP.

The model shall include at least three deposition tunnels in order to include the effect of interaction between the tunnels. The distance between the deposition tunnels shall be chosen as the previously determined minimum distance between deposition tunnels, see section 5.4.2 in UDP.

The deposition holes shall not be modelled in the analysis.

The size of the model shall be chosen so that the model's lines do not influence the result. The length of the deposition tunnels shall be set at 300 m in the model.

The risk of spalling shall be calculated as the ratio of the greatest tangential stress along the tunnel periphery to the uniaxial compressive strength of the intact rock. One value for roof, one for floor and one for wall – floor transition shall be calculated. The calculation shall apply to a section located centrally along the middle tunnel.

The mean value of the initial stresses, mechanical properties and strength shall be used in the analyses.

The uncertainty in the direction of the major horizontal stress shall be taken into account, however.

4.2.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Description of software used.
4. Description of model chosen.
5. Presentation of calculated risk of spalling for different tunnel orientations, depths and rock domains.
6. Give the optimal tunnel direction with respect to the risk of spalling.
7. Possible references.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.3.4.

4.3 Analysis of suitable orientation of deposition tunnels with a view towards the volume of unstable wedges in deposition tunnels

4.3.1 General

According to UDP section 5.4.3.3 point 3, a suitable orientation of deposition tunnels with respect to the volume of unstable wedges in deposition tunnels shall be analyzed.

4.3.2 Input data

The statistical description of the direction, size and strength properties of the fractures within a given rock domain shall be taken from the site description, model version 1.2.

Form and diameter of deposition tunnels shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

4.3.3 Analysis method

A stochastic fracture network shall be created within a volume of width 300 m, height 400 m and length 500 m with software acceptable for generating stochastic fracture networks, see section 3.3.

A 300 m long deposition tunnel shall be placed in the centre of this volume.

The deposition holes shall not be modelled in the analysis.

The aggregate volume of the unstable rock wedges formed between the fractures and the tunnel contour along the tunnel shall be calculated.

Mean values of the strength of the fractures shall be used in the analyses.

Rock support shall not be taken into account in the analyses.

The calculation shall be done with software acceptable for analysis of wedge stability, see section 3.4.

In the analysis, the direction of the deposition tunnels shall be varied in relation to the mean direction of the major horizontal stress and for different rock domains and depths, according to section 5.4.3.3 in UDP.

For each direction of the deposition tunnel, at least 20 fracture networks shall be generated and the statistical distribution of the volume of unstable blocks shall be calculated for each tunnel orientation.

The uncertainty in the data, for example if there are alternative interpretations, shall be taken into account.

The analysis method is described by Starzec P. (2002).

4.3.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Description of software used.
4. Description of model chosen.
5. Presentation of the calculated distribution of the volume of unstable blocks in deposition tunnels for different tunnel orientations, depths and rock domains.
6. Give the optimal tunnel direction with respect to the volume of unstable blocks in deposition tunnels.
7. Possible references.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.3.4.

4.4 Analysis of suitable orientation of deposition tunnels with a view towards the volume of unstable wedges in deposition holes

4.4.1 General

According to UDP section 5.4.3.3 point 3, a suitable orientation of deposition tunnels with a view towards the volume of unstable wedges in deposition holes shall be analyzed.

4.4.2 Input data

The statistical description of the direction, size and strength properties of the fractures within a given rock domain shall be taken from the site description, model version 1.2.

Form and diameter of deposition holes shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

4.4.3 Analysis method

A stochastic fracture network shall be created within a volume of width 300 m, height 400 m and length 500 m with software acceptable for generating stochastic fracture networks, see section 3.3.

Vertical deposition holes shall be placed in the centre of this volume along a 300 m long line. The distance between the deposition holes shall be assumed to be the minimum distance determined according to section 5.4.2 in UDP.

In the analysis, the direction of the line of deposition holes shall be varied in relation to the mean direction of the major horizontal stress and for different rock domains and depths, according to section 5.4.3.3 in UDP.

The total volume of the unstable rock wedges formed between the fractures and the hole contour shall be calculated for all deposition holes along the line.

Mean values of the strength of the fractures shall be used in the analyses.

Rock support shall not be taken into account in the analysis.

The calculation shall be done with software acceptable for analysis of wedge stability, see section 3.4.

For each direction of the deposition tunnel, at least 20 fracture networks shall be generated and the statistical distribution of the volume of unstable blocks shall be calculated for each tunnel orientation.

The uncertainty in the data, for example if there are alternative interpretations, shall be taken into account.

4.4.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.

3. Description of software used.
4. Description of model chosen.
5. Presentation of the calculated distribution of the volume of unstable blocks in deposition holes for different tunnel orientations, depths and rock domains.
6. Give the optimal direction with respect to the volume of unstable blocks in deposition holes.
7. Possible references.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.3.4.

4.5 Analysis of loss of deposition holes due to the minimum permissible distance between deposition holes and stochastically determined fractures/fracture zones with radius R > 100 m

4.5.1 General

Loss of deposition holes due to the minimum permissible distance between deposition holes and stochastically determined fractures/fracture zones with radius R > 100 m shall be calculated according to criteria in UDP, section 5.4.4.3, point 1. The analysis shall be coordinated with other analyses of loss of deposition holes according to instructions in section 5.4.4.5 in UDP.

4.5.2 Input data

The stochastic description of the direction, size and strength properties of the fractures or fracture zones within a given rock domain shall be taken from the site description, model version 1.2.

Form and diameter of deposition holes shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

4.5.3 Analysis method

A stochastic fracture network shall be created within a volume of width 300 m, height 400 m and length 500 m with software acceptable for generating stochastic fracture networks, see section 3.3.

Vertical deposition holes shall be placed in the centre of this volume along a 300 m long line.

The direction of the line shall be set equal to the direction determined for the deposition tunnels according to section 5.4.3 in UDP.

The distance between the deposition holes shall be assumed to be the minimum distance determined according to section 5.4.2 in UDP.

The number of approved deposition holes, N_G, shall be calculated along the 300 m long line.

In order for a position for a deposition hole to be approved, the distance between the periphery of the deposition hole and a fracture or fracture zone with radius R > 100 m may not be less than the distances given in section 5.4.4.3 point 1 in UDP. If a position is not approved, the deposition hole is moved forward 1 metre and a new check is performed.

The distances determined between the plug and the first deposition hole and between the last deposition hole and the tunnel end according to section 5.4.1 in UDP shall be taken into account. The location of the plug shall be assumed to be at the beginning of the line.

The percentage loss of deposition holes, p, within the rock domain shall be calculated as

$$p = (N_M – N_G) / N_M \quad (1)$$

Where N_M is the theoretically possible number of deposition holes along the line without taking loss into account.

The calculation shall be carried out for at least 20 different fracture networks and the statistical distribution of the percentage loss of deposition holes shall be calculated.

The analysis for each fracture network shall be carried out at the same time as analysis according to section 4.6. The analysis should also be carried out at the same time as analysis according to Appendix 2, section 4.4.

The uncertainty in the data, for example if there are alternative interpretations, shall be taken into account.

4.5.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Description of software used.
4. Description of model chosen.
5. Presentation of calculated distribution of the loss of deposition holes for the different rock domains and depths.
6. Possible references.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.4.4.

