# R-07-33

# Final repository facility
# Underground design premises/D2

Svensk Kärnbränslehantering AB

December 2007

**Svensk Kärnbränslehantering AB**
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1402-3091
SKB Rapport R-07-33

# Final repository facility
# Underground design premises/D2

Svensk Kärnbränslehantering AB

December 2007

# Summary

This report “Underground design premises/D2” is the steering document for the underground design of a final repository facility for spent fuel during design step D2 of the site investigation phase. The document is called “UDP/D2”. UDP/D2 includes design premises, strategy and instructions for the preliminary design of underground openings and rock construction works at the two candidate sites Laxemar and Forsmark.

Many of the constraints that are needed to ensure the safe performance of a Final repository facility with respect to radionuclide containment are unique for the final repository. The design premises are based on current SKB requirements and on specially elaborated documents, based on the experiences from previous design steps and the needs and objectives of the underground design in design step D2. The instructions are presented in this report, in other steering documents and in SKB’s management system. The design premises have been divided into requirements and restrictions.

The overall purpose of the final repository facility is to isolate the spent fuel so that unacceptable quantities of radionuclide do not migrate to the biosphere. The design of the final repository facility must address a number of considerations related to the project objective not faced in a traditional mining or civil engineering underground projects. This involves the characterisation of a large volume of rock, assessment of thermal effects, the construction of underground openings that meets strict quality control requirements, and the need to consider an extremely long design life. The major tasks for the underground design for the final repository facility are described in the UDP/D2 and are summarised below:

- Outline a design for the site, considering site adaptation, functional requirements and stepwise development in parallel to operation of the final Repository.
- Examine the feasibility for grouting, and estimate the required grout quantities
- Establish the rock support required and estimate the support quantities
- Perform a technical risk analysis of the potential hazard(s) for the project that are considered in the design process, and propose measures to reduce the risk from these hazards within the next design step.

As outlined in UDP/D2, in underground engineering there are some major aspects that must be addressed during the design phase. The repository design must be safe, economically feasible and meet the requirements from long-term safety based on a realistic estimate of the expected ground conditions and their potential behaviour as a result of the excavation.

SKB plans to carry out the design process for the final repository facility project in agreement with the European standard for construction, Eurocode, and in particular the standard for geotechnical design, section 2.7 in /Eurocode EN 1997-1:2004/, which will be implemented in Sweden in 2009. This allows for the application of the Observational Method in underground design and construction. The Observational Method is a risk-based approach to underground design and construction that employs adaptive management, including advanced monitoring and measurement techniques, to substantially reduce costs while protecting capital investment, human health, and the environment. The Observational Method shall be applied in design step D2 to address the uncertainty and variability in the geological setting and ground structure interaction.

The design process using the Observational Method has several steps and is constantly updated during each step, as more information becomes available. During the design steps, the inherent complexity and variability in the geological setting prohibits a complete picture of the ground structure and quality to be obtained before the facility is excavated. Thus during design, statisti-

cal methods may be used to evaluate the sensitivity of the design to the variability as well as the quality of the existing data. This is most important during the early stages of design when trying to quantify project risks and cost estimates. As new data are acquired during subsequent investigations the site descriptive model will systematically be updated, and the parameter distributions refined.

An overview of the design in relation to the Observational Method is given in the table below. The scope of the design tasks in design step D2 will be primarily limited to the following five requirements of the Observation Method stated in /Eurocode EN 1997-1:2004/, section 2.7:

1. Establish acceptable limits of behaviour;
2. Assess the range of possible behaviour and show that there is an acceptable probability that the actual behaviour will be within the acceptable limits;
3. Develop a plan for monitoring the behaviour, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully;
4. The response time of the monitoring and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system;
5. Develop a contingency plan, which may be adopted if the monitoring reveals behaviour outside acceptable limits.

The Observational Method has several caveats. One must be able to define an action plan for every possible adverse condition based on current site understanding. The method cannot be used if a predictive model for the behaviour cannot be developed, i.e., it is necessary to establish a model that can calculate the parameters that will subsequently be monitored during construction.. This means that the monitoring plan must be chosen very carefully with a good understanding of the significance to the problem. Hence it is important the Observational Method be considered a key component of all stages of design and those key parameters that can be used for monitoring are identified during the design steps.

**Design documents in an iterative design process; focus on SKB design step D2.**

| Design Document | General content | SKB document corresponding to design document |
|---|---|---|
| Engineering geological documents | Engineering – geological description of rock domain distribution and properties, tectonics and ground water conditions in the investigated volume of rock. | Site Descriptive Models, SDM Site |
| Engineering description of the rock mass | The rock mass is divided into separate ground types based on rock mass quality and the estimated ground behaviour. The description and characterization of each ground type consider both geology rock mechanics and hydrogeology. | Site Engineering Reports, SER.<br><br>Construction and engineering experiences from the areas adjacent to the target volumes are compiled in CECR reports. |
| Design documents for excavation, rock support, grouting | Description of possible construction-, support- and grouting solutions.<br><br>Preliminary assessment of the rock mass response based on the proposed excavation, support and grouting measures.<br><br>Preliminary assessment of the character and frequency of potential hazards related to the underground works. | The design works for this preliminary design shall be postulated in this document, the Underground design premises (UDP) D2.<br><br>The design methodology is summarised in Chapter 5. Chapters 6–10 describes the design studies in this Design step. |
| Control programme | Outline which parameters that may be monitored and observed during construction. Such parameters shall relate to the critical issues described in the design documents | This is handled on a general level in design step D2, mainly covered in Chapter 10. |

The procedures in the Observational Method that addresses the construction phase will be regarded in future design steps.

# Sammanfattning

Denna rapport ”Underground design premises/D2” (Projekteringsförutsättningar för bergprojektering/D2) är styrdokumentet för den bergtekniska designen av en slutförvarsanläggning för använt bränsle under undersökningsskedets designsteg D2. Dokumentet kallas ”UDP/D2”. UDP/D2 innehåller designförutsättningar, strategi och instruktioner för design av undermarksutrymmen för de båda kandidatområdena Laxemar och Forsmark.

Många av de restriktioner som krävs för att garantera ett säkert genomförande av en slutförvarsanläggning med avseende på förvar av använt kärnbränsle och radioaktivt avfall är unika för slutförvaret. Designförutsättningarna är baserade på nuvarande SKB-krav och på särskilda utarbetade dokument, som i sin tur är baserade på erfarenheter från tidigare designskeden och på den bergtekniska designens behov och syfte under designsteg D2. Instruktionerna presenteras i UDP/D2, i andra styrdokument och i SKB:s kravdatabas. Designförutsättningarna har delats in i krav och restriktioner.

Det övergripande syftet med slutförvarsanläggningen är att isolera använt kärnbränsle, så att oacceptabla mängder av radionuklider inte når biosfären. Designen av slutförvarsanläggningen måste inrikta sig på ett antal överväganden kopplade till anläggningens syfte, vilket i många avseenden är annorlunda verksamhet jämfört med andra traditionella undermarksanläggningar. Detta inbegriper karakterisering av stora bergvolymer, bedömning av termisk påverkan, uppförande av undermarksutrymmena på ett sådant sätt, att det uppfyller strikta systemkrav och behovet att beakta kravet på en extremt lång teknisk livslängd. Huvuduppgifterna avseende layout och design av undermarksanläggningen beskrivs i UDP/D2 och kan sammanfattas enligt följande:

- Presentera huvuddragen av en design avseende plats med beaktande av platsanpassning, funktionella krav och stegvis utbyggnad parallellt med kärnteknisk drift
- Undersöka genomförbarheten av injektering och bedömning av injekteringsmängder.
- Fastställa erforderlig bergförstärkning och bedömning av erforderlig mängd bergförstärkning.
- Genomföra en teknisk riskanalys avseende de potentiella projektrisker, som bedöms föreligga i designprocessen och föreslå åtgärder för att reducera dessa under nästa designskede.

I undermarksbyggande är det, som framgår av UDP/D2, flera betydelsefulla aspekter, som måste behandlas under designskedet. Designen av slutförvaret måste vara säker, ekonomiskt genomförbar och uppfylla kraven på långtidssäkerhet baserat på en realistisk bedömning av förväntade berg- och markförhållanden och deras potentiella beteende som ett resultat av berguttaget.

SKB planerar att genomföra designprocessen för slutförvarsanläggningen i enlighet med ”European standard for construction, Eurocode”, och särskilt enligt ”standard for geotechnical design, section 2.7 in /Eurocode EN 1997-:2004/”, som kommer att tillämpas i Sverige under 2009. Detta medger tillämpning av observationsmetoden vid undermarksdesign och undermarksbyggande. Observationsmetoden är en riskbaserad tillämpning vid undermarksdesign och byggande, som använder sig av anpassad styrning, kvalitetssäkrade kontroll- och analysmetoder för att väsentligt reducera kostnader och samtidigt skydda kapitalinvesteringar, hälsa och miljö. Observationsmetoden skall tillämpas i designsteg D2 för att bedöma osäkerhet och variation i den geologiska miljön och de geologiska strukturernas växelverkan.

Designprocessen med tillämpande av observationsmetoden omfattar flera steg och är ständigt uppdaterad under varje steg i takt med att mer information blir tillgänglig. Under dessa steg kommer bergets faktiska egenskaper och beteende att vara fullständigt kända först när berguttaget genomförts, vilket innebär att statistiska metoder kan användas under designskedet för att utvärdera känsligheten i designen i förhållande till olikheter i egenskaper liksom utvärdera

kvalitet hos föreliggande data. Detta är i synnerhet viktigt under de tidiga skedena av designen, då kvantifiering och bedömningar görs av projektrisker och kostnader. I takt med att nya data insamlas under påföljande undersökningar blir den platsbeskrivande modellen systematiskt uppdaterad och fördelningen av parametrar förfinad.

Relationen mellan design och observationsmetoden visas översiktligt i nedanstående tabell. Omfattningen av designuppgifterna i designsteg D2 är främst begränsade till följande krav tillhörande observationsmetoden och angivet i /Eurocode EN 1997-1:2004/, section 2.7:

1. Gränser för acceptabelt geotekniskt beteende skall upprättas.
2. Intervall för möjligt beteende skall fastläggas, och det ska visas, att det finns en acceptabel sannolikhet, för att det faktiska beteendet ska vara inom de fastställda gränserna för acceptabelt beteende.
3. En kontrollplan skall utarbetas, som kan visa om det faktiska beteendet ligger inom gränserna för det acceptabla beteendet. Kontroller ska ske i god tid och med tillräckligt korta intervall för att möjliggöra att framgångsrika åtgärder kan vidtas.
4. En åtgärdsplan skall utarbetas, som kan användas om mätningarna visar på att konstruktionen inte uppför sig som förväntat.

Observationsmetoden har flera begränsningar. Det måste vara möjligt att definiera en åtgärdsplan för varje tänkbart ogynnsamt förhållande, som grundar sig på rådande platsförståelse. Metoden kan inte användas om en prognosmodell av bergmassans respons inte kan utarbetas, dvs det är nödvändigt att fastställa en modell som kan beräkna parametrarna som successivt kommer att kontrolleras under byggskedet. Detta innebär att kontrollplanen måste väljas mycket noggrant, med en god förståelse av problemets betydelse. Det är alltså väsentligt att observationsmetoden betraktas som en nyckelkomponent under alla designskeden, och att de nyckelparametrar som kan användas för kontroll identifieras under de olika designskedena.

**Designdokument i en iterativ designprocess; fokuserat på SKB designsteg D2.**

| Designdokument | Allmänt innehåll | SKB dokument för motsvarande designdokument |
|---|---|---|
| Ingenjörsgeologiska dokument | Ingenjörsgeologiska beskrivningar av fördelning och egenskaper av bergdomäner, tektoniska och grundvattenförhållanden i den undersökta bergvolymen. | Platsbeskrivande modeller, SDM Site |
| Bergteknisk beskrivning av bergmassan | Bergmassan är indelad i skilda typer av berg (ground types) baserat på bergmassan kvalitet och bedömt beteende. Beskrivning och karakterisering av varje typ av berg tar hänsyn till både geologi, bergmekanik och hydrogeologi. | Site Engineering Reports, SER (summerar SDM i designvärden, motiverar designvärden.<br>Bygg- och ingenjörsmässiga erfarenheter från undermarksarbeten angränsande till planerade förvarsområden är sammanställda i CECR rapporter. |
| Designdokument för berguttag, bergförstärkning, injektering | Beskrivning av tänkbara bygg-, förstärknings- och injekteringslösningar. | Designarbetena för denna preliminära design skall anges i detta dokument, UDP/D2. |
| | Preliminära bedömningar av bergmassans respons baserat på föreslagen berguttags-förstärknings- och injekteringssåtgärder. | Designmetodiken sammanfattas i kapitel 5. Kapitel 6–10 beskriver designstudierna i designsteg D2. |
| Kontrollprogram | Beskrivning av vilka parametrar som kan kontrolleras och observeras under byggskedet. Dessa parametrar skall relatera till kritiska frågor och problem beskrivna i designdokumenten. | Detta behandlas på en allmän nivå i designsteg D2; i huvudsak i kapitel 10. |

Tillvägagångssättet i observationsmetoden som inriktar sig på byggskedet skall beaktas i kommande designsteg.

# Contents

# 1 Introduction

## 1.1 Background

### 1.1.1 The KBS-3 method and system

SKB's task is to manage spent nuclear fuel and radioactive waste from the Swedish nuclear power plants in such a way that man and environment are protected in short and long term. SKB's main alternative for management of spent nuclear fuel is deposition in a Final repository facility based on the KBS-3 method, (Figure 1-1):

– The spent nuclear fuel is encapsulated in watertight and load bearing canisters.

– The canisters are deposited at 400–700 metres depth in crystalline rock.

– A buffer preventing water flow and protecting the canister surrounds the canisters.

– The rock cavities required for the deposition are backfilled.

To accomplish final disposal of spent nuclear fuel in a KBS-3 repository a system – the KBS-3 system – requires a canister factory, an encapsulation plant and a Final repository facility. A transport system and an interim storage facility are currently in operation.

Research on the safety of the KBS-3 method and development of a programme for implementation and construction of the KBS-3 system have been going on since the early nineteen eighties. Important documents produced in the process are SKB safety assessments /SKBF/KBS-3 1983/, /SKB 1991, 1992/, /SKB 1999/, /SKB 2006g/, and SKB RD&D-programme, /SKB 1986, 1989, 1992, 1994, 1995, 1998, 2000, 2001, 2004a, 2007/. In 2002 site investigations for the final repository facility for spent nuclear fuel were initiated in the municipalities of Östhammar and Oskarshamn. This includes also consultations on Environmental Impact, for example /SKB 2008c/. In 2010, SKB plans to apply for a licence for the construction and operation of the final repository facility.

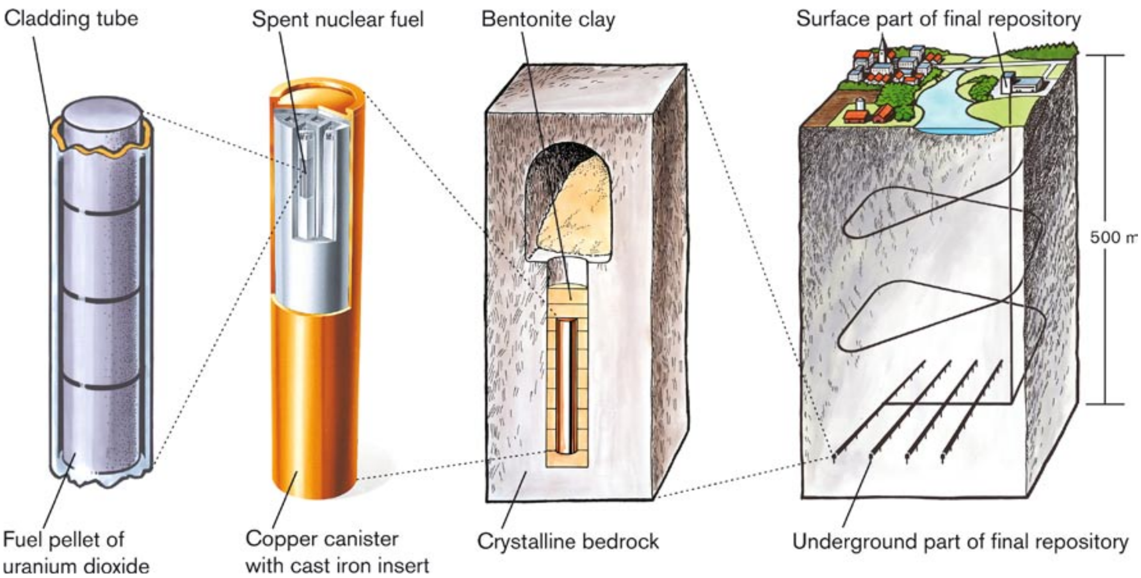



***Figure 1-1.*** *A Final repository facility for spent nuclear fuel based on the KBS-3 method.*

### 1.1.2 Final repository facility programme

The process of siting, building and operating a Final repository facility for spent fuel is divided into the following phases: feasibility study phase, site investigation phase, construction and detailed characterisation phase, test operating phase and routine operating phase.

Programmes for the site investigations during the current phase, the site investigation phase, are given in /SKB 2000, SKB 2001b/. The site investigation phase provides the information required for evaluating the possibilities to establish the final repository facility at the investigated sites. The site investigation phase (SI) is divided into two main stages: initial site investigation (ISI) and complete site investigation (CSI). Principal activities during the site investigation phase are investigations, site modelling, design, safety assessment and environmental impact assessment.

The stages of the site investigation are linked to design steps in the design process. 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 from the corresponding stage of the site investigations. The design steps carried out during the site investigation phase are named D0, D1 and D2.

The initial site investigations were initiated in the beginning of 2002 in the municipalities of Oskarshamn and Östhammar, and concluded through the publication of the Site Descriptive Model (SDM) reports versions 1.2 /SKB 2005cd, 2006b/. After completing the initial site investigations (ISI) SKB decided to continue the site investigations at the Laxemar site in Oskarshamn and the Forsmark site in Östhammar /SKB 2005b, 2006c/.

The underground design work during the ISI was based on Underground design premises/D1 /SKB 2004b/. The results are presented in preliminary design reports for Simpevarp /SKB 2006f/, for Laxemar /Jansson et al. 2006/ and for Forsmark /Brantberger et al. 2006/, and also presented in preliminary facility descriptions /SKB 2006de/.

Based on the results of the underground design work and the Site Descriptive Models of the ISI, the long term safety were primarily evaluated in the Preliminary Safety Evaluation (PSE) and analysed in-depth in the long term safety assessment SR-Can /SKB 2006g/. Surface conditions were investigated with respect to ecological, cultural and social aspects /SKB 2005cd, 2006b/. This formed a basis for early consultations according to the Swedish Environmental Code and the environmental impact assessment (EIA).

**Table 1-1 Final repository facility project during the site investigation phase – relationships between different stages, versions of site descriptive models and design steps in the final repository facility project.**

| Final repository facility 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 | 2.3 | Conclusions |
| Site descriptive model version* | 1.1 full site model | 1.2 full site model | 2.1 compilation of new data and minor update of SDM 1.2 | 2.2 site model (geology, rock mechanics, thermal and hydrogeological) in target area | 2.3 site model, (geology, rock mechanics, thermal and hydrogeological) | SDM Site full site model |
| Design step | D0 | D1 | D2 | | | |

* A site descriptive model (SDM) is an integrated model for geology, rock mechanics, thermal properties hydrogeology, hydro geochemistry, migration properties and a description of the surface system.

The results from the underground design work and the assessments mentioned above are used as guidance for the continued site investigations and a basis for the continued site modelling, design, safety and environmental impact assessments. The purpose of the complete site investigations is to gather the information that is required to select a site and apply for a permit for the final repository facility. This means that knowledge of the rock and its properties for each of the investigated sites needs to be increased so that a site-adapted repository layout can be proposed and its safety and environmental impact analysed.

The design works will in a subsequent stage be detailed for a) the accesses, b) the central area and c) the initial area for deposition during the test operation period. The site investigations will be more detailed, initially in the chosen locations for the initial construction works (the accesses), later within the repository area.

### 1.1.3 Requirements management

In order to get an overall picture of the requirements and restrictions that comprise the design premises for the final repository facility, SKB has developed a methodology for systematic management of requirements and other design premises. An overall purpose of systematic requirements management is to clarify objectives and facilitate system understanding. In this way, details in the work of engineering and design are put into context and can be derived from stipulated requirements. Results from the preceding development phase, which constitute the basis for the subsequent phase, are documented as restrictions in a requirements database. The background data on which layout and restrictions are based are also documented. This ensures that the development of the entire system will be traceable. Systematic requirements management also provides a basis for designing inspection programmes so that they focus on satisfying stipulated requirements.

The design premises have been divided into *requirements* and *restrictions*. The requirements are expressions or statements made by different interest groups for accepting the final repository facility or any of its parts. Restrictions are conditions, properties, events or processes that influence the layout and thereby may limit freedom of choice. Examples of restrictions affecting the underground for the final repository facility are the properties of the site, and accepted inflow from operational/backfilling point of view etc. The proposed dimensions of the tunnels are both a requirement and a restriction.

The requirements are grouped into levels related to the final repository facility, its subsystems and components – from overall objectives and principles to detailed specifications (see ***Figure 1-2***). At the uppermost level are the *stakeholder requirements*. The next two requirement levels are *system-* and *subsystem requirements.* An overview of the different sub-systems is given in Section 4.1 and Section 4.4 outlines the sub-system requirements for the underground openings.

