

**Technical Report**

**TR-10-17**

**Design, production and  
initial state of the closure**

Svensk Kärnbränslehantering AB

December 2010

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# Preface

An important part of SKB's licence application for the construction, possession and operation of the KBS-3 repository is the safety report. The safety report addresses both safety during operation of the KBS-3 repository facility (**SR-Operation**), and the long-term safety of the KBS-3 repository (**SR-Site**).

For the construction of the KBS-3 repository SKB has defined a set of production lines:

- the spent nuclear fuel,
- the canister,
- the buffer,
- the backfill,
- the closure, and
- the underground openings.

These production lines are reported in separate *Production reports*, and in addition there is a *Repository production report* presenting the common basis for the reports.

This set of reports addresses design premises, reference design, conformity of the reference design to design premises, production and the initial state, i.e. the results of the production. Thus the reports provide input to **SR-Site** concerning the characteristics of the as built KBS-3 repository and to **SR-Operation** concerning the handling of the engineered barriers and construction of underground openings.

The preparation of the set of reports has been lead and coordinated by Lena Morén with support from Roland Johansson, Karin Pers and Marie Wiborgh.

This report has been authored by David Gunnarsson and Roland Johansson.

## Summary

The report is included in a set of *Production reports*, presenting how the KBS-3 repository is designed, produced and inspected. The production reports are included in the safety report for the KBS-3 repository and repository facility.

The report provides input on the *initial state* of the closure and plugs in underground openings other than deposition tunnels for the assessment of the long-term safety, **SR-Site**. The initial state refers to the properties of the engineered barriers once they have been finally placed in the KBS-3 repository and will not be further handled within the repository facility. In addition, the report provides some input to the operational safety report, **SR-Operation**, on how the closure and plugs shall be handled and installed.

The report presents the design premises and reference designs of the closure and plugs and verifies their conformity to the design premises. It also briefly deals with the production of the closure and plugs. Finally, the initial state of the closure and plugs and their conformity to the reference designs and design premises are presented.

### Design premises for the closure

The design premises are based on regulations; the functions of the KBS-3 repository; the design basis cases from the assessment of the long-term safety; the design basis events from the assessment of the operational safety; technical feasibility and the planned production.

The closure is one of the engineered barriers in the KBS-3 repository. The closure is the material installed in boreholes and underground openings other than deposition tunnels, in order to fill and close them. In the KBS-3 repository the closure shall sustain the multi-barrier principle by preventing the formation of water conductive channels between the repository and the surface and by preventing the backfill in deposition tunnels to expand or to be transported out from the deposition tunnels. The closure shall also keep the closure in underlying or adjacent underground openings in place. In the upper part of the ramp, shafts and boreholes the closure shall significantly obstruct unintentional intrusion into the repository. The hydraulic conductivity of the installed closure is the property that is of most importance for its barrier function. Design premises with respect to the hydraulic conductivity are based on results from assessments of the long-term safety.

The closure plugs have no barrier function in the KBS-3 repository. Their purpose is to provide mechanical restraint and hydraulic control functions. They are needed as long as the underground opening on one side of the plug is unsealed to keep the installed closure material in place. Plugs also contribute to a feasible, safe and secure installation of the closure.

The closure and plugs shall also be designed to conform to design premises related to production and operation of the repository facility. With respect to technical feasibility the closure impose design premises for the main- and transport tunnels and for the lower part of ramp and shafts.

### The reference design of the closure and its conformity to the design premises

The closure in main tunnels, transport tunnels and in the lower part of the ramp and shafts has the same conceptual design as the backfill in deposition tunnels. In practice, neither the material composition nor the installed density needs to be the same. In main tunnels and transport tunnels there is no need to prevent buffer expansion and the acceptable hydraulic conductivity is larger than in deposition tunnels. Nevertheless, the same material as for the backfill in deposition tunnels is selected at this stage of development, and the verifying analyses presented for the backfill are considered relevant to support the conformity of the closure reference design to the design premises.

The only function of the closure of the cavities in the central area is to occupy the space with no other design premise than to prevent substantial convergence and subsidence of the surrounding rock. With respect to this the reference design is compacted crushed rock.

In the upper part of the ramp and shafts the closure shall significantly obstruct unintentional intrusion into the repository. To meet this requirement effectively compacted rock fill is chosen as reference design. In the uppermost 50 m of the ramp and shafts very coarse crushed rock is used for the closure.

Comprehensive experience of placement and compaction of rock fill is available from road construction, from the construction of hydro power dams and also from SKB's experiments at Äspö HRL.

Investigation boreholes going deeper than the top sealing have to be sealed. The reference design is highly compacted bentonite in perforated copper tubes. The assessment of the conformity to the design premises is based on results from many years of RD&D work.

### **The production of the closure**

Closure of the repository will, with the exception of some boreholes that have to be sealed earlier, not take place until all spent nuclear fuel has been deposited. This means that the closure activities lie well in the future. It also means that the production and installation of the closure will be based on comprehensive experience from the production and installation of backfill and plug in deposition tunnels.

### **The initial state of the closure**

The initial state of the closure is the state when all closure material in a specific underground opening or borehole is installed and the borehole, rock cavity, shaft or tunnel has been closed. The initial state will depend on the composition of the closure material, the dimensions and density of the installed closure components, the portions of the rock cavity, shaft or tunnel filled with blocks and pellets or rock fill as well as on the dimensions of the rock cavity. For underground openings that shall be filled with compacted clay blocks and pellets the estimations are based on results presented for backfill in deposition tunnels. For closure of the other underground openings and for boreholes the initial state is given by reasonable values of parameters that has been estimated based on results from experiments and tests or proven experience.

# Sammanfattning

Rapporten ingår i en grupp av *Produktionsrapporter* som redovisar hur KBS-3-förvaret är utformat samt hur det ska produceras och kontrolleras. Produktionsrapporterna ingår i säkerhetsredovisningen för KBS-3-förvaret och försvarsanläggningen.

Rapporten redovisar indata om *initialtillståndet* för förslutningen, inklusive pluggar, i alla bergutrymmen utom deponeringstunnlar för analysen av långsiktig säkerhet, **SR-Site**. Initialtillståndet avser egenskaperna hos de tekniska barriärerna då de slutligt satts på plats i slutförvaret och inte hanteras ytterligare inom slutförvarsanläggningen. Dessutom ger rapporten viss information till driftsäkerhetsredovisningen, **SR-Drift**, om hur förslutningen och pluggar ska hanteras och installeras.

Rapporten redovisar konstruktionsförutsättningar och referensutförningar för förslutning och pluggar och verifierar deras överensstämmelse med konstruktionsförutsättningarna. Den behandlar också kortfattat produktion av förslutning och pluggar. Vidare redovisas initialtillståndet för förslutning och pluggar och deras överensstämmelse med referensutförning och konstruktionsförutsättningar.

## Konstruktionsförutsättningar för förslutning och pluggar

Konstruktionsförutsättningarna är baserade på föreskrifter, KBS-3-förvarets funktioner, konstruktionsstyrande fall från analysen av långsiktig säkerhet, konstruktionsstyrande händelser från redovisningen av driftsäkerhet, teknisk genomförbarhet och den planerade produktionen.

Förslutningen är en av de tekniska barriärerna i KBS-3-förvaret. Förslutningen utgörs av det material som installeras i borrhål och alla bergutrymmen utom deponeringstunnlar. I KBS-3-förvaret ska förslutning och pluggar upprätthålla flerbarriärprincipen genom att hindra att det bildas konduktiva vattenvägar mellan försvarsområdet och markytan samt hindra att återfyllningen expanderar ut ur i deponeringstunnlarna. Förslutningen ska också hålla förslutningen i de bergutrymmen som ligger intill och nedanför på plats. I den övre delen av ramp och schakt ska förslutningen avsevärt försvåra oavsiktligt intrång i förvaret. Den installerade förslutningens hydrauliska konduktivitet är den egenskap som har störst betydelse för dess barriärfunktion. Angivna konstruktionsförutsättningar med avseende på hydraulisk konduktivitet baseras på resultat från analyser av den långsiktiga säkerheten.

Pluggar som ingår i förslutningen har ingen barriärfunktion i KBS-3-förvaret. Deras uppgift är att underlätta installation av förslutningen genom att hålla redan installerat material på plats och att begränsa inflödet av vatten. Pluggarna ska också bidra till att installationen av förslutningen kan genomföras på ett säkert sätt.

Förslutning och pluggar ska även utformas så att konstruktionsförutsättningar med hänsyn till produktion och drift av försvarsanläggningen uppfylls. Med hänsyn till teknisk genomförbarhet ger förslutning och pluggar konstruktionsförutsättningar för utförande av stam- och transporttunnlar samt nedre delen av ramp och schakt.

## Referensutförning för förslutning och pluggar och överensstämmelse med konstruktionsförutsättningarna

Förslutningen i stam- och transporttunnlar samt nedre delen av ramp och schakt har i princip samma utförning som återfyllningen i deponeringstunnlar. I praktiken behöver varken materialsammansättningen eller den installerade densiteten vara densamma. I stam- och transporttunnlar finns inget krav med hänsyn till att bufferten sväller och tillåtet värde för hydraulisk konduktivitet är högre än i deponeringstunnlar. I avvaktan på resultat från utvecklingsarbete specifikt för förslutningen har samma material valts som för återfyllningen i deponeringstunnlar. Detta betyder att de verifierande analyser som redovisas för återfyllningen bedöms vara relevanta och att referensutförningen för förslutningen således överensstämmer med konstruktionsförutsättningarna.

I centralområdet har förslutningen ingen annan funktion än att fylla ut bergutrymmena så att de inte deformeras. För att klara detta har förslutning med kompakterad bergkross valts som referensutformning.

I övre delen av ramp och schakt ska förslutningen avsevärt försvåra oavsiktligt intrång i förvaret. För att möta detta krav har välkompakterat bergmaterial valts som referensutformning. I den allra översta delen av ramp och schakt utförs förslutningen med grovt krossmaterial.

Omfattande erfarenheter av utläggning och kompaktering av bergkross finns från vägbyggen, bygge av vattenkraftdammar och även från SKB:s experiment vid Äspölaboratoriet.

Undersökningsborrhål som går djupare än toppförslutningen ska förslutas. Referensutformning är högkompakterad bentonit i perforerade kopparrör. Erfarenheter och resultat från många års forskning och utveckling visar att denna utformning uppfyller konstruktionsförutsättningarna.

### **Produktionen av förslutning och pluggar**

Med undantag för vissa undersökningsborrhål kommer förslutning av förvaret inte att påbörjas förrän allt använt kärnbränsle har deponerats. Detta innebär att utförandet av förslutningen ligger långt in i framtiden. Det betyder också att produktion och installation av förslutningen kommer att kunna baseras på omfattande erfarenheter från produktion och installation av återfyllning och pluggar i deponeringstunnlarna.

### **Förslutningens initialtillstånd**

Förslutningens initialtillstånd är tillståndet när borrhål och alla bergutrymmen har förslutits. Initialtillståndet kommer att bero av förslutningsmaterialets sammansättning, dimensioner och densitet på de installerade förslutningskomponenterna, hur stor del av bergutrymmena som fyllts med block och pelletar alternativt bergmaterial samt måtten på bergutrymmena. För de bergutrymmen som försluts med block och pelletar baseras bedömningen av initialtillståndet på resultat som redovisats för återfyllning i deponeringstunnlar. För förslutning av övriga bergutrymmen samt av borrhål redovisas initialtillståndet som rimliga parametervärden som har bedömts med ledning av resultat från experiment alternativt beprövad erfarenhet.

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# 1 Introduction

## 1.1 General basis

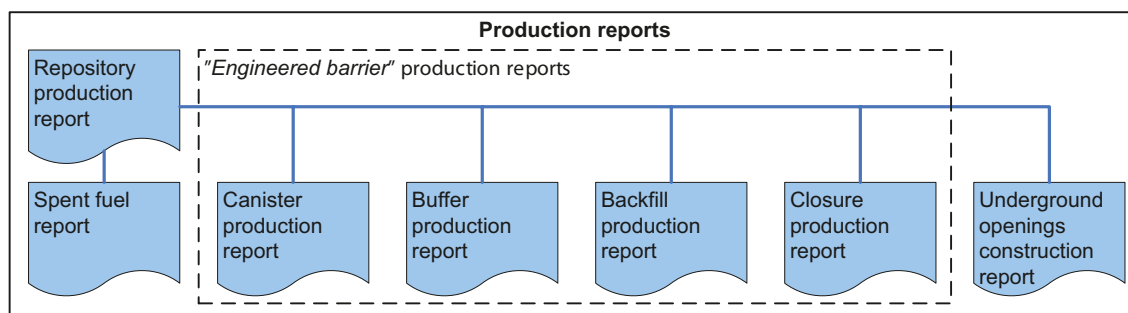
### 1.1.1 This report

This report presents the reference design, production and initial state of the closure in underground openings other than deposition tunnels in the KBS-3 repository for spent nuclear fuel. It is included in a set of reports presenting how the KBS-3 repository is designed, produced and inspected. The set of reports is denominated *Production reports*. The Production reports and their short names are illustrated in Figure 1-1. The reports within the set referred to in this report and their full names are presented in Table 1-1.

