# Ansökan enligt kärntekniklagen

**Toppdokument**
Begrepp och definitioner

- **Bilaga SR**
  Säkerhetsredovisning för slutförvaring av använt kärnbränsle
  - **Bilaga SR-Drift**
    Säkerhetsredovisning för drift av slutförvarsanläggningen
    - **Kapitel 1**
      Introduktion
    - **Kapitel 2**
      Förläggningsplats
    - **Kapitel 3**
      Krav och konstruktionsförutsättningar
    - **Kapitel 4**
      Kvalitetssäkring och anläggningens drift
    - **Kapitel 5**
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    - **Kapitel 6**
      Radioaktiva ämnen i anläggningen
    - **Kapitel 7**
      Strålskydd och strålskärmning
    - **Kapitel 8**
      Säkerhetsanalys
  - **Bilaga SR-Site**
    Redovisning av säkerhet efter förslutning av slutförvaret
    - **Repository production report**
    - **Design premises KBS-3V repository report**
    - **Spent fuel report**
    - **Canister production report**
    - **Buffer production report**
    - **Backfill production report**
    - **Closure production report**
    - **Underground opening construction report**
      - Ramprogram för detaljundersökningar vid uppförande och drift
    - **FEP report**
    - **Fuel and canister process report**
    - **Buffer, backfill and closure process report**
    - **Geosphere process report**
    - **Climate and climate related issues**
    - **Model summary report**
    - **Data report**
    - **Handling of future human actions**
    - **Radionuclide transport report**
    - **Biosphere analysis report**
    - **Site description of Forsmark (SDM-Site)**
- **Bilaga AV**
  Preliminär plan för avveckling
- **Bilaga VP**
  Verksamhet, organisation, ledning och styrning
  Platsundersökningsskedet
- **Bilaga VU**
  Verksamhet, ledning och styrning
  Uppförande av slutförvarsanläggningen
- **Bilaga PV**
  Platsval – lokalisering av slutförvaret för använt kärnbränsle
  - **Comparative analysis of safety related site characteristics**
- **Bilaga MV**
  Metodval – utvärdering av strategier och system för att ta hand om använt kärnbränsle
- **Bilaga MKB**
  Miljökonsekvensbeskrivning
  - **Samrådsredogörelse**
  - **Metodik för miljökonsekvensbedömning**
  - **Vattenverksamhet Laxemar-Simpevarp**
  - **Vattenverksamhet i Forsmark I Bortledande av grundvatten**
  - **Vattenverksamhet i Forsmark II Verksamheter ovan mark**
  - **Avstämning mot miljömål**
- **Bilaga AH**
  Verksamheten och de allmänna hänsynsreglerna

Technical Report

# TR-10-15

# Design, production and initial state of the buffer

Svensk Kärnbränslehantering AB

December 2010

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ISSN 1404-0344
SKB TR-10-15

# Design, production and initial state of the buffer

Svensk Kärnbränslehantering AB

December 2010

*Keywords:* SKBdoc id 1177185, Buffer, Safety report, Design premise, Verification, Verifying analysis, Reference design, Production, Manufacturing, Inspection, Initial state.

A pdf version of this document can be downloaded from www.skb.se.

# 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 Lennart Börjesson, David Gunnarsson, Lars-Erik Johannesson and Esther Jonsson.

# Summary

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

The report provides input on the *initial state* of the buffer 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 input to the operational safety report, **SR-Operation**, on how the buffer shall be handled and installed.

The report presents the design premises and reference design of the buffer and verifies the conformity of the reference design to the design premises. It also describes the production of the buffer, from excavation and delivery of buffer material to installation in the deposition hole. Finally, the initial state of the buffer and its conformity to the reference design and design premises is presented.

### Design premises for the buffer

The design premises for the buffer 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.

In the KBS-3 repository the buffer shall prevent flow of water and protect the canister. In case the containment provided by the canister should be breached the buffer shall prevent and retard transport of radioactive substances from the canister to the bedrock. The properties of the buffer of most importance for its barrier functions are its hydraulic conductivity, swelling pressure and stiffness/strength. These properties are related to its montmorillonite content and density. Design premises for the acceptable montmorillonite content and density are provided from the assessment of the long-term safety which also includes other design premises related to the functions of the buffer within the KBS-3 repository. The buffer shall also be designed to conform to design premises from other engineered barriers, and to production and operation of the repository facility. With respect to technical feasibility the buffer imposes design premises for the deposition holes.