4.6 Analysis of loss of deposition holes due to potential wedge breakout

4.6.1 General

Loss of deposition holes due to potential wedge breakout shall be calculated according to criteria in UDP section 5.4.4.3 point 3. The analysis shall be coordinated with other analyses of loss of deposition holes according to instructions in section 5.4.4.5 in UDP.

4.6.2 Input data

The stochastic description of the direction, size and strength properties of the fractures within a given rock domain shall be taken from the site description, model version 1.2.

Form and diameter of deposition holes shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

4.6.3 Analysis method

The analysis shall be carried out at the same time as analysis according to section 4.5.

A stochastic fracture network shall be created within a volume of width 300 m, height 400 m and length 500 m with software acceptable for generating stochastic fracture networks, see section 3.3.

Vertical deposition holes shall be placed in the centre of this volume along a 300 m long line. The direction of the line shall be set equal to the direction determined for the deposition tunnels according to section 5.4.3 in UDP.

The deposition holes approved according to the analysis in section 4.5 shall be placed along the line.

The volume of the unstable rock wedges formed between the fractures and the hole contour shall be calculated for each approved deposition hole.

The calculation shall be done with software acceptable for analysis of wedge stability, see section 3.4.

Mean values of the strength properties of the fractures shall be used to check wedge stability.

The number of deposition holes, N_B, with unstable wedges that have a volume in excess of the critical volume according to section 5.4.4.3 point 3 in UDP shall be calculated. The percentage loss of deposition holes, p, shall be calculated as

$$p = N_B / (N_G - N_F) \quad (2)$$

where N_G is the number of approved deposition holes along the line from section 4.5 and N_F is the number of holes where the seepage is greater than the critical value according to calculations in UDP Appendix 2, section 4.4.

The calculation shall be carried out for at least 20 fracture networks and the statistical distribution of the percentage loss of deposition holes shall be calculated.

The same fracture network as for analysis according to section 4.5 shall be used.

The uncertainty in the data, for example if there are alternative interpretations, shall be taken into account.

4.6.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.

2. Description of input data to the analysis.
3. Description of software used.
4. Description of model chosen.
5. Presentation of the calculated distribution of the loss of deposition holes due to wedge breakout for different rock domains and depths.
6. Possible references.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.3.4.

4.7 Analysis of loss of deposition holes due to the risk of spalling

4.7.1 General

Loss of deposition holes due to the risk of spalling shall be calculated according to criteria in UDP section 5.4.4.3 point 4.

4.7.2 Input data

The mechanical properties of the rock mass (E, ν), the strength of the intact rock (σ_{ci}) and the initial stresses (σ_1, σ_2, σ_3) in the rock mass for a given rock domain shall be taken from the site description, model version 1.2.

Form and diameter of deposition tunnels and deposition holes shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

4.7.3 Analysis method

Three-dimensional elastic finite element, boundary element or finite difference analysis shall be used. If the finite element or finite difference method is used, elastic boundaries shall be used on the model.

A deposition tunnel shall be placed in the centre of the model. The direction of the tunnel is set equal to the direction of the deposition tunnels determined according to section 5.4.3 in UDP. The distance between the deposition holes is assumed to be the minimum distance determined according to section 5.4.2 in UDP.

The length of the tunnel shall be set to 300 m in the model. At least three deposition holes shall be placed centrally in the model in order to include the effect of interaction between holes.

The risk of spalling shall be calculated as the ratio of the greatest tangential stress along the tunnel periphery to the uniaxial compressive strength of the intact rock. One value shall be calculated for a horizontal section 1.5 m beneath the floor of the deposition tunnel and one value for a section through half the height of the canister. The calculation shall be carried out for the central deposition hole in the model.

The distribution of the risk of spalling shall be calculated taking into account specified distributions in the magnitude and orientation of the initial stresses and the variation in the uniaxial compressive strength of the intact rock.

The uncertainty in the data, for example if there are alternative interpretations, shall be taken into account.

> *The analysis can be performed by means of "Monte Carlo simulation" or by means of the "Point-Estimate Method", according to Christian and Baecher, 1999.*

4.7.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Description of software used.
4. Description of chosen calculation model.
5. Presentation of the calculated distribution of the risk of spalling for different depths and rock domains.
6. Possible references.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.3.4.

5 References

Christian J T, Baecher G B, 1999. Point-Estimate Method as Numerical Quadrature. Journal of Geotechnical and Geoenvironmental Engineering, Sept. 1999.

Dershowitz W, Carvohla J, Foxford T, 1995. Frac Man / Rock Block. Discrete Fracture Rock Block Stability Analysis. User documentation version 1.0 Golder Associates.

Derschowitz W, Lee G, Geier JE, La Pointe P, Thomas A, 1998. Frac Man. Interactive Discrete feature Data analysis, Geometric Modeling and Exploration Simulation. User documentation version 2.6. Golder Associates.

Martin C D , Christiansson R, Söderhäll J, 2001. Rock stability considerations for siting and constructing a KBS-3 repository. Based on Experiences from Äspö HRL, AECL´s URL, tunneling and mining. SKB Report R-01-38, Swedish Nuclear Fuel and Waste Management Co., Stockholm.

Starzec P, 2002. Sannolikhetsbaserade prognoser av instabila block i undermarksobjekt. SveBeFo Rapport 57.

Appendix 2

Instructions for hydrogeological analyses

1 Introduction

1.1 Contents and validity

This appendix is one of three subdocuments to "Uderground Design Premises", called "UDP", see Figure 1-1 in UDP. This Appendix 2 contains instructions for the hydrogeological analyses to be carried out during design step D1.

1.2 Abbreviations and definitions

For an overview of abbreviations used and definitions of different parts of the deep repository's hard rock facility, see Chapter 1.6 in UDP.

1.3 Data flow and comparisons

The following figure 1-1 shows schematically how data flow, analyses and sections are related to each other.

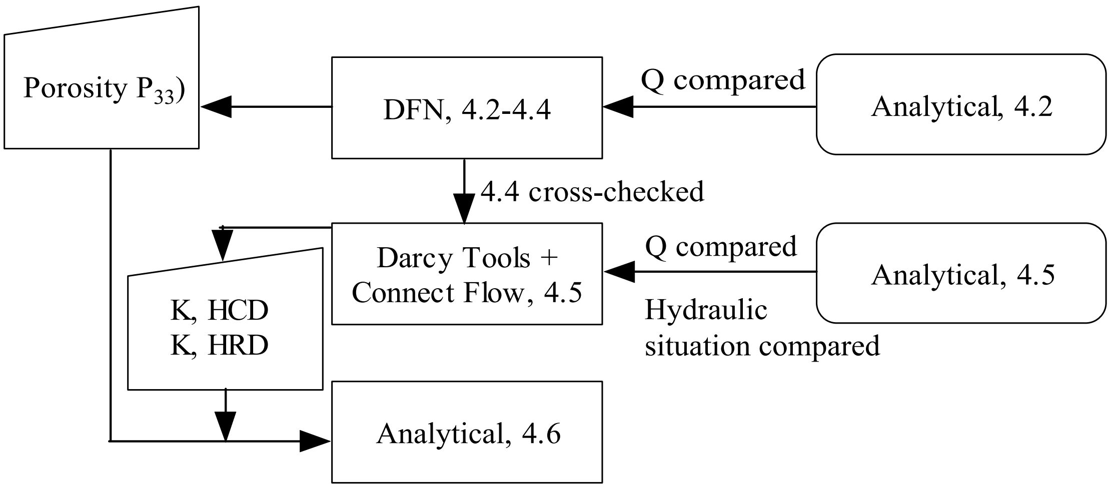


Figure 1-1. *Data flow. (DFN = Discrete Fracture Network, HCD = Hydraulic Conductor Domain, HRD = Hydraulic Rock Domain).*

2 Design basis

In design step D1, the design basis documentation shall be used for design according to Chapter 4 in UDP.