This report is part of the safety report for the KBS-3 repository and repository facility, see **Repository production report**, Section 1.2. It is based on the results and review of the most recent long-term safety assessment and on the current knowledge and technology and results from research and development.

### 1.1.2 The design of the closure and plugs

The presented designs of the closure and plugs presumes a repository based on the KBS-3 method with vertical deposition of canisters in individual deposition holes as further described in Chapter 3 in the **Repository production report**.



**Figure 1-1.** The reports included in the set of reports describing how the KBS-3 repository is designed, produced and inspected.

**Table 1-1.** The reports within the set of Production reports referred to in this report.

Full title	Short name used within the Production reports	Text in reference lists
Design and production of the KBS-3 repository	Repository production report	<b>Repository production report, 2010.</b> Design and production of the KBS-3 repository. SKB TR-10-12, Svensk Kärnbränslehantering AB.
Design, production and initial state of the buffer	Buffer production report <sup>1</sup>	<b>Buffer production report, 2010.</b> Design, production and initial state of the buffer. SKB TR-10-15, Svensk Kärnbränslehantering AB.
Design, production and initial state of the backfill and plug in deposition tunnels	Backfill production report <sup>1</sup>	<b>Backfill production report, 2010.</b> Design, production and initial state of the backfill and plug in deposition tunnels. SKB TR-10-16, Svensk Kärnbränslehantering AB.
Design, construction and initial state of the underground openings	Underground openings construction report	<b>Underground openings construction report, 2010.</b> Design, construction and initial state of the underground openings. SKB TR-10-18, Svensk Kärnbränslehantering AB.

<sup>1</sup> Commonly referred to as the “Engineered barrier” production reports.

The reference design of the closure and plugs and the reference methods to produce them presented in this report constitutes solutions that are technically feasible. It is, however, foreseen that the design premises, the designs as well as the presented methods for production, test and inspection will be further developed and optimised before actual construction of the KBS-3 repository facility commences. This particularly concerns properties of the closure and plugs that require detailed information on the conditions at repository depth. In this context it should be mentioned that there are alternative designs that conform to the design premises as well as alternative ways to produce the reference design. In addition, the safety assessment **SR-Site**, as well as future safety assessments, may result in up-dated design premises. SKB's objective is to continuously develop and improve both design and production and adapt them to the conditions at the selected site.

### 1.1.3 The production of the closure and plugs

The presented production of the closure and plugs in underground openings other than deposition tunnels is based on that there is a system, the KBS-3 system, comprising the facilities required to manage the spent nuclear fuel and finally deposit it in a KBS-3 repository. The KBS-3 system and its facilities etc are presented in Chapter 4 in the **Repository production report**.

The installation of the closure and plugs in underground openings other than deposition tunnels is part of the decommissioning of the KBS-3 repository facility, and commences when the decommissioning phase of the KBS-3 system and its facilities is initiated.

## 1.2 Purpose, objectives and limitations

### 1.2.1 Purpose

The purpose of this report is to describe how the closure and plugs in underground openings other than deposition tunnels are designed, constructed and inspected in a manner related to their importance for the safety of the KBS-3 repository. The report shall provide the information on the design, production and initial state of the closure and plugs in underground openings other than deposition tunnels required for the long-term safety report, **SR-Site**, as well the information on how to produce and inspect the closure and plugs required for the safe decommissioning of the KBS-3 repository facility.

With this report SKB intends to present the design premises for the closure and plugs in the KBS-3 repository and demonstrate how they can be designed and produced to conform to the stated design premises. The report shall present the reference designs and production methods and summarise the research and development efforts that supports that the closure and plugs in underground openings other than deposition tunnels can be produced in conformity to the design premises.

### 1.2.2 Objectives

Based on the above purpose the objectives of this report are to present:

- the design premises for the closure and plugs,
- the reference design of the closure and plugs,
- the conformity of the reference design to the design premises,
- the planned production,
- the initial state of the closure and plugs, i.e. the expected result of the production comprising as built data on the properties taken credit for as contributing to, or affecting, the barrier functions and safety.

### 1.2.3 Limitations

The **Closure production report** primarily includes design premises related to the long-term safety of the KBS-3 repository. The presented reference design must conform to these design premises and consequently they have in most cases determined the design. Design premises related to other aspects than safety and radiation protection are only included if they have determined the design of the closure and plugs or the methods to produce them.

The **Closure production report** also includes the design considerations taken with respect to the application of best available technique with regard to safety and radiation protection, and the related design premises for the design and development of methods to produce the closure and plugs. Motivations for the presented reference designs and methods as being the best available are reported elsewhere.

### 1.3 Interfaces to other reports included in the safety report

The role of the Production reports in the safety report is presented in Section 1.2 in the **Repository production report**. A summary of the interfaces to other reports included in the safety report is given below.

#### 1.3.1 The safety report for the long-term safety

By providing a basic understanding of the repository performance on different time-periods and by the identification of scenarios that can be shown to be especially important from the standpoint of risk the long-term safety assessment provides feedback to the design of the engineered barriers and underground openings. The methodology used for deriving design premises from the long-term safety assessment is introduced in the **Repository production report**, Section 2.5.2. A more thorough description as well as the resulting design premises are given in the report “Design premises for a KBS-3V repository based on results from the safety assessment SR-Can and some subsequent analyses” /SKB 2009a/, hereinafter referred to as **Design premises long-term safety**. These design premises constitute a basic input to the design of the closure and plugs in underground openings other than deposition tunnels.

As stated in Section 1.2 this report shall provide information on the initial state of the closure and plugs in underground openings other than deposition tunnels for the long-term safety assessment. This report shall also provide data concerning the design of the closure and plugs, and the initial state used in the calculations included in the long-term safety assessment.

#### 1.3.2 The safety report for the operational safety

The production of the closure and plugs in underground openings other than deposition tunnels is part of the decommissioning of the final repository facility. Consequently, this report has no interfaces to the report for the operational safety. However, it provides information on the design of the closure and plugs and the technical systems used to manufacture, handle, install, test and inspect them for the safe decommissioning of the repository facility.

#### 1.3.3 The other production reports

The **Repository production report** presents the context of the set of Production reports and their role within the safety report. It also includes definitions of some central concepts of importance for the understanding of the Production reports.

The **Repository production report** sets out the laws and regulations and demands from the nuclear power plant owners applicable to the design of a final repository for spent nuclear fuel. In addition, it describes the functions of a KBS-3 repository and how safety is provided by the barriers and their barrier functions. The report goes on to describe how design premises are derived from laws and regulations, owner demands and the iterative processes of design and safety assessment and design and technique development respectively. The starting point for the design premises presented in this report is the barrier functions and design considerations introduced in the **Repository production report**, Chapter 3.

The design and production of the different engineered barriers and underground openings are inter-related. An overview of the design and production interfaces is provided in the **Repository production report**, Chapter 4. The design premises imposed by the closure and plugs on the design and production of the other engineered barriers and underground openings are presented in this report. These design premises are repeated and verified in the production reports for the engineered barriers and underground openings on which the closure and plugs impose design premises.

## 1.4 Structure and content

### 1.4.1 Overview

The general flow of information in the **Closure production report** can be described as follows:

- design premises,
- reference design,
- conformity of the reference design to the design premises,
- production,
- initial state.

The listed bullets are further described in the following sections. In addition, the context of the report is presented in this chapter.

### 1.4.2 Design premises

The design premises set out the information required for the design. The design premises for the closure and plugs in underground openings other than deposition tunnels are presented in Chapter 2 of this report. The chapter starts with the definition of the closure and plugs, their purpose and basic design. After that follows a presentation of the barrier functions the closure shall provide, and the functions the plugs shall provide to contribute to the safety of the final repository and the considerations that shall be made in the design with respect to the application of a well-tested and reliable technique. Finally, the detailed design premises for the closure and plugs are given. They state the properties the reference design shall have to maintain the functions and to conform to the design considerations.

### 1.4.3 Reference design

The descriptions of the reference designs comprise the closure and plug materials and components and the installed closure and plugs. The reference designs are presented in Chapter 3. The reference designs are specified by a set of variables denominated *design parameters*, e.g. montmorillonite content and block bulk density. The design parameters shall be inspected in the production and acceptable values for them are given for the reference designs. The design premises and considerations that have determined the design parameters are presented.

### 1.4.4 Conformity of the reference design to the design premises

An important part of this report is the analyses verifying the conformity of the reference design to the design premises. The conformity to each of the design premises given as feedback from the long-term safety assessment as well as the design premises related to technical feasibility, production and operation is analysed and concluded.

### 1.4.5 Production of the closure and plugs

The presentation of the production of the closure and plugs comprise an overview of:

- the main parts and different stages of the production,
- short descriptions of methods for production, test and inspection.

### 1.4.6 Initial state of the closure and plugs

In Chapter 5, the initial state chapter, the expected values of the design parameters, and other parameters required for the assessment of the long-term safety, at the initial state are presented. The expected values are based on the current experiences from the production trials, and they are discussed and justified with respect to the currently available results presented in Chapter 4. Finally, the conformity of the closure and plugs at the initial state to the design premises stated in **Design premises long-term safety** is summarised.

## 2 Design premises for the closure

In this chapter the design premises for the closure are presented. They comprise the barrier functions and properties the closure shall sustain in the KBS-3 repository and premises for the design. *The required functions and design premises are written in italics.*

### 2.1 General basis

#### 2.1.1 Identification and documentation of requirements and design premises

The methodology to derive, review and document design premises is presented in the **Repository production report** Chapter 2. The design premises are based on:

- international treaties, national laws and regulations,
- the functions of the KBS-3 repository,
- the safety assessment,
- technical feasibility,
- the planned production.

The **Repository production report**, Section 2.2 includes a presentation of the laws and regulations applicable for the design of a final repository for spent nuclear fuel. Based on the treaties, laws and regulations SKB has substantiated functions and considerations as a specification of the KBS-3 repository, and as guidelines for the design of its engineered barriers and underground openings. In Section 3.6.2 of the **Repository production report** the barrier functions and properties the closure shall sustain in order to contribute to the functions of the KBS-3 repository are presented. The functions of the plugs are presented in Section 3.8.2 of the **Repository production report**. Section 3.9 of the **Repository production report** introduces the design considerations to be applied in the design work. The presented barrier functions of the closure, the functions of the plugs and the considerations that shall be applied in the design work are repeated in Section 2.2 in this report.

The design premises related to the barrier functions of the closure in the KBS-3 repository are based on the results from the latest performed long-term safety assessment and some subsequent analyses. These design premises for the closure are provided in **Design premises long-term safety**, and are presented in Section 2.3.1 in this report. Corresponding design premises for the plugs are presented in Section 2.5.

Design premises related to technical feasibility refer to the properties the closure and plugs shall have to fit, and work, together with the engineered barriers and other parts of the final repository during the production. The general approach to substantiate this kind of design premises is presented in Section 2.5.1 in the **Repository production report** and the interfaces to the engineered barriers and other parts in the production are summarised in Sections 4.7.2 and 4.8.2 in the **Repository production report**. In this report, these design premises are presented in Section 2.3.2 for the closure and in Section 2.5 for the plugs. In Sections 2.4 and 2.6 the design premises the closure and plugs impose on other parts of the KBS-3 repository are presented.

Finally, design premises related to the operation of the KBS 3 repository facility and the production of the closure and plugs are presented in Sections 2.3.3 and 2.5 in this report for the closure and plugs respectively. The methodology to substantiate these kinds of design premises is presented in Section 2.5.4 in the **Repository production report**.

### 2.1.2 Definition, purpose and basic design of the closure

The closure is one of the engineered barriers in the KBS-3 repository. The closure is the material installed in boreholes and underground openings other than deposition tunnels, in order to fill and close them. The purpose and function of the closure is to considerably obstruct unintentional intrusion into the final repository and to restrict groundwater flow through the underground openings.

The closure of the final repository includes the filling and sealing of main tunnels, transport tunnels, the rock cavities of the central area, the ramp and shafts for transport and ventilation. It also includes sealing of investigation boreholes from the surface and from underground openings in the final repository.

The design premises for the closure in underground openings where the flow of water shall be restricted are based on the use of compacted bentonite clay blocks and pellets. In underground openings where there are no restrictions on flow of water the design premises for the closure are based on that it consists of rock material, and that the material will be compacted at site in the underground opening.

### 2.1.3 Definition, purpose and basic design of the plugs

The plugs have no barrier function in the KBS-3 repository. The purpose of the plugs is to provide mechanical restraint and hydraulic control functions. Plugs are needed as long as the underground opening on one side of the plug is unsealed to keep the installed closure material in place. Plugs also contribute to a feasible, safe and secure installation of the closure.

The design premises for the plugs are based on the use of concrete providing the required strength, and that the concrete is complemented with clay and/or permeable material parts for tightening and drainage.

## 2.2 Barrier functions and design considerations

In this section the barrier functions of the closure, the functions of the plugs and the design considerations for the closure and plugs are presented. They are based on the functions of the KBS-3 repository presented in Section 3.1.2 in the **Repository production report** and have been divided into:

- barrier functions and properties the closure shall sustain in order for the final repository to maintain its safety (Section 2.2.1),
- functions and properties the plugs shall sustain (Section 2.2.2),
- issues that shall be considered when developing the design of closure and plugs and methods for manufacturing, preparation, installation, test and inspection (Section 2.2.3).