## 1.2 Feedback from design step D1

Feedback reports from design step D1 to the CSI have been produced based on SDM v1.2 /Brantberger et al. 2006, Jansson et al. 2006/. This will be implemented in the following Site Descriptive Models (SDM), cf. Table 1-1. Another general feedback to the design is the need of a document that synthesises the SDM into a model adapted for design use and design values as required. Such a document will be included in the design step D2 and is termed Site Engineering Report (SER), and is further explained in Section 5.3. In addition, the need was identified to establish a systematic summary of the current overall planning of the final repository facility in terms of dimensions and general specifications of the repository as a reference for the continued design. The report, “The Reference Layout” is further described in Section 1.3.

A feedback from the long-term safety point of view was done as part of the Preliminary Safety Evaluation (PSE) that has been carried out based on the ICI results and the proposed layout from design step D1. The PSE is an overall assessment against the geoscientific suitability indicators and criteria listed by /Andersson et al. 2000/. A more in-depth analysis of the long-term

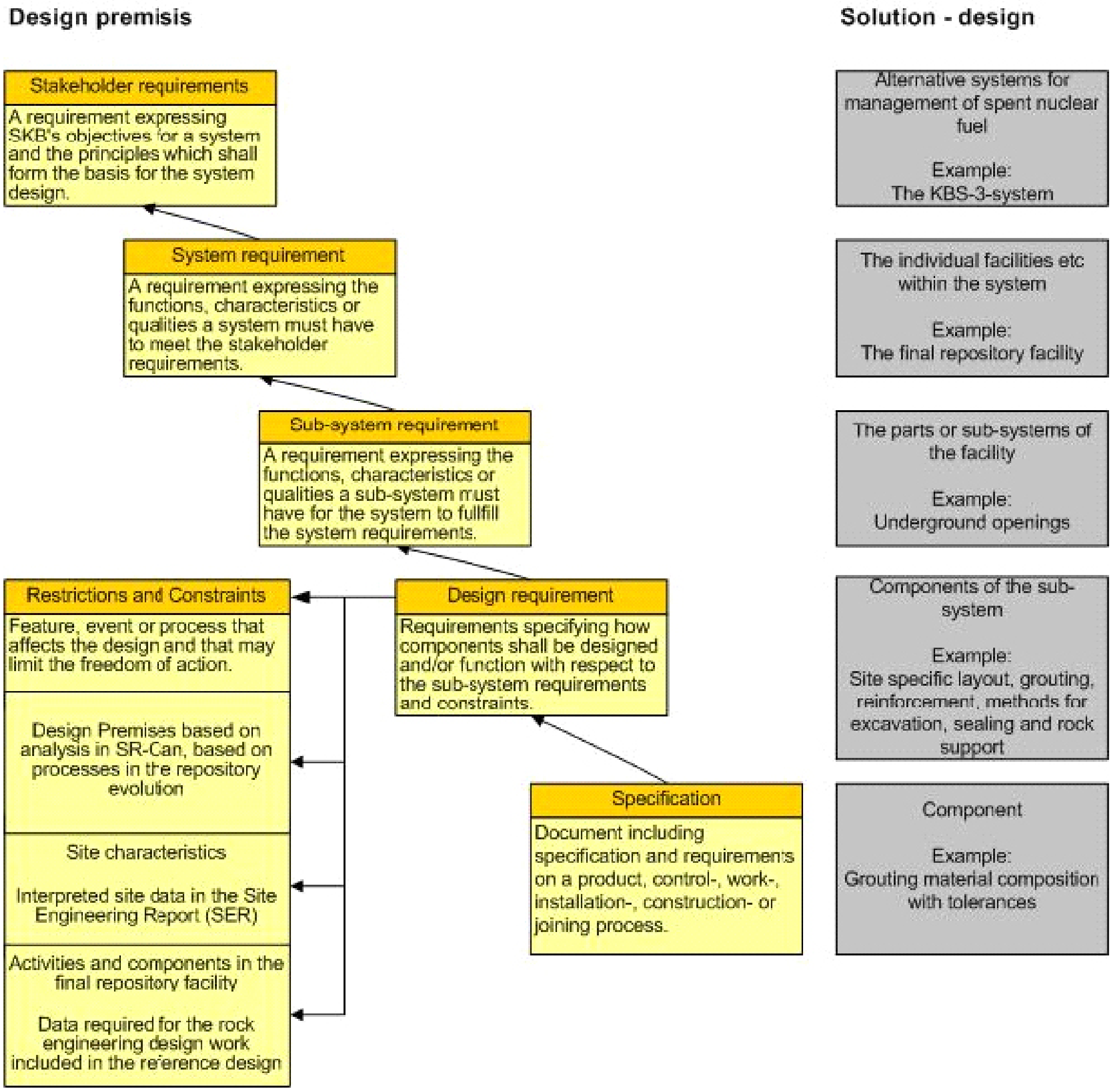



***Figure 1-2.*** *The design premises consist of requirements and restrictions. They are based on laws and regulations, stakeholder requests and the chosen method for management of the spent fuel, the KBS-3 method. The figure shows the different kinds of design premises, their definitions and correspondence to different degrees of detail in the design. The arrows point towards the requirement that shall be met by the underlying requirement or specification.*

safety has been carried out, SR-Can /SKB 2006g/, based on SDM v1.2 /SKB 2005d, 2006b/ and on the layout from Design step D1 /Brantberger et al. 2006, Jansson et al. 2006/.

Surface conditions have been investigated with respect to ecological, cultural and social aspect /SKB 2005c, SKB 2005d, SKB 2006b/. This formed a basis for early consultations at the sites in accordance with the Environmental Impact Code /Swedish Environmental Code 1998/. These results gave input to the overall planning by SKB management on the possible siting of the industrial area of the final repository facility and its infrastructure /SKB 2003ab, 2005be/. The overall results are concluded and formulated as decisions by SKB with focus on the CSI, as well as the future direction of the design works.

Design D1 was the first stage of design within the Site Investigations. In the iterative process, information is successively added and uncertainties reduced, and consequently the analysis resulting in design D1 needs to be reviewed and possibly amended in light of the new and more detailed information.

## 1.3 Documents for the design D2

### 1.3.1 General

This document "Underground design premises/D2" is the steering document for the underground design during design step D2 of the site investigation phase (see Section 1.1.2). The document is hereinafter called "UDP/D2". UDP/D2 includes design premises and instructions for the design of underground openings and rock construction works at the two candidate sites Laxemar and Forsmark. The design premises are based on current SKB requirements and on specially elaborated documents, based on the experiences from previous design steps and the needs and objectives of the underground design in design step D2. The instructions are presented in UDP/D2, in other steering documents and in SKB's management system. An overview of the documents to be used in the underground design in design step D2 is given in Figure 1-3. The design premises have been divided into requirements and restrictions. The requirements are presented in Chapter 4.

For the implementation of environmental requirements in the design of the final repository facility, a specific steering document "Miljöprogram" (Environmental programme) shall be used /SKB 2007/. The Environmental programme responds to the Environmental Code /Swedish Environmental Code 1998/ and the objectives stated in that code, as well as on the SKB Environmental objectives. A section of these objectives states:

> *"For new facilities, methods and technology, we pursue preventive environmental and safety efforts. Safety always has top priority, but great opportunities also exist in the early stages of construction projects to achieve environmental gains, and we try to take advantage of these opportunities taking a preventive approach. Our preventive work is pursued within the framework of environmental impact assessment, and the result is an optimization of the entire Swedish system from both a safety and environmental viewpoint."*
>
> *The SKB policy and environmental work could be found more in detail at www.skb.se.*

The Environmental programme has broken down the environmental objectives to objectives for the final repository facility project. To meet these objectives, the design of facility parts, access roads, technical systems as well as activities in or methods used for the development and operation of the facility shall focus on minimising the impact on the environment. The proposed measures to meet these objectives shall be justified from the environmental protection point of view by the Designer, and be feasible from a technical and economical point of view.

The Reference Layout of the final repository facility is a reference non-site specific design of the final repository facility, presenting current ideas on operational activities, installations and equipment needed. The Reference Layout also presents the estimated required spaces. These are summarised in Appendix 1 as preliminary typical drawings of the geometries of the openings. The Reference Layout is a living internal SKB document. Current status of the Reference Layout is implemented in this report as actual restrictions to be considered in design D2.

The site properties from a design and engineering perspective are presented in a report entitled "Site Engineering Report" hereinafter referred to as "SER", building on the more scientifically oriented SDM reports. The SER establish geological engineering parameters for the actual site, highlights issues that require special attention during the repository design and layout, and establish a procedure for dealing with uncertainties and some hazards in some elements of the design process. The SER is presented further in Section 5.3.

Other documents that shall be used in the underground design during design step D2 are the Construction Experience Compilation Reports (CECR) /Carlsson and Christiansson 2007ab/, new versions of the Site Descriptive Model Reports and results and conclusions from the safety assessment /SKB 2006g/ and further environmental impact assessment studies. These documents can be described as supportive documents including information that may facilitate the work and improve the results of the underground design. An overview of the relations between different design documents is given in Figure 1-3.

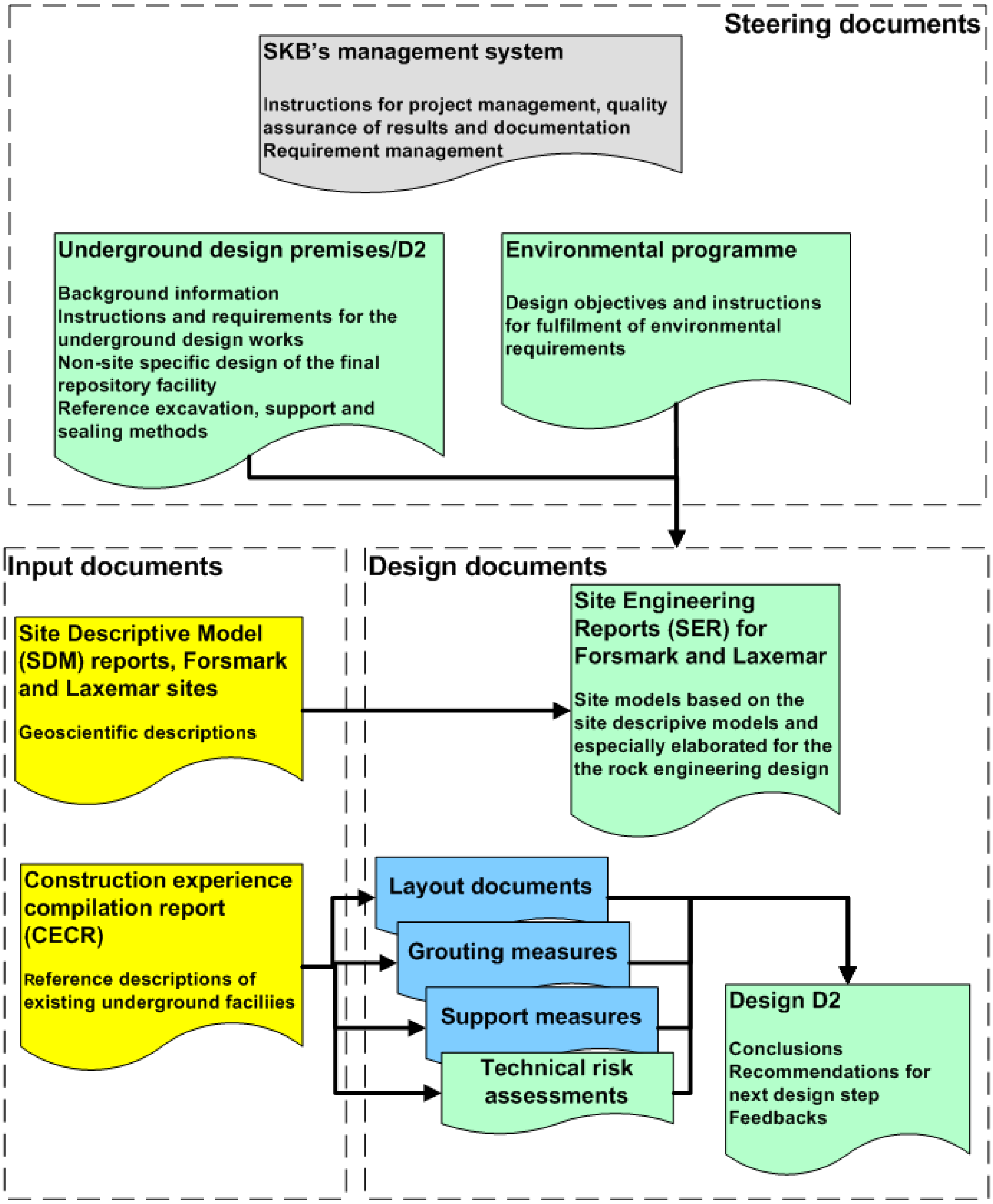



***Figure 1-3.*** *Overview of the documents that shall be used in the underground design in design step D2.*

### 1.3.2 Introduction to UDP/D2

This document presents the premises for the underground design studies to be carried out in the SKB design step D2. The structure is as follows:

- Chapter 2 presents the objectives of design step D2
- Chapter 3 presents the roles and responsibilities in this design step. It also gives the requirements for the quality assurance.
- Chapter 4 gives an overview of the requirements and design considerations for this design step.
- Chapter 5 gives an overview of the design methodology to be followed in design step D2. The chapter also give an outline of the design activities to be carried out and expected deliverables.
- Chapter 6 describes how the design studies shall be initiated by examining previous works so that the design organisation gets familiar with the status of the project, the critical issues for the studied site, the results and feed-back from design step D1.
- Chapter 7 outlines the different layout studies that shall be carried out.
- Chapter 8 describes the studies to be carried out with respect to proposed grouting measures to meet the required level of sealing. It is also outlined how the designer shall cooperate with the ground water modelling resources to explore the possible environmental impact in terms of ground water draw down.
- Chapter 9 describes the studies to be carried out with respect to rock mass response to the planned excavations, and the proposed support measures.
- Chapter 10 outlines how the assessments of technical risks shall be carried out and documented.

### 1.3.3 Reading instructions

The text in the Chapters 6–10 of this document is divided into requirements/instructions and advice/comments. Advice and comments are written with *italics*.

# 2 Objectives and scope of work for underground design

## 2.1 General

The design studies according to the specifications given in this report shall result in a site-specific design of a Final repository facility for spent nuclear fuel. The design shall be sufficiently detailed to be able to support a siting application for such a repository.

The underground design work regarding the underground facility is a subset of all design studies needed for the final repository facility. An overview of all design activities is given in Figure 2-1. The scope of work for the underground design in step D2 is shown under the heading Underground facility. The design studies have also to consider the surface facility, the technical systems required, all special equipments for the operational phase and the activities needed for construction and operation of the facility.

## 2.2 Design objectives in design step D

The objectives of the design activity during the site investigations are to:

– Develop facility description(s) for the two sites where the CSI are being made with a proposed layout for the final repository facility's surface and underground parts as a part of the supporting document for an application. The description shall present constructability, technical risks, costs, environmental impact and reliability/effectiveness. The underground layout shall be based on site-specific information from the CSI phase and serves as a basis for the safety assessment.

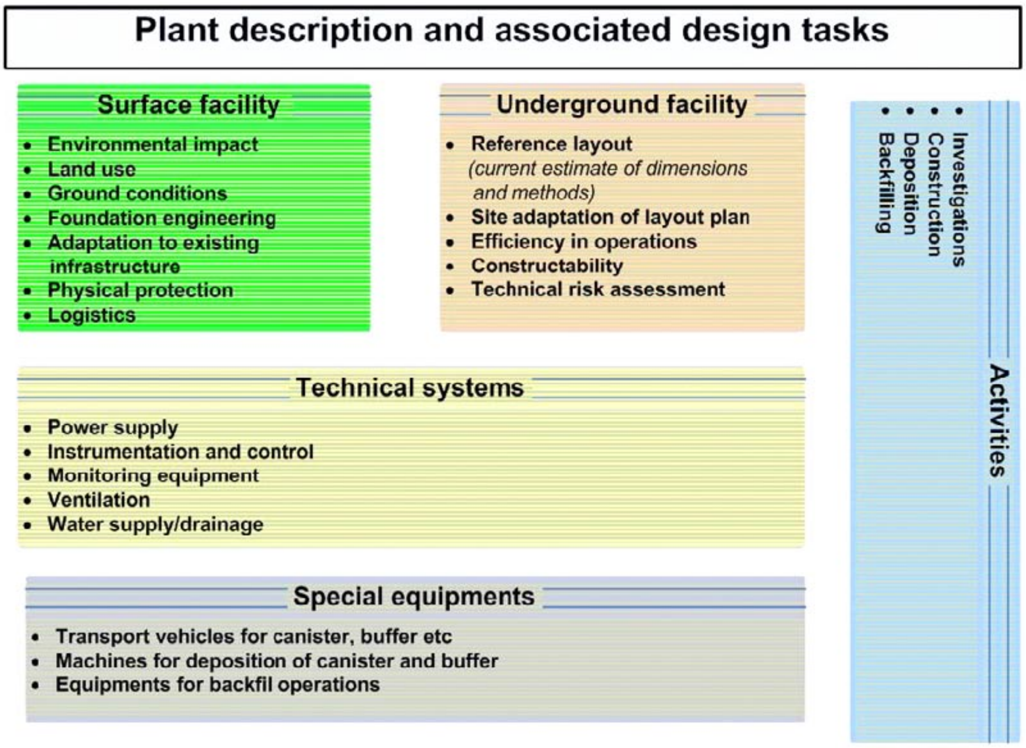



***Figure 2-1.*** *A general overview of different design activities for the final repository facility.*

*Also the layout of the surface facilities shall be based on information from the CSI. Furthermore, it is the entire resulting (underground) design that will form a base for the long-term safety assessment. The entire design will be a base for the preliminary operational safety assessment that will be needed for the site application.*

– Provide a basis for the environmental impact assessment and statement (EIA respectively EIS) and the corresponding consultations regarding the site of the final repository facility's surface and underground parts with proposed final locations of ramp and shafts, plus the environmental impact of construction and operation.
– Provide a base for the EIA included in the application.
– To provide a firm base for the planning of the initial construction phase.

The documentation of design D2 shall also explain which underground openings, parts, equipments and buildings do not need to be engineered in detail in this phase.

## 2.3 Underground design objectives in design step D2

The purpose of this document is to guide the underground design work in design step D2 during CSI towards the established objectives, presented below, thus allowing uniformity in the site-specific underground design work between the two sites with respect to approach, content and level of detail.

The objectives of the underground design during design step D2 are to present a site-specific facility description that:

- Demonstrate a site-specific adaptation for a repository considering the overall requirements on functionality, reliability and long term safety based on current state of knowledge after the CSI.
- Demonstrate the constructability and the effectiveness of a step-wise development of the underground parts of the repository.
- Identify site-specific facility-critical issues and provide feedback to:
  - The design organisation regarding technical risks as well as additional studies that need to be addressed in the next design phase.
  - The safety assessment organisation regarding technical criteria that have an impact on the extent of the repository and its engineered barriers.
  - The SKB management regarding investigation strategies that needs to be included into the step-wise development of the repository.
- Provide material for consultations and EIA according to Chapter 6 of the Environmental Code regarding:
  - The location of the surface facility.
  - The location and extent of the underground facility and the justification of the proposed layout.
  - The technical and functional description of the layout including justification of proposed measures for grouting and support.

# 3 Organisation and quality

## 3.1 Roles and responsibilities

The organisation for the Spent Fuel Project is presented in Figure 3-1. Design shall cooperate and coordinate its work with investigations/site modelling, EIA and safety assessment. Design and its interaction with other activities and products during the complete site investigation phase are shown in Figure 3-2.

The "Design Coordinator" shall take responsibility for design vis-à-vis the Project Manager. The Design Coordinator shall engage internal or external resources, hereinafter called "the Designer", to carry out design, as well as other independent resources, hereinafter called "Reviewers", to review the results of design. The overall organisation and interfaces with respect to division of responsibilities and information flow within design and between design and the Client in design step D2 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 3-3).

Responsibilities with respect to the information flow in the interfaces according to Figure 3-3 are described in Table 3-1.