3 Verification of used software

3.1 General

Only widely recognized and verified models and verified program codes shall be used.

Examples of software acceptable for hydrogeological analyses are:

Fracman and MAFIC, (Dershowitz et al., 1999), Darcy Tools and Connect Flow (Rhén et al., 2003 and CONNECTFLOW, 2002, and other references).

4 Questions to be analyzed

4.1 General

A detailed description of the design process and the design tasks in design step D1 is found in section 5 in UDP.

The analyses described in sections 4.2.3, 4.3.2 and 4.4.2 that are to be carried out with the aid of stochastically generated fracture networks shall be coordinated so that the same realizations of stochastic fracture networks are used for all analyses. They shall also be coordinated with the rock mechanical analyses that are carried out with stochastically generated fracture networks.

Analysis of loss of deposition holes according to sections 4.4.2 shall be coordinated with the rock mechanical analyses according to the instructions in UDP, Appendix 3.

4.2 Analysis of suitable orientation of deposition tunnels with a view towards water leaking into deposition tunnels

4.2.1 General

According to UDP, section 5.4.3.3, point 1, a suitable orientation of deposition tunnels shall be analyzed on the basis of estimated quantity of water leaking into deposition tunnels.

The purpose of the analyses is prediction for unsealed rock of the flow of water leaking into a deposition tunnel with different directions in the horizontal plane for combinations of different depths and different rock domains within the depth range 400–700 metres.

The analyses shall be carried out by means of:

- analytical method according to section 4.2.2,
- numerical method using DFN (Discrete Fracture Network) according to section 4.2.3.

A compilation of the results of the two analysis methods shall be presented, along with a comparison between the calculations, see section 4.2.4.

4.2.2 Analytical methods

4.2.2.1 General

This section provides an analytical method that roughly describes steady-state leakage into a deposition tunnel. Other methods can be used. The analytical method is supplemented by analysis by numerical method according to section 4.2.3.

Prediction of seepage shall be done using recognized analytical methods which are, but are not necessarily limited to, developments of Darcy's Law.

4.2.2.2 Input data

Input data shall be site-representative. Input data shall primarily be taken directly from the site description, model version 1.2, in the form of expected values and distributions, or indirectly by means of the necessary transformations, or as calculation results based on data from the site description.

Critical or complex input data, such as hydraulic conductivities, shall be chosen in consultation with the administrator of the site description.

> *Two orthogonal hydraulic conductivities in the x–y–plane, K_{max} and K_{min}, can be transformed to a representative hydraulic conductivity K_α in an arbitrary direction α (Harr 1999): $K_\alpha = K_{max}K_{min}/[K_{max}\sin^2\alpha+K_{min}\cos^2\alpha]$, and furthermore $K_b=K_{xy}=\sqrt{K_{max}K_{min}}$, where K_b is the representative hydraulic conductivity of the rock mass in the x–y plane. For calculation, it can approximately be assumed that $K_b=\sqrt{K_\alpha K_z}$ for in-plane flow and $K_b=\sqrt[3]{K_xK_yK_z}$ for radial flow.*

Form and diameter of deposition tunnel shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

If input data in direct or indirect form cannot be obtained from the site description, the necessary input data shall be obtained from other sources. The degree of applicability of input data to the site in question shall be assessed and described.

Direct and indirect input data, transformations and calculations performed as a basis for input data, and sources of input data shall be specified.

Hydraulic conductivity shall represent tunnel scale (100 metres) in blocks of 100*100*100 m and represent the properties of the rock in different directions.

If only range of variation, mean value or best estimates of input data are available, appropriate distributions must also be assumed and explained. Uncertainty and variable distribution of input data shall be taken into account, used in the calculations and carried further to the prediction results.

> *By using input data distributions, and not just mean values or best estimates, the expected value and estimated uncertainty of the prediction results are demonstrated.*

4.2.2.3 Analysis method

The analysis work shall include preparation of input data, calculation and critical result analysis.

The deposition tunnel shall be simulated as a circular horizontal drain without deposition holes. As an analytical simplification, the calculations shall be done for a single tunnel without other open tunnels in the vicinity. Simplified model for steady-state seepage according to Equation (1) shall be used (Alberts and Gustafson 1983), see also Figure 4-1. Supplementary methods can be used.

In the analyses, the direction of the deposition tunnel shall be varied in relation to the mean direction of the greatest horizontal stress for different rock domains and depths according to section 5.4.3.3 in UDP, point 1, but only directions in the range 0–90° need be analyzed.

> *The principles of the hard rock facility's hydraulic connection with the environs are described by Axelsson and Follin (2000).*

In Equation (1), boundary conditions are determined by a water-filled mirror tunnel situated at a distance equivalent to the tunnel depth above the groundwater table.

$$q_s = \frac{2\pi K_b d}{\ln[\frac{2d}{r_w}] + \xi} \qquad (1)$$

q = steady-state seepage to deposition tunnel (m^3/s,m)

d = deposition tunnel's centre depth below groundwater table (m)

r_w = radius of deposition tunnel = $[A_{tunnel}/(\pi)]^{0,5}$ (m)

K_b = representative hydraulic conductivity of rock mass for analyzed tunnel orientations (m/s)

ξ = deposition tunnel's natural skin factor (dimensionless)

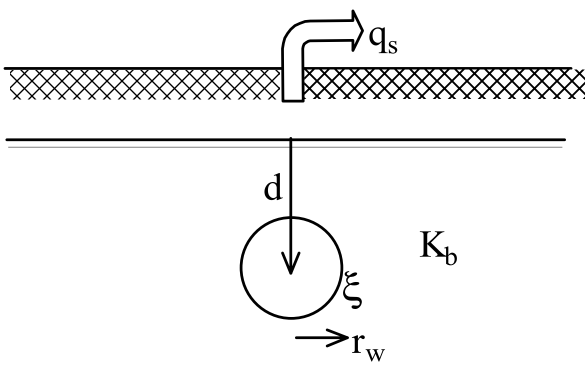


Figure 4-1. *Analytical calculation model for deposition tunnel.*

Uncertainty and variable distribution of input data shall be taken into account, used in the calculations and carried further to the prediction results. In order to take variation and uncertainties into account, Monte Carlo simulation shall be carried out or an equivalent method shall be used. The number of simulations is determined on the basis of the distributions of the constituent variables and requirements on confidence and method.

Monte Carlo simulation obtains input data for the calculation model from the distributions of the input data variables, taking into account the relative probability of the input data values.

For each tunnel orientation according to UDP section 5.4.3.3 point 1, simulations shall be carried out whose number is determined on the basis of the variation of the constituent variables and confidence requirements.

At least 100 simulations should be carried out for each tunnel orientation in Monte Carlo simulation.

Output data shall be seepage to deposition tunnel with associated probabilities, calculated for each combination of rock domain, depth and tunnel orientation. Calculated seepage to deposition tunnel shall be reported as l/min,m.