### 2.2.1 Barrier functions of the closure in the KBS-3 repository

In order for the KBS-3 repository to maintain the multi-barrier principle and have several barriers which individually and together contribute to maintain the barrier functions the closure shall:

- *prevent that water conductive channels, that may jeopardise the barrier functions of the rock, are formed between the repository and the surface,*
- *not significantly impair the barrier functions of other barriers.*

To maintain the multi-barrier principle the closure in different underground openings shall have the following barrier functions.

- *The closure in main tunnels shall prevent that the backfill in deposition tunnels swells/expands or is transported out from the deposition tunnels.*
- *The closure shall keep the closure in underlying or adjacent underground openings in place.*



In the design of the KBS-3 repository, unintentional intrusion shall be considered so that the repository site after closure of the repository facility can be utilised without compromising the freedom of action, needs and aspirations of future generations. From this follows that:

- *The closure in the upper part of the ramp, shafts and boreholes shall significantly obstruct unintentional intrusion into the repository.*

For the final repository to provide protection against harmful effects of radiation as long as required regarding the radiotoxicity of the spent nuclear fuel and to withstand events and processes that can affect the post-closure performance the closure shall:

- *be long-term durable and maintain its barrier functions in the environment expected in the final repository.*

### **2.2.2 Functions and properties of plugs in the KBS-3 repository and repository facility**

In order for the barrier system of the final repository to withstand conditions, events and processes that may impact their functions, plugs shall:

- *withstand prevailing hydrostatic pressure at any location where a plug is installed,*
- *limit water flow past the plug until the adjacent rock cavity (tunnel, ramp, shaft etc) is filled and saturated,*
- *be durable and maintain its functions until the closure in the underground opening in question is saturated.*

In the long-term perspective in the final repository, in order for the repository to maintain the multi-barrier principle, the plugs must:

- *not significantly impair the barrier functions of the engineered barriers or rock.*

These functions and properties shall be secured and maintained during different periods of the lifetime of the plugs, see further Section 2.4.

### **2.2.3 Design considerations**

This section presents the design considerations that shall be regarded in the design of the closure and plugs and in the development of methods to manufacture, install, test and inspect them and their components. When a reference design is determined it, together with the design considerations, forms the basis for the detailed requirements on methods to manufacture, prepare, install and inspect the closure and plugs.

The system of barriers and barrier functions of the final repository shall withstand failures and conditions, events and processes that may impact their functions. Hence, the following shall be considered.

- *The designs of the closure and plugs and methods for preparation, installation, test and inspection shall be based on proven or well-tried techniques.*

The construction, manufacturing, installation and non-destructive tests of the barriers of the final repository to be dependable, and the following shall be considered.

- *Closure and plugs with specified properties shall be possible to prepare and install with high reliability.*
- *The properties of the closure and plugs shall be possible to test and inspect against specified acceptance criteria.*

A reliable production is also required with respect to SKB's objective to achieve high quality and cost-effectiveness. Regarding cost-effectiveness the following shall be considered.

- *The closure and plug designs and methods for preparation, installation, test and inspection shall be cost-effective.*
- *Closure and plug installation shall be possible to perform at the prescribed rate.*



Further environmental impact such as noise and vibrations, emissions to air and water, impact on groundwater and consumption of material and energy shall be considered in the design. Methods to prepare and install the closure and plugs must also conform to the regulations for working environment and industrial safety. Design premises related to these aspects can generally be met in alternative ways for designs of closure and plugs that comply with the safety and radiation protection design premises. Together with design considerations related to efficiency and flexibility they are of importance for the design of technical equipment used in the production of the closure and plugs. The design of the technical equipment is not discussed in this report.

## 2.3 Design premises for the closure

In this section the design premises for the closure are given. They constitute a specification for the design of the closure. The design premises comprise the properties and parameters to be designed and premises such as quantitative information on features, performance, events, loads, stresses, combinations of loads and stresses and other information, e.g. regarding environment or adjacent systems, which form a necessary basis for the design.

The design premises are relating to the barrier functions presented in Section 2.2.1 and to the design considerations presented in Section 2.2.3. The design premises are also based on, and constitute a concise summary of, the current results of the design process and feedback from technology development and safety assessment iterations, see Section 2.5.1 in the **Repository production report**.

The design premises given as feedback from the long-term safety assessment are compiled in **Design premises long-term safety**.

The design premises from other engineered barriers given as feedback from the technical development are based on the reference designs of the other parts of the KBS-3 repository. The design premises related to the production and operation are preliminary at this stage of development.

### 2.3.1 Design premises related to the barrier functions in the KBS-3 repository

The design premises related to the barrier functions in the KBS-3 repository are compiled in Table 2-1. In the leftmost column of the table the barrier functions which form the basis for design premises and that were presented in Section 2.2.1 are repeated; the middle column contains the closure properties and design parameters to be designed and in the rightmost column the design premises as stated in **Design premises long-term safety** are given.

**Table 2-1. Barrier functions, properties and parameters to be designed and design premises for the closure.**

Barrier function	Part of closure, property and design parameters to be designed	Design premises long-term safety
<i>The closure shall prevent that water conductive channels, that may jeopardise the barrier functions of the rock, are formed between the repository and the surface.</i>	<p>Closure in ramp, shafts and tunnels other than deposition tunnels below the level of the top sealing<sup>1</sup>.</p> <p>Properties that affect swelling pressure and hydraulic conductivity of the saturated closure.</p> <p>Material composition: <i>Montmorillonite content.</i></p> <p>Installed density: <i>The dry density and water content of blocks, pellet filling and bottom bed, the portions of the tunnel, shaft etc filled with blocks, pellet filling and bottom bed.</i></p>	<p><i>Below the location of the top sealing, the integrated effective connected hydraulic conductivity of the backfill in tunnels, ramp and shafts and the EDZ surrounding them must be less than <math>10^{-8}</math> m/s. This value need not be upheld in sections where e.g. the tunnel or ramp passes highly transmissive zones.</i></p>
	<p>Closure in the cavities of the central area.</p> <p>—</p>	<p><i>There is no restriction on the hydraulic conductivity in the central area.</i></p>
	<p>Closure in the top sealing (i.e. in the part of the ramp and shafts close to the surface).</p> <p>—</p>	<p><i>The top sealing has no demands on hydraulic conductivity.</i></p> <p><i>The depth of the top sealing can be adapted to the expected depth of permafrost during the assessment period, but must not be deeper than 100 m above repository depth.</i></p>
	<p>Boreholes (connected to the surface).</p> <p>Properties that affect swelling pressure and hydraulic conductivity of the saturated closure.</p> <p>Material composition: <i>Montmorillonite content.</i></p> <p>Installed density: <i>The dry density and water content of clay blocks.</i></p>	<p><i>Boreholes must be sealed such that they do not unduly impair containment or retention properties of the repository. This is preliminary achieved if the hydraulic conductivity of the borehole seal &lt; <math>10^{-8}</math> m/s, which is ensured if the swelling pressure of the seal is &gt; 0.1 MPa. This value need not be upheld in sections where e.g. hole passes highly transmissive zones.</i></p>
<i>The closure shall be long-term durable and maintain its barrier functions in the environment expected in the final repository.</i>	<p>Closure in boreholes and in ramp, shafts and tunnels other than deposition tunnels below the level of the top sealing.</p> <p>Properties that affect swelling pressure and hydraulic conductivity of the saturated closure.</p> <p>Material composition: <i>Montmorillonite content.</i></p> <p>Installed density: <i>The dry density and water content of blocks, pellet filling and bottom bed, the portions of the tunnel, shaft etc filled with blocks, pellet filling and bottom bed.</i></p>	<p>—</p>
	<p>Closure in cavities of the central area.</p> <p>Installed density.</p>	<p>—</p>
	<p>Closure in the top sealing (i.e. in the part of the ramp and shafts close to the surface).</p> <p>Installed density.</p>	<p>—</p>

Barrier function	Part of closure, property and design parameters to be designed	Design premises long-term safety
<i>The closure in main tunnels shall prevent that backfill in deposition tunnels swells/expands or is transported out from the deposition tunnels.</i>	Closure in main tunnels. Properties that affect the compactability of the saturated closure: Material composition: <i>Montmorillonite content.</i> Installed density: <i>The dry density and water content of blocks, pellet filling and bottom bed, the portions of the tunnel, shaft etc filled with blocks, pellet filling and bottom bed.</i>	–
<i>The closure shall keep the closure in underlying or adjacent underground openings in place.</i>	All closure. Properties that affect the compactability of the saturated closure: Material composition (clay closure): <i>Montmorillonite content.</i> Installed density: <i>The dry density and water content of blocks, pellet filling and bottom bed, the portions of the tunnel, shaft etc filled with blocks, pellet filling and bottom bed.</i>	
<i>The closure must not significantly impair the barrier functions of the other barriers.</i>	All closure. Properties that affect the chemical conditions around the buffer and canister: Material composition.	<i>Only low pH (&lt; 11) materials are allowed below the level of the top seal.</i> Limits for the composition of the rock material used to close the central area – is discussed in Design premises long-term safety Section 3.5.1.
<i>Closure in the upper part of the ramp, shafts and boreholes shall significantly obstruct unintentional intrusion into the repository.</i>	Closure in the top sealing (i.e. in the part of the ramp and shafts close to the surface). Properties that affect the effectiveness (strength, durability etc) of the top sealing: Installed density: <i>Particle size, strength and compaction of rock material.</i> Strength of the concrete: <i>Composition of concrete.</i>	–

<sup>1</sup> “Top sealing” is the term used for the closure in the part of the ramp and shafts close to the surface.

### 2.3.2 Design premises from the other engineered barriers

There are no design premises related to technical feasibility imposed on the closure by the other barriers.

### 2.3.3 Design premises related to the production and operation

In this section the design premises for the closure and its components related to their production and the operation of the KBS-3 repository facility are given. In addition to the design considerations presented in Section 2.2.3, they are based on the preliminary planned procedure to close the different kinds of underground openings of the final repository facility.

The design premises related to the production and operation are presented in Table 2-2. In the leftmost column the design considerations from Section 2.2.3 are repeated.

**Table 2-2. Design requirements and premises for the closure related to the production and operation.**

Design consideration	Required property	Design premises
<i>The closure shall be based on well-trying or tested techniques.</i>	<i>The closure material must be possible to compact to required density.</i>	–
<i>Closure with specified properties shall be possible to prepare and install with high reliability.</i>	<i>The closure components shall be designed so that installation can be performed with high reliability.</i>	–

## 2.4 Design premises imposed by the closure

In this section the design premises imposed by the closure on the underground openings, i.e. the cavities of the central area, the ramp, shafts, tunnels other than deposition tunnels, in order to achieve a technically feasible design and reliable production are given.

In order for the closure to maintain its barrier functions the closure density shall be high enough throughout the cross section and length of tunnels, the ramp and shafts. Further it must be possible to pack the closure material to the required density. To achieve the required density the variation in tunnel/shaft geometry must be limited and known.

For underground openings where the flow of water shall be restricted, closure using the same backfill concept as for deposition tunnels is selected, i.e. backfilling with pre-compacted blocks. The design premises imposed by the closure on these underground openings concern the same properties of the underground openings as the design premises imposed by the backfill on the deposition tunnels. These properties are acceptable inflow and acceptable dimensions and geometry, also see Table 2-2 and 2-3 in the **Backfill production report**. However, since a lower installed density is anticipated to be accepted for the closure, the acceptable variations will most probably be larger than those stated for the backfill in deposition tunnels. At this stage of development of the closure, no quantitative design premises are given for the acceptable geometries of the underground openings. For the inflow, 10 litres per minute and 100 meter tunnel length is set to an acceptable level.

## 2.5 Design premises for the plugs

In the final repository during the post closure phase the plugs must not significantly impair the barrier functions of the engineered barriers or the rock. The design premises related to this requirement are presented in Table 2-3.

At this stage of development no detailed design premises related to the functions of the plugs during the decommissioning of the final repository facility are established.

**Table 2-3. Design premises for the plugs related to their properties in the final repository during the post closure phase.**

Required function or property	Property and design parameters to be designed	Design premises
<i>The plugs must not significantly impair the barrier functions of the engineered barriers or rock.</i>	<i>Volume and compressibility of the plugs (all parts)</i>	<i>The material shall remain in its place and not decrease significantly in volume.</i>
	<i>Concrete plug material composition Concrete recipe: composition of binder and additional ingredients</i>	<i>Only low pH (&lt; 11) materials are allowed below the level of the top seal.</i>

### 3 Reference designs

In this chapter the reference designs of the closure in the different categories of underground openings are presented. In addition to the underground opening to be closed the design will depend on the different functions of the closure in different parts of the underground opening. This results in the following reference designs which are presented in the following sections:

Section 3.2 – closure of the central area.

Section 3.3 – closure of the ramp and shafts below the level of the top sealing.