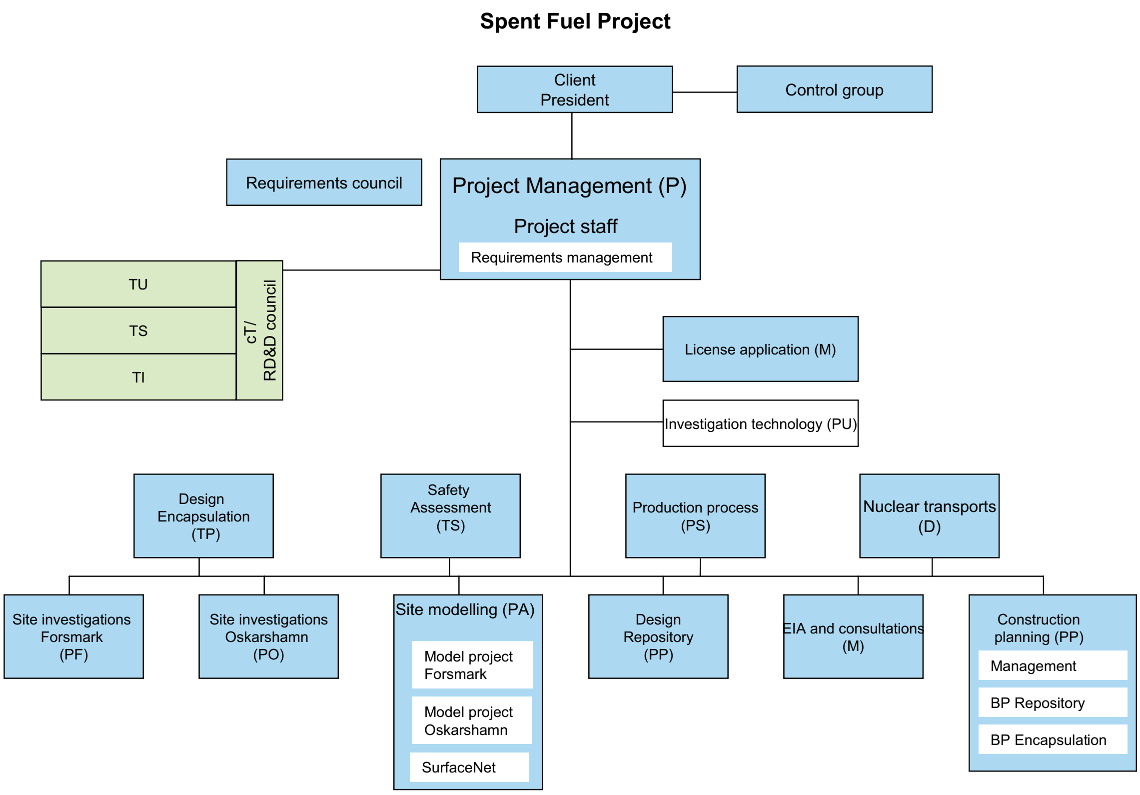



*Figure 3-1. The organisation for the Spent Fuel Project /2008/.*

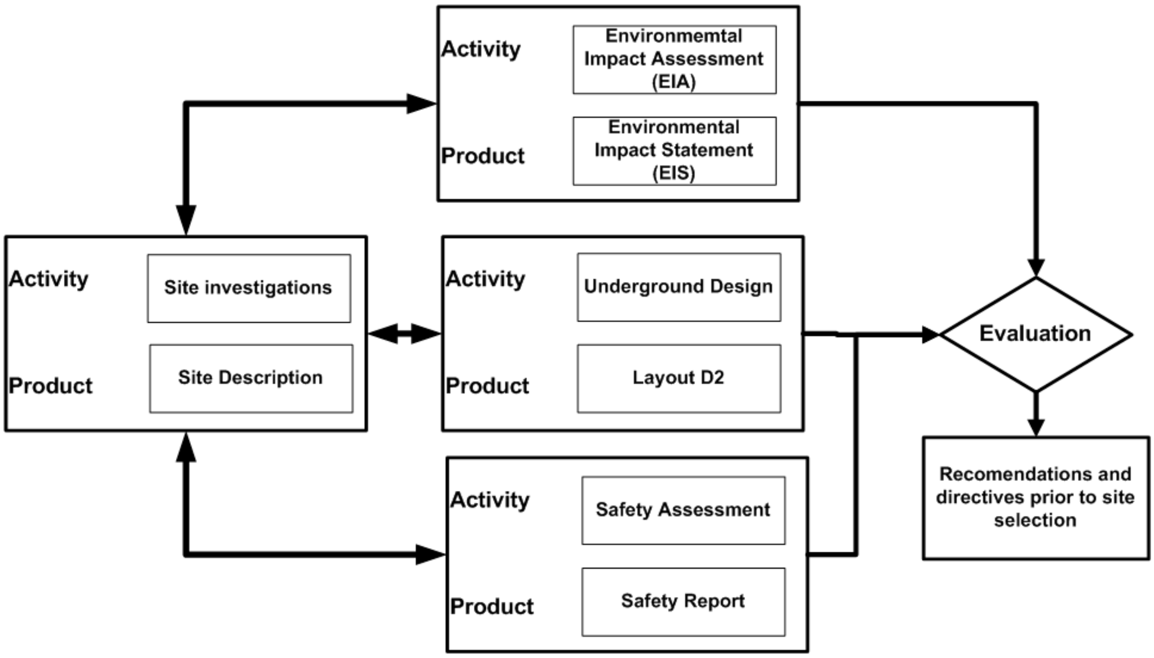



***Figure 3-2.*** *Interaction between design and other activities and products during the Site Investigation phase. The underground is a sub-task to design, see Figure 2-1.*

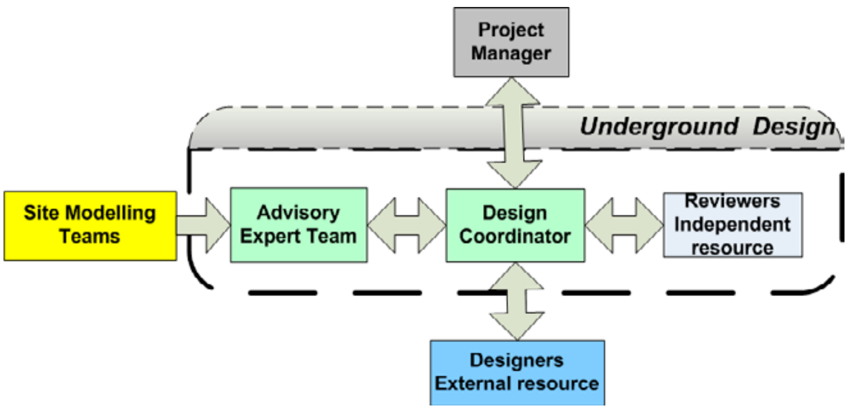



***Figure 3-3.*** *Overall Organisation of the Underground Design and its interfaces with respect to division of responsibilities and information.*

**Table 3-1. The Underground Design and its interfaces and deliverables with respect to division of responsibilities and information (cf. Figure 3-3).**

| | |
|---|---|
| **Interface 1** | |
| Project Manager to Design Coordinator | • Design premises according to UDP/D2.<br>• Schedule including dates for his delivery of site descriptions, site models and facility descriptions.<br>• Project plan for the final repository facility project, including schedule for the Design Coordinator's deliveries of documentation of interim and final results from design.<br>• Overall operational control of the final repository facility.<br>• Site descriptions, site models and facility descriptions.<br>• Reference layout. |
| Design Coordinator to Project Manager | • Project plan for the underground design.<br>• Documentation of results from design according to Chapter 5 in UDP/D2.<br>• Justification of accepting/rejecting design results.* |
| **Interface 2** | |
| Design Coordinator to Advisory Expert Team | • Definition of specifications for the Site Engineering Reports (SER) Forsmark and Laxemar including input for issues related to long-term safety.** |
| Advisory Expert Team to Design Coordinator | • Delivers step-wise updates of the SER. |
| **Interface 3** | |
| Design Coordinator to Designer | • Devising procedures for meetings with external design resources as well as the required schedules.*** |
| Designer to Design Coordinator | • Design results. |
| **Interface 4** | |
| Design Coordinator to Reviewer | • Establish a review plan in accordance with SKB requirements.<br>• Guidelines and schedules for review. |
| Reviewer to Design Coordinator | • Review reports. |

* Interim and final results from design shall be reviewed by an independent resource prior to delivery.
** Issues such as loss of deposition holes due to acceptance criteria for canister positioning, canister spacing due to thermal criteria and deformation zones requiring a respect distance. This also involves utilisation of the Hydrogeological model to estimate ground water inflow to the repository during construction, and the subsequent ground water draw down.
*** The division in responsibilities in interface 3 shall be defined in the project plan for the underground design and in contract documents between the Design Coordinator and the external resources (the Designer).

## 3.2 Feedback from previous work

The Design Coordinator shall ensure himself that the Designer has access to relevant information from previous works and understands its impact on the works during design step D2 (see Chapter 6). This concerns results from technique development, site investigations and site modelling as well as feedback from the safety and environmental impact assessments /SKB 2006g/. Further feedback loops to site investigations and EIA studies will be required as integrated parts of the design step D2.

## 3.3 Quality assurance

### 3.3.1 General

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

The Designer shall work in accordance with a systematic management system, and shall prepare quality and environmental plans for the design assignment. This shall ensure that the Designer's responsibility for quality in his own work and his sub-consultants are fulfilled, as well as to meet the environmental objects for the Spent Fuel Project. An independent source shall review the execution of design; i.e. fulfilment of the requirements in UDP, in accordance with 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.

### 3.3.2 Checking and review of design results

The Design Coordinator shall keep constant track of the design development and results by means of technical meetings and reviews. Scope and procedures for meetings and reviews shall be documented in an assignment description.

A step-by-step decision-making process shall be applied in design step D2. The step-by-step decision-making process is controlled by check/evaluation stations ("milestones") at which the Design Coordinator checks and evaluates the design result and makes a decision regarding the direction of the continued design work after consultation with the Project Manager. The milestones consist of delivery of results in accordance to Chapters 7–10.

SKB requests documentation so that the decision process to identify the technology proposed as the Best Available Technology (BAT) is traceable. This means that the most effective technology or measure – within reasonable costs – to prevent release of radioactive substances, ensure that requirements on nuclear safety are met and that man and environment are protected in short and long term shall be applied. Any justification of a design solution shall be documented. Also discarded alternative solutions shall be documented. More detailed information is given in /SKB 2007/.

The Designer shall have a quality and environmental protection plan for his tasks. This plan shall include plans for formal documented reviews of the design results at appropriate stages of his design. The Design Coordinator after consultation with the Reviewers approves or disapproves the design results. After the conclusion of the design process, the Design Coordinator performs acceptance review after consultation with the Project Manager.

The design documentation prior to each decision point shall, in addition to the documentation stipulated in each design step activity, also include documentation of the following checks/reviews:

- That all design premises are documented and taken into account,
- That uncertainties in the design have 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.

## 3.4 Document management

Documentation of the design work; i.e. design results, on what grounds design have been carried out (design premises), what available site data have been utilised, motivation for selected alternatives, fulfilment of environmental guidelines etc., as well as assumptions made in the design work – are fundamental in ensuring traceability through the design process.

The basis for decisions in the different design activities shall be documented according to the design methodology in Chapter 7–10. This documentation shall be named "Design Report" and comprise internal project material during a design step. These "Design Reports", together with minutes of meetings, any separate decision documents prepared after a check/evaluation point shall be managed and administered in accordance with SKB's document management system following ISO 9001and ISO 14001.

The Designer's quality and environmental protection plan shall include the guidelines for his management of all documents that steer his work.

### 3.4.1 Drawings

The drawings shall be based on three-dimensional (3D) CAD modelling. The 3D layout shall be compatible with the site model. The delivery of the layout requires that the Designer applies quality control to

- The completeness of the 3D model
- The correctness of lines/symbols used
- Correctness in delivered coordinates, e.g. for tunnels, deposition holes

The Designers quality plan shall include traceable records of his control.

### 3.4.2 Calculations

Any analysis method used in the design shall be justified by the Designer and submitted to the Design Coordinator for review.

Calculations shall be documented in accordance to the requirements given in Chapters 7–10.

Numerical calculations, such as mesh geometry and input data for rock mechanic simulations or spread sheets developed on purpose for the Design task shall be delivered to SKB for full traceability.

# 4 Requirements

## 4.1 Introduction

The requirements on the final repository facility are based on law and regulations, and on needs and demands put forward by the nuclear power producers and other involved stakeholders. SKB has proposed to meet the requirements by a complete system for handling, encapsulation and deposition of the spent fuel. The system is called the KBS-3 system. The KBS-3 system is divided into sub-systems, each having their requirements:

- Underground openings
- Sealing
- Backfill
- Buffer
- Canister
- Spent fuel

The different sub-systems of the KBS-3 system are illustrated in **Figure 4-1**.

## 4.2 The final repository facility

The final repository facility consists of the man-made parts of the final repository facility; the underground openings, the civil works above and below ground surface, and the technical systems required to establish and operate the repository.

The different parts or sub-systems of the final repository facility are accounted for in Table 4-1. The table also includes information, on which parts of the final repository facility, which will remain when the facility has been phased down and sealed and thus must be considered in the long-term safety assessment. Some of these parts also contribute to the post-closure barrier functions of the repository. In the environmental impact and operational safety assessments as well as in cost calculations and other studies related to efficiency, all parts of the final repository facility need to be considered by SKB.

The underground design work in design step D2 comprises the site-specific design of the underground openings. An overview of the activities is given in Section 5.4.

The underground openings shall, with respect to the long-term safety of the final repository facility, be adapted to the host rock in such a manner that the rock can contribute to prevent, reduce and retard of radioactive matter to the biosphere.

**Table 4-1. The different parts of the final repository facility and the parts remaining when the facility has been phased down and sealed i.e. the final repository facility. Note that the items in the table have been inserted without order of precedence.**

| Part or sub-system | Description | Part of final repository facility | Long-term barrier function |
|---|---|---|---|
| Technical systems | Installed auxiliary systems for communication, safety, drainage, ventilation etc required to carry out the activities during the construction and operation phases. Technical systems also include mobile equipment, machines, vehicles etc required for the activities. | No | No |
| Surface facilities | Civil works and buildings on ground required to establish and operate the final repository facility. Civil works and buildings on ground comprise the materials, dimensions and disposition of the civil works and buildings. | No | No |
| Sub-surface facilities | The spaces in the rock and the civil works and buildings below ground required to establish and operate the final repository facility. The sub-surface facilities comprise the dimensions and disposition of the spaces and the materials, dimensions and disposition of the civil works and buildings. | No | No |
| Underground openings | The underground openings required to accomodate the sub-surface facilities. | Yes | 1) |
| (Described in this report) | – The actual location and geometry of the underground openings.<br>– The rock surrounding the openings affected by the rock excavation, support and grouting works.<br>– Civil works and stray materials remaining when the underground openings are backfilled. | | |
| Borehole sealing | Materials and methods used to seal boreholes. | Yes | Yes |
| Backfill in deposition tunnels | Materials and methods used to backfill deposition tunnels. | Yes | Yes |
| Backfill in other underground openings | Materials and methods used to backfill other underground openings. | Yes | Yes |
| Plug in deposition tunnels | The construction and sealing of deposition tunnels during the construction and operation phase. | Yes | No |
| Buffer | Clay containing swelling minerals. The buffer surrounds the canister and fills the space between canister and rock. | Yes | Yes |
| Canister | A container comprising a tight casing and a load-bearing insert in which the spent nuclear fuel is placed for deposition in the final repository. | Yes | Yes |
| Encapsulated spent fuel | The spent nuclear fuel encapsulated for deposition in the final repository. The encapsulated fuel also comprises the gases and fluids that remain in the cavities of the canister when it is sealed. | Yes | Yes |

1) The barrier function of the host rock is maintained by the placement and geometry of the underground openings, deposition positions and by construction works that limit impact on the near field rock.

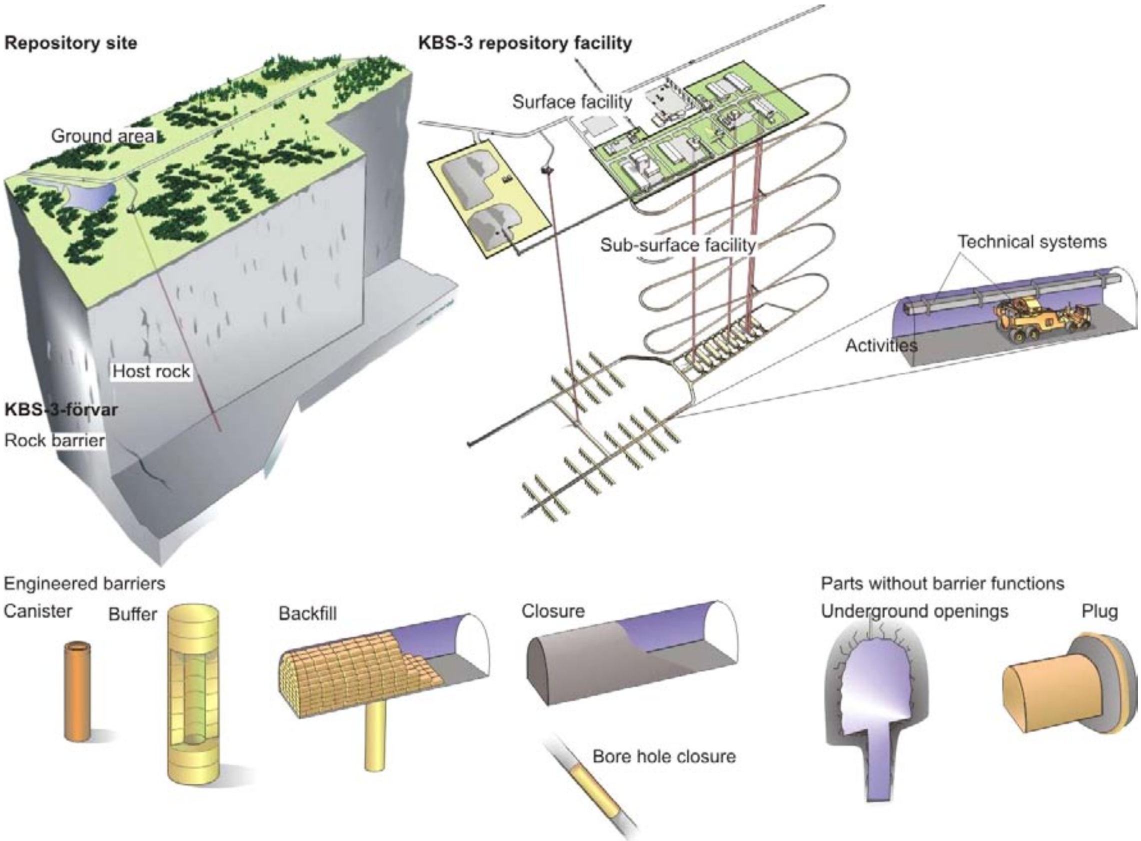



***Figure 4-1.*** *The different parts of the final repository facility and their status during design step D. In this report design premises and instructions for the adoption of the facility to the candidate sites are given. (The backfill is divided into backfill in deposition tunnels and backfill in other underground openings.) .*

## 4.3 The underground openings

The underground openings are the rock openings required to accommodate the sub-surface facility.

The term underground opening is defined as:

– The actual location and geometry of the rock openings.

– The rock surrounding the openings that is affected by the rock excavation, support and grouting works.

*As a rule of thumb, based on general rock mechanics experiences, this could include a rock volume within 1.5–2 tunnel diameters around the opening. This distance is mainly governed by redistribution and magnitude of rock stress, rock mass strength, by the installation of rock bolts and the spread of grouting material. At a much smaller distance from the rock contour of the openings, the rock mass may be disturbed by blasting activities and mechanical impact from full face drilling and scaling*.

– Civil works and stray materials remaining in the surrounding rock and in underground openings when the openings are backfilled.

The design of the underground openings shall comprise development and description of:

– Methods, material and temporary installations needed for the construction of the underground openings to reach sufficient water tightness, load-bearing capacity, stability and durability.

The object of and function of the KBS-3 repository:

- Containment and retardation can be sustained by means of a verified site adaptation to the currently known rock conditions.

The object and function of the KBS-3 repository facility:

- Deposition can be carried out according to specification.
- Backfill can be installed according to specification.
- Sub-surface facilities are established in a safe, efficient and environmentally suitable way by means of adaptation to the repository site conditions.

In general, the design of the underground openings shall comprise:

- A strategy for site adaptation of the repository with respect to long-term safety as well as efficiency and flexibility during construction and operation.
- Identification and reducing potential hazards during construction and operation
- Methods, materials and temporary installations to locate and excavate the openings
- Methods to verify that the technical requirements are accomplished in terms of required grouting levels, structural stability and maintenance required.
- Methods to verify that the site adaptation of underground openings is acceptable in relation to the long-term safety requirements and the surrounding rock conditions.

## 4.4 Sub-system requirements on underground openings

### 4.4.1 General sub-system requirements to be considered in design step D2.

The system requirements take into account the stakeholder requirements, Swedish legislation and the purpose and function of the system, in this case a Final repository facility intended for final deposition of spent nuclear fuel in crystalline rock according to the KBS-3 method (see Section 1.1.3).

The requirements on the subsystem Underground Openings and the related rock excavation works must comply with the sub-system requirements in order for the final repository facility to comply with the system requirements. This in turn is a prerequisite for the final repository facility to meet the stakeholder requirements, see Figure 1-2.

The sub-system requirements express the functions and characteristics that the different sub-systems or parts must have in order for the final repository facility to meet the system requirements /SKB Requirements Management System/.

The sub-system requirements are, for all parts of the final repository facility, organised under the headlines:

- Nuclear safety and radiation protection.
- Environmental impact.
- Other safety issues and industrial welfare.
- Quality, flexibility and cost efficiency.

The current sub-system requirements for the underground openings and some methods employed in the rock construction works relevant for design step D2 are presented and commented in the following sections.

Under each headline the requirements have been organised as relating to function and characteristics in the final repository facility or design considerations. The design considerations are those design requirements, in accordance to Figure 1-2, regarded to be of concern for design step D2.

### 4.4.2 Nuclear safety and radiation protection

#### *Requirements function/characteristics*

In order for the final repository facility to provide isolation and containment for as long time as required considering the radio toxicity of the spent nuclear fuel and to contribute to the retardation, the underground openings of importance for the long term safety shall be adapted to the host rock so that the rock provides hydraulically, chemically, mechanically and thermally sufficient conditions and sufficient hydrologic and transport conditions to ensure the isolation objective according to the long-term safety assessment and specifically in accordance with the recommendations given by the SKB Safety Assessment SR-Can, Section 13.6.8. In this context, the repository depth shall be optimised with respect to:

- In-situ temperature and thermal conductivity.
- Frequency of long fractures.
- Hydrogeology considerations.
- Hydro geochemical considerations.
- Spalling considerations.
- Available space considering long-term safety restrictions – site adaptation.
- Construction costs.
- Environmental impact.

To sustain the multi-barrier principle the underground openings:

– Must not significantly impair the barrier functions of the repository rock, backfill, buffer or canister.

– Must allow deposition of canister and buffer with required barrier functions.

– Must allow that backfill with required barrier functions can be installed.