Seepage shall be described with statistical measures. Seepage shall be presented in logarithmic form in normal probability plots and in non-logarithmic form as percentiles in a table, and also as median and arithmetic mean value and as seepage values corresponding to probabilities of 90%, 95% and 99% that the actual value will be less. Output data with uncertainty range shall be presented versus hydraulic conductivity as different graphs for each rock domain, depth and tunnel orientation.

In calculating the mean value for a lognormally distributed variable x, first the transformation $y_i = \ln x_i$ is performed and then the following is taken into account for x (Aitchison et al. 1957, Shen 1998, Wu et al. 2003):

$\mu_x = \exp[\mu_y + \sigma_y^2/2]$

$\sigma_x^2 = [\exp(\sigma_y^2) - 1][\exp(2\mu_y + \sigma_y^2)]$

4.2.2.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Presentation of calculation model used.
4. Presentation of other assumptions.
5. Presentation of expected values, percentile tables and distributions for output data.
6. Presentation of optimal orientation with a view towards seepage.
7. Description of uncertainties in input data and output data.
8. Expert judgement and comparison with experience.
9. References.

4.2.3 DFN (Discrete Fracture Network)

4.2.3.1 General

This section gives directions for a numerical method that calculates the water flow in the rock in a discrete fracture network to a deposition tunnel in the horizontal plane.

The method described is supplemented by analysis by analytical method according to section 4.2.2.

In the DFN water flow model, the water flow takes place in a discrete fracture network (DFN), see Dershowitz et al. (1999). The fracture network consists of three-dimensional flat fractures in the shape of polygons. Connected fractures in a rock domain create many possible flow paths.

4.2.3.2 Input data

Input data shall be taken from the site description's DFN model, current site descriptive model (1.2).

Critical or complex input data shall be chosen in consultation with the administrator of the site description.

Geometric input data to the DFN model shall for each rock domain and fracture set consist of:

- fracture size (fracture radius),
- orientation (statistical distribution of strike and dip),
- intensity (P_{32}: total fracture area per volume unit),
- clustering (describes whether the fractures are evenly distributed in the rock domain or concentrated around different positions).

Input data in direct or calculated form for a given rock domain and fracture set shall be:

- transmissivity (statistical distribution),
- storage coefficient (statistical distribution),
- hydraulic fracture aperture (statistical distribution).

Hydraulic boundary conditions around the repository in the rock mass for a given rock domain shall consist of hydrostatic head or water flow at the boundaries of the DFN model.

Shape and diameter of deposition tunnel shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

4.2.3.3 Analysis method

The analysis work shall include estimation of boundary conditions, preparation of input data, calculation and critical result analysis.

The calculations shall be done for a single tunnel without other openings in the vicinity. Deposition holes shall not be taken into account. The length of the deposition tunnel shall be set at 300 m.

> *A suitable size of the model could be 400 m x 300 m x 500 m (height x width x length).*

In the analyses, the direction of the deposition tunnel shall be varied in relation to the mean direction of the greatest horizontal stress for each combination of rock domain and depth according to section 5.4.3.3 in UDP.

Uncertainty and variable distribution of input data shall be taken into account, used in the calculations and carried further to the prediction results. In order to take variation and uncertainties into account, Monte Carlo simulation shall be carried out or an equivalent method shall be used. The number of simulations is determined on the basis of the distributions of the constituent variables and requirements on confidence and method. For each tunnel orientation, simulations shall be carried out whose number is determined on the basis of the distributions of the constituent variables and requirements on confidence and method.

> *Monte Carlo simulation here involves carrying out a number of realizations of the DFN model, where the uncertain variables assume different values within given distributions. This gives a large number of independent fracture networks, and each of the realizations has the same probability of occurring. By evaluating the results of these realizations, the uncertainties in input data are preserved through all modelling steps and the result will thus also be a probability distribution.*

> *At least 20 simulations should be carried out for each tunnel orientation in Monte Carlo simulation.*

Since the analyses are to be carried out for the construction phase, boundary conditions in the tunnel should be set at atmospheric pressure.

Boundary conditions should be specific heads, but may also be specific flow.

Calculated seepage to the deposition tunnel shall be reported as:

- total seepage to the whole tunnel (l/min),
- seepage per unit length (l/min,m),
- distribution of seepage along the tunnel.

In addition to the above, P_{33} shall also be determined, analyzed and reported for the sealed rock volume in order to achieve a given sealing level (see UDP, section 5.8.2, point 2). P_{33} shall be reported and averaged on the 20 metre scale.

P_{33} is an estimate of the total fracture volume per unit volume.

P_{33} comprises input data to analysis according to section 4.6.

The results of the analyses shall be presented as inflows to deposition tunnel with associated probabilities and P_{33} for each combination of rock domain, depth and tunnel orientation.

Output data shall be described with statistical measures. Output data shall be presented in logarithmic form in normal probability plots and in non-logarithmic form as percentiles in a table, and also as median and arithmetic mean value and as seepage values corresponding to probabilities of 90%, 95% and 99% that the actual value will be less. Seepage prediction with uncertainty range shall be presented versus hydraulic conductivity as different graphs for each combination of rock domain, depth and tunnel orientation.

For estimation of mean value and standard deviation for a lognormally distributed variable, see section 4.2.2.3.

4.2.3.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Presentation of calculation model used.
4. Presentation of other assumptions.
5. Presentation of expected values, percentile tables and distributions for output data.
6. Presentation of optimal orientation with a view towards seepage.
7. Description of uncertainties in input data and output data.
8. Expert judgement and comparison with experience.
9. References.

4.2.4 Documentation of integrated assessment

Two methods are described. Reporting of results shall be integrated. The documentation shall comprise a calculation report including at least:

1. Summary.
2. Presentation of analysis methods used, input data and other assumptions.
3. Presentation of calculated seepage for different tunnel orientations, depths and rock domains for analysis methods used, plus uncertainties.
4. Comparison between the methods used (including expert judgement and comparison with experience) and presentation of the optimal orientation with a view towards seepage.
5. References.

The documentation from each analysis method according to sections 4.2.2.4 and 4.2.3.4 shall be presented in an appendix to the calculation report.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.3.4.

The results shall be compared and evaluated with the calculations carried out according to section 4.3, which covers calculation of seepage to deposition tunnel with deposition holes, and seepage separated into seepage to deposition tunnel and to deposition holes.18.

4.3 Analysis of suitable orientation of deposition tunnels with a view towards water leaking into deposition tunnels and deposition holes

4.3.1 General

According to section 5.4.3.3, point 1, a suitable orientation of deposition tunnels based on the quantity of water leaking into deposition tunnels and deposition holes shall be analyzed.

The purpose of the analyses is prediction for unsealed rock of the flow of water leaking into a deposition tunnel with deposition holes, and divided into deposition tunnel and deposition holes, as a function of different directions for a deposition tunnel in the horizontal plane.

The analyses shall be carried out by numerical method using DFN (Discrete Fracture Network) according to section 4.3.2.

4.3.2 DFN (Discrete Fracture Network)

4.3.2.1 General

This section gives provides a numerical method that analyzes water flow via a discrete fracture network to a deposition tunnel and deposition holes as a function of different directions for a deposition tunnel in the horizontal plane.