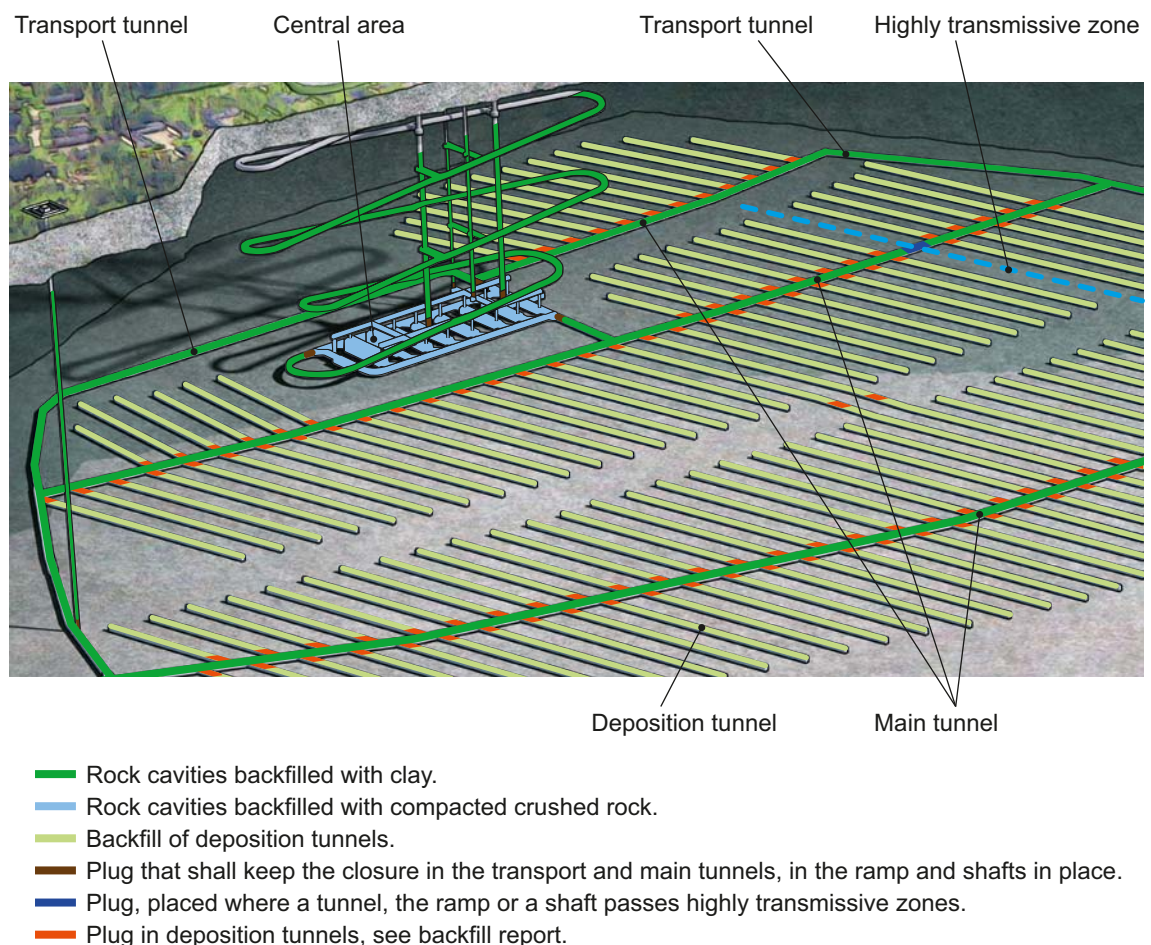
Section 3.4 – top sealing.

Section 3.5 – borehole sealing.

Section 3.6 – plugs.

The reference design specifies the current designs of the closure and plugs. The reference designs shall conform to the design premises presented in Sections 2.3 and 2.5 respectively and they shall be technically feasible to produce by applying the methods for preparation and installation described in Chapter 4. The conformity of the references designs to the design premises are presented in connection to the presentations of the reference designs.

An outline of the different kinds of closure and plugs is given in Figure 3-1.



**Figure 3-1.** Outline of the closure and plugs in the different categories of underground openings.



## **3.1 Closure of main tunnels and transport tunnels**

### **3.1.1 Reference design of the closure in main tunnels and transport tunnels**

To conform to the design premises the closure in main tunnels and transport tunnels (see Table 2-1) have the same conceptual design as the backfill in deposition tunnels, see Chapter 3 in the **Backfill production report**. Figure 3-1 shows the main tunnels and transport tunnels for which this concept is the reference design.

### **3.1.2 Conformity of the reference closure in main tunnels and transport tunnels to the design premises**

The same conceptual design as used for the backfill in deposition tunnels is selected as the reference design of the closure in main tunnels and transport tunnels. In practice, neither the material composition nor the installed density needs to be the same. In main tunnels and transport tunnels there is no need to prevent buffer swelling/expansion and the acceptable hydraulic conductivity is larger than in deposition tunnels. Nevertheless, the same material as for the backfill in deposition tunnels is selected at this stage of development, and the verifying analyses presented for the backfill in Chapter 4 in the **Backfill production report** are considered relevant to support the conformity of the closure reference design to the design premises.

SKB has studied the feasibility of several backfilling methods and backfill materials, see e.g. /Gunnarsson et al. 2006, Johannesson and Nilsson 2006, Johannesson 2008/. Results from these investigations indicate that also with other materials, e.g. alternative bentonite clay products or mixtures of bentonite and ballast, the closure in main tunnels and transport tunnels will conform to the design premises, see Figure 3-2 and 3-3.

## **3.2 Closure of the central area**

### **3.2.1 Reference design of the closure in the central area**

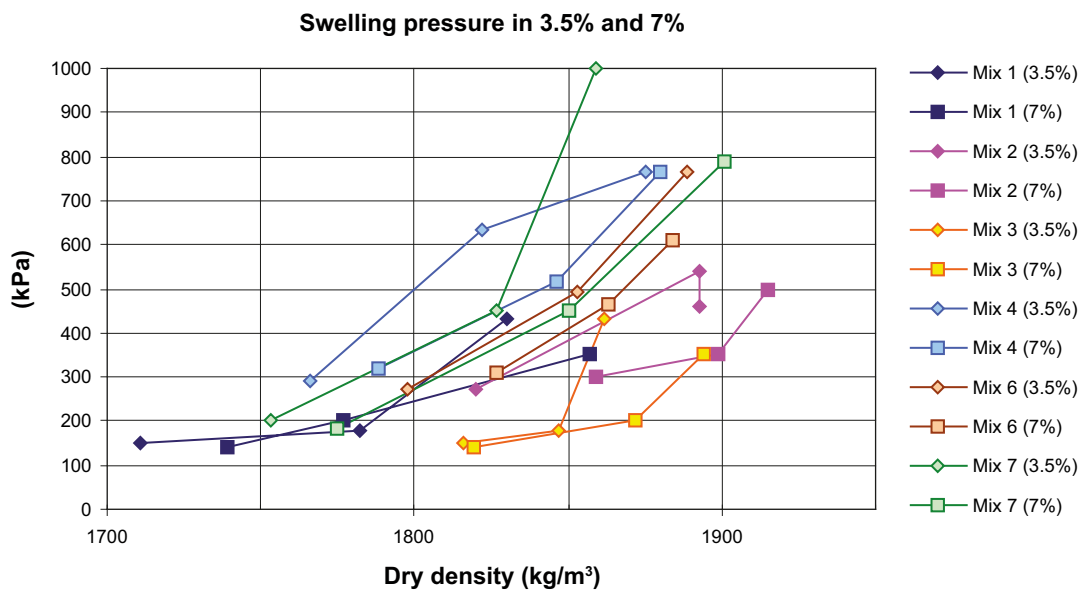
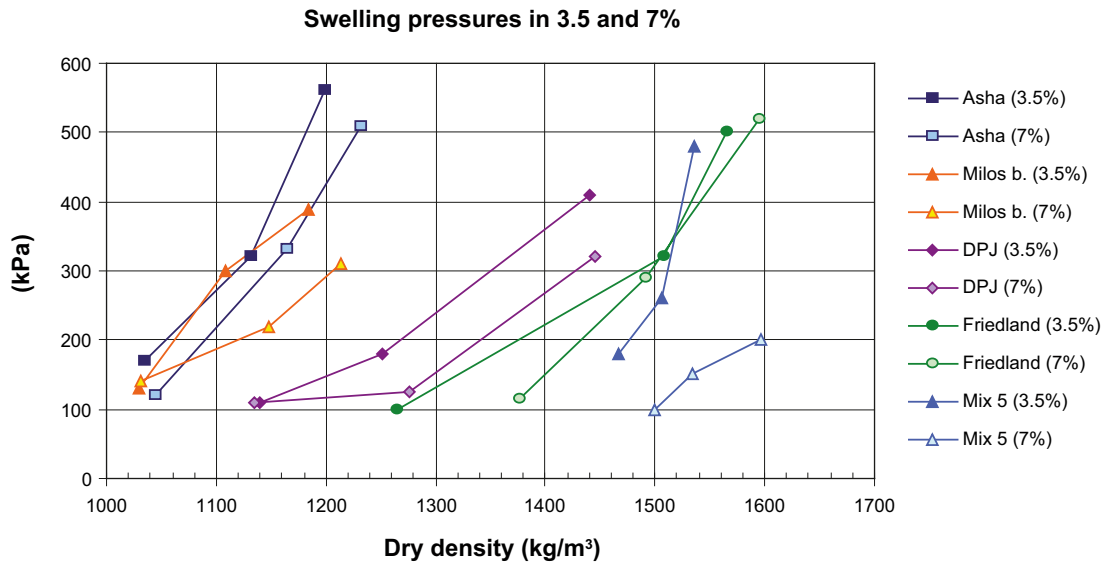
The only function of the closure of the cavities in the central area is to occupy the space with no other design premise than to prevent substantial convergence and subsidence of the surrounding rock. With respect to this the reference design is to use crushed blasted rock that will be placed by tractors in horizontal layers and then compacted.

The following shall be considered when determining a reference design:

- size distribution and shape of rock particles depending on excavation method,
- density of rock fill: loose layering; moderately compacted; or very effectively compacted,
- techniques for compaction; dry and wet,
- compressibility and settlement of rock fill,
- shear strength of rock fill,
- hydraulic conductivity of rock fill,
- petrological compositions of rock fill.

In /Pusch 2008/ a condensed description and overview of these items are given. The report presents experience from road and dam construction as well as results from SKB's backfilling experiments in the Prototype Repository Project and the Backfill and Plug Test at Äspö HRL.

The petrological composition is important as the closure must not significantly impair the barrier functions of the engineered barriers or rock. To guarantee that the rock fill doesn't contain minerals in a proportion that could result in a negative impact, a careful inspection and analysis of the mineral composition is vital. In the current reference design the rock material will be taken from the rock produced during excavation of the repository facility. This means that the mineral composition of the material will be the same as in the surrounding rock. Information on the properties of the rock in Forsmark is found in /Stephens et al. 2007, Section 3.4/.



**Figure 3-2.** The swelling pressure as a function of dry density for different backfill materials; results at 3.5 and 7% salinity. Details on materials etc are given in /Gunnarsson et al. 2006/.

<sup>1</sup> Explanation of abbreviations in Figure 3-2 and 3-3:

Asha = India Asha 230, a low-grade Na-bentonite.

Milos b = Milos backfill a low-grade Ca-bentonite.

Dep. CA-N = Deponite CA-N, a non-activated high-grade Ca-bentonite from Milos.

MX 80 = A high grade Na-bentonite from Wyoming.

DPJ = Dnešice-Plzensko Jih, a smectite-rich mixed-layer clay; Ca-bentonite

Friedland = Friedland clay, a smectite-rich mixed-layer clay, Na-bentonite.

SPV = SPV200, a high grade Na-bentonite from Wyoming.

Mx 1 = A mixture of 30% MX 80 and 70% crushed rock (0–5 mm), fine fraction 0%.

Mx 2 = A mixture of 30% SPV and 70% crushed rock (0–5 mm), fine fraction 0%.

Mx 3 = A mixture of 30% Dep. CA-N and 70% crushed rock (0–5 mm), fine fraction 0%.

Mx 4 = A mixture of 40% Dep. CA-N and 60% crushed rock (0–5 mm), fine fraction 0%.

Mx 5 = A mixture of 50% Dep. CA-N and 50% crushed rock (0–5 mm), fine fraction 0%.

Mx 6 = A mixture of 30% Dep. CA-N and 70% sand.

Mx 7 = A mixture of 30% Dep. CA-N and 70% crushed rock (0–5 mm), fine fraction 12%.