*The requirement that the underground openings must allow backfilling also originates from the system requirements that the barrier functions of the final repository facility shall be passive and that the final repository facility shall be technically feasible to seal. The recommended repository depth for the specific site is presented and justified in the SER.*

The sub-surface facility shall be designed with respect to safety and physical protection related to nuclear activities, i.e. the handling of canisters with spent fuel /SKB Requirements Management System/.

#### *Design considerations in design step D2*

The following considerations related to nuclear safety shall be observed in the design and evaluation of underground openings:

- Excavations need to follow certain geometrical constraints and must not create too much damage to the rock.
- Design of excavation methods. SKB has chosen drill & blast as an excavation reference method.
- The grouting methods and rock reinforcement methods used for the excavation works shall be based on well-established, tried and tested technique.
- Underground openings shall satisfy safety requirements regarding nuclear safety and radiation protection so that the rock's contribution to the safety of the repository will be as good as reasonably achievable.
- The design of the underground openings shall provide against disturbances and mishaps related to nuclear engineering operation.

*SER suggest how the final repository facility could be adapted to the site conditions. The safety Assessment will audit the design results to check that the design satisfies the safety requirements.*

- The properties/characteristics of the underground openings shall be allowed to be verified against specified acceptance criteria.

Detailed inspection and monitoring programmes shall not be developed in design step D2.

### 4.4.3 Environmental impact

#### *Requirements function/characteristics*

SKB has elaborated a specific steering document "The Environmental Programme" containing design objectives for the environmental requirements and instructions how they shall be met at the two candidate sites. The Environmental programme is based on the Swedish Environmental Code /Swedish Environmental Code 1998/ and the objectives stated in that act, as well as on the SKB Environmental objectives (Section **1.3.1**).

The objectives in the environmental legislation and SKB's policy have been expressed in the Environmental programme as overall environmental objectives for the Spent Nuclear Fuel Project. The programme also includes more specific objectives for utilisation of land, impact of noise and vibrations, impact on groundwater and emissions to surface waters and air, giving practical instructions of which considerations shall be made to meet the overall environmental objectives at the two candidate sites. Issues of special concern for the design of the underground openings are:

o The siting of surface facility parts that connects to the underground facility. The consultations on environmental impact of the industrial establishment have preliminary indicated the location for the surface facility and access routes to the underground facility as a starting point for design D2.

o Impact on ground water conditions.

o Efficient use of energy and resources

o Measures to minimise the overall disturbance caused by excavation, especially with regard to traffic in the underground facility.

#### *Design considerations in design step D2*

The underground design work of the underground openings shall consider the objects of the environmental programme in order to comply with the environmental sub-system requirements concerning:

- The utilisation of land considering the layout of the accesses to repository depth. This has been assessed by SKB and given to the Designer as a prerequisite. However, the Designer shall consult environmental experts regarding siting of ventilation shafts.
- The impact on groundwater considering the layout. This is further described in Chapters **8** and **10**.
- Noise and vibrations considering rock excavation, grouting, and rock support methods.
- Emissions to water considering rock excavation, grouting, and rock support methods.
- Emissions to air considering rock excavation, grouting, and rock support methods.
- Economise with the use of natural resources and energy in the layout of the underground openings.
- Economise with the use of natural resources and energy regarding rock excavation, grouting, and rock support methods. This is further described in Section **7.3.5**.
- Environmentally adapted choice of material and consumable supplies to be used in the underground openings.

The proposed measures to meet the objectives shall be justified from the environmental protection point of view by the Designer, and be feasible from a technical and economical point of view.

### 4.4.4 Other safety issues and industrial welfare

***Requirements function/characteristics***

The underground openings shall be designed so that the activities in the sub-surface facility can be carried out in a safe manner. This means that excavation, grouting and rock reinforcement in underground openings shall be designed with respect to stability and maintenance required of the underground openings and the different parts of the underground facility and activities they shall house.

***Design considerations in design step D2***

In the design of rock construction works and the stepwise excavation and establishment of the final repository facility at the two candidate sites the safety and industrial welfare shall be considered so that ventilation and escape routes and means of evacuation are secured at all times. Instruction how this shall be achieved is given in Section **7.3.5**.

Both safety and industrial welfare shall be considered in the design of technical systems and the layout of the sub-surface facility. The technical systems are designed to provide a satisfactory work environment and so that incidents and accidents are avoided. Further there will be technical systems, which are installed to avoid incidents and mitigate the effects should an incident or accident occur, e.g. systems to locate personnel, fire sensors and sprinkler systems. The sub-surface facility contains firewalls and doors and rescue containers. Furthermore, the ventilation system and the layout of the repository shall be designed so that smoke and gases can be ventilated and personnel evacuated in case of a fire. The layout shall also describe how shafts and ramp shall be used for evacuation and as access paths for fire brigade and rescue teams.

### 4.4.5 Quality, flexibility and cost efficiency

***Requirements function/characteristics***

- The underground openings shall contain the underground repository with the approved number of deposition holes, which are required for the deposition of the total number of canisters.
- The underground openings shall be sited so that they can be constructed in a cost efficient way; i.e. according to time schedule, a low probability for interruptions during construction and to minimise the need for grouting and rock support.
- The layout of the underground openings shall allow for a cost effective construction and operation of the repository.
- The underground openings shall be grouted and supported so that the final repository facility can be operated in a cost efficient way. Acceptable water inflows to different underground openings are given in Table 8-1.
- The methods to be applied to construct the underground openings and to reach sufficient tightness and stability shall be cost effective; i.e. to a reasonable cost, construct the underground openings according to time schedule and that the probability is low for interruptions during construction. The required technical working life of underground openings is given in Table 9-1.

***Design considerations function/characteristics in design step D2***

This design step shall not include optimisation of the underground openings and their design; i.e. this design step shall provide a nominal design. The feasibility of the proposed design shall be based on described activities in Chapter 7.

The dimensioning of the underground openings is guided by SER and Section 7.2.

# 5 Design methodology

## 5.1 General

In underground engineering, there are generally two major aspects that must be addressed during the design phase. The first is developing a realistic estimate of the expected ground conditions and their potential behaviour as a result of the excavation. The second is to design an economic and safe excavation and support method for the determined behaviour.

The design process has several steps and is constantly updated during each step, as more information becomes available. During the design steps the inherent complexity and variability in the geological setting prohibit a complete picture of the ground structure and quality to be obtained before the facility is excavated. Thus, during design statistical methods may be used to evaluate the sensitivity of the design to the variability as well as the quality of the existing data. This is most important during the early stages of design such as for the SKB design step D2 when trying to quantify cost estimates and project risks. As new data are acquired during subsequent investigations, the site descriptive model is updated and the parameter distributions refined. By the time construction begins, there should be a highly refined estimate of the distribution of ground conditions and the expected methods of construction for the deposition areas, access shafts and ramp.

One of the design methodologies used in underground design and construction to address the uncertainty and variability of the geological setting and ground structure interaction is the Observational Method. The Observational Method is a risk-based approach to underground design and construction that employs adaptive management, including advanced monitoring and measurement techniques, to substantially reduce costs while protecting capital investment, human health, and the environment. SKB's approach to the Observational Method is further described in Section 5.2.

The level of detail to be achieved in design step D2 shall consider the relatively early stage of the design. General guidelines are:

- Design should be based on experience or accepted principles and aims to show how current SKB requirements can be handled with best available technology.
- Estimation of quantities should be based on accepted principles and current technology.
- All design tasks should have an outline of a control programme on which parameters that may be monitored and observed during construction.
- All design tasks should include feedback to relevant parties as per instruction in this document.

## 5.2 The design strategy

### 5.2.1 Guiding documents

*SKB plans to carry out the design process for the underground excavations of the final repository facility in agreement with the European standard for construction, Euro code, and in particular the standard for geotechnical design, EN 1997-1:2004 section 2.7, which is planned to be implemented in Sweden 2009. The latter sets out the following conditions for using the Observational Method in design:*

(*1) When prediction of geotechnical behaviour is difficult , it can be appropriate to apply the approach known as "the Observational Method", in which the design is reviewed during construction.*

*(2) The following requirements shall be met before construction is started:*

- *acceptable limits of behaviour shall be established;*
- the range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits;
- a plan for monitoring the behaviour shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully;
- the response time of the monitoring and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system;
- a plan of contingency actions shall be devised which may be adopted if the monitoring reveals behaviour outside acceptable limits.

*(3) During construction, the monitoring shall be carried out as planned.*

*(4) The results of the monitoring shall be assessed at appropriate stages and the planned contingency actions shall be put in operation if the limits of behaviour are exceeded.*

*(5) Monitoring equipment shall either be replaced or extended if it fails to supply reliable data of appropriate type or in sufficient quantity."*

*This is in close agreement to other descriptions of the Observational Method, first introduced by /Peck 1969/.*

*The application of the Observational Method in design step D2 is presented in the following. It is emphasized that this is the very first step in an iterative design process and that the level of detail will be increased in future design steps. The scope of design tasks will be primarily limited to (2) above. An overview of the coverage of design in relation to the Observational Method is given in* Table 5-1.

**Table 5-1. Phases and design documents in an iterative design process following on SKB design step D2.**

| Design document | General content | SKB document corresponding to design document |
|---|---|---|
| Engineering geological documents | Engineering – geological description of rock domain distribution and properties, tectonics and ground water conditions in the investigated volume of rock. | Site Descriptive Models, SDM Site. |
| Engineering description of the rock mass | The rock mass is divided into separate ground types based on rock mass quality and the estimated ground behaviour. The description and characterisation of each ground type consider both geology, rock mechanics and hydrogeology. | Site Engineering Reports, SER.<br>Construction and engineering experiences from the areas adjacent to the target volumes are compiled in CECR reports. |
| Design documents for excavation, rock support, grouting | Description of possible construction-, support- and grouting solutions.<br>Preliminary assessment of the rock mass response based on the proposed excavation, support and grouting measures.<br>Preliminary assessment of the character and frequency of potential hazards related to the underground works. | The design works for this preliminary design shall be postulated in this document, the Underground design premises (UDP) D2.<br>The design methodology is summarised in Chapter 5 . Chapters 6–10 describes the design studies in this Design step. |
| Control programme | Outline which parameters that may be monitored and observed during construction. Such parameters shall relate to the critical issues described in the design documents. | This is handled on a general level in design step D2, mainly covered in Chapter 10. |

The procedures in the Observational Method that addresses the construction phase will be regarded in future design steps.

### 5.2.2 The application of the Observational Method in design step D2

*The SDM for the Complete Site Investigations are based on results from investigations at the surface and by means of borehole investigations. The purpose of the SDM is to give a good description of the rock mass properties, as well as the likely location of large deformation zones. The description of the rock mass is primarily based on statistical treatments of data, and the locations of heterogeneities in the rock mass contain uncertainties. The SER is based on the SDM and to previous construction experiences (the CECR) and provides design parameters for the rock mass. The design process enables the assessment of hazards related to the underground works. However, it may not be possible to say at this early design step where all the hazards may occur.*

In design step D2 the focus in relation to the contents of the Observational Method shall be on the following issues:

- Assess acceptable limits of behaviour for the construction in accordance with the overall requirements given in this document.
- The range of possible behaviour shall be assessed in relation to the proposed design.
- Outline the content and the parameters for a monitoring plan in line with the proposed design solutions.

Figure 5-1 provides a general flow chart for the design of the various underground openings associated with the repository. /Modified from Schubert and Goricki 2004, see also Palmström and Stille 2006/

As shown in Figure 5-1 the first phase of the underground design is to extract the relevant data from the Site Descriptive Model to develop an engineering description of the rock mass. This is provided in the Site Engineering Report (SER), see Section 5.3. This description considers the rock domains (relating to intact rock properties), fracture domains, ground water conditions and in situ stress conditions, obtained from the SDM, and incorporates parameters that are required to provide an engineering description of the rock mass. The product of this description is the ground types (GT), which will be encountered during construction. The number of ground types is site-specific and depends on the design step, as well as on the complexity of the geological conditions and the version of Site Descriptive Model. In early versions of the Site Descriptive Model, a few ground types may be adequate while in the construction phase several ground types may be required. The ground types used for design step D2 are described and defined in the SER.

The second step in Figure 5-1 involves evaluating the potential ground behaviour considering each ground type. The ground behaviour must be evaluated for the underground opening in each of the functional areas without considering the effect of support, or the benefit of any modifications including the excavation method and/or sequence, and support or other auxiliary measures. The ground behaviour must also consider the influencing factors, as well as the relative orientation of relevant discontinuities to the excavation, ground water conditions, in situ stresses.

The final step in Figure 5-1 requires an assessment of the System Behaviour; i.e. the interaction between the ground behaviour and construction measures. After the Ground Types and the ground behaviour have been determined, appropriate construction methods (excavation method and sequence, support methods, and auxiliary measures such as grouting) are determined. The scope of work for design step D2 is outlined in Chapters 8 and 9. The system behavior can be assessed using analytical methods, numerical methods, and/or comparative studies, based on experience from previous similar underground projects. For example it may be acceptable to use the Construction Experience Compilation Report (CECR) for the existing facilities at a site to evaluate the system behaviour at this stage of the design. The results from the system behaviour analyses shall be compared to the design requirements.

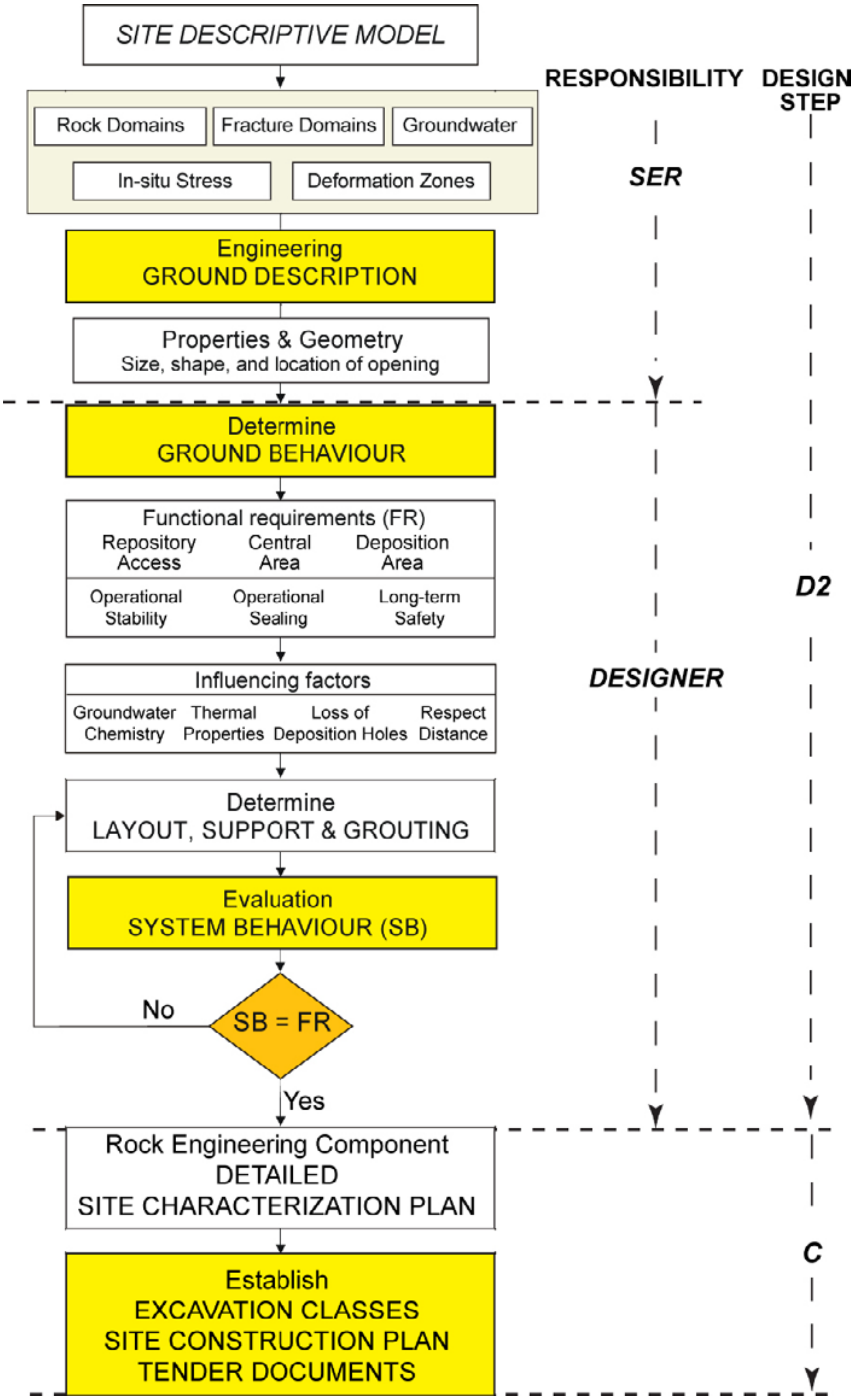



***Figure 5-1.*** *Flow Chart for the design of underground openings associated with the final repository facility /Modified from Schubert and Goricki 2004/.*

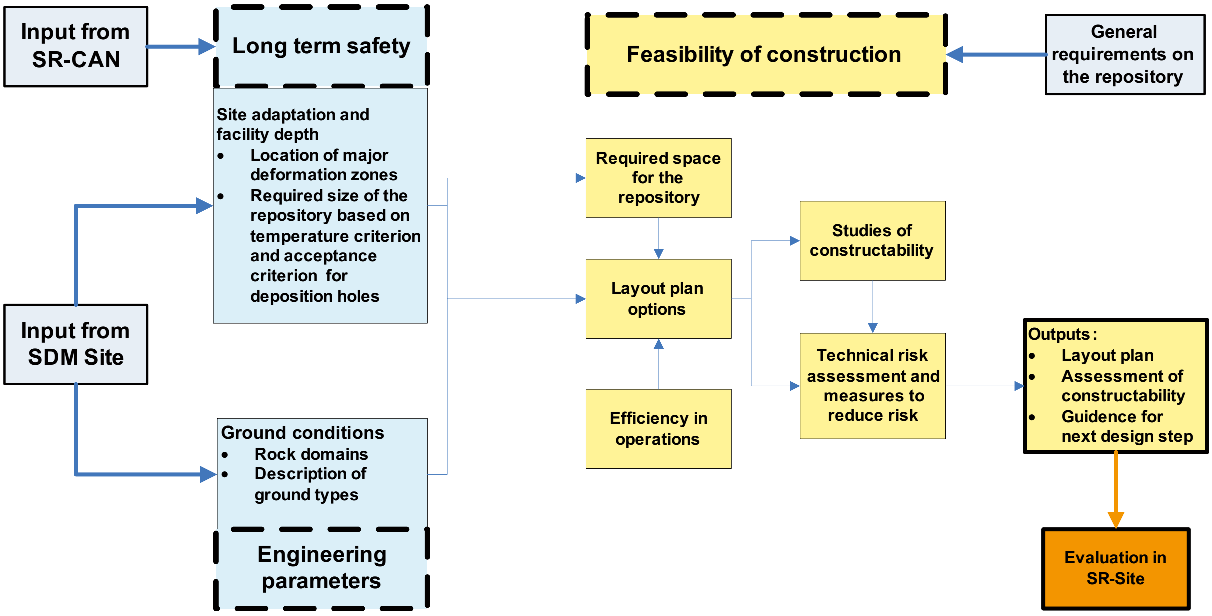



***Figure 5-2.*** *Overview of constraints and main deliverables from the Site Engineering Report with respect to long-term safety (blue) and major outputs from design (yellow); cf. Chapter 7–9 and /SKB 2008ab/.*

The analysis of the system behaviour shall confirm:

- The stability of the underground openings.
- Compliance with repository design requirements; i.e. respect distance, loss of deposition holes, etc.
- Acceptable seepage limits.

All analyses used to assess the system behaviour have to be documented in a way that is traceable and auditable in accordance with Section 3.3.

In Figure 5-1 there is a final stage in the design process called Detailed Site Characterisation Plan and the requirement to develop the Excavation Classes, Site Construction Plan and Tender Documents. The Excavation Classes are defined based on the evaluation of the support, excavation and grouting requirements. The distribution of the expected ground behavior and the excavation classes in the repository provides the basis for establishing construction plan and tender documents. This stage of the design is not considered in design step D2 and would take place during a later design step.

## 5.3 Site Engineering Report

*The Site Engineering Report (SER) presents general guidelines and site-specific constraints for the design of underground openings required for the repository. The general guidelines are based on the current state of practice for underground design while respecting the special needs of the long term safety requirements of the repository. The constraints provided in the SER are site specific and based on the site descriptive model.*

The SER will provide:

- Design parameters for the underground design.
- Design procedures/approaches for addressing site specific constraints.
- Engineering guidelines based on analysis of problems of specific concern for the repository.

The SER will also provide respect distances to deformation zones >3,000 m.

- Degree of utilisation of the tentative deposition areas in terms of % loss of canister positions based on statistical information of tentative unsuitable conditions such as fractures with a length or a transmissivity estimated to be unsuitable from a long-term safety point of view.
- Evaluation of canister spacing caused by the thermal properties of the rock mass and any restriction caused by rock mechanics conditions.

The working method for the SER is to extract the relevant data from the SDM to develop an engineering description of the rock mass. The SDM considers the rock domains (relating to intact rock properties), fracture domains, ground water conditions and in situ stress conditions, and incorporates parameters that are required to provide an engineering description of the rock mass. The product of this description is the ground types (GT), which will be encountered during construction. The number of ground types is site-specific and depends on the design step, as well as on the complexity of the geological conditions (cf. Section 5.2.2).