In a DFN water flow model, the water flow in the rock takes place in a discrete fracture network (DFN), see Dershowitz et al. (1999). The fracture network consists of three-dimensional flat fracture planes shaped as polygons. Connected fractures in a rock domain create many possible flow paths.

4.3.2.2 Input data

Shape and diameter of deposition holes shall be assumed to be according to facility description Layout E, see section 4.1 in UDP. The distance between deposition holes shall be assumed to be the minimum distance determined according to section 5.4.2 in UDP.

Other input data shall be in accordance with section 4.2.3.2.

4.3.2.3 Analysis method

The analysis work shall include estimation of boundary conditions, preparation of input data, calculation and critical result analysis.

The calculations shall be done for a single tunnel with deposition holes without other openings in the vicinity. The length of the deposition tunnel shall be set at 300 m.

A suitable size of the model could be 400 m x 300 m x 500 m (height x width x length).

In the analyses, the direction of the deposition tunnel shall be varied in relation to the mean direction of the greatest horizontal stress for each combination of rock domain, depth and tunnel orientation according to section 5.4.3.3 in UDP, point 1.

Uncertainty and variable distribution of input data shall be taken into account, used in the calculations and carried further to the prediction results. In order to take variation and uncertainties into account, Monte Carlo simulation shall be carried out or an equivalent method shall be used. The number of simulations is determined on the basis of the distributions of the constituent variables and requirements on confidence and method. For each tunnel orientation, simulations are carried out whose number is determined on the basis of the distributions of the constituent variables and requirements on confidence and method.

For a description of Monte Carlo simulation, see section 4.2.3.3.

At least 20 simulations should be carried out for each tunnel orientation in Monte Carlo simulation.

Boundary conditions should be chosen according to section 4.2.3.3.

Calculated seepage shall be reported as:

- total seepage to deposition tunnel and deposition holes (l/min),
- total seepage to deposition tunnel (l/min),
- seepage per unit length to deposition tunnel (l/min,m),
- normal probability plot (normal or lognormal distribution transformation) of seepage to deposition holes (l/min).

The results of the analyses shall be presented as the probability of inflow to deposition tunnel and deposition holes for each combination of rock domain, depth and tunnel orientation.

Output data shall be described with statistical measures. Output data shall be presented in logarithmic form in normal probability plot and in non-logarithmic form as percentiles in a table, and also as median and arithmetic mean value and as seepage values corresponding to probabilities of 90%, 95% and 99% that the actual value will be less. Seepage prediction with uncertainty range shall be presented versus hydraulic conductivity as different graphs for each combination of rock domain, depth and tunnel orientation.

> *For estimation of mean value and standard deviation for a lognormally distributed variable, see section 4.2.2.3.*

4.3.2.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Presentation of calculation model used.
4. Presentation of other assumptions.
5. Presentation of expected values, percentile tables and distributions for output data.
6. Presentation of optimal orientation with a view towards seepage.
7. Description of uncertainties in input data and output data.
8. Expert judgement and comparison with experience.
9. References.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.3.4.

4.3.3 Documentation of integrated assessment

The interim result in the form of seepage to the deposition tunnel from section 4.3.2 shall be compared and evaluated with the calculations carried out according to section 4.2, which covers calculation of seepage to deposition tunnel without deposition holes.

4.4 Analysis of loss of deposition holes due to in-leaking water

4.4.1 General

Loss of deposition holes due to in-leaking water shall be calculated according to criteria in UDP section 5.4.4.3.

The analyses of loss of deposition holes according to sections 4.4.2 shall be coordinated with the rock mechanical analyses according to the UDP section 5.4.4.3, points 1 and 3, so that the losses are not added, see Appendix 3 to UDP.

Loss of deposition holes is calculated in sequence based on four criteria 1–4 according to Appendix 3. Criterion 2, "Loss of deposition holes due to seepage", is dealt with in this section 4.4. Section 4.4 aims at a prediction of loss of deposition holes due to the quantity of in-leaking water for unsealed rock.

The analyses shall be carried out by numerical method using DFN (Discrete Fracture Network) according to section 4.4.2.

4.4.2 DFN (Discrete Fracture Network)

4.4.2.1 General

This section gives directions for a numerical method that analyzes the loss of deposition holes due to water leaking in via a discrete fracture network.

Analysis of loss of deposition holes due to the quantity of in-leaking water makes use of DFN modelling. In a DFN water flow model, the water flow in the rock takes place in a discrete fracture network (DFN), see Dershowitz et al. (1999). The fracture network consists of three-dimensional flat fracture planes shaped as polygons. Interconnected fractures in a rock domain create many possible flow paths.

4.4.2.2 Input data

Input data shall be according to section 4.2.3.2. Shape and diameter of deposition holes shall be assumed to be according to facility description Layout E, see section 4.1 in UDP. The distance between deposition holes shall be as determined in calculation of loss according to UDP section 5.4.4.3, point 1.

Critical or complex input data shall be chosen in consultation with the administrator of the site description.

4.4.2.3 Analysis method

The analysis work shall include estimation of boundary conditions, preparation of input data, calculation and critical result analysis.

The calculations shall be done for a single tunnel with deposition holes without other openings in the vicinity. The length of the deposition tunnel shall be set at 300 m.

A suitable size of the model could be 400 m x 300 m x 500 m (height x width x length). Model size is coordinated with the rock mechanical instructions.

Orientation of deposition tunnel shall be in accordance with UDP section 5.4.3.

Hydraulic boundary conditions shall consist of hydrostatic head at the outer boundaries of the model. The head shall be varied to simulate different degrees of drawdown (groundwater lowering).

Suitable drawdowns to analyze will be determined during the design step, but can be 0, 50 m and 100 m.

Zero flow boundary shall be set at tunnel start and tunnel end.

Since the analyses are to be carried out for the construction phase, boundary conditions in the tunnel and deposition holes should be set at atmospheric pressure.

The analyses shall be carried out for each geological unit, depth and drawdown.

Uncertainty and variable distribution of input data shall be taken into account, used in the calculations and carried further to the prediction results. In order to take variation and uncertainties into account, Monte Carlo simulation shall be carried out or an equivalent method shall be used. The number of simulations is determined on the basis of the distributions of the constituent variables and requirements on confidence and method. For each rock domain, depth and drawdown, simulations shall be carried out whose number is determined on the basis of the distributions of the constituent variables and requirements on confidence and method.

For a description of Monte Carlo simulation, see section 4.2.3.3.

At least 10 simulations should be carried out per rock domain, depth and drawdown (calculation case) in Monte Carlo simulation. The needed number of simulations is coordinated with rock mechanical instructions.

The results of the analyses shall be presented as inflow to deposition holes with associated probability calculated for each combination of rock domain, depth and drawdown.

The loss of deposition holes shall be calculated as percentage of deposition holes with too high inflow for a given drawdown.

Output data shall be described with statistical measures. Output data shall be presented in logarithmic form in normal probability plots and in non-logarithmic form as percentiles in a table, and also as median and arithmetic mean value and as seepage values corresponding to probabilities of 90%, 95% and 99% that the actual value will be less.

4.4.2.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Presentation of calculation model used.
4. Presentation of other assumptions.
5. Presentation of expected values, percentile tables and distributions for output data.
6. Presentation of the calculated distribution of the loss of deposition holes due to calculated seepage for different rock domains, depths and drawdowns.
7. Description of uncertainties in input data and output data.
8. Expert judgement and comparison with experience.
9. References.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.4.4.4.