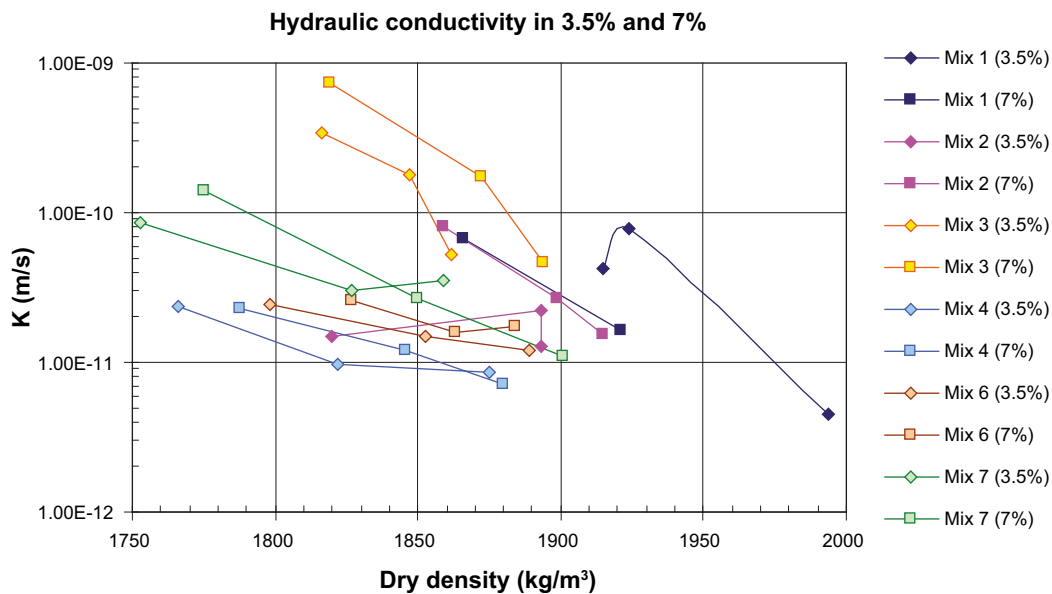
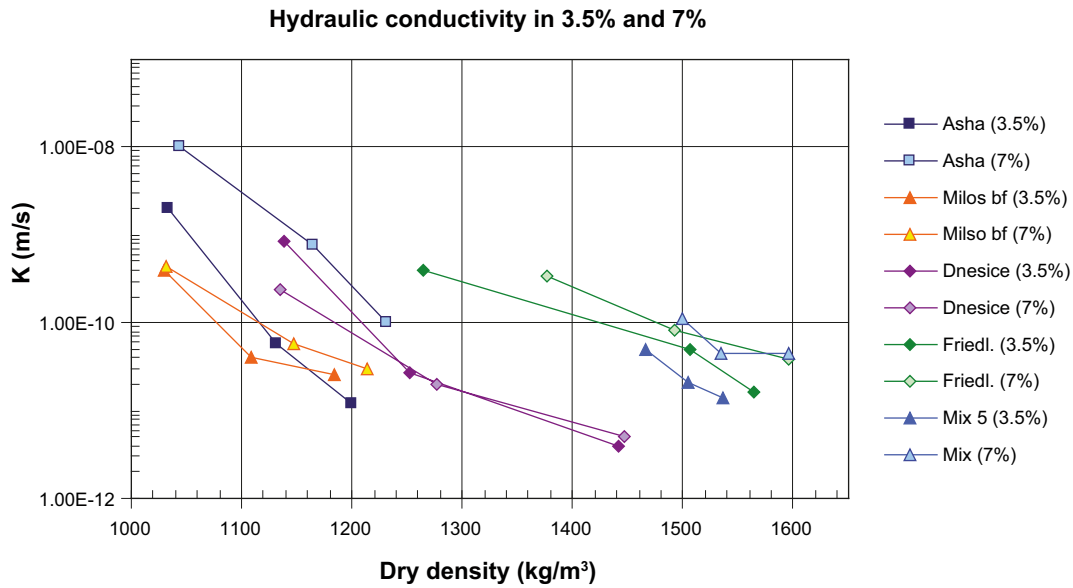


Figure 3-3. The hydraulic conductivity as a function of dry density for different backfill materials. Results at 3.5 and 7% salinity. Details on materials etc are given in /Gunnarsson et al. 2006/.

### 3.2.2 Conformity of the reference closure of the central area to the design premises

In the cavities in the central area the rock fill will undergo small self compaction; 5–10 mm according to /Pusch 2008/. This would be acceptable as there is no restriction of the hydraulic conductivity of the closure in the central area. However, it is important to yield sufficient density of the installed closure material and the densities that can be achieved based on current experiences are summarised below.

Comprehensive experience of placement and compaction of rock fill is available from road construction and from the construction of hydro power dams. For road embankments compacted by ordinary vibratory rollers (5–10 tonnes) common density values are in the range of 2,050 to 2,200 kg/m³ /Pusch 2008/.



For earth dam construction thicker layers and larger boulders than for road construction are accepted. By using vibrating single-rollers with 6 tonnes weight dry densities of about 2,000 kg/m<sup>3</sup> can be achieved /Pusch 2008/.

SKB has performed backfilling experiments in the “Field test of tunnel backfilling” and the “Backfill and Plug Test” at Äspö HRL. They involved placement of rock debris from tunnel boring (TBM-muck) with and without compaction. Some tests were made with material that had been stockpiled without further treatment while crushed muck was used in certain other tests.

*Field test of tunnel backfilling* included placement and compaction of virgin and crushed TBM-muck in horizontal and inclined (sloping) layers /Pusch 2008/. Horizontal layers of virgin TBM-muck compacted by a 5 t vibratory roller had a dry density of 2,430 kg/m<sup>3</sup> while crushed muck had a maximum dry density of 2,210 kg/m<sup>3</sup> /Pusch 2008/. Placement of virgin TBM-muck without compaction to form inclined layers gave a dry density of 1,600 to 2,120 kg/m<sup>3</sup> while compaction gave 2,210–2,330 kg/m<sup>3</sup>. Crushed rock gave a dry density of 2,140 kg/m<sup>3</sup> of inclined layers.

*The Backfill and Plug Test* looked into the placement and compaction of crushed TBM-muck to form inclined layers /Gunnarsson et al. 2001/. The density was found to range between 2,110 and 2,210 kg/m<sup>3</sup>. These experiments included placement of compacted clay blocks on top of the rock-fill.

TBM-muck was used in the trials at Äspö HRL. The experiences are therefore not in all respects relevant for the reference design. But as the results are in line with experience from road and dam construction /Pusch 2008/ the reference design must be judged to be appropriate and feasible.

Dry densities for rock filling according to the above presented experiences are summarised in Table 3-2.

There is no design premise for restriction of hydraulic conductivity for the closure in the cavities of the central area. Nevertheless, the hydraulic conductivity has been estimated. Experiments and tests indicate that compacted crushed rock fill with a dry density of about 2,000 kg/m<sup>3</sup> will obtain a hydraulic conductivity in the order of 10<sup>-7</sup> m/s. The combined effect of the crown space, i.e. the gap between the top of the rock fill and the roof of the underground opening, and the dry density of the rock fill determine the resulting hydraulic conductivity for the closure in the central area. A preliminary judgement is that a resulting hydraulic conductivity of about 10<sup>-5</sup> m/s can be achieved.

**Table 3-2. Dry densities for rock fill – results achieved in road and dam constructions and in backfilling experiments at Äspö HRL.**

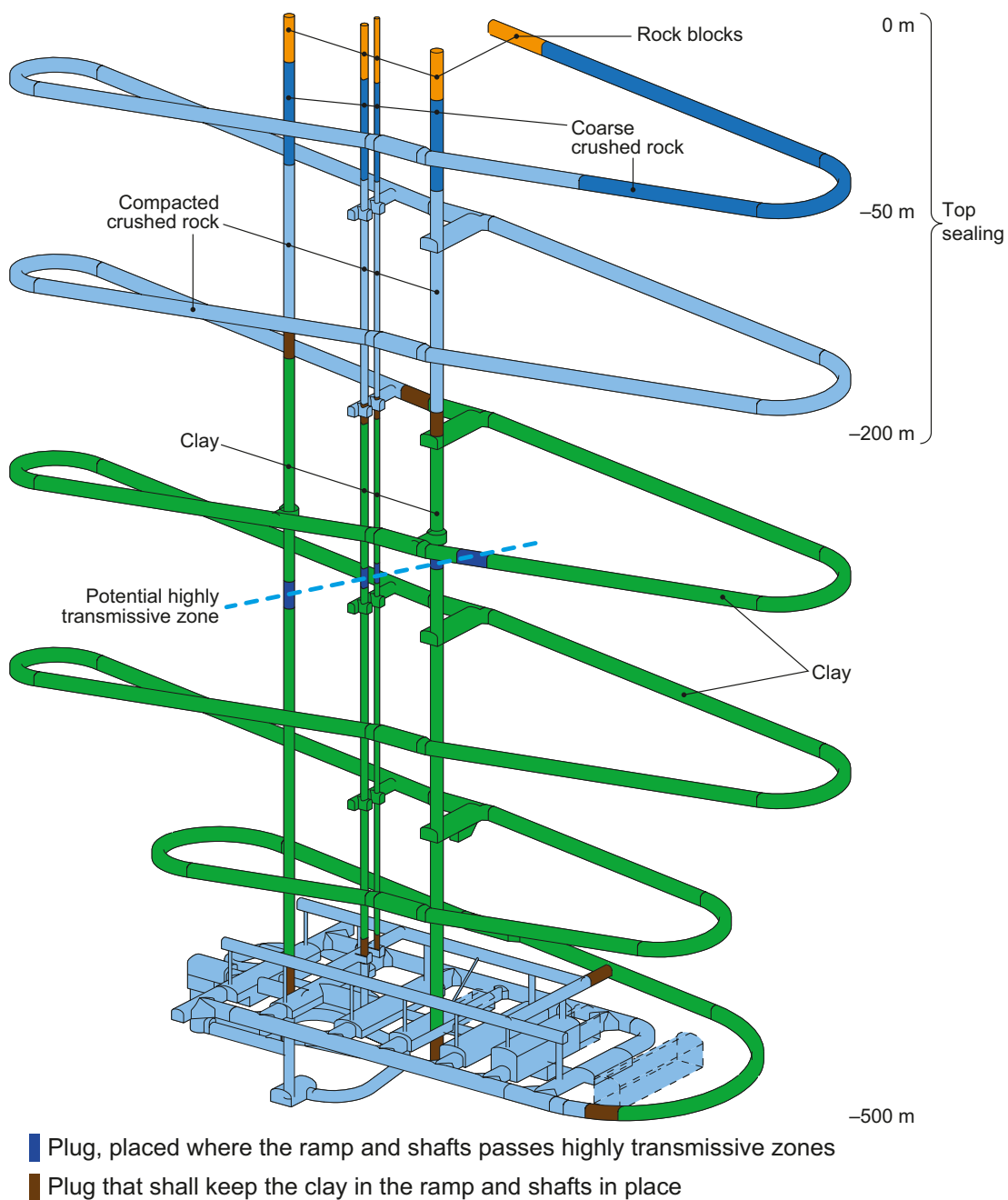
<b>Horizontal layers compacted by a 5 tonnes vibratory roller</b>	
<b>Rock fill material</b>	<b>Dry density, kg/m<sup>3</sup></b>
Virgin TBM-muck	2,390–2,470
Crushed TBM-muck	2,100–2,300
Road embankments	2,050–2,200
Dam constructions (6 t vibratory roller)	2,000
<b>Inclined layers</b>	
<b>Rock fill material</b>	<b>Dry density, kg/m<sup>3</sup></b>
Virgin TBM-muck without compaction	1,600–2,120
Virgin TBM-muck after compaction	2,210–2,330
Crushed TBM-muck	2,110–2,210

### 3.3 Closure of ramp and shafts below the top sealing

#### 3.3.1 Reference design of the closure in ramp and shafts below the top sealing

To restrict water flow below the level where the top sealing starts (see Table 2-1), SKB has chosen the same conceptual design for the closure in this deeper part of the ramp and shafts as for backfill in deposition tunnels, see the **Backfill production report**, Chapter 3.

In the reference design the ramp and shafts are backfilled with clay up to –200 meters depth, where the top sealing starts. The depth of the top sealing is determined by the presence of water conducting structures and the expected depth of permafrost in Forsmark. Figure 3-4 shows the parts of the ramp and shafts belonging to the top sealing, the deeper parts filled with clay and the use of plugs in ramp and shafts.



**Figure 3-4.** Top sealing, the parts of the ramp and shafts filled with clay and the placement of plugs in ramp and shafts.

### 3.3.2 Conformity of the reference closure in ramp and shafts to the design premises

Below the level of top sealing the same conceptual design as for the backfill in deposition tunnels is selected as reference design for closure of ramp and shafts. In practice, neither the material composition nor the installed density will be the same. In ramp and shafts there is no need to limit buffer swelling/expansion and the accepted hydraulic conductivity is larger than in deposition tunnels. Nevertheless, the same material as for the deposition tunnels is selected as reference material at this stage of development, and the verifying analyses presented for the backfill in Chapter 4 in the **Backfill production report** are considered relevant to support the conformity of the reference design for the closure in ramp and shafts below the top sealing to the design premises.

SKB has studied the feasibility of several backfilling methods and backfill materials. Results from these investigations indicate that the design premises for the closure of ramp and shafts below the level of top sealing could be met also with other backfill materials (clays with less demanding properties or mixtures of bentonite and ballast), see Section 3.1.2.

## 3.4 Top sealing

“Top sealing” is the term used for the closure of the upper part of the ramp and shafts.

### 3.4.1 Reference design for the top sealing

To maintain the function to “*significantly obstruct unintentional intrusion into the repository*” (Section 2.2.1) the ramp and shafts are, from –200 to –50 m depth from the zero level, filled with crushed rock having a maximum particle size of 200 mm. The rock fill is effectively compacted to minimise self-compaction under its own weight and overburden /Pusch 2008/.

The depth of the top sealing depends on site-specific conditions, e.g. presence of water conducting structures and the expected depth of permafrost. In the reference design the top sealing goes down to a depth of –200 meters. The parts of the shafts and ramp belonging to the top sealing are shown in Figure 3-4.