*Experiences from nearby facilities are compiled in separate reports. This will cover construction and maintenance experiences. Based on requirements of the actual facility, construction experiences are summarised from excavation, sealing and support point of view. The maintenance records are used to conclude the operational experiences of primarily rock support solutions.*

The Construction Experience Compilation Report (CECR) can be used as a reference and alternative to other empirical methods.

*The findings on construction experience, support requirements, seepage, grouting, maintenance and any special conditions encountered during the construction and operation have also been used by the SER to assign design parameters to the engineering geological model.*

The SER will consist of a report and 3D models for each of the sites.

## 5.4 Overview of design activities

The design activities are fit to the SKB schedule for the Spent Fuel Project.

The design works in step D2 can be divided in five main activities. An overview of activities, input to the activities and deliverables is given in Table 5-2. Activity 1 and 2 are supposed to be carried out without access to the results of the final site investigations, while the remainder activities require the results of the CSI.

**Table 5-2. Activity overview for the design work in step D2.**

| Main Activity | Sub-activities | Input to Consider | Documentation required | Where described in the UDP |
|---|---|---|---|---|
| 1) A study, based on the design results from design step D1 considering available site information, and defining to what extent new information have any impact on the early design sketches | Study of new data since SDM v 1.2.<br>Identify the new information that may have impact on previous design results (from step D1) | SDM 1.2 + SDM 2.1, SER draft #1<br>Seminar hosted by the Design Coordinator | No formal documentation<br>Establish an understanding for the status of the project within the design organisation (Section 6.4) | Chapter 6. |

| Main Activity | Sub-activities | Input to Consider | Documentation required | Where described in the UDP |
|---|---|---|---|---|
| 2) Study the functionality of the repository | Consider:<br>a. Current knowledge of geometrical constraints such as unsuitable geological conditions.<br>b. A step-wise excavation and simultaneous deposition activity.<br>c. All requirements related to physical protection.<br>d. All requirements related to workers occupational safety during the step-wise development of the repository.<br>e. The effectiveness in construction and operation.<br>f. The management of drain water. | SDM 1.2 + SDM 2.1, SER | • Alternative preliminary layout plans for the step-wise development of the repository.<br>• Proposed principles for site specific physical protection and fire protection during the step-wise development of the repository.<br>• Proposed locations of ventilation shafts.<br>• Proposed principles for drainage, such as number of pump pits required during the step-wise development.<br>• The estimated depth range required for the proposed drainage principles.<br>• Proposed extent of the construction steps up to 4,500 respectively 6,000 canisters (1–5 years).<br>• Estimate how the need for resources may increase with time, especially due to longer transports underground or any difficult passage.<br>• Transport work required for each of the proposed construction steps.<br>• Estimated additional deposition capacity for the studied area. | Sections 7.1–7.3. |
| 3. Update the estimated required size of the repository and outline an updated sketch layout, in similar detail as the D1 layout. | a. Establish an updated layout.<br>b Evaluate the studies, and conclude the alternative(s) that are most favourable. | SDM 2.2, SER draft #2 | • 3-D layout (Section 3.4.1)<br>• Documentation in agreement with Sections 7.5 and 7.6 | Section 7.4. |
| 4. For the layout alternative that is estimated to be most beneficial, study the impact on constructability and assess the System Behaviour, i.e., the interaction between the ground behaviour and construction measures. | a. Acceptable seepage limits can be achieved.<br>b. The stability of the underground openings is adequate. | | Documentation in agreement with Section 8.3 and Section 9.3. | Chapters 8 and 9. |
| 5. Carry out a risk assessment for the proposed layout and proposed design solutions | Consider that:<br>a. The design is in compliance with repository design requirements.<br>b. Propose measures for the next design step. | | See previous main activity.<br>Documentation in agreement with Section 10.3. | Chapter 10. |

# 6 Examination of previous studies

## 6.1 General

As pointed out in Section 3.2, the feedback from the Design step D1 shall be evaluated before the design step D2. The objective for the review of previous site results is that the Designer shall become thoroughly familiar with pre-existing works for the site:

> *Specifications of pre-existing works of importance for design step D2 is provided by SKB for each site.*

The introductory presentation by SKB on the current status of investigations and design, as well as feedback given to the design works after design step D1 will include at least;

- The first outlined layout and the site conditions considered to have impact on a tentative layout.
- The sensitivity analyses that have been carried out with respect to the objective to determine whether there is adequate space to accommodate the final repository facility at the site, and the outcome of the Technical Risk Assessment carried out in terms of feedback to the site investigations.
- The updated site investigations and model results described in SDM v2.1 and the Site Engineering Report.
- The outcome of the Preliminary Safety Evaluations /SKB 2005a, 2006a/, as well as of the Main report of the SR-Can project /SKB 2006g/, especially the section "Feedback to rock engineering".

The Design Coordinator shall be responsible for devising procedures for meetings needed during the review activities. The Designer shall ensure that his organisation for the assignment understands the status of the design process in the CSI.

## 6.2 Field reconnaissance

The Designer shall in the initial stage carry out a field reconnaissance with the objectives to obtain an on-the-ground understanding of the geology, overburden materials and the realities of working in the site area, and to become directly familiar with the

- Present investigation stage on site.
- Surface geology.
- Field locations of civil features of the project.
- Subsurface conditions by studying the SER
- Construction experiences by studying the CECR and visiting nearby underground facilities.
- Current status of design and safety assessment studies.

The Design Coordinator and the Designer shall jointly plan the field reconnaissance.

## 6.3 Examination of design D1 and subsequent site information

Each site investigation constitutes a successive build-up of knowledge, in which each new result may influence the interpretation of earlier investigation results and thereby influence the development of the design. Therefore, the results presented in the Site Descriptive Model version 1.2, shall be presented by SKB to the Designer together with an overview of new result obtained after version 1.2. Special emphasis shall be paid to their possible consequences on the design D2 such as, but not limited to the following issues given in the SER.

- Access ramp and shafts.
- Design of main tunnels, deposition tunnels and deposition holes.
- Distance between deposition tunnels and between deposition holes.
- Orientation of deposition tunnels.
- Rock conditions unsuitable for deposition holes.
- Repository depth and location

*The results from the Design Step D1 is presented in Brantberger et al. 2006 for the Forsmark site, and in Jansson et al. 2006 for the Laxemar site. The design reports summarise the input data from the site descriptive models /SKB 2005d, 2006b/ that have been used. Of special concern is that the Designer in consultation with SKB gets familiar with:*

- *The layout and the presumptions that have influenced the layout, both site conditions and administrative decisions by SKB.*
- *The outcome of different sensitivity analyses carried out.*
- *The recommendations for further site investigations.*

*Additional information on the preliminary facility description is given in /SKB 2006de/.*

SKB shall inform the Designer on the current plans for completion of the site investigations.

*The Designer has the possibility to interact with the completion of the site modelling and the completion of SER in the early phase of his assignment, by addressing any issue that may have been overlooked by SKB.*

## 6.4 Documentation

No formal documentation is required from this initial activity. The Designer shall keep the knowledge obtained from the examination of previous works available within his organisation.

# 7 Layout studies

## 7.1 General

Proposals for alternative layouts of a Final repository facility during the sequential construction shall be developed to explore the potential of the candidate area. The layouts shall be conceptual and based on the overall requirements, the environmental objects and the specific requirements related to D2 given in Chapter 4. The overall aim shall be to investigate and to demonstrate the functionality of the facility.

The layout works shall for each proposed layout demonstrate conceptually how the sequential construction of a facility may be carried out. The layouts shall, as far as reasonable, in locating ramp, shafts, and rock openings of the handling and operational area, tunnels and deposition areas, assess the conditions that are governing the functionality and the efficiency of the facility in concern. There are many issues involved in determining the potential of the candidate area and the layout works shall in particular assess, but is not restricted to, the aspects listed in the Table 7-1. The layout assumes a single storey repository.

## 7.2 Concurrent construction of the underground facility

The deposition area shall be developed step-wise. The overall functionalities for concurrent construction and operation are described in Section 7.3.2. The Designer shall account for the demand of physical protection between the two activities, construction and operation of the nuclear facility. The illustration of a concurrent construction shall consider the deposition rates given below. The layout works shall provide conceptual drawings showing the required space for such a construction step for the following layout works with respect to the concurrent construction.

**Table 7-1. Aspects to consider in the layout studies.**

| Aspect | Key words | Reference |
|---|---|---|
| Concurrent construction | The functionality of a concurrent construction in parallel with investigation, deposition, backfilling and closing of deposition tunnels and deposition areas | Sections 7.2, 7.3.2 |
| Services | Ventilation and drainage | Section 7.3.5 |
| Occupational health | Safe working environment | /Arbetsmiljöverket 2003/ (AFS 2003:2) |
| Deformation zones | Location, respect distances, hydrogeological conditions, ground type, ground behaviour. | Site Engineering Report |
| State of stress | Stability issues related to excavation in various ground types | Site Engineering Report |
| Distance between deposition tunnels and deposition holes | Thermal and mechanical rock mass properties | Site Engineering Report |
| Degree of utilisation/ loss of canister position | Rock mass fracturing and transmissivity | Site Engineering Report |

The layout D2 shall demonstrate areas enabling deposition of 6,000 canisters. The layout works shall describe the sequential construction of the deposition areas, and describe how far the construction has reached at the following times after functional tests have been carried out.

1. The first year, assumed deposition of 50 canisters.
2. The second year, assumed deposition of 100 canisters.
3. The third year, assumed deposition of 150 canisters.
4. The following regular operations shall be assumed to have a capacity for disposal of 150–200 canisters per year up to when the deposition has reached 6,000 canisters.

The layout studies shall estimate suitable time periods for each deposition stage.

In addition, the layout works shall demonstrate the possible deposition of canisters exceeding 6,000 canisters within the geological and administrative limits outlined by SKB.

The need to carry out site characterisation of the following construction stage for the detailed design shall be considered for each sequential construction stage. Such investigations may for example focus on to define the areal extent of next construction stage, including geological constraints and updated prediction on degree of utilisation. This may influence on layout plans for transport tunnels.

> *Further detailed investigations for deposition tunnels and deposition holes are not considered in this design step.*

## 7.3 Functional studies of the sub-surface facilities

### 7.3.1 General

The purpose of these functional studies is to study the overall functionality of the repository with respect to:

- The concurrent construction in parallel with investigation, deposition, backfilling and closing of deposition tunnels and deposition areas (Section 7.2 and Section 7.3.2).
- Physical protection (Section7.3.2).
- Site adaptation (Section 7.3.3).
- Health and safety (Section 7.3.4).
- Optimisation of the working place (Section 7.3.5).

The details in the studies to be carried out are given in the following sections in this Chapter. The studies shall consider the requirement on physical protection to separate the construction and the operation areas in all excavation phases, the rational adaptation to the site with respect to the site conditions as well as health, safety and effectiveness in all underground works during the operational time of the repository. Geological constraints from the long-term safety point of view are given in the SER.

The studies have to be done as an iterative process. This may possibly lead to that compromise has to be considered. It is therefore important to establish a priority between the different functional aspects. The highest priority shall be physical protection of the operational area, followed by health and safety aspects in general. The possibility to a site adaptation that allows for an effective use of the site with respect to any geotechnical constraints is regarded equal to the aspect of a optimisation of the working place in terms of logistics etc.

### 7.3.2 Separate main activities

The layout studies shall include a division of the repository area into a number of deposition areas, based on the results from the performed site investigations and in accordance with SER. The construction of the repository area during operation shall be developed step-wise, where each step comprises a loop through one or several deposition areas, alternatively only through a part of a deposition area. One step may time-wise run from a few years up to about 10 years. The excavation of the deposition area(s) included in the first step is commenced during the initial stage of the construction of the repository.

Deposition handling and rock excavation works during operation of the repository are carried out in parallel, but separated from each other. Deposition handling and rock excavation works shift sides in a cyclic manner. During the first years of operation, the number of deposited canisters is successively increased after each shift of side. The desired deposition rate is assumed to be reached at the commencement of the regular operation.

Separation of sides for deposition and rock excavation works is made in order to separate reloading and deposition of canisters from other activities in the repository. The separation is also vital in disconnecting the deposition handling from emissions to air and water resulting from the excavation works.

The time period of the deposition and rock excavation cycles is adjusted so that it enables the construction to be performed in an efficient way.

The physical protection requirement to always separate handling of radioactive material from construction activities puts demand on the layout such that separate areas are dedicated for the transport of the canisters.

Appendix 1 presents the current design principles that have to be considered in the layout studies. This includes the caverns in the central area, as well as the guiding principles to separate construction from canister transport and deposition underground.

***Execution***

- To demonstrate layout for concurrent construction separating construction and operation (construction steps according to Section 7.2).
- To demonstrate a minimum of 80 m spacing between construction area and deposition area of already deposited canisters.
- To outline layouts illustrating strategies for excavation sequences and simultaneous deposition operations for each construction step (one flowchart per construction step).

### 7.3.3 Site adaptation

A potential placement of the deposition area, adapted to respect distances to deformation zones, has been developed in design step D1 based on the SDM v 1.2 taking into account a repository for 6,000 canisters. Account has also been taken to loss of deposition holes according to provisions given in SER.

The siting and the development of the layout of the repository in D1 consider deformation zones, rock stress and thermal properties as given in SDM 1.2. The Designer shall update this layout work, considering the information given in SER.

### *Execution*

The development of the site adaptation in D2 shall incorporate any relevant modifications of the Site Description obtained since SDM 1.2, as identified in the SER.

A three-dimensional layout shall be elaborated showing the Central area being the lowest level of the final repository facility containing rock drainage basins.

The site adaptation in D2 shall involve a step-wise development in accordance to the assumptions given in Section 7.2.

Furthermore, D2 shall involve an evaluation of additional available space within the area directed by SKB for deposition of additional canisters above nos. 6,000.

The site adaptation shall consider the locations of all existing investigation holes drilled during the entire investigation phases. A minimum distance from a tunnel to a drill hole shall be set to one tunnel diameter (rock mechanics estimate – no influence from tunnel to borehole). The Designer shall assume that borehole locations could be identified with high accuracy during construction.

The layout D2 shall apply the requirements for physical protection between the parallel activities construction and operation.

## 7.3.4 Health and safety

### *General*

The Designer shall comply with the health and safety requirements set out in current guidelines and standards relevant to the construction and/or relevant industrial enterprises of similar character.

### *Execution*

A risk audit shall be implemented according to AFS 2003:2 implying a simplistic risk analysis for the purpose of estimating risks of the underground work activities.

Principally, the risk analysis (occupational health and safety) shall comprise the following steps:

1. Definition of objectives of analysis.
2. Collection and handling of data.
3. Identification of sources risk.
4. Estimation of risks.

The risk audit shall be carried out step-wise. In this design step (D2) a general and broad outline shall be carried out in order to identify areas of problem (minimum demand is ranking of risks). This study will be detailed in later design steps. In D2, the objectives of analysis, such as underground road safety during construction and operation, escape routes and ventilation system, shall be geographically and functionally well defined.

A fire risk analysis shall be carried out in consultation with parallel ongoing studies at SKB.

> *Subsequently, a more detailed approach shall be applied with the purpose of carrying out a more thorough analysis.*

### 7.3.5 Optimisation/efficiency

***General***

The layout work in D2 shall elaborate a conceptual plan for efficient and optimal strategy for the concurrent construction of the underground facility providing for a simultaneous step-wise excavation and deposition.

The overall aim shall be to investigate and to demonstrate that the various construction operations do not disrupt each other at any time and do not conflict with any of the deposition activities.

There are a number of issues that should be taken into consideration, and the optimisation work shall in particular consider for each construction step, but not restricted to, items such as:

- Physical protections.
- Health and safety.
- Geological uncertainties.
- Strategies for investigation during the stepwise construction.
- Transport and hoisting efficiency from repository level to ground surface (actual time and transport distance per ton).
- Ventilation (number and placement of ventilation shafts).
- Environmentally economising.

***Execution***

Present a conceptual layout that demonstrates decoupled working operations and decoupled layout elements, i.e., each working activity may be in progress in its own layout element independently of any other activity within the underground repository area.

### 7.3.6 Evaluation

The Designer shall judge upon the design risks related to his proposed optimisation of the layout in accordance to Section 7.3.5.

- Functionality.
- Has the design study exposed unforeseen safety issues related to the operation of the repository?
- Does the attempted strategy for priorities between different items allow for a practical and efficient working place?
- What type of issues has formed the primary guiding principles for the proposed optimisation, and are there any tentative risks related to these decisions?

## 7.4 Layout

### 7.4.1 General

Based on the design process carried out according to Sections 7.1–7.3 and requirements as described below, a complete layout for the sub-surface facilities shall be prepared based on the final SER.

The layout shall, with a view towards concurrent construction 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.

Deposition areas shall be placed in rock domains decided on by the Design Coordinator according to the SER.

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

*In preparing subsequent layouts (D2:2, 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 shall be done in consultation with the Design Coordinator.*

Dimensions of the repository (tunnel cross section areas, slope of tunnels, needed space for vehicles and installations etc) are given in Appendix 1.

The distance between deposition tunnels and between deposition holes shall be chosen according to the SER.

The orientation of deposition tunnels shall be chosen according to the SER.

The placement of deposition areas shall take into account any constraints of geological reasons, such as the respect distance of deposition tunnels to deterministically determined deformation zones and depth of the final repository facility according to the SER.

*If the chosen tunnel orientation leads to an unreasonably low utilisation of an available rock domain, another orientation may be chosen which may result 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 for the alternative orientation and in consultation with the Design Coordinator.*

Deposition areas shall hold 6,000 canisters. Account shall be taken to the loss of deposition holes according to the SER 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 the SER. The layout works shall describe the concurrent construction of the deposition areas in accordance to Section 7.2.

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, considering geometries in accordance with Appendix 1 and also any restriction given in the SER.

Space requirements for material handling shall be demonstrated in connection with deposition and sealing, in particular space requirement for placement of buffer and buffer material.

*SKB will provide information on space requirements for the material handling during deposition and backfilling operations.*

The central area shall be placed in rock domains decided on by the Design Coordinator according to the SER. Caverns in the central area, shafts, ramp and other transport tunnels should be assumed that these are designed according to Appendix 1.

The minimum distance between deposition tunnels and caverns in the central area, shafts, ramp and transport tunnels shall for design step D2 be assumed to be minimum 50 m. Along both sides of the central area a distance of 40+80=120 m shall be preserved for future development of ramps at both sides of the central area, if a two-storey repository should be developed; see Appendix 1.

*This measure is only based on restrictions related to vibrations from blasting. This measure may be revised based on the actual blast design during construction or conclusions based on safety assessment.*

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 minimised. This shall be done in consultation with the SKB Site Investigations 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 according to the SER should be considered. Central area, shafts, ramp and transport tunnels shall be placed with respect to water-bearing zones so that seepage is minimised wherever possible.

> *It may be assumed that deterministically determined minor deformation zones are allowed to intersect ramp and shafts.*

### 7.4.2 Layout of ramp

The requirements of the ramp are given in Appendix 1 and in SER. Special attention shall be given, but is not restricted to, the following aspects:

- Layout of ramp with respect to current knowledge of the geotechnical and hydrogeological conditions.
- Accessibility to shafts at each loop of the ramp.
- The connection between the lower part of the ramp and the nearest cavern in the operation and handling area. The easiest possible access to the handling cavern for canisters shall be considered.

### 7.4.3 Layout of central area and shafts

The requirements and guidelines of the operation and handling area and the shafts are given in Appendix 1 and in the SER. Special attention shall be given, but is not restricted to, the following aspects:

- SKB decision on location of the industrial area.
- Alignments of the caverns in the operation and handling area with respect to the rock mechanical situation.
- Flexibility in siting, especially for the shafts and their connection with the surface facilities.
- Flexibility in access routes to the deposition areas, especially with respect to physical protection requirements.

### 7.4.4 Layout of deposition area

The requirements of the deposition area including deposition tunnels are given in Appendix 1 and in SER. Special attention shall be given to studies carried out in Section 7.1–7.3 and, but is not restricted to, the following aspects:

- Concurrent construction according to Section 7.2.
- Physical protection requirements according to Section 7.3.2.
- Site adaptation according to Section 7.3.3.

The layout shall demonstrate flexibility within the deposition area with respect to the concurrent construction enabling site investigations of future construction steps.

## 7.5 Documentation

The documentation shall comprise a design report including at least:

- A description of the reasoning behind each layout decision; i.e. how this UDP and the provided input were used to arrive at the selected layout.
- Layout of each construction step.
- A description of the methodology of fulfilling the requirements on physical protection and fire sectioning of each construction step.
- Layouts of escape routes for each construction step.
- An illustration of how site-specific ventilation may work, especially the locations of ventilation shafts, and roughly when they need to be constructed.
- A 3-D CAD model of the deposition area in relation to geology for a deposition area of 6,000 canisters.
- A description and layout of possible deposition area for deposition of canisters exceeding 6,000 canisters. The layout shall demonstrate location of access routes to the additional deposition area for > 6,000 canisters.
- Tables summarising input data, assumptions and conclusions for e.g. various construction steps and structures influencing the layout.

## 7.6 Evaluation

The design study D1 concluded that the objectives to determine whether the final repository facility can be accommodated within the study area could be met for both sites. This question shall however be addressed again. The guiding principle shall be focused on the uncertainties given in the SER regarding:

- Uncertainty in the geometrical model for deformation zones that may have impact on the layout. The SER summarises the uncertainty spans that shall be considered regarding location of deformation zones and their related respect distances. Special concern shall be paid to that a tentative deposition unit divided by deformation zones may be too small to be utilised for the repository.
- The impact of the uncertainty in any site-specific critical parameter. The SER points out the estimated uncertainty spans in relevant design parameters for the site.
- Any uncertainty in the degree of utilisation given in SER
- Outline of critical parameters that shall be observed and monitored during construction.