4.5 Analysis of seepage and hydrogeological situation around repository

4.5.1 General

Seepage and the hydrogeological situation around the repository shall be analyzed according to UDP section 5.8.3.

> *One purpose is to meet the need for supporting material concerning hydraulic impact (UDP section 2.2) for early consultation and meet the needs in design step D1.*
>
> *By hydrogeological situation during design step D1 is meant the lowering of the groundwater table in rock (drawdown). Some principles for the deep repository's hydraulic connections with the environs are described by Axelsson and Follin (2000).*

The analysis for the deep repository's hard rock facility shall include predictions for the open facility of seepage, lowering of the groundwater table (drawdown), and total salinity (TDS, Total Dissolved Solids) in the seepage water at defined points in time (stages/degrees of mining) and sealing levels.

4.5.2 Analytical methods

4.5.2.1 General

> *This section gives directions for some analytical methods for approximately estimating leakage into the deep repository's hard rock facility and the hydrogeological situation around the repository on the basis of the site description.*

Leakage into the deep repository's hard rock facility and the geological situation outside it shall be analyzed by:

- analytical methods according to section 4.5.2,
- the site modelling's analysis tools (DarcyTools and ConnectFlow) according to section 4.5.3.

Hydrogeological predictions shall be done using recognized analytical methods. The analytical predictions shall not be limited to methods described in section 4.5.2.3. Supplementary methods can be used.

A compilation of the results of the two different analysis methods shall be presented, along with a comparison between the calculations, see section 4.5.4.

4.5.2.2 Input data

The predictions shall be done on the deep repository scale for unsealed rock and for defined points in time (stages/degrees of mining) and sealing levels (resulting K-values for grouting and rock mass) according to UDP section 5.8.2. Sealing levels are determined by the design coordinator in consultation with the units for site modelling, safety assessment and EIA, see UDP section 5.8.2.

Input data shall primarily be taken directly from the site description, model version 1.2, in the form of expected values and distributions, or indirectly by means of the necessary transformations, or as calculation results based on data from the site description.

Critical or complex input data, such as hydraulic conductivities, shall be chosen in consultation with the administrator of the site description.

Form and dimensions of the different chambers of the hard rock facility shall be assumed to be according to facility description Layout E, see section 4.1 in UDP.

> *Note that tunnels Type B according to facility description Layout E shall have a cross-sectional area of about 49 m^2 and not 30 m^2 as incorrectly stated.*

Otherwise input data shall meet requirements according to section 4.2.2.2.

4.5.2.3 Analysis methods

The prediction work shall include conceptual modelling, estimation of boundary conditions, preparation of input data, calculation and critical result analysis.

Predictions of steady-state seepage and seepage at various points in time/stages shall be done with Equation (3), developed by Gustafson (based on Alberts and Gustafson 1983), see Figure 4-2.

The hydraulic horizontal radius of influence shall be estimated with Equation (4) according to Alberts and Gustafson (1983) and water balance calculation.

> *Drawdown for a given seepage can be calculated with Equations (3), (5) and (6).*
>
> *The drawdown can be estimated with Equation (5) (Fetter 2001), and steady-state drawdown as a function of seepage and groundwater recharge according to Equation (6), see Figure 4-3.*
>
> *The influence of leakage from soil to rock on the groundwater table is not taken into account in design step D1.*

Upconing of the salt water layer, as a basis for estimation of salinity (TDS) in the seepage water, shall be estimated with Equation (7) from Bear et al. (1999) and Motz (1992), see Figure 4-4.

Uncertainty and variable distribution of input data shall be taken into account, used in the calculations and carried further to the prediction results. In order to take variation and uncertainties into account, Monte Carlo simulation shall be carried out or an equivalent method shall be used. The number of simulations is determined on the basis of the distributions of the constituent variables and requirements on confidence and method.

> *At least 20 simulations should be carried out for each calculation case in Monte Carlo simulation.*

Prediction of seepage

Seepage to the deep repository for different points in time and sealing levels shall be estimated with Equation (3), where a vertical well of large diameter in a closed reservoir roughly represents the deep repository, see Figure 4-2. Maximum steady-state seepage for an open deep repository shall furthermore be estimated, as well as seepage for different drawdowns at the deep repository.

Study of the theoretical effect of seepage to the deposition tunnel alone can be done with Equation (2). In Equation (2), the boundary condition is a water-filled mirror tunnel situated at a distance equivalent to the tunnel depth above the groundwater table.

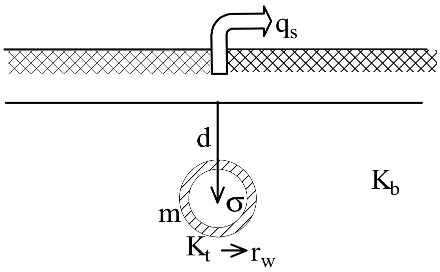
Equation (3) applies only to a confined aquifer and steady-state conditions, but seepage at different points in time/stages is simulated approximately by using input data from different points in time/stages in Equation (3).

$T_b=K_b(h_0+h_w)/2$ converts Equation (3) from confined to unconfined aquifer, where $(h_0+h_w)/2$ is the mean height of the groundwater thickness, according to Hermance (1999). For calculation of the rock's representative hydraulic conductivity K_b, see section 4.2.2.2.

Maximum steady-state seepage Q_s in an open facility is given approximately by Equation (3) at an assigned drawdown $\Delta s=D$ at the deep repository. For a given drawdown Δs, the seepage Q can be calculated for different impermeabilities with Equation (3).

The boundary condition for Equation (3) is R_0 and can be initially set at maximum 2,500 m in the rock, depending on the analyzed point in time/stage. R_0 is checked against groundwater recharge to rock within the area of influence. Groundwater recharge to rock within the area of influence shall balance calculated seepage for the point in time/stage in question. R_0 is adjusted and the calculation is repeated.

$$q_s=\frac{2\pi K_b d}{\ln[\frac{2d}{r_w}]+[\frac{K_b}{K_t}-1]\ln[1+\frac{m}{r_w}]+\sigma} \qquad (2)$$



$$Q_s=\frac{2\pi T_b \Delta s}{\ln[\frac{R_0}{r}]+[\frac{K_b}{K_t}-1]\ln[1+\frac{m}{r}]+\sigma} \qquad (3)$$

$$T_b = K_b h_{avg}=K_b(h_0+h_w)/2$$

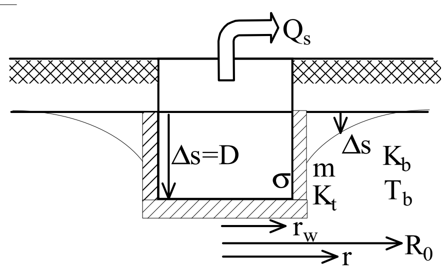


***Figure 4-2.** Analytical models for steady-state seepage calculation.*

Distance within which the groundwater table is lowered in rock

Seepage, sealing and environmental influence are related. The radial distance r for environmental influence grows approximately with the square root of the pumping time multiplied by the hydraulic diffusivity T/S (de Marsily 1986) according to $r = 1.5\sqrt{Tt/S}$*). The drawdown is primarily expanded by conductive zones.*

The influence radius at steady-state in rock shall be estimated for different points in time and sealing levels with Equation (4) and Equation (6) for different seepages. The influence radius shall be checked by means of a water balance calculation, so that the groundwater recharge (m/s) on the lowered groundwater table (m^2) and any seepage from the boundaries is equivalent to the seepage (m^3/s).