The uppermost 50 m of the ramp and shafts is backfilled with very coarse crushed rock that is effectively compacted to minimise self-compaction. The shallowest parts of the ramp and shafts are filled with fairly well fitted blocks of crystalline rock. Good but not perfect fitting of the blocks eliminates arching, and possibly occurring open spaces between the rock blocks are not considered to significantly affect the settlement.

### 3.4.2 Conformity of the reference top sealing to the design premises

The reference design for the top sealing is to fill the ramp and shafts with crushed rock and rock blocks, i.e. essentially the same material that is used for closure of the central area, see Section 3.2.

The function of the uppermost 50 m of the ramp and shafts is to significantly obstruct unintentional intrusion into the repository. The selected reference design is judged to maintain this function. The judgment is based on experience from the quarrying industry and diabase pits which proves that boring in fractured rock is very difficult and that production of rock blocks for the suggested masonry at the top is an established technique /Pusch 2008/.

## 3.5 Borehole sealing

A number of investigation boreholes, both holes drilled from the surface and holes drilled from underground openings have to be sealed, at the decommissioning of the final repository facility. With respect to that the closure shall “*prevent that water conductive channels that may jeopardise the barrier functions of the rock, are formed between the repository and the surface*”, only boreholes going deeper than the top sealing (thus passing –200 meter) have to be sealed. In the layout of the final repository facility the locations of the boreholes are considered in order to avoid that boreholes connected to the surface intersect underground openings. Deposition tunnels must not be intersected by investigation boreholes connected to the surface, and deposition holes must not be intersected by any investigation boreholes.

The geometry of a borehole seal is mainly determined by the dimensions of the drilled holes. The length of surface-based boreholes ranges from a few metres to more than 1,000 metres and the diameter will range from 56 to 120 mm. The tunnel-based boreholes are expected to have a length of a few hundred metres and a diameter of 56 to 76 mm. The shallowest parts of the boreholes may have larger diameters. Some boreholes may be more or less horizontal.

In addition a large number of grouting holes and holes for installation of rock support will be drilled during construction of the repository, see the **Underground openings construction report**. However, they do not need to be sealed.

SKB has studied and developed several concepts for borehole sealing. The main principles for sealing boreholes as well as results from tests and experiments are summarised in /Pusch and Ramqvist 2007/.

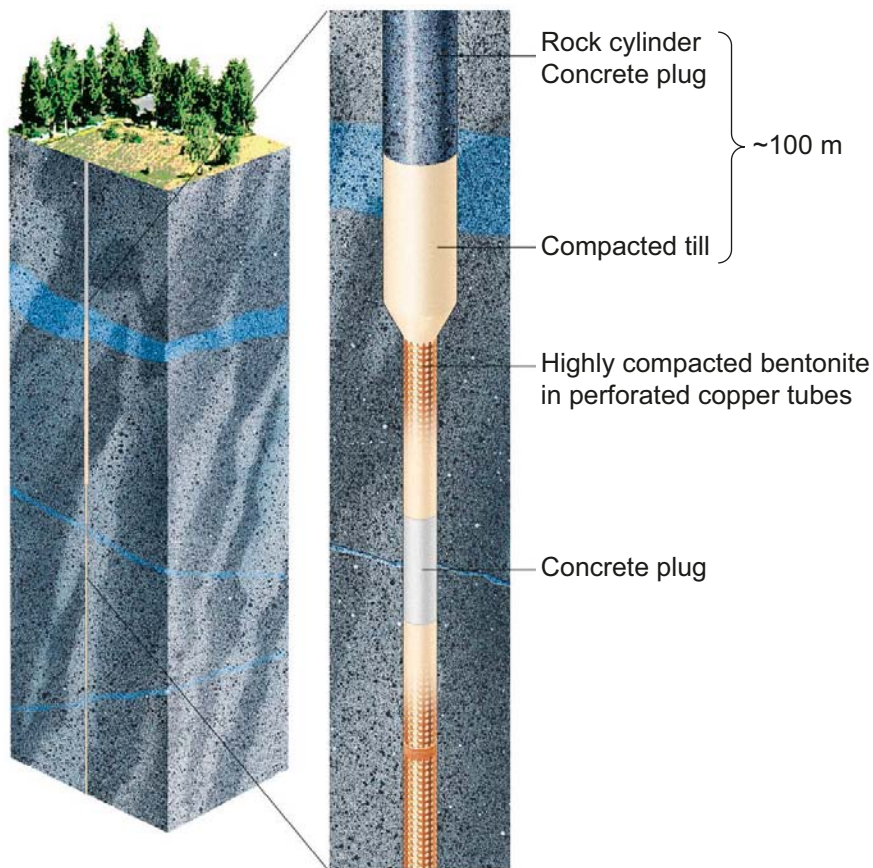
### 3.5.1 Reference design of borehole sealing

To conform to the design premises for borehole sealing (see Table 2-1) the following reference design is applied.

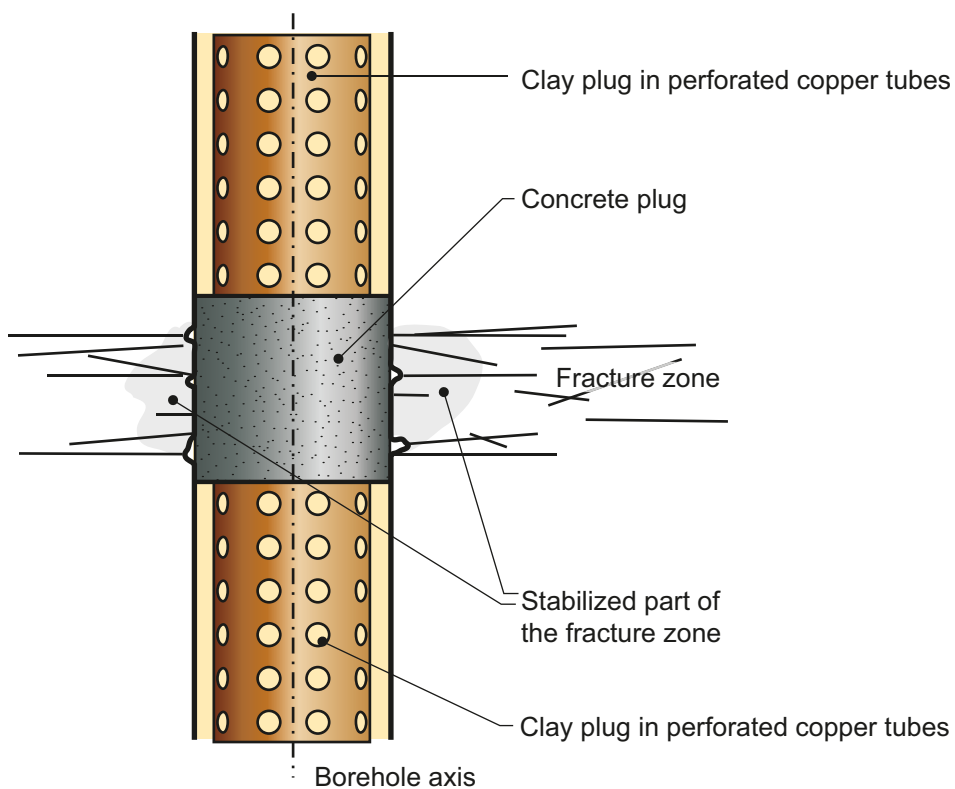
Highly compacted bentonite is used where tight seals are needed and cement-stabilised plugs are cast where the boreholes pass through fracture zones, see Figure 3-6 and 3-7. For the reference design MX-80 bentonite is chosen. To prevent erosion during the installation phase the clay shall be pre-dried to a water content of about 6% and then compacted to a dry density of 1,900 kg/m<sup>3</sup>. The clay blocks are contained in perforated copper tubes that are jointed as they are inserted into the holes. The copper tubes provide mechanical protection against abrasion in the installation phase. The reference borehole has a diameter of 80 mm (investigation holes with a original diameter of 76 mm have to be enlarged) and the perforated copper tube an outer diameter of 76.1 mm and an inner diameter of 72.1 mm (which is a standard dimension). The tubes have a perforation ratio of 50% with 10 mm diameter holes in order to allow the clay to swell into the volume between the tube and the rock.

Along sections where the borehole passes water-conducting fracture zones the clay could potentially erode. In such positions the holes are therefore filled with silica concrete, which is a permeable and erosion-resistant material, see Figure 3-6. These plugs do not need to have a low conductivity but must be physically stable for supporting the surrounding rock and the clay plugs that rest on them or are located below them. In the construction phase they must be stable and rapidly become strong enough to carry overlying clay plugs without settling. This is attained by using a fast curing cement binder. To minimise the negative impact of cement contacting clay plugs, the cement content will be very low and low-pH cement will be utilised. Further details are found in /Pusch and Ramqvist 2007/.

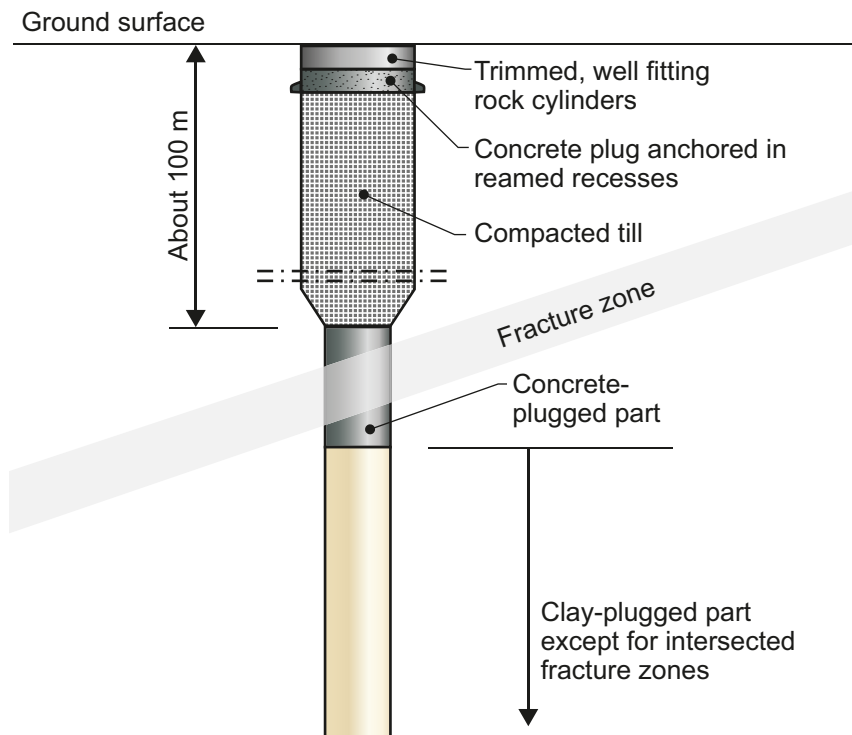
The upper part of boreholes connected to the surface will be sealed with material that can sustain the swelling pressure exerted by the clay part and offer resistance to mechanical impact like intrusion, erosion and glaciations. For the reference design the concept illustrated in Figure 3-5 is selected. The main components are: rock cylinders, concrete plugs cast on site and anchored in reamed recesses and well compacted till /Pusch and Ramqvist 2007/.



**Figure 3-5.** Reference concept for sealing investigation boreholes from the surface.



**Figure 3-6.** Schematic sketch of the construction of concrete plugs in parts where the borehole passes water-conducting fractures.



**Figure 3-7.** The principle for closure of the upper part of a borehole with well compacted till below concrete and fitted rock blocks.

### 3.5.2 Conformity of the reference borehole sealing to the design premises

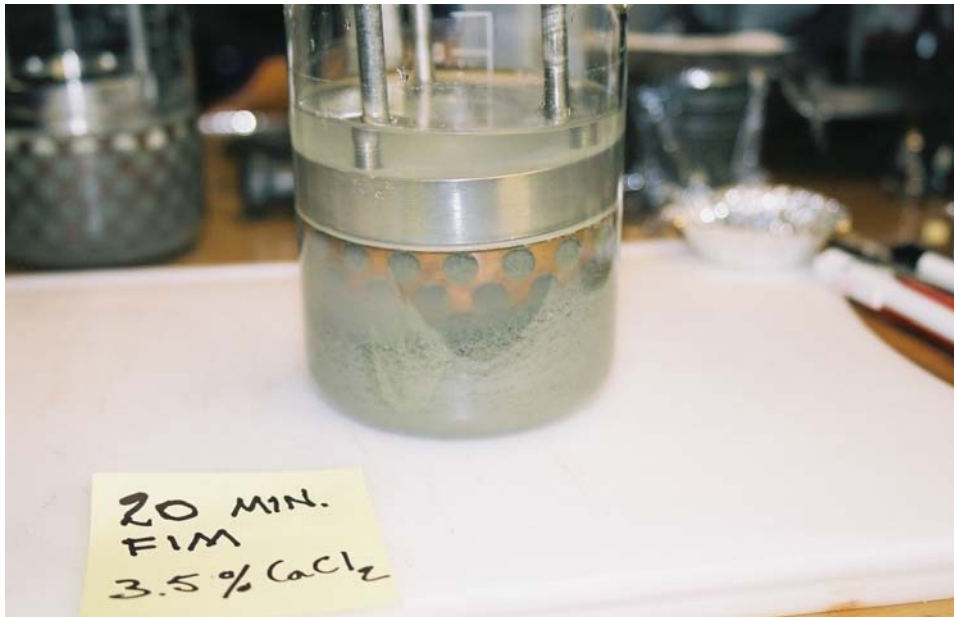
SKB has, in cooperation with Posiva and as part of SKB's RD&D programme, developed concepts for sealing of long and short boreholes. The concepts are based on the one tested in Stripa and used in SFR and are postulated to work in both steeply and gently dipping boreholes /Pusch and Ramqvist 2007/.