*The design studies in step D1 may serve as a reference /Brantberger et al. 2006/, /Jansson et al. 2006/.*

# 8 Ground behaviour, grouting measures and hydrogeological situation

## 8.1 General

The overall objective for the analyses of ground behaviour and grouting measures is to show that it is feasible to seal the rock by grouting to the levels estimated for the Spent Fuel Project. This means

– demonstrating that there is a technology that can cope with the predicted site conditions and other prevailing premises and that can fulfil the requirements on resulting sealing

– indicating amount of materials and other resources for the suggested preliminary design of Layout D2.

For each of the functional areas, repository access, central area and deposition area the Designer's task is to:

- Assess the distribution of ground types and possible ground behaviour in terms of water inflow to the different facility parts without considering the effect of grouting measures.
- Determine the appropriate grouting measures based on the assessment of ground behaviour and considering the requirements and the function of the facility part.
- Assess the system behaviour in terms of water inflow based on interaction between ground types and grouting measures.

## 8.2 Execution

### 8.2.1 References and instructions

The analyses are to be based on the outlines and recommendations given in the SER-reports. The total acceptable amounts of inflow of water to the different underground openings are given in Table 8-1.The facility layout is according to the results of studies under Section 7.4.

In design step D2 the grouting measures can be based on analytical solutions or experiences. Vital is the use of engineering judgement for evaluation and any choices made.

> *State of art regarding grouting with cement based grouts in hard rock is described in for example /Eriksson and Stille 2005/. This publication is based on theoretical and practical studies and experiences. It includes references and some recommendations.*
>
> *Grouting in hard rock with gelling liquids with focus on Silica sol is described in /Funehag 2004/.*

**Table 8-1. Acceptable water inflow to different underground openings.**

| | | |
|---|---|---|
| Deposition hole | Spot-wise | ≤ 0.1 l/min |
| Deposition tunnel | 1.7 l/min, 100 m | |
| Deposition tunnel | Spot-wise | ≤ 1 l/min |
| Shafts and ramp | 10 l/min, 100 m* | |
| Other openings | 10 l/min, 100 m | |

*Mean value for the whole ramp/shaft. Higher inflow might be accepted locally if the environmental impact could be shown to be acceptable.

*A method for a statistical analyses of fractures and water ingress to tunnels is given in /Gustafson et al. 2004/.*

*Examples from design and execution of grouting works are given in among others /Emmelin et al. 2004/.*

*Construction and maintenance experiences from nearby facilities are given in the Construction Experience Compilation Reports (CECR). Some recommendations regarding grouting methods are also given in the SER-reports.*

*A study of tunnelling through water-bearing fracture zones, based on properties of a fracture zone at Äspö HRL, is presented in /Chang et al. 2005/.*

Independent of the methods used for analyses of the design, the following shall be reported:

- Choice of methods for grouting and proposed grouting measures shall be clearly motivated.
- Uncertainties must be described and assessed.
- The need for further studies shall be evaluated.
- Relevant experiences shall be described.
- References shall be given.

### 8.2.2 Ground behaviour

For each functional area, the Designer shall identify and assess the distribution of ground types given in the SER. The probable ground behaviour in terms of inflow for selected ground types without considering the effect from grouting measures shall also be predicted for the different functional areas. The most unfavourable distribution of ground behaviour shall also be assessed for each of the functional areas considering the location of the underground opening. The layout of the facility shall be according to the results of the studies made under Section 7.4. The ground types, for which the ground behaviour shall be assessed, are to be selected together with the Design Coordinator.

### 8.2.3 Grouting measures

For selected ground types according to Section 8.2.2, appropriate grouting measures shall be determined using the ground behaviour and grouting types provided in SER. The grout hole length, number of holes, spacing, pressure, grouting material, execution and controls are not provided as part of the grouting types, that decision remains with the Designer when all the functional requirements and influencing factors are considered. The need for special measures in order to cope with for example highly conductive deformation zones and a high water pressure should also be described.

As a basis for the design of grouting measures, calculations of water inflow to tunnels considering the effect of grouting can be made. Based on these calculations an estimation of the target hydraulic conductivity and extent of the grouted zone can be made. The results of these calculations can also be used for estimating the apertures that need to be grouted (see /Eriksson and Stille 2005/.

The Designer should base the design on existing technology, but also consider that grouting material and grouting equipment are currently subjected to ongoing development, especially concerning the grouting material. The Design Coordinator will present properties and recipes of currently available grouts and the Designer shall if possible use these grouts. The Designer shall however evaluate and clearly address the need of other properties of the grout than those given by the Design Coordinator.

In the view of the SKB's requests to on one hand limit the disturbance on the surrounding rock and on the other to have a robust process, the need of systematic pre-grouting shall be evaluated. Drilling holes (probing, grouting or control holes) should be placed in such a manner that it does not interfere or risk to interfere with any possible location for a deposition hole.

*If otherwise comperable methods are discussed, the method giving the lowest material use should be favoured provided that the objectives are fulfilled.*

*Systematic pre-grouting should, if possible, be avoided in deposition tunnels.*

### 8.2.4 System behaviour

For each functional area and selected ground types the system behaviour in terms of water inflow to the different facility parts shall be predicted. This is the interaction between the ground behaviour and the grouting measures. The system behaviour can be assessed using analytical methods and/or comparative studies, based on experience from previous similar projects (see for example the Construction Experience Compilation Report). The results from the system behaviour analyses shall be compared to the sealing requirements of the underground openings and that the design is in compliance with repository design requirements.

The most probable system behaviour as well as the most unfavourable system behaviour shall be assessed in terms of inflow of water, conductivity and/or transmissivity achieved after grouting.

### 8.2.5 Compilation of materials and other resources

Based on the proposed grouting measures an estimation of materials and resources needed for the execution shall be made. For materials the amount should be given in $m^3$ and tons. The estimated number of drill holes should also be estimated for each scenario. For each functional area the amounts presented should relate to the most probable system behaviour as well as the most unfavourable system behaviour.

The quantities shall be divided into the functional areas:

- Repository access (ramp and vertical shafts).
- Central area (caverns and tunnels in the area for operation and handling).
- Deposition area (deposition tunnels and transport tunnels).

The Designer shall estimate amount of grouting materials based on the assumption that the porosity in the rock is filled with grout at a certain distance from the tunnel periphery. The estimation of porosity shall be made based on the hydrogeological properties of the rock mass given in the SER-reports and the grout spread distance from the tunnel periphery should be set to the estimated distance required to fulfil the sealing requirements. The method for estimating porosity shall be justified.

Amount of materials in grouting holes must also be estimated. The uncertainties in the estimation of amount of materials should be discussed together with a comparison with experience.

For the estimation and compilation of amount of materials, the Designer is restricted to use the grouts specified by the Design Coordinator.

Furthermore other necessary resources shall be described. These resources could be required for example when passing highly conductive deformation zones.

*The amount of materials needed for fracture domains and ground types that are not further studied according to Section 8.2.2, should be estimated based on quantity estimations for analysed fracture domains.*

### 8.2.6 Assessment of hydrogeological situation around the repository

Assessment of water inflow into the repository and the hydrogeological situation around the repository shall be based on the SER-reports and the layout proposed in Chapter 7.4.

The hydrogeological model established in the SDM shall be used for simulations of the different excavation steps outlined for the layout. The assessment shall also take into account the system behaviour after grouting.

> *This work is carried out by specialists from the site modelling teams, is coordinated by the Design Coordinator and involves the Designer primarily in aspects dealing with the geometrical outline of the underground facilities and the uncertainties considered in the layout works.*

Uncertainties in the hydrogeological model need to be considered. Sensitivity studies shall be carried out to:

1. Estimate a likely span of ground water draw-down with and without the assessed system behaviour in accordance with Section 8.2.4, considering also surface conditions such as conductivity of actual soil deposits covering the outcrop of a deformation zone.
2. Identify if there are any specific objects that may be affected by the possible draw-down, and study to what extent special measures may be needed for the protection of the object.

Based on the estimated ground water table draw down the Design Coordinator shall consult the environmental impact studies carried out with the purpose to identify any risk object. If required, after the studies in accordance to this section and the integrated risk assessment in accordance to Chapter 10, a feasibility study shall be carried out by the Designer on the most suitable measure to reduce damage. The feasibility study shall compare and recommend one of the two following alternatives:

1. Efforts to reduce water inflow by grouting. The risks outlined in Section 8.2.7 shall be assessed.
2. Measures for maintaining the ground water table by infiltration. Location and capacity of such installation shall be proposed, and the environmental impact of the installation shall be assessed.

### 8.2.7 Overall judgement of feasibility and uncertainty

The feasibility of the project shall be assessed from a grouting point of view. It shall therefore discuss:

- Motives for suggested measures.
- The confidence in predicted results.
- The robustness of analysis methods used and of suggested grouting measures from an execution point of view.
- Any special demands on equipment or other resources or premises needed for successful execution.
- Critical design parameters shall be identified for the purpose of being incorporated in an observation programme that shall be executed during construction.
- Possible measures in case of non-performance.

Furthermore, the need of additional studies shall be addressed.

The overall risk that the acceptable remaining water inflow after grouting (Table 8-1) may not be met shall be assessed, considering uncertainties in the hydraulic conditions and uncertainties in the conductivity of the grouted zone.

An assessment of the acceptable limits of behaviour for grouting measures should form a basis for assessment of hazards during the construction works as well as for technical risks related to the operation phase (see Chapter 10).

## 8.3 Documentation

Reporting shall comprise a report including at least;

- Description of the premises, motives for selection of ground types and grouting types that have been analysed, chosen methods for analyses and references, execution and system behaviour according to Section 8.2.4.
- Tables presenting amounts of drill holes and amount of grout materials for the functional areas given in Section 8.2.5.
- Drawings showing the proposed grouting measures.
- Drawings or tables showing the assessed distribution of ground types, ground behaviour grouting types and grouting measures.
- If required, SKB directs the Designer to propose measures for maintaining the ground water table in sensitive locations by means of infiltration.
- Assessment and feasibility and uncertainties in accordance with section 8.2.7.

In addition the risk assessment shall be incorporated and reported in the overall evaluation of technical risks in accordance to Chapter 10.

# 9 Ground behaviour and support measures

## 9.1 General

The design strategy is outlined in Section 5.2. The overall objective for the analyses of ground behaviour and support measures in design step D2 is to show that the construction and operation of the final repository facility are feasible from a rock mechanics point of view.

SER divides the final repository facility into functional areas. For each of the functional areas, repository access, central area and deposition area the Designer's task is to:

- Assess the distribution of ground types as well as the ground behaviour without considering the effect from support measures or sequential excavation.
- Determine the appropriate support measures based on the assessment of ground behaviour and considering the requirements and the function of the facility part.
- Assess the system behaviour based on interaction between ground types, support measures and construction measures.

## 9.2 Execution

### 9.2.1 Design step D1

Design step D1 included a preliminary assessment of rock mass stability during construction. The stability studies were limited to assessment of risk for stress induced spalling and for the risk of sliding or free falling wedges. The main findings are concluded in /Martin 2005/. There are uncertainties remaining whether there may be a risk for stress related stability problems. This was mainly related to uncertainties in data on stress conditions and strength of the rock. The first activity within rock mechanics is a review of previous works, and new data in accordance to Chapter 6.

> *Additional rock mechanics studies from design step D1 can be found in for example /Brantberger et al. 2006/.*

The CECR reports /Carlsson and Christiansson 2007ab/ summarise the construction and maintenance experiences from nearby underground facilities. The SER outlines the extent of which the CECR may be used as empirical reference for assessing suitability and long-term performance of rock support measures.

The requirements on technical working life of the underground openings are given in Table 9-1.

**Table 9-1. Technical working life of underground openings.**

| Underground opening in the final repository facility | Technical working life |
|---|---|
| Deposition tunnels and deposition holes | a minimum of 5 years |
| Other underground openings | a minimum of 100 years |

### 9.2.2 Ground behaviour

For each functional area the Designer shall identify and assess the distribution of ground types. The probable ground behaviour for each ground type without considering the effect from support measures or sequential excavation shall be determined. The most unfavourable distribution of ground behaviour shall also be assessed for each of the functional areas considering size, shape and location of the underground opening. The layout of the facility shall be according to the results of the studies made under Section 7.4 (the geometries of the different openings in the facility are presented in Appendix 1).

### 9.2.3 Support measures

For each identified ground type the appropriate support measure shall be determined. The basis for design is the identified ground behaviour and support types provided in SER. Considering all the functional requirements and influence factors the bolt type, spacing and length, and shotcrete thickness and necessary specifics not detailed in the support types shall be determined. The support measures shall form the basis for a preliminary estimate of the amount of materials and other resources needed for accomplishing the support works.

*A specific support measure may be fit for purpose for more than one ground behaviour.*

The requirements on construction materials shall be considered. If otherwise equal approaches are discussed, the approach giving the lowest material use should be favoured.

### 9.2.4 System behaviour

For each functional area the system behaviour shall be predicted. The different geometries specified in Appendix 1 must be considered from a constructability point of view for each functional area. In addition, spalling in the deposition tunnels and deposition holes shall also be considered from a long-term safety point of view based on the approach proposed by /Martin 2005/. This is the interaction between the ground behaviour and the construction measures; i.e. excavation sequence and support methods. The system behaviour can be assessed using analytical methods, rock characterisation methods, numerical methods, and/or comparative studies, based on experience from previous similar projects. For example it may be acceptable to use the CECR for the existing facilities at site to evaluate the system behaviour for the repository access. The results from the system behaviour analyses shall be compared to the design requirements and confirm the stability of the underground openings and that the design is in compliance with repository design requirements.

The most probable system behaviour shall be determined for each ground type considering the effect from support measures and sequential excavation. The most unfavourable system behaviour shall also be assessed for each of the functional areas.

### 9.2.5 Compilation of amount of materials and other resources

Based on preliminary designs, an estimation of materials and resources needed for the execution shall be made. For materials, the amount should be given in $m^3$ and tonnes. For each functional area the amounts presented should relate to the most probable system behaviour as well as the most unfavourable system behaviour.

The quantities shall be divided into the functional areas:

- Repository access (ramp and vertical shafts).
- Central area (caverns and tunnels in the area for operation and handling).
- Deposition area (deposition tunnels and transport tunnels).

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

> *The Design Coordinator provides supporting material for calculation of the quantity of concrete and reinforcement in the temporary plugs.*

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

For concrete structures and shotcrete, quantities shall be specified for concrete and reinforcement. Both components shall be specified as volume (m3) and weight of cement/steel (tonnes). In addition, rock bolts shall be specified as number of bolts (Nos.) and length of bolts (m).

### 9.2.6 Assessment of feasibility and uncertainties

The objective is to confirm that construction and operation of the final repository facility is feasible from a rock mechanics point of view. This includes an outline of uncertainties identified for stability issues. The uncertainties may for instance be related to confidence in the predicted results, robustness of preliminary designs and any special demands on equipment or other resources or premises needed in the execution stage. Critical design parameters shall be identified for the purpose of being incorporated in an observation programme that shall be executed during construction.

An assessment of the acceptable limits of behaviour for critical support measures should form a basis for assessment of hazards during the construction works as well as for technical risks related to the operation phase.

## 9.3 Documentation

The documentation shall comprise a documentation including at least:

- Description of the premises, used methods and references, performance and results according to this Chapter.
- Premises and motives for selection of support measures
- Supporting calculations.
- Analysis of the risk for overbreak in deposition holes due to spalling during construction.
- Quantities in accordance with section 9.2.5
- Assessment of feasibility and uncertainties in accordance with 9.2.6
- Drawings showing the proposed support measures.
- Drawings or tables showing the assessed distribution of ground types, ground behaviour support measures.

All reporting shall meet the requirements given in Section 3.4.

In addition, the identified uncertainties shall be incorporated in the overall evaluation of technical risks in accordance to Chapter 10.

# 10 Technical risk assessment

## 10.1 General

The technical risk assessment shall be limited to the completed design in design step D2 and shall include proposals for measures aimed at preventing the occurrence of damage events. The proposals for preventive measures shall focus on recommendations for further studies and investigations. The risk assessment shall not include risks related to QA not being performed during construction.

Based on the objectives for design step D2 given in Chapter 2 and the completed design studies in accordance to Chapters 7, 8 and 9, a technical risk assessment shall be carried out.

Examples of types of technical risks can be:

- Unexpected deformation zones
- Unexpected inflow of water
- Unforeseen ground conditions

The technical risk assessment is performed to establish a feedback between the design results and the objectives of the underground design in design step D2 according to Section 2.3. 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 objects.

The technical risk assessment shall at least contribute towards meeting the following objectives according to Section 2.3:

1. Demonstrate a possible site adaptation for a repository.
2. Demonstrate the constructability and the effectiveness of a step-wise development of the underground parts of the repository.
3. Identify site-specific facility-critical issues and provide feedback to:
    - The design organisation regarding technical risks as well as additional studies that needs to be addressed in the next design phase.
    - The safety assessment organisation regarding technical criteria that have an impact on the extent of the repository and its engineered barriers.
    - The SKB management regarding investigation strategies that needs to be included into the step-wise development of the repository.

The technical risk assessment shall cover at least utilised areas up to the time when the repository is developed for 6,000 canisters.

## 10.2 Execution

### 10.2.1 General

The outcome of previous technical risk assessments from design step D1 shall be evaluated.

The input data to the risk assessment shall be derived from the Designer's experience from the completed design work in design step D2.

The methodology and structure for the technical risk assessment shall be devised in consultation with the Design Coordinator.

### 10.2.2 Layout

The results of the evaluation, in accordance with Section 7.6, shall be introduced into the technical risk assessment. The outcome of the optimisation studies, in accordance with Section 7.3.6, shall be evaluated with respect to:

- Foreseeable technical risks within each of the construction steps (cf. Section 7.2).
- Uncertainties during construction related to functionality, physical protection and occupational health and safety.
- Degree of uncertainty in extent of utilisation (extent of required area) regarding the sequential development (Section 7.2) due to uncertainties in the SER.
- Particular resources needed for any of the construction steps such as detailed investigations for the construction, additional resources for construction, and environmental protective measures (see Section 8.2.6).

### 10.2.3 Grouting

The result of the overall judgements of feasibility and uncertainty in accordance with Section 8.2.7 shall be introduced into the technical risk assessment.

The main overall risk assessment shall deal with the objective given in Section 8.1: "The overall objective of the analyses of ground behaviour and grouting measures is to show that it is feasible to seal the rock by grouting to the levels estimated for the Spent Fuel Project."

### 10.2.4 Stability

The result of the assessment of feasibility and uncertainties in accordance with Section 9.2.6 shall be introduced into the technical risk assessment.

The main overall risk assessment shall deal with the objective given in Section 9.1: "The overall objective for the analyses of ground behaviour and support measures in design step D2 is to show that the construction and operation of the final repository facility are feasible from a rock mechanics point of view."

## 10.3 Documentation

The documentation shall comprise a design report including at least:

- Summary.
- Description of premises and execution.
- Table or other format showing structure and content for the technical risk assessment.
- Ranking of damage events with respect to conceivable consequences for proposed access ramp and shafts, central area for handling and operation, and deposition area.
- Proposals for measures to prevent the occurrence of damage events, giving reasons and feedback to the objectives in design step D2. The measures proposed are primarily expected to be related to further investigations in order to reduce identified uncertainties, and shall at least include:
  - o Investigations recommended to be carried out for the construction phase from surface prior to detailed design of the proposed access ramp, shafts, central area and the deposition area for the first five year of operation.
  - o Investigations recommended to be carried out during the aforementioned construction phase.
  - o A strategy for dealing with investigations during the step-wise construction of the repository during the operational phase up to the capacity of deposition of 6,000 canisters. The outcome of the studies specified in Section 10.2.2, last bullet point, shall be introduced into this item.
  - o Any other proposed measure based on the technical risk assessment according to Sections 10.2.3 and 10.2.4.
- Technical risk assessment of any proposed measure for maintaining the ground water table by infiltration in accordance with Section 8.2.6.

# References


**Andersson J, Ström A, Svemar C, Almén K-E, Ericsson L O, 2000.** What requirements does the KBS-3 repository make on the rock? – Geoscientific suitability indicators and criteria for siting and site evaluation. SKB TR-00-12, Svensk Kärnbränslehantering AB.

**Arbetsmiljöverket, 2003.** AFS 2003:2.

**Brantberger, M, Zetterqvist A, Arnbjerg-Nielsen T, Olsson T, Outters N, Syrjänen P, 2006.** Final repository facility for spent nuclear fuel. Underground design Forsmark, Layout D1. SKB R-06-34, Svensk Kärnbränslehantering AB.

**Chang Y, Swindell R, Bogdanoff I, Lindström B, Termén J, Starsec P, 2005.** Study of tunnelling through water-bearing fracture zones. Baseline study on technical issues with NE-1 as reference. SKB R-05-25, Svensk Kärnbränslehantering AB.

**Carlsson A, Christiansson R, 2007a.** CECR – Construction experiences from underground works at Forsmark. Compilation report. SKB R-07-10, Svensk Kärnbränslehantering AB.

**Carlsson A, Christiansson R, 2007b.** CECR – Construction experiences from underground works at Oskarshamn. Compilation report. SKB R-07-66, Svensk Kärnbränslehantering AB.

**Emmelin A, Eriksson M, Fransson Å, 2004.** Characterisation, design and execution of two grouting fans at 450 m level, Äspö HRL. SKB R-04-58, Svensk Kärnbränslehantering AB.

**Eriksson M, Stille H, 2005.** Cementinjektering i hårt berg. Stiftelsen Bergtekninsk Forskning, SveBeFo.

**Eurocode EN 1997-1, 2004.** Eurocode 7: Geotechnical design – Part 1: General rules. European Committee for standardization, CEN, Brussels.