The extent of the drawdown area shall furthermore be estimated for different seepages.

$$R_0 = r_w \, e^{\left[\frac{2\pi T_b \Delta s}{Q_s}\right]}$$
$$T_b = Kh_{avg} = K(h_0 + h_w)/2 \qquad (4)$$

Lowering of groundwater table – drawdown

Drawdown, the lowering of the groundwater table, at different points in time and sealing levels shall be estimated.

Environmental influence is here limited to the drawdown of the groundwater table, which is governed by seepage and sealing.

The transient drawdown can be estimated according to Neuman's method Equation (5) (Fetter 2001).

The seepage under steady-state conditions Q_s *is equivalent to groundwater recharge W within a radial distance* r_Q *so that the product* $\pi r_Q^2 W$ *is equivalent to the seepage. The distance* r_Q *grows until a balance has been reached between seepage, influx and groundwater recharge.*

The relationship between hydraulic head h at radial distance r, the resulting hydraulic conductivity of the rock and the grouting, steady-state seepage Q_s *and groundwater recharge W, given conductive thickness* h_0 *at the distance (boundary condition)* R_0*, can be estimated with Equation (6) (Wilson 1990).*

The size of the drawdown at different distances can be estimated graphically in a graph of linear Δs *– log r, given at least two known pairs of distance-drawdown.*

$$\Delta s(t)=h_1-h_0=\frac{Q}{4\pi T_b}W[u_A, u_B, \Gamma] \qquad (5)$$

$$u_A=\frac{r^2S}{4T_bt} \text{ (early stage)} \qquad u_B=\frac{r^2S_y}{4T_bt} \text{ (late stage)}$$

$$\Gamma=\frac{r^2K_y}{h_0K_h}$$

$$h_0^2 - h^2 = \frac{Q_s}{\pi K}\ln\left[\frac{R_0}{r}\right]-\frac{W}{2K}[R_0^2 - r^2] \qquad (6)$$

$$Q_s = AW = \pi r_Q^2 W$$

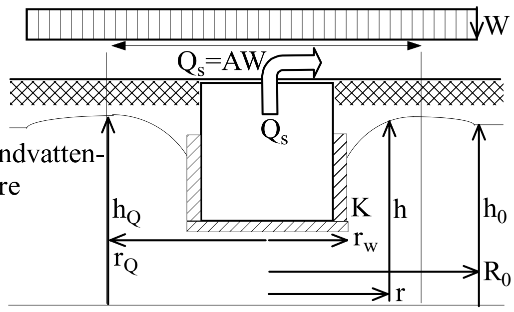


Figure 4-3. *Analytical models for the drawdown process (5) and steady-state drawdown (6).*

Total salinity (TDS)

Upconing height and maximum critical steady-state seepage (pump flow) shall be approximately calculated with Equation (7), to be used as a basis for estimating total salinity (TDS) in the seepage water.

> *Pumping raises the underlying saline water interface. The height of upconing is estimated with Equation (7) (Bear et al. 1999, Motz 1992). Total salinity (TDS) is then estimated indirectly and approximately by mixing of saline and non-saline water with different flows and densities, i.e. based on the height of upconingof the saline waterinterface, critical seepage (=pump flow) for risk of seepage of saline water (ibid) and the amount of upflow. Stable upconing of the saine water interface is judged to be no more than about 0.25–0.60 of the distance between the lowest part of the deep repository and the saline water interface (review by Motz 1992). Greater upconing height entails an increased risk of upconing and a higher salinity of in-leaking water (TDS). Requirements are specified more fully in the safety assessment.*

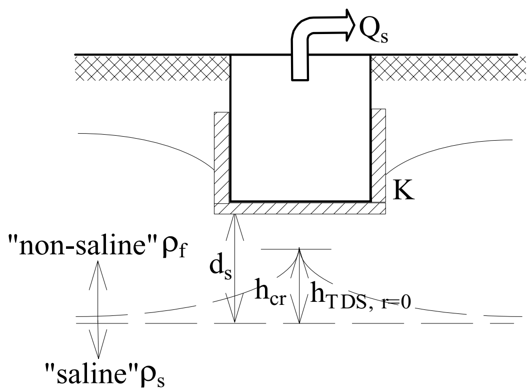
$$h_{TDS} = \frac{Q_s}{2\pi[(\rho_s - \rho_f)/\rho_f]Kd_s} \qquad (7)$$

$$Q_{max} = 2\pi\, d_s^2 K[(\rho_s - \rho_f)/\rho_f]$$

$$Q_{design} = Q_{max} C$$

$$h_{cr} = d_s C$$

(C ~ 0,25-0,60)



Requirements are specified more fully in the safety assessment.

Figure 4-4. *Analytical model for salt water upconing under steady-state conditions.*

Key to symbols in Figures 4.2–4.4 and Equations (2)–(7)

A = area (m^2)

d = deposition tunnel's centre depth below groundwater table (m)

D = distance to bottom of repository from groundwater table (m)

d_s = distance between bottom of deep repository and saline water interface (m)

H = thickness of groundwater aquifer (~D) (m)

h = hydraulic head (m)

h_0 = hydraulic head at outer boundary condition (m)

h_{cr} = critical upconing height for unstable equilibrium (m)

h_{TDS} = upconing height of saline water interface under steady-state conditions (m)

h_Q = radius of hydraulic influence (m)

i = hydraulic gradient in fracture zone (dimensionless)

K = representative hydraulic conductivity for rock and grouting (m/s)

K_b = representative hydraulic conductivity of rock mass (m/s)

K_h = horizontal hydraulic conductivity for rock and grouting (m/s)

K_t = representative hydraulic conductivity of grouting (m/s)

K_v = vertical hydraulic conductivity of rock and grouting (m/s)

K_{zone} = representative hydraulic conductivity of fracture zone (m/s)

m = thickness of grouting (m)

Q = seepage (m^3/s)

Q_s = seepage under steady-state conditions (m^3/s)

q = seepage ($m^3/s,m$)

q_s = seepage under steady-state conditions (m^3/s,m)

r_Q = horizontal distance for lowered bedrock water level (radius of influence), steady-state conditions (m)

r_w = deep repository's representative radius, tunnel radius (m)

R_0 = distance to boundary conditions (m)

r = distance (m)

S = storativity (dimensionless)

S_y = specific yield (dimensionless)

t = time after pumping start (s)

T_b = representative transmissivity of rock mass (m^2/s)

W = groundwater recharge in rock (m/s)

Δs = drawdown (m)

ρ = density of saline ρ_s and non-saline groundwater ρ_f (kg/m^3)

ξ = natural skin factor (dimensionless)

σ = skin factor inside grouting (dimensionless)

For further instructions on methodology and processing of output data, see section 4.2.2.3.

4.5.2.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Presentation of calculation models used.
4. Presentation of other assumptions.
5. Presentation of expected values, percentile tables and distributions for output data for predictions 1–4 according to point 6 below.
6. Presentation of: 1) maximum and expected steady-state in-leaking flow to the repository, 2) salinity (TDS) in seepage water 3) lowering of groundwater table (drawdown) 4) groundwater influence radius and 5) extent of drawdown area at critical points in time and with different assumed sealing levels.
7. Description of uncertainties in input data and output data.
8. Expert judgement and comparison with experience.
9. References.