Examples of results reported in /Pusch and Ramqvist 2007/ are summarised below.

- The long-term tests show that a high degree of swelling and homogenisation is obtained after 10–20 days. The measured mean swelling pressure against the rock for the initial dry density  $1,905 \text{ kg/m}^3$  of the clay plug core is 2,800 kPa in fresh water and 600 kPa in saline water (Äspö). After saturation the clay plug will reach a density of  $2,025 \text{ kg/m}^3$  which corresponds to a dry density of  $1,630 \text{ kg/m}^3$ . Measurement of the hydraulic conductivity of the clay paste between the copper tube and rock showed that it was lower than  $9 \times 10^{-13} \text{ m/s}$  for saturation and percolation with fresh water and  $2 \times 10^{-12} \text{ m/s}$  for saline water.
- Plugging the upper end of deep boreholes can be made by use of copper plugs and CBI silica concrete plugs, both of which can take axial pressures of more than 30 MPa. The shear strength and deformation moduli of concrete plugs of silica concrete can be significantly improved by mixing in centimetre-sized quartzite fragment.
- The function of plugs of the investigated type has been fully demonstrated. For the concrete plugs the recorded strength in full-scale tests has been found to agree well with predicted values derived from laboratory experiments. For clay plugs a very high degree of homogeneity has been documented by investigation of several years old plugged boreholes, demonstrating also that the swelling potential and the hydraulic conductivity agree well with predictions.

Tests also show that clays with Na as the major adsorbed cat ion should be used, since Ca-saturated clay does not expand readily during the saturation phase in either fresh or salt water. They show that the density of the soft gel that migrates out through the holes in the copper tube is not sufficient to make it form a coherent mass, see Figure 3-8. It will therefore settle in the gap between the tube and the borehole wall especially in salt water. When a Na-clay plug has been saturated and homogenised, which will happen within a week or two, the density of the outer part of the clay plug is high enough





*Figure 3-8. Example of quick release of clay through the perforation of copper tubes in a borehole plug in salt water. The clay that migrated out through the perforation did not form a coherent clay gel but settled as a coagulated dispersed sol in the space between tube and glass vessel /Pusch and Ramqvist 2004/.*

to prevent negative effects on the plug properties (hydraulic conductivity and swelling pressure) caused by ion exchange leading to the calcium saturation /Pusch and Ramqvist 2004/. For the reference design MX-80 bentonite is chosen.

The performance and technical design of different types of boreholes drilled during the site investigation at Forsmark, such as telescopic boreholes, core-drilled boreholes of standard type, and percussion-drilled boreholes in solid bedrock are described in /SKB 2005/. Some geometrical borehole characteristics are displayed in /SKB 2008, Table 2-1 and Table 2-2/.

## 3.6 Plugs

The plugs shall separate backfilled and closed underground openings from underground openings that remain to be closed. The plugs shall keep the closure material in the closed parts in place until the underground opening on the other side of the plug is filled and the material saturated. Plugs are also used in areas containing conductive features in the rock. The plugs also contribute to a safe and secure installation of the closure. The plugs must not contain materials that may impair the barrier function of any of the other barriers.

The design of the plugs will be site specific and depend on the local conditions in the host rock. What is important at one location may be irrelevant in another. A number of tunnel plug/seal tests have already been conducted by various organizations interested in deep geologic disposal of spent nuclear fuel. There also exists a considerable amount of literature on the performance of plugs/seals installed for other purposes (e.g. mining operations, hydroelectric plants, environmental remediation). These experiences are briefly reviewed in /Dixon et al. 2009/.

### 3.6.1 Reference designs of plugs

As stated in the previous section the design of plugs depends on conditions at the site and at this stage only an overview of the anticipated kinds of plugs and examples of conceptual designs are provided.

Based on the different purposes of the plugs stated in the previous section the plugs can be divided into the following types.

- A. Plugs separating underground openings filled with clay from underground openings filled with crushed rock.
- B. Plugs used where tunnels, the ramp and shafts pass water-bearing structures.
- C. Plugs facilitating the installation of closure material in large underground openings e.g. the cavities in the central area.

Plugs of type A are installed where the transport tunnels, ramp and shafts connect to the central area. Figure 3-1 outlines the placement of such plugs. For these plugs the same conceptual design as for the plugs in deposition tunnels is selected as reference design, see Section 7.1 in the **Backfill production report**.

Plugs of type B are installed where a main or transport tunnel, or the parts of the ramp and shafts filled with clay blocks and pellets, intersect fracture zones. An example of such a plug in a shaft is illustrated in Figure 4-1.

Plugs of type C are installed when needed for construction reasons. The location and design depend on the local conditions

### 3.6.2 Conformity of the reference plugs to the design premises

A number of studies that examine aspects of closing openings in granitic rock have been conducted since the early 1980s. Beginning with the first large-scale field tests at the *Stripa* site and then continuing at the *Äspö HRL* and *Canadian Underground Research Laboratory (URL)* facilities, the influence of plugging material, length of plug, influence of keying features to cut off the EDZ and effect of excavation technique on seepage have been investigated. Valuable insight and knowledge related to plug construction have been gained in these studies. It should also be emphasised that none of these demonstrations were intended to test an optimised design, and in most cases the purpose was to assess which parameters had the largest impact on the post-construction seepage.

At *Stripa* both a shaft and a tunnel sealing test was conducted. The tests were designed to determine the effectiveness of swelling clay-based plugs in limiting water flow at interfaces between concrete bulkheads and backfilled excavations. Both sealing trials had the same goal of limiting the movement of water past the plug and evaluating the role of the excavation damaged zone (EDZ) in this flow. From these two tests it is clear that bentonite used in conjunction with concrete provides an effective seal. These tests were run for a very short duration; the longer-term behaviour and effects of groundwater flow on bentonite or fracture-filling materials were not assessed /Gray 1993 Chapter 3, Pusch et al. 1987a, b/.

At the *Canadian URL* several tests related to the sealing and plugging of underground openings were conducted. *The Tunnel Sealing Experiment* was a study that was designed to characterise the sealing potential of two well-constructed bulkheads. *The Composite Seal Experiment* was originally envisaged as being the first in a series of tests that examined the performance of a number of composite sealing system designs but only the first of these was completed. The tests at URL confirmed that the use of bentonite seals is an effective way of reducing the seepage past a plug /Martino et al. 2003, Kjartanson and Martino 2004, Dixon et al. 2004/.

More recent tests at *Äspö HRL* have extended some of the studies conducted at *Stripa* or the *Canadian URL* by incorporating bentonite gaskets into concrete bulkheads or plugs and other structures. *The Backfill and Plug test* incorporated both a bentonite gasket in a concrete bulkhead that was keyed into the rock and also contained bentonite-rich materials in the upper regions of the tunnel adjacent to it. The seepage past this type of structure at 6 MPa hydraulic head is estimated to be 13.6 L/h. *In the Prototype Repository*, a similar approach to plugging the tunnel to the Backfill and Plug Test was adopted. For references, see the **Backfill production report**.

Before detailed designs of plugs used in connection to closure are determined, similar development work will be performed. The experiences gained from the design and installation of deposition tunnel plugs can be applied to shaft plugs. The experiences from plugs in deposition tunnels make it clear that such a development can be based on conventional technique. More information on verifying analyses for the selected reference design is found in the **Backfill production report**, Chapter 8.



## 4 Production of the closure

### 4.1 Introduction

Closure of the repository will, with the exception of some boreholes that have to be sealed earlier, not take place until all spent nuclear fuel has been deposited. This means that the closure activities lie well in the future. So far SKB has prioritised the development of the backfill and plug in deposition tunnels. For that reason, this section refers to the **Backfill production report** for the production of closure for main tunnels and transport tunnels and the ramp and shafts below the level of the top sealing.

For the closure of the central area a short overview is given. This is considered sufficient at this stage of development, since there are no design premises related to the long-term safety given for the central area.

As mentioned in Section 3.5, SKB has studied and developed several concepts for borehole sealing. A short summary of methods to manufacture and install borehole seals used in these tests is given at the end of this chapter.

Prior to closure of any underground opening, construction features such as road beds and building components and installations will, as part of the decommissioning, be removed and the underground opening cleaned. Routines for these activities remain to be specified.

The main stages for closure of the repository are:

- backfilling of and, if necessary, installation of plugs in the outer ventilation shaft,
- backfilling of and, where necessary, installation of plugs in main tunnels and transport tunnels,
- installation of plugs where the transport tunnels connect to the central area,
- backfilling of the central area,
- installation of plugs where the central area connects to shafts and ramp,
- backfilling of and, where necessary, installation of plugs in the ramp and remaining shafts; these activities must be very well coordinated and accomplished gradually,
- installation of top seal.

Borehole seals are installed at suitable occasions before or during the other closure activities.

### 4.2 Closure of main tunnels and transport tunnels

The manufacturing of components, i.e. blocks and pellets, as well as the handling, and filling can largely be done using the same methods as those developed for the backfill, see the **Backfill production report**, Chapter 5.

### 4.3 Closure of the central area

The production of the closure material for the central area and its installation includes the following activities.

- Blasted rock from the storage of rock from excavated tunnels is transported to the crusher.
- The blasted rock is cleaned.
- The blasted rock is crushed and sieved to a pre-determined grain size distribution that facilitates compaction.

- The crushed rock is transported to an intermediate storage at the repository level adjacent to the central area.
- The quality of the material is inspected with respect to weight, mineral composition, grain size distribution, water ratio and density.
- The rock fill is placed in the tunnel or rock cavity.
- The crushed rock is compacted in inclined layers.

All activities are well known from many kinds of construction work. Experience from road and dam construction as well as results from SKB's backfilling experiments in the Prototype Repository and the Backfill and Plug Test are summarised in /Pusch 2008/. Further details on SKB's backfilling experiments are reported in a large number of reports; assessments of different backfill concepts are found in /Gunnarsson et al. 2004/. See also Section 3.3.2.

#### 4.4 Closure of ramp and shafts

During installation of the closure in the ramp the inflow of water will probably be greater than during installation of backfill in deposition tunnels. The reason is that the ramp will most probably intersect a number of highly transmissive zones. This has to be solved by means of a water management system and plugs for wet sections of the tunnels. Such a system will be designed, constructed and tested /Gunnarsson et al. 2004/.

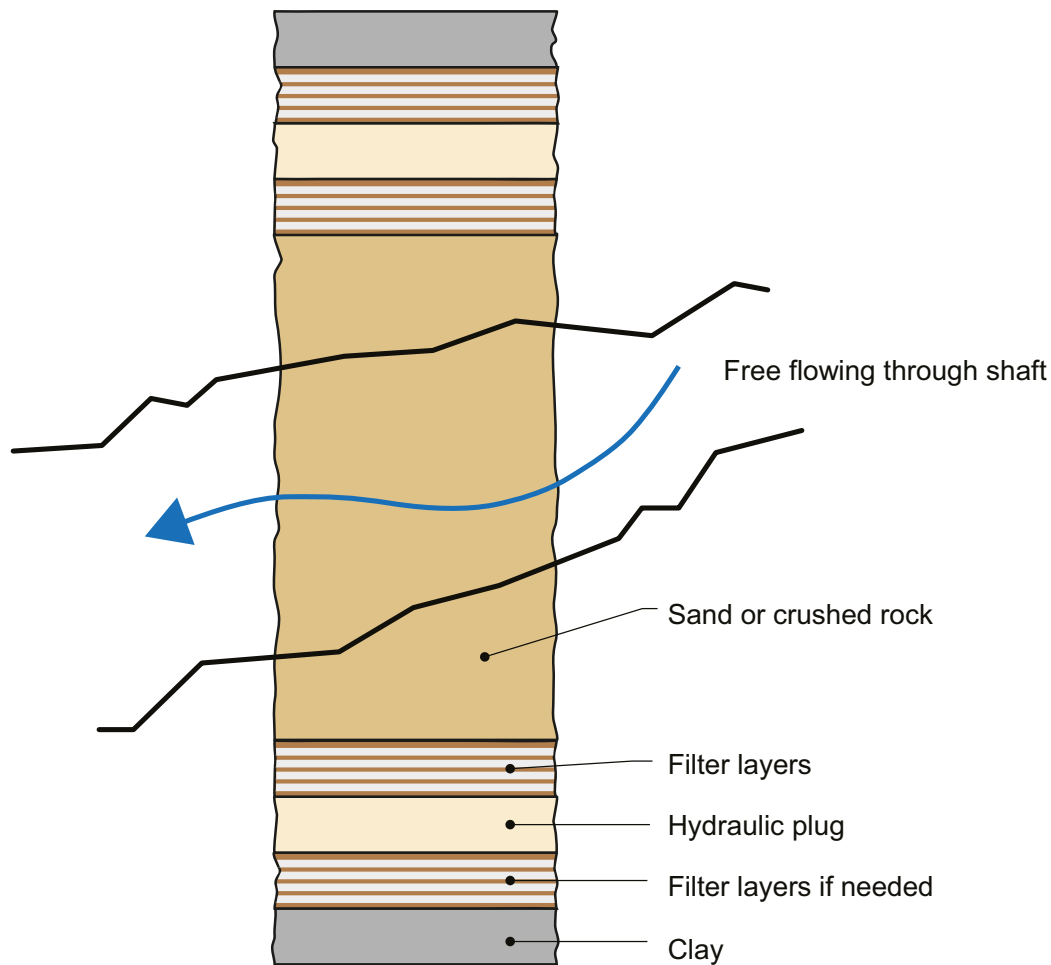
In shafts other types of compaction technique is used. Here, higher compaction energy can be applied and higher density obtained than in tunnels. Possible compaction techniques involve: stamping; use of vibrating plates; falling weight and self-compaction by gravity. The water inflow can be greater for shafts than for the deposition tunnels. The water coming from below is handled with plugs and drainage sections in a similar way as for the ramp. The water coming from above is collected to avoid softening of the backfill surface. A special water interception and collection system for doing this will be designed. A system for bringing material down in the shaft and past the compaction equipment will also be developed /Gunnarsson et al. 2004/.