**Funehag J, 2004.** Grouting and analyses of a fracture in Äspö HRL. Characterisation, grouting an dverification of grouting results for Silicasol. Department of GeoEngineering, Chalmers Univ. of Technology, Sweden.

**Gustafson G, Fransson Å, Funehag J, Axelsson M, 2004.** Ett nytt angreppssätt för beskrivning och analysprocess för injektering. Väg- och vattenbyggaren nr 4.

**Jansson T, Magnusson J, Bergvall M, Olsson R, Cusiat F, Skurtveit E, Grimstad E, 2006.** Final repository facility for spent nuclear fuel. Underground design Laxemar, Layout D1. SKB R-06-36, Svensk Kärnbränslehantering AB.

**Martin C D, 2005.** Preliminary assessment of potential underground stability (wedge and spalling) at Forsmark, Simpevarp and Laxemar sites. SKB R-05-71. Svensk Kärnbränslehantering AB.

**Palmström A, Stille H, 2006.** Ground behaviour and underground tools for underground excavations. Tunnelling and Underground Space Technology 2006.

**Peck R B, 1969.** Ninth Rankine Lecture: Advantages and limitations of the observational method in applied soil mechanics. Geotechnique, 19:171–187.

**Schubert W, Goricki A, 2004.** Probabilistic assessment of rock mass behaviour as basis for stability analyses of tunnels. In: Proceedings of the Rock Mechanics Meeting, Stockholm, Sweden, March 2004, pp. 1–20 (Published by SvBeFo, Swedish Underground Research).

**SKB, 1986.** R&D-Programme 86. Handling and final disposal of nuclear waste. Programme for research, development and other measures. Svensk Kärnbränslehantering AB.

**SKB, 1989.** RD&D-Programme 89. Handling of final disposal of nuclear waste. Programme for research, development and other measures. Svensk Kärnbränslehantering AB.

**SKB 1991.** Slutlig förvaring av använt kärnbränsle. Berggrundens betydelse för säkerheten. Svensk Kärnbränslehantering AB.

**SKB 1992.** RD&D Programe 92. Treatment and final disposal of nuclear waste. Programme for research, development and other measures. Svensk Kärnbränslehantering AB.

**SKB 1994.** RD&D-Programme 92 – Supplement. Treatment and final disposal of nuclear waste. Supplement to the 1992 programme in response to the Government decision December 16, 1993. Svensk Kärnbränslehantering AB.

**SKB, 1995.** RD&D Programe 95. Treatment and final disposal of nuclear waste. Programme for encapsulation, deep geological disposal and research, development and demonstration. Svensk Kärnbränslehantering AB.

**SKB, 1998.** RD&D Programe 95. Treatment and final disposal of nuclear waste. Programme for research, development and demonstration of encapsulation and geological disposal. Svensk Kärnbränslehantering AB

**SKB 1999.** SR97 – Deep repository for spent nuclear fuel. SR97 – Post-closure safety. Main report – Vol I, Vol II and Summary. SKB TR-99-06, Svensk Kärnbränslehantering AB.

**SKB 2000.** Integrated account of method, site selection and programme prior to the site investigation phase. SKB TR-01-03, Svensk Kärnbränslehantering AB.

**SKB 2001.** RD&D-Programme 2001. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste. SKB TR-01-30, Svensk Kärnbränslehantering AB.

**SKB, 2001b.** Site investigations – Investigation methods and general execution programme. SKB TR-01-29, Svensk Kärnbränslehantering AB.

**SKB 2003a.** Prioritering av områden för platsundersökningen i Oskarshamn. SKB R-03-12. Svensk Kärnbränslehantering AB.

**SKB 2003b.** Förslag till förläggning av ovanjordsanläggning för djupförvar i Oskarshamn. SKB R-03-32, Svensk Kärnbränslehantering AB.

**SKB 2004a.** RD&D-Programme 2004. Programme for research, development and demonstration of methods for management and disposal of nuclear waste, including science research. Svensk Kärnbränslehantering AB.

**SKB 2004b.** Deep repository. Underground design premises. Edition D1/1. SKB R-04-60, Svensk Kärnbränslehantering AB.

**SKB 2005a.** Preliminary safety evaluation for the Forsmark area. Based on data and site descriptions after the initial site investigation stage. SKB TR-05-16, Svensk Kärnbränslehantering AB.

**SKB 2005b.** Programme for further investigations of geosphere and biosphere. Forsmark site investigation. SKB R-05-14, Svensk Kärnbränslehantering AB.

**SKB, 2005c.** Preliminary site description. Simpevarp area – version 1.2. SKB R-05-08. Svensk Kärnbränslehantering AB.

**SKB, 2005d.** Preliminary site description. Forsmark area – version 1.2. Updated 2005-11-09. SKB R-05-18, Svensk Kärnbränslehantering AB.

**SKB2005e.** Program för fortsatta undersökningar av berggrund, mark, vatten och miljö inom delområde Laxemar. Platsundersökningar Oskarshamn. SKB R-05-37.Svensk Kärnbränslehantering AB.

**SKB, 2006a.** Preliminary safety evaluation for the Laxemar subarea. Based on data and site descriptions after the initial site investigation stage. SKB TR-06-06. Svensk Kärnbränslehantering AB.

**SKB, 2006b.** Preliminary site description. Laxemar subarea – version 1.2. SKB R-06-10, Svensk Kärnbränslehantering AB.

**SKB, 2006c.** Programme for further investigations of bedrock, soil, water and environment in Laxemar subarea. Oskarshamn site investigation. SKB R-06-29, Svensk Kärnbränslehantering AB.

**SKB, 2006d.** Slutförvar för använt kärnbränsle. Preliminär anläggningsbeskrivning – layout D Oskarshamn, delområde Laxemar. SKB R-06-32, Svensk Kärnbränslehantering AB.

**SKB, 2006e.** Slutförvar för använt kärnbränsle. Preliminär anläggningsbeskrivning – layout D Forsmark. SKB R-06-33, Svensk Kärnbränslehantering AB.

**SKB, 2006f.** Final repository facility for spent nuclear fuel. Underground design Simpevarp, Layout D1. SKB R-06-35, Svensk Kärnbränslehantering AB.

**SKB 2006g.** Long term safety for KBS-3 repositories at Forsmark and Laxemar – a first evaluation. Main report of the SR-Can project. SKB TR 06-09. Svensk Kärnbränslehantering AB.

**SKB 2007.** Övergripande styrande dokument för projektering och därtill kopplad teknikutveckling av slutförvaret för använt kärnbränsle, inom Kärnbränsleprojektet i skede D2. SKBdoc ID 1084110.

**SKB, 2008a.** Site Engineering Report, SER. Guidelines for underground Design Step D2. Forsmark. SKB R-08-83, Svensk Kärnbränslehantering AB.

**SKB, 2008b.** Site Engineering Report, SER. Guidelines for underground Design Step D2. Laxemar. SKB R-08-88, Svensk Kärnbränslehantering AB.

**SKB 2008c.** Samråd enligt miljöbalken. Samråd 2007. ISBN 978-91-976891-5-1.

**SKB Requirements Management System (data base).**

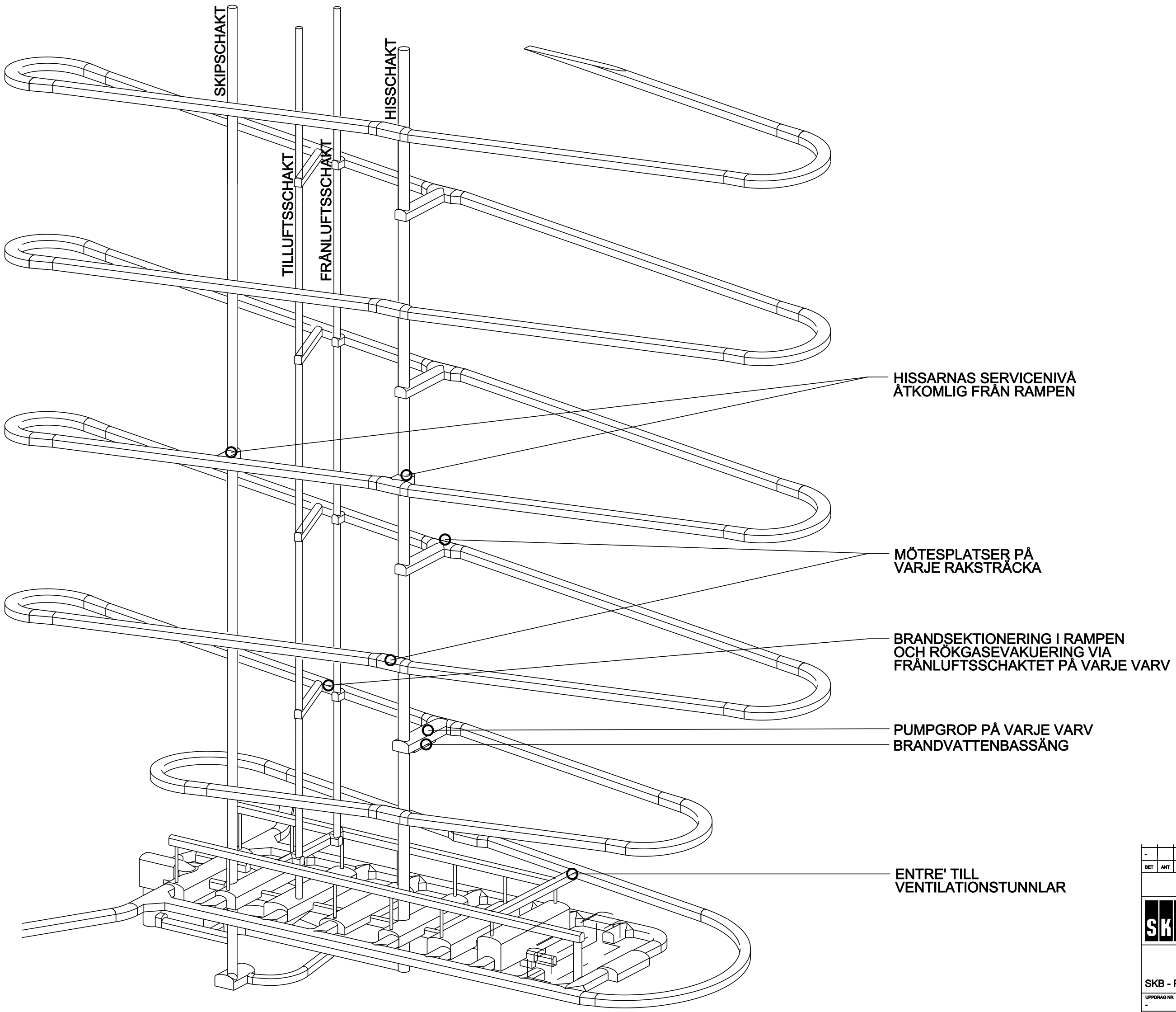
**SKBF/KBS, 1983.** Final storage of spent nuclear fuel – KBS-3. Summary. Svensk Kärnbränsleförsörjning AB.

**Swedish Environmental Code, 1998.** SFS 1998:808.

# Appendix

## Typical drawings of the underground openings

| Specification | Drawing No |
|---|---|
| Repository access, ramp & shafts 3D-general view | 9-C140-R-00-0001 |
| Central area, ramp & shafts, typical sections | 9-C140-R-00-0011 |
| Central area, 3D-perspective | 9-C130-C-00-0001 |
| Central area, plan view | 9-C130-C-00-0011 |
| Central area, plan view | 9-C130-C-00-0201 |
| Deposition Area, Main- and transport tunnels, exhaust shaft, typical sections | 9-C140-D-00-0011 |
| Deposition Area, overview | 9-C140-D-00-0001 |
| Deposition Area, Deposition tunnel and Deposition hole typical sections | 9-C140-D-00-0021 |