4.5.3 Analyses with site modelling's analysis tools (DarcyTools and ConnectFlow)

4.5.3.1 General

Numerical modelling with DarcyTools and ConnectFlow shall be done with the aid of resources associated with SKB's site modelling work. The instructions below are to be regarded only as rough guidelines.

4.5.3.2 Input data

Data shall be obtained from the site description, model version 1.2, and the layout prepared in section 5.6 in UDP.

Critical or complex input data, such as hydraulic conductivities, shall be chosen in consultation with the administrator of the site description.

4.5.3.3 Analysis methods

The analyses shall be carried out by numerical modelling with DarcyTools and/or ConnectFlow.

> *DarcyTools: Continuum (DFN-based). Site-specific geometries and hydraulic properties for deterministic and stochastic structures/domains are implemented in DarcyTools. DarcyTools is a finite difference code that can handle and simulate groundwater flow for groundwater with different densities (Rhén et al., 2003, and other references).*
>
> *ConnectFlow (CONtinuum and NEtwork Contaminant Transport and FLOW): Used for modelling of groundwater flow and transport in porous and fractured media. Based on the software NAMMU (porous medium) and NAPSAC (fractured medium) (CONNECTFLOW, 2002 and other references).*

The chosen tunnel layout is implemented in DarcyTools and/or ConnectFlow (where site-specific geometries and hydraulic properties have also been implemented).

Properties of (unsealed) deterministic determined fractured zones (Hydraulic Conductor Domains, HCDs) and rock domains (Hydraulic Rock Domains, HRDs) that are iintersected by the tunnel system shall be obtained in the form of hydraulic conductivities.

> *The above properties comprise input data to analyses according to section 4.6.*

Water leaking into the repository, salinity (TDS) and groundwater drawdown shall be estimated for defined points in time (stages/degrees of mining) and sealing levels according to UDP section 5.8.2.

4.5.3.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis: Presentation of properties (unsealed) for the large deterministic zones (Hydraulic Conductor domains, HCDs) and rock domains (Hydraulic Rock Domains, HRDs) that are intersected by the tunnel system for the chosen Layout. This comprises input data to analysis of quantity of grout, section 4.6.

3. Description of software used.
4. Presentation of other assumptions.
5. Presentation of points in time (stages/degrees of mining) and sealing levels (resulting K-values for rock and grouting).
6. Presentation of output data: 1) Water leaking into the repository, 2) salinity (TDS) and 3) groundwater lowering (drawdown) at critical points in time and different sealing levels.
7. Description of uncertainties in input data and output data.
8. Expert judgement and comparison with experience.
9. References.

4.5.4 Documentation of integrated assessment

Two methods are described. Reporting of results shall be integrated. The documentation shall comprise a calculation report including at least:

1. Summary.
2. Presentation of analysis methods used, input data and other assumptions.
3. Presentation of critical points in time (stages/degrees of mining) and sealing levels (resulting K-values).
4. Presentation of results from analysis methods used.
5. Comparison between the results of the analysis methods used, including a creditability assessment.
6. Presentation of an integrated assessment and uncertainties.
7. References.

The documentation from each analysis method according to sections 4.5.2.4 and 4.5.3.4 shall be presented in an appendix to the calculation report.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.8.4.

4.6 Analysis of quantity of grout

4.6.1 General

According to UDP section 5.9.3, the quantity of grout shall be analyzed.

The purpose of the analysis is to estimate the quantity of grout needed to seal the rock to the sealing levels defined in execution of design according to section 5.8.2 in UDP.

Quantity of grout shall be estimated by means of analytical methods according to section 4.6.2.

4.6.2 Analytical method

4.6.2.1 General

This section gives instructions for analytical methods for approximate estimation of quantity of grout.

The analytical calculations shall be based on input data for the properties of the rock (both deterministically and statistically described properties).

4.6.2.2 Input data

The statistical description of the transmissivity distribution on the 20 metre scale in the different parts of the repository, interpreted to a distribution of conductivities on the 20 metre scale, and input data to deterministically defined structures shall be used for analysis of sealing work.

Critical or complex input data shall be chosen in consultation with the administrator of the site description.

P_{33} shall be used as a measure of the porosity from DFN data. Input data in the form of porosity (P_{33}) to Equation (9) are given by section 4.2.3. The porosity (P_{33}) shall be averaged on the 20 metre scale.

Input data with distribution of conductivities in the ungrouted rock are obtained in conjunction with the analyses of seepage according to section 4.5 (for example from Hydraulic Rock Domains, HRDs, and Stochastic Continuum on the 20 metre scale).

Deterministic structures (Hydraulic Conductor Domains, HCDs) shall be treated separately.

4.6.2.3 Analysis method

Estimation of grout quantities shall be based on two alternative analytical methods:

1. Assumption of a given grouting technique that results in a given injected volume per borehole according to Equation (8).
2. Assumption that the porosity in the rock is filled with injection grout out to the distance from the tunnel periphery that corresponds to a certain sealing level determined in design according to UDP, section 5.8.2.

Equation (8) describes a relationship that links conductivities (K_b) to a borehole (of length L) to a grout volume (V) (After Janson, 1998).

$$V = \left(\frac{\Delta p}{2 \cdot \tau_0} \right)^2 \cdot \frac{12 \cdot K_b \cdot L \cdot \mu_w \cdot \pi}{\rho_w \cdot g} \qquad (8)$$

where Δp (Pa) is the injection pressure above the groundwater pressure, τ_0 (Pa) the flow limit of the grout, μ_w (Pas) the viscosity of the water and ρ_w (kg/m^3) the density of the water.

K_b is hydraulic conductivity on the 20 metre scale. In the deterministically described zones, the interpretation is based on the given transmissivity, i.e. K_bL can be replaced by T.

In the case of analyses based on the porosity of the rock, the following methods shall be used to estimate the porosity:

- Estimation of porosity from DFN data (P_{33}) according to section 4.2.3.
- Estimation of porosity via an empirical relationship between porosity and conductivity for fractured rock, e.g. according to Equation (9) (Brotzén, 1990) or other documented studies.

> *P_{33} designates fracture volume per volume of rock according to Dershowitz et al. (1999).*
>
> *A relationship linking a porosity to a given conductivity was presented by Brotzén (1990). It should be noted that Equation (9) according to Brotzén (1990) expresses an approximate relationship for estimates of porosity:*

$$\log\ p = 0{,}17 \log K_b - 1{,}7 \pm 0{,}3 \qquad (9)$$

where p (dimensionless) designates the porosity and K_b (m/s) the hydraulic conductivity.

4.6.2.4 Documentation

The documentation shall comprise a calculation report including at least:

1. Summary.
2. Description of input data to the analysis.
3. Presentation of analysis methods used.
4. Presentation of other assumptions.
5. Presentation of output data: estimated quantities of grout for the different points in time and sealing levels for a given analysis method, broken down among different facility parts.
6. Comparison between the above results for the methods used (including expert judgement and comparison with experience) and presentation of an integrated assessment.
7. Description of uncertainties in input data and output data.
8. References.

The calculation report shall comprise an appendix to the documentation according to UDP, section 5.9.4.

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