The self-weight of the closure material in shafts as well as lithostatic, hydrostatic and other stresses are quite large and as a result some deformations are expected. These deformations, which are mainly settlement, will be dominated by the elastic and plastic deformation (including creep) of the closure material. The magnitude of the settlement will depend on the mechanical properties of the material as well as the behaviour of plugs along the length of the shafts. The total settlement will be the cumulative settlement under the backfilling sequence and part of settlement will happen during the construction. The deformation properties of the materials are stress-dependent; and they will change during the saturation process and at higher pressures. Prior to closure of shafts detailed design and deformation calculations will be performed.

Because the compaction work can be done in horizontal layers it is possible to achieve higher densities (and thus lower conductivities) in the shafts than can be achieved in horizontal excavations using inclined compaction.

One important consideration to repository backfilling and closure is placement of material in the locations where the excavations intersect a number of highly transmissive zones. These intersections can either have a permeable closure material such as sand or crushed rock. In such cases the water of the fracture zone can flow freely through the backfilled section without impact on adjacent volumes. Another option is to backfill the intersection area with a material with very low permeability, e.g. bentonite blocks. In that case the water in the fracture zone flows around the shaft but there are potential issues associated with this approach (e.g. erosion during placement and longer-term loss of materials into the fracture zone). The first alternative, illustrated in Figure 4-1, is assessed to conform to the design premises and to be the most reliable.

To handle inflowing water in the ramp and shafts drainage systems and temporary plugs are foreseen. Water that flows along the walls in the ventilation and lift shafts can be taken care of at the connections between the ramp and these shafts. In the skip shaft and the outer ventilation shaft this means is not available. Therefore measures will be designed, constructed and tested.



*Figure 4-1. Concept with permeable closure material where a shaft intersects a highly transmissive zone.*

Based upon experience from the backfilling trials e.g. in the Prototype Repository and the Backfill and Plug Test SKB's opinion is that development work on reliable methods for production and installation of closure in ramp and shafts will be finished in good time before the methods have to be applied /Gunnarsson et al. 2004/.

## 4.5 Top sealing

The reference design for the top sealing is to fill ramp and shafts with crushed rock and rock blocks, i.e. essentially the same material that is used for the closure of the central area.

The uppermost 50 m of the ramp and shafts is sealed with very coarse crushed rock that is effectively compacted. The activities involved are on the whole the same as for closure of the central area. The shallowest parts of ramp and shafts will be filled with fairly well fitted blocks of crystalline rock. These rock blocks are taken from building stone quarries and are shaped to fit to each other at the location.

## 4.6 Borehole sealing

Borehole sealing can be made at nearly any time and as long as the activities are adapted to the monitoring plan. Holes extending from repository tunnels, rooms etc must be plugged before the rooms are backfilled and closed.

Sealing of boreholes comprise the following activities /Pusch and Ramqvist 2007/.

- Remaining old instrumentation and other obstacles like rock fragments are removed if needed.
- If needed the borehole is reamed to its original diameter or to any desired new diameter.
- The borehole walls are stabilised where the borehole pass zones of weakness. This is achieved by widening the borehole and filling it with silica concrete. A hole of the same diameter as the rest of the borehole is drilled through the concrete.
- The borehole geometry is checked by dummy testing
- Perforated copper tubes filled with highly compacted smectite rich clay are installed. A practical solution for use of copper tubes implies 24 m long segments consisting of jointed 2.5 m long parts. The tensile strength is sufficient, assuming 4-fold safety, and safe attachment to the drill string can be achieved. The thickness of the tube wall should be 2–3 mm and the outer diameter about 4 mm smaller than the diameter of the hole. Each 24 m segment is lowered into the desired position, i.e. in the space between two stabilised fracture zones, and left there. Several segments can be placed in series without coupling them together. Their weight guarantees that they will rest on the underlying ones without moving in the axial direction.
- Concrete plugs are cast at suitable positions, primarily where the borehole is intersected by fracture zones. For minimizing negative impact on contacting clay plugs the cement content in the concrete will be very low and low-pH cement will be utilised.
- The borehole is plugged.

The method described above to seal boreholes has worked well, but needs to be tested in holes deeper than 500 metres /SKB 2007/.

## 4.7 Plugs

As mentioned in Section 3.6, a number of plugs will be needed for closure of the repository. The design of these plugs will depend on their purpose and conditions at the location where they are needed. Development work will be performed before a detailed description of the production and inspection of these plugs is provided. In the **Backfill production report**, Chapter 9, some important issues to be considered in the production of the plugs are presented.

## 5 Initial state

### 5.1 Introduction

The initial state refers to properties of the engineered barriers once they have been finally placed in the final repository. The initial state of the closure is the state when all closure material in a specific underground opening or borehole is installed and the borehole, rock cavity, shaft or tunnel has been closed. Inflow of groundwater to an underground opening or a borehole and its impact on the closure is not accounted for in the initial state.

For the assessment of the long-term safety it shall be confirmed that the closure at the initial state conforms to the design premises related to the barrier functions in the final repository. This will be done by verification of:

- the conformity of the reference design to the design premises,
- the conformity of the installed closure to the reference design.

The conformity of the reference design to the design premises is discussed in Chapter 3. In this chapter the initial state of the closure is presented. This chapter also presents information regarding the closure materials that are of importance for the assessment of the long-term safety.

### 5.2 Initial state of the closure

The initial state of the closure in the different underground openings and boreholes are presented in Table 5-1. At this stage of development, the closure properties are described as a compilation of reasonable values of some main parameters that can be estimated based on the current results and experiences. For underground openings that shall be filled with compacted clay blocks and pellets the estimations are based on the results presented in the **Backfill production report**. For the underground openings filled with rock material the estimations are based on the studies referred to in Sections 3.2, 3.4 and 4.3 and for the boreholes they are based on /Pusch and Ramqvist 2007/. The volumes of closure materials to be used are based on information in /SKB 2009b/. The data given in Table 5-1 are preliminary and carry a degree of uncertainty.

### 5.3 Material composition

#### 5.3.1 Clay in main tunnels and transport tunnels, the ramp and shafts up to the top seal

The material composition of the clay must be such that the density of the installed closure material has capability to provide the required functions. As illustrated in Figure 3-2 there are several materials that can provide the desired hydraulic conductivity and swelling pressure. The clay used for the reference design of the closure is the same as that used for the backfill in deposition tunnels.

For the construction of plugs low-pH cement will be used. The composition is given in Table 5-3.

#### 5.3.2 Clay for borehole seals

Long term tests described in Section 3.5.2 show that a high degree of swelling and homogenisation is obtained after 10–20 days. The measured mean swelling pressure against the rock for the initial dry density  $1,905 \text{ kg/m}^3$  of the clay plug core is 2,800 kPa in fresh water and 600 kPa in saline water (Äspö). Measurement of the hydraulic conductivity of the clay paste between tube and rock showed that it was lower than  $9 \times 10^{-13} \text{ m/s}$  for saturation and percolation with fresh water and  $2 \times 10^{-12} \text{ m/s}$  for saline water /Pusch and Ramqvist 2007/.

**Table 5-1. The initial state of the closure in the different underground openings and boreholes.**

	Material	Volume (m <sup>3</sup> )	Installed dry density (kg/m <sup>3</sup> )	Density of solid particles (kg/m <sup>3</sup> )	Porosity (%)	Dry weight of installed closure (tonne)	Integrated hydraulic conductivity (m/s)	Assessments and further details
<b>Main tunnels</b>	Clay. (Note 1)	390,000	1,460	2,780	47.5	569,400	< 10 <sup>-8</sup>	See Section 3.1.2 in this report and Section 6.1 and 6.2 in the <b>Backfill production report.</b>
<b>Transport tunnels</b>	Clay. (Note 1)	225,000	1,460	2,780	47.5	328,500	< 10 <sup>-8</sup>	See Section 3.1.2 in this report and Section 6.1 and 6.2 in the <b>Backfill production report.</b>
<b>Central area</b>	Crushed rock	125,000	1,900	2,670	28.8 in the compacted rock fill; 100% in the crown space	237,500	about 10 <sup>-5</sup>	See Section 3.2.2
<b>Ramp</b> (up to level – 200 m)	Clay. (Note 1)	115,000	1,460	2,780	47.5	167,900	< 10 <sup>-8</sup>	See Section 3.3.2 in this report and Section 6.1 and 6.2 in the <b>Backfill production report.</b>
<b>Shafts</b> (up to level – 200 m)	Clay. (Note 1)	25,000	1,460	2,780	47.5	36,500	< 10 <sup>-8</sup>	See Section 3.3.2 in this report and Section 6.1 and 6.2 in the <b>Backfill production report.</b>
<b>Top sealing</b>	Crushed rock	95,000	1,600	2,670	40.1 in the compacted rock fill; 100% in the crown space	152,000	10 <sup>-1</sup>	See Section 3.4.2 in this report and Section 6.1 and 6.2 in the <b>Backfill production report.</b> Due to self compaction 10 cm crown space will develop above the compacted rock fill.
<b>Boreholes</b>	Clay, copper, concrete	For geometry, see Section 3.5.1	1,630 (clay)	2,780	28.1		< 10 <sup>-8</sup>	See Section 3.5.2 in this report.
<b>Plugs</b>	Reinforced concrete							See Section 10.1 in the <b>Backfill production report.</b>

Note 1: The clay used for the reference design is the same as that used for the backfill in deposition tunnels.

### 5.3.3 Copper for borehole seals

The copper is standard ISO R1337 Cu DHP containing 99.9% copper with the density 8,930 kg/m<sup>3</sup>. The tensile strength = 60 MPa and Poisson's ratio = 0.3.

### 5.3.4 Concrete

Silica concrete will be used in parts of the repository where there are chemical restrictions on the concrete (pH < 11). Based on experiences from SKB's borehole sealing tests the composition of a suitable concrete mix is given in Table 5-2.

### 5.3.5 Rock material

The mineral composition of the rock material will be the same as in the surrounding rock. Information on the properties of the rock in Forsmark is found in /Stephens et al. 2007, Section 3.4/.

### 5.3.6 Geometry

The geometry of the tunnels, the central area, the ramp and shafts are given in /SKB 2009b/.

The borehole seals are mainly determined by the dimensions of the drilled holes. The length of surface-based boreholes ranges from a few metres to more than 1,000 metres and the diameter will presumably range from 56 to 120 mm. The tunnel-based boreholes are expected to have a length of a few hundred metres and a diameter of 56 to 76 mm. In the reference design the boreholes are enlarged to get a diameter of 80 mm. The shallowest parts of the boreholes may have larger diameters. Some boreholes may be more or less horizontal. Only boreholes going deeper than the top sealing (thus passing –200 meter) have to be sealed.

**Table 5-2. Concrete composition for plugging of boreholes /Pusch and Ramqvist 2007/.**

Components	Amount (kg/m <sup>3</sup> concrete)	Manufacturer
White cement	60	Aalborg Portland
Silica Fume	60	Elkem
Fine ground α-quartz M300	200	Sibelco
Fine ground cristobalite M6000	150	Sibelco
Superplasticiser Glenium® 51	4.375 (dry content)	Degussa
Granitic aggregates 0–4 mm	1,700	Jehandars grus
Water	244.27	Local

**Table 5-3. Composition for the concrete in the plugs /Backfill production report, Table 7-2/.**

Design parameter	Nominal design [kg/m <sup>3</sup> if not specified]
<b>Binder</b>	
Cement CEM I 42.5 MH/LA/SR	120
Silica fume (densified)	80
<b>Other components</b>	
Water	165
Limestone filler L25	369
Sand 0–8 mm	1,037
Gravel 8–16 mm	558
Superplasticiser Glenium® 51	6.38
Water/cement	1.375 kg/kg
Water/binder	0.825 kg/kg
Water/powder	0.29 kg/kg

## 5.4 Conformity to design premises long-term safety at the initial state

In Chapter 3 the conformity of the reference designs to the design premises stated in **Design premises long-term safety** are discussed. In the previous section the conformity of the installed closure to the reference design is addressed.

SKB's judgement is that the properties (mainly density) of the installed closure that is necessary to conform to the design premises will be achieved.



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