| BET | ANT | ÄNDRINGEN AVSER | DATUM | SIGN |
|---|---|---|---|---|
| - | | - | - | - |

SKB Slutförvar för använt kärnbränsle

SKB - PROJEKTERING SLUTFÖRVAR

| UPPDRAG NR | RITAD | GRANSKAD |
|---|---|---|
| - | SWECOOS | - |
| DATUM | GODKÄND | |
| 2009-06-25 | - | |

REFERENSUTFORMNING
RAMP OCH SCHAKT
PERSPEKTIV
ÖVERSIKT

| SKALA | NUMMER | BET |
|---|---|---|
| | 9-C140-R-00-0001 | - |

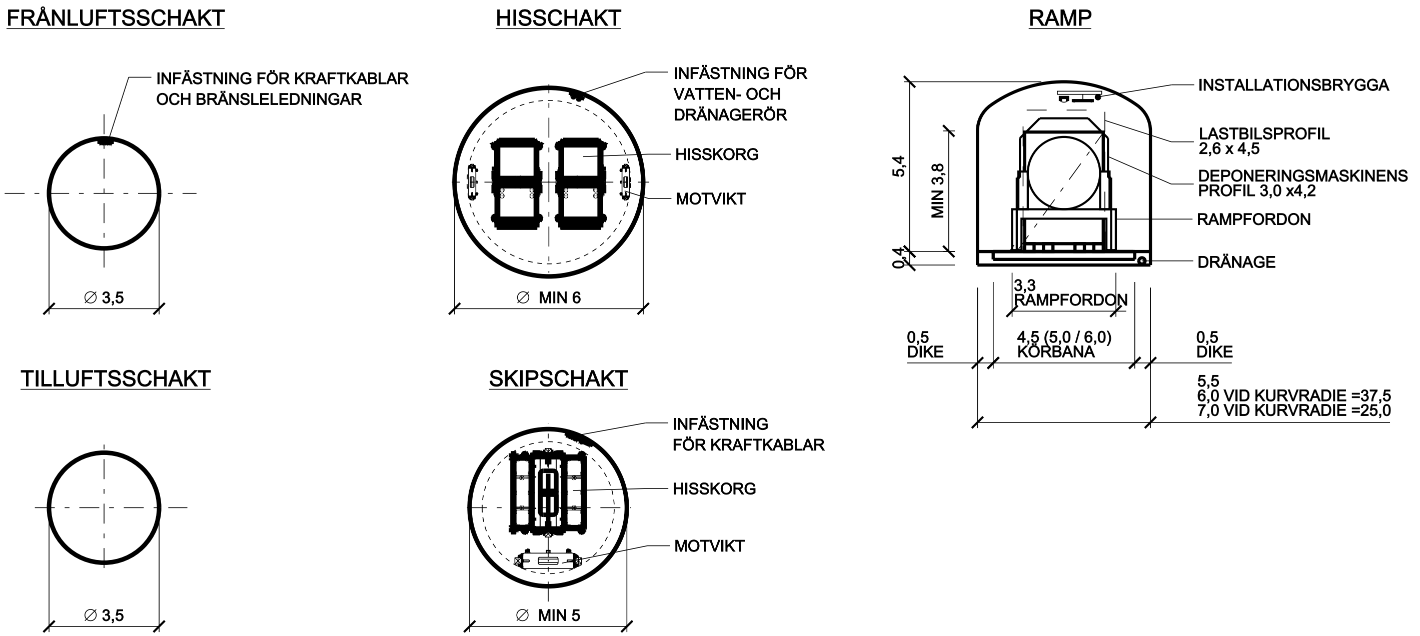
9_C140R_00_0001.dgn

PLOT:2009-06-25 15:16

REF: 9_130LC000_9001.hln

-

FÖRKLARINGAR




0 5 10m
1:200

| | | | | |
|---|---|---|---|---|
| - | | - | - | - |
| BET | ANT | ÄNDRINGEN AVSER | DATUM | SIGN |

SKB Slutförvar för använt kärnbränsle

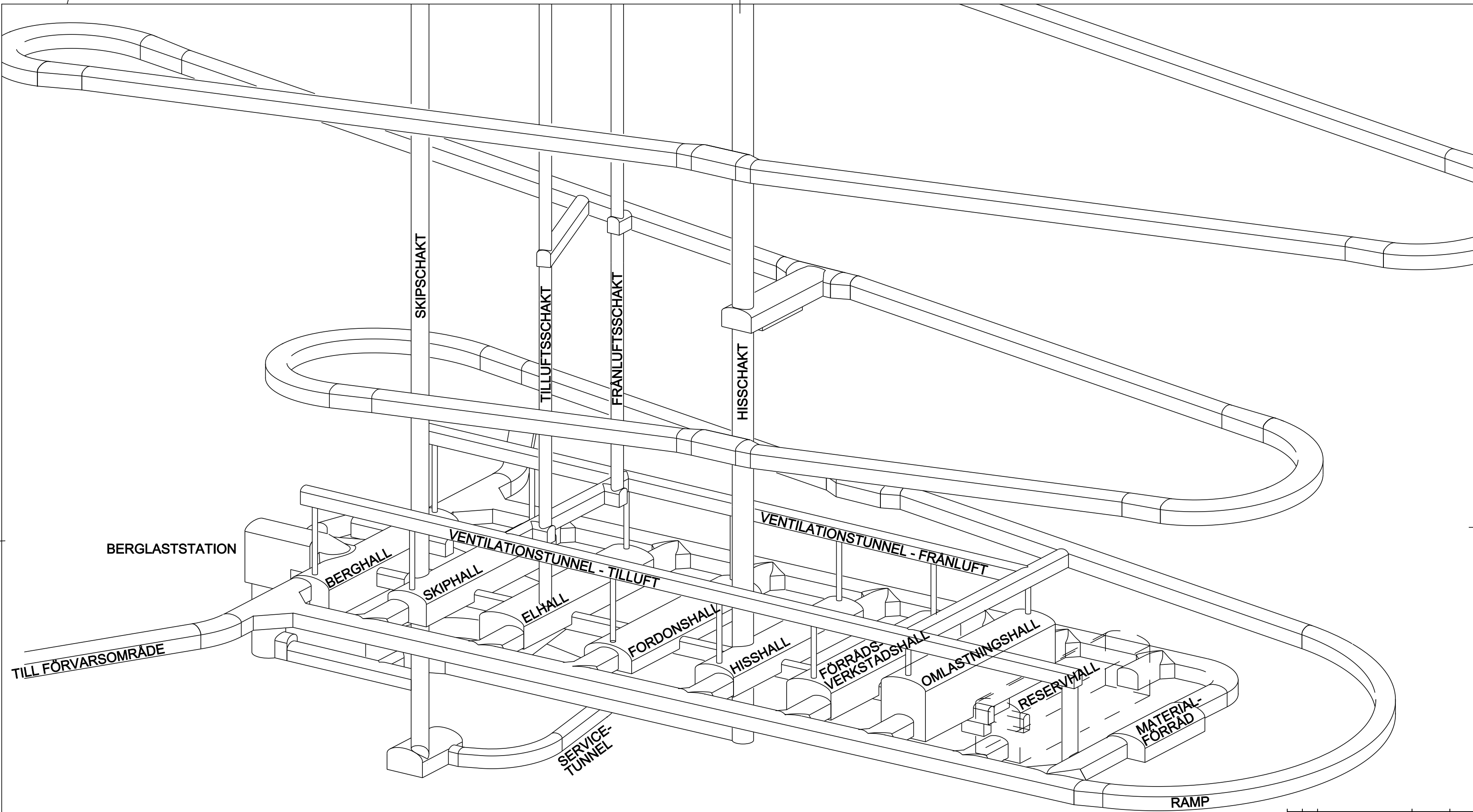
SKB - PROJEKTERING SLUTFÖRVAR

| UPPDRAG NR | RITAD | GRANSKAD |
|---|---|---|
| - | SWECOOS | - |
| DATUM 2009-06-25 | GODKÄND - | |

REFERENSUTFORMNING
RAMP OCH SCHAKT
TUNNEL- OCH SCHAKTPROFILER
MÅTT

| SKALA | NUMMER | BET |
|---|---|---|
| 1 : 200 | 9-C140-R-00-0011 | - |

9_C140R_00_0011.dgn
PLOT:2009-06-25 15:17
REF: 9_140CAB00_0001.dgn




| BET | ANT | ÄNDRINGEN AVSER | DATUM | SIGN |
|---|---|---|---|---|
| - | | - | - | - |

Slutförvar för använt kärnbränsle

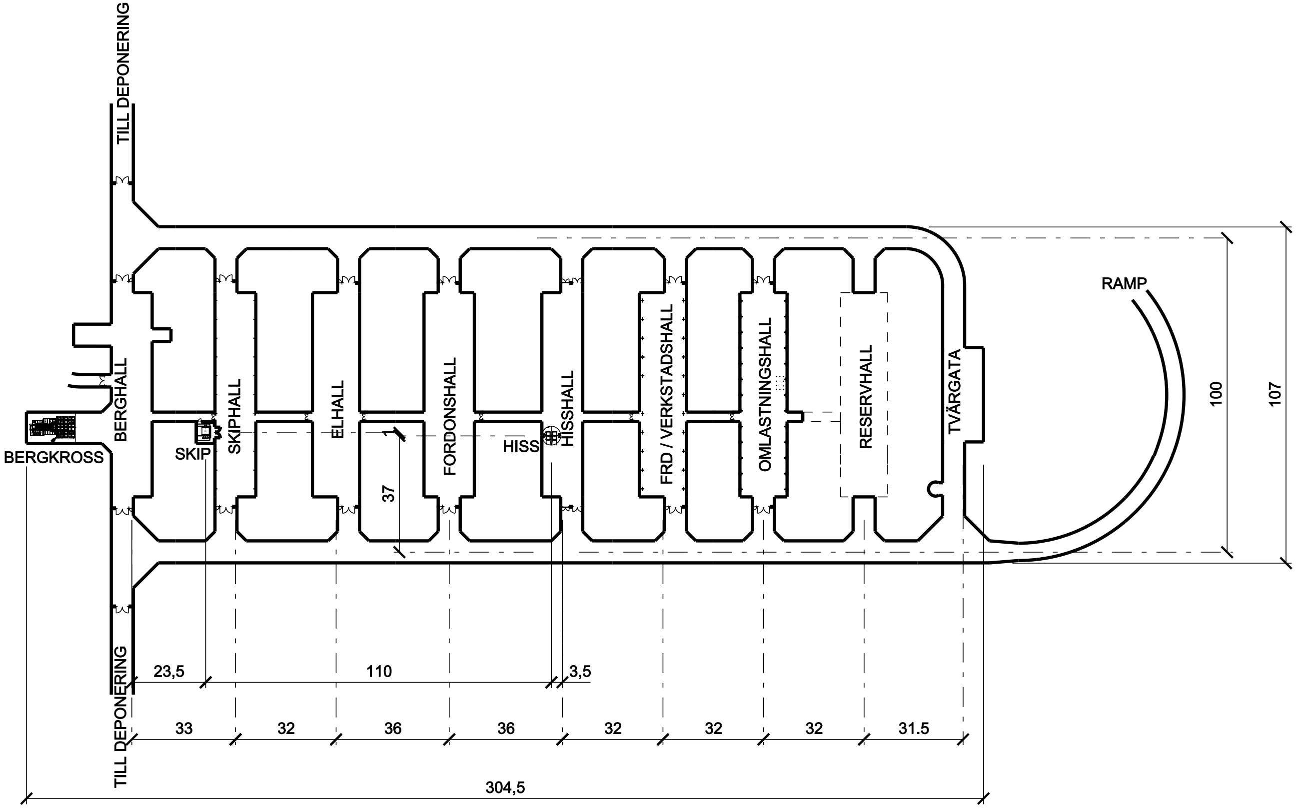
SKB - PROJEKTERING SLUTFÖRVAR

| UPPDRAG NR | RITAD | GRANSKAD |
|---|---|---|
| - | SWECOOS | - |
| DATUM 2009-06-25 | GODKÄND - | |

REFERENSUTFORMNING
CENTRALOMRÅDE
PERSPEKTIV
ÖVERSIKT

| SKALA | NUMMER | BET |
|---|---|---|
| | 9-C130-C-00-0001 | - |

9_C130C_00_0001.dgn
PLOT:2009-06-25 14:53
REF: 9_130CC000_9001.hln




0 50 100m
1:2000

| BET | ANT | ÄNDRINGEN AVSER | DATUM | SIGN |
|---|---|---|---|---|
| - | - | - | - | - |

SKB Slutförvar för använt kärnbränsle

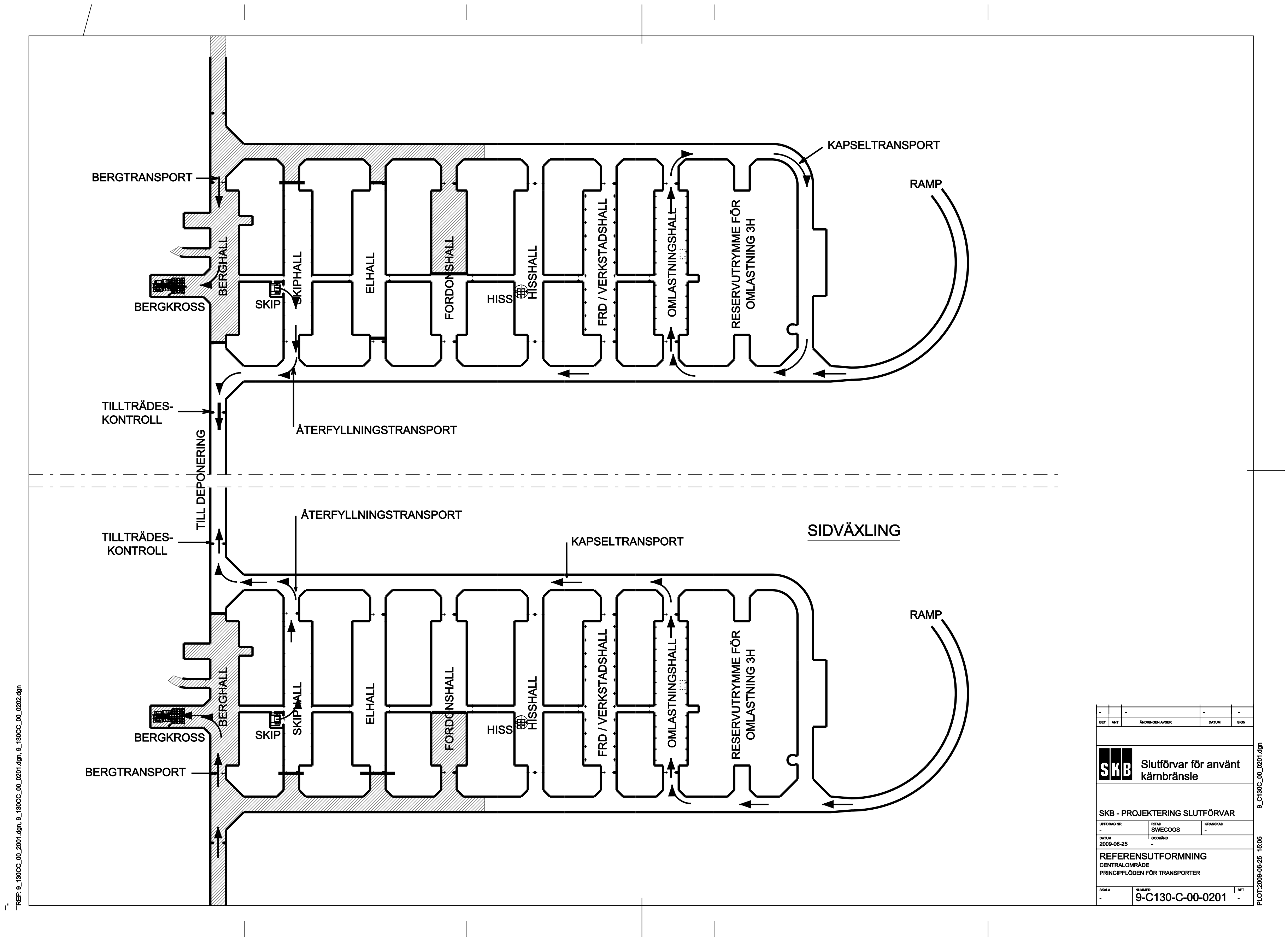
SKB - PROJEKTERING SLUTFÖRVAR

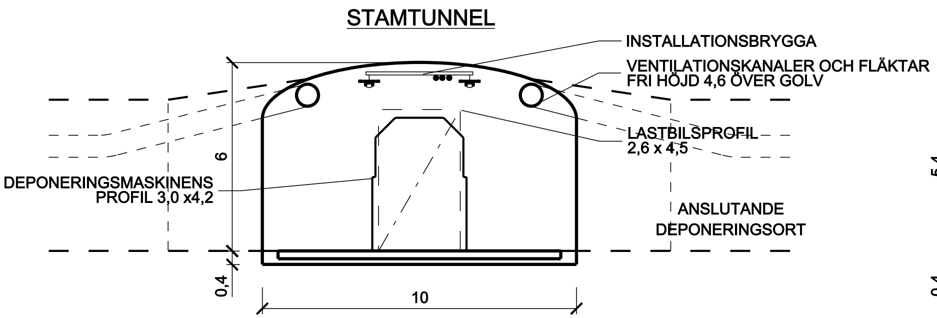
| UPPDRAG NR | RITAD | GRANSKAD |
|---|---|---|
| - | SWECOOS | - |
| DATUM | GODKÄND | |
| 2009-06-25 | - | |

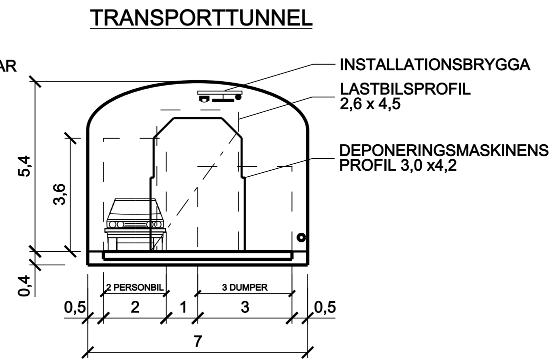
REFERENSUTFORMNING
CENTRALOMRÅDE
PLAN HUVUDNIVÅ
ÖVERSIKT

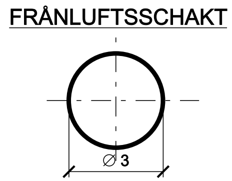
| SKALA | NUMMER | BET |
|---|---|---|
| 1:2000 | 9-C130-C-00-0011 | - |

9_C130C_00_0011.dgn
PLOT:2009-06-25 16:09
REF: 9_130CC_00_2001.dgn


BERGTRANSPORT
KAPSELTRANSPORT
RAMP
BERGHALL
BERGKROSS
SKIP
SKIPHALL
ELHALL
FORDONSHALL
HISS
HISSHALL
FRD / VERKSTADSHALL
OMLASTNINGSHALL
RESERVUTRYMME FÖR OMLASTNING 3H
TILLTRÄDES-KONTROLL
ÅTERFYLLNINGSTRANSPORT
TILL DEPONERING
ÅTERFYLLNINGSTRANSPORT
TILLTRÄDES-KONTROLL
KAPSELTRANSPORT
SIDVÄXLING
RAMP
BERGHALL
BERGKROSS
SKIP
SKIPHALL
ELHALL
FORDONSHALL
HISS
HISSHALL
FRD / VERKSTADSHALL
OMLASTNINGSHALL
RESERVUTRYMME FÖR OMLASTNING 3H
BERGTRANSPORT
Slutförvar för använt kärnbränsle
SKB - PROJEKTERING SLUTFÖRVAR
SWECOOS
2009-06-25
REFERENSUTFORMNING
CENTRALOMRÅDE
PRINCIPFLÖDEN FÖR TRANSPORTER
9-C130-C-00-0201
REF: 9_130CC_00_2001.dgn, 9_130CC_00_0201.dgn, 9_130CC_00_0202.dgn
9_C130C_00_0201.dgn
PLOT:2009-06-25 15:05




0 5 10m
1:200

| BET | ANT | ÄNDRINGEN AVSER | DATUM | SIGN |
|---|---|---|---|---|
| - | | - | - | - |

**SKB** Slutförvar för använt kärnbränsle

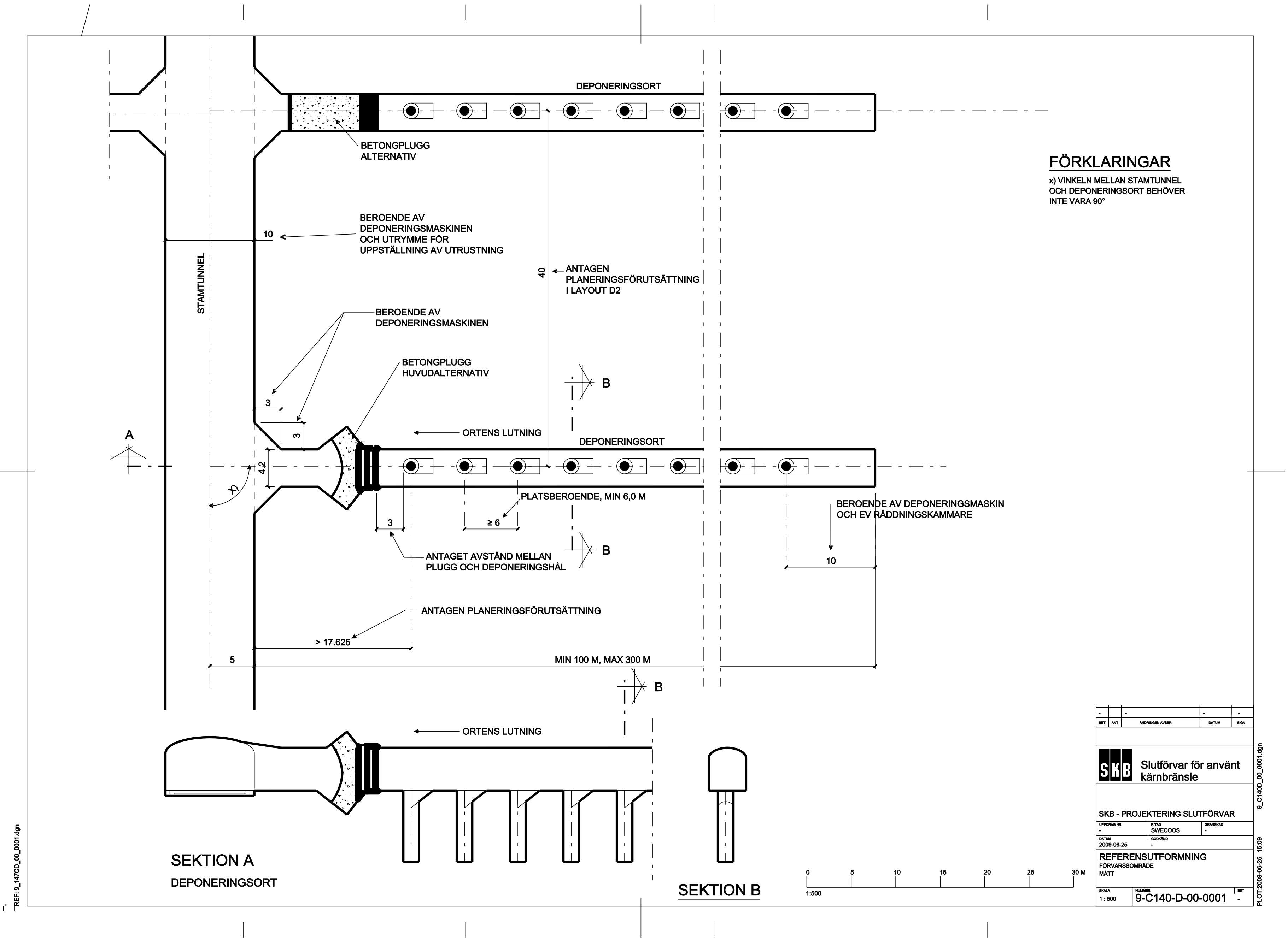
SKB - PROJEKTERING SLUTFÖRVAR

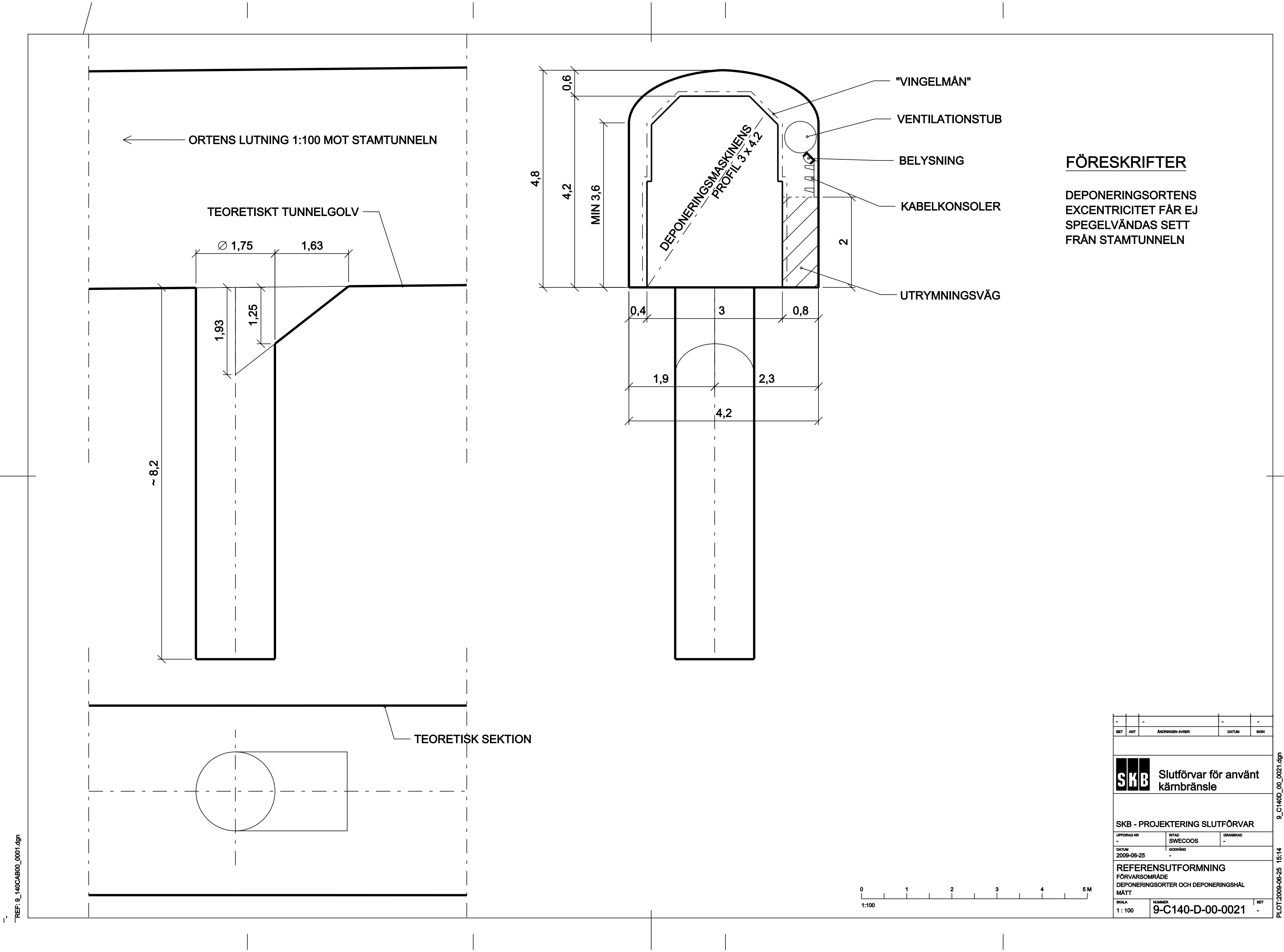
| UPPDRAG NR | RITAD | GRANSKAD |
|---|---|---|
| - | SWECOOS | - |
| DATUM 2009-06-25 | GODKÄND - | |

**REFERENSUTFORMNING**
FÖRVARSOMRÅDE
PROFILER AV TUNNLAR OCH SCHAKT

| SKALA | NUMMER | BET |
|---|---|---|
| 1 : 200 | 9-C140-D-00-0011 | - |

9_C140D_00_0011.dgn
PLOT:2009-06-25 15:12
REF: 9_140CAB00_0001.dgn


DEPONERINGSORT
BETONGPLUGG ALTERNATIV
FÖRKLARINGAR
x) VINKELN MELLAN STAMTUNNEL OCH DEPONERINGSORT BEHÖVER INTE VARA 90°
BEROENDE AV DEPONERINGSMASKINEN OCH UTRYMME FÖR UPPSTÄLLNING AV UTRUSTNING
10
STAMTUNNEL
40
ANTAGEN PLANERINGSFÖRUTSÄTTNING I LAYOUT D2
BEROENDE AV DEPONERINGSMASKINEN
BETONGPLUGG HUVUDALTERNATIV
B
3
3
A
ORTENS LUTNING
DEPONERINGSORT
4.2
x
PLATSBEROENDE, MIN 6,0 M
3
≥ 6
BEROENDE AV DEPONERINGSMASKIN OCH EV RÄDDNINGSKAMMARE
B
ANTAGET AVSTÅND MELLAN PLUGG OCH DEPONERINGSHÅL
10
ANTAGEN PLANERINGSFÖRUTSÄTTNING
> 17.625
5
MIN 100 M, MAX 300 M
B
ORTENS LUTNING
SEKTION A
DEPONERINGSORT
SEKTION B
0 5 10 15 20 25 30 M
1:500
Slutförvar för använt kärnbränsle
SKB - PROJEKTERING SLUTFÖRVAR
SWECOOS
2009-06-25
REFERENSUTFORMNING
FÖRVARSOMRÅDE
MÅTT
1 : 500
9-C140-D-00-0001
9_C140D_00_0001.dgn
PLOT:2009-06-25 15:09
REF: 9_147CD_00_0001.dgn


ORTENS LUTNING 1:100 MOT STAMTUNNELN
TEORETISKT TUNNELGOLV
∅ 1,75
1,63
1,93
1,25
~ 8,2
TEORETISK SEKTION
0,6
4,8
4,2
MIN 3,6
DEPONERINGSMASKINENS PROFIL 3 x 4.2
"VINGELMÅN"
VENTILATIONSTUB
BELYSNING
KABELKONSOLER
2
UTRYMNINGSVÄG
0,4
3
0,8
1,9
2,3
4,2
FÖRESKRIFTER
DEPONERINGSORTENS EXCENTRICITET FÅR EJ SPEGELVÄNDAS SETT FRÅN STAMTUNNELN
0 1 2 3 4 5 M
1:100
BET ANT ÄNDRINGEN AVSER DATUM SIGN
SKB
Slutförvar för använt kärnbränsle
SKB - PROJEKTERING SLUTFÖRVAR
UPPDRAG NR -
RITAD SWECOOS
GRANSKAD -
DATUM 2009-06-25
GODKÄND -
REFERENSUTFORMNING
FÖRVARSOMRÅDE
DEPONERINGSORTER OCH DEPONERINGSHÅL
MÅTT
SKALA 1 : 100
NUMMER 9-C140-D-00-0021
BET -
9_C140D_00_0021.dgn
PLOT:2009-06-25 15:14
REF: 9_140CAB00_0001.dgn