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

The reference material used for the buffer is bentonite clay with a nominal montmorillonite of content of 80–85 wt-% and an acceptable variation within 75–90%. In addition, maximum acceptable content of organic carbon, sulphide and total sulphur are defined for the reference buffer material.

The installed buffer consists of compacted solid blocks below and above the canister and ring shaped blocks around the canister. A gap between the blocks and the deposition hole walls is required to accommodate auxiliary equipment used during the installation to prevent saturation and swelling of the buffer before the backfill in the deposition tunnel is installed. In the reference design the gap is filled with compacted buffer pellets. To allow deposition of the canister, and to achieve an even buffer thickness the centre line of the deposited buffer blocks shall coincide with the centre line of the deposition hole.

The conformity of the reference design to the design premises has been verified by means of calculations and laboratory tests. The reference material composition conforms to the design premises. The average installed density conform to the design premises for all acceptable buffer block and pellet densities, installed geometries and cross sections of the deposition hole. However, if the extremes in accepted deposition hole geometries and block and pellet densities are combined the calculated saturated density will locally, in the most unfavourable part of the cross section, fall outside the accepted interval. In practice this can only occur if there has been a rock fall and solely radial homogenisation over the cross section.

### The production of the buffer

The methods to manufacture buffer components and to inspect their properties are based on established technique from similar industrial applications. The reference method to manufacture blocks is uniaxial compression and the reference method to manufacture pellets is roller compaction of small briquettes. The blocks are installed by controlled placing of the blocks in the deposition hole with a gantry crane. In the period between the installation of the blocks and pellets the blocks are protected by a rubber sheet and the deposition hole is drained. The pellets are poured into the gap when the auxiliary equipment has been removed.

The production of the buffer comprises the main parts excavation and delivery; manufacturing of blocks and pellets and handling and installation. Each main part is divided into several stages. Production-inspection schemes describing the processes performed to alter and/or inspect the buffer design parameters in each stage are included in the report.

Experiences and results from performed material deliveries, test manufacturing and installation show that material, buffer components and installed buffer well within the acceptable variations specified for the reference design can be achieved. To reduce the variation in density of blocks and pellets the manufacturing needs to be adapted to the selected material.

### The initial state of the buffer

The initial state of the buffer is the state when the auxiliary equipment used during installation is removed and all buffer components are installed in the deposition hole. The initial state will depend on the composition of the buffer material, the dimensions and density of the installed buffer components and on the dimensions of the deposition holes. To describe the buffer at the initial state the material composition and buffer component dimensions and densities that can be expected based on current experiences from the production are combined with the deposition hole geometries that can be expected based on experiences from the drilling of deposition holes.

Experiences show that material with montmorillonite content within the interval specified for the reference design and with acceptable content of organic carbon, sulphides and total sulphur can be delivered, and its composition inspected with sufficient accuracy. The inspection methods will be further developed to enhance the accuracy.

The dimensions of the buffer below and above the canister will solely depend on the dimensions of the buffer blocks, and the variation from the nominal thicknesses of 0.5 and 1.5 m respectively is expected to be in the order of single millimetres. The nominal thickness around the canister is 35 cm. The thickness will depend on the diameter of the deposition hole and the placement of the ring shaped blocks within the hole. The variation of the diameter of deposition holes is expected to be in the order of single millimetres and the maximum un-centred placement of the blocks due to deviations in deposition hole straightness has been estimated to ±10 mm. In addition, larger thickness may occur in case of rock fall out.

The installed density will mainly depend on the density of the buffer blocks and the dimensions of the deposition hole. The accepted saturated density is 1,950–2,050 kg/m$^3$. The calculated saturated densities in sections around, above and below the canister are within the range in deposition holes without rock fall out. If spalling occurs in sections around the canister, the blocks are selected randomly and the depth of the rock fall out exceeds the nominal diameter with 40 mm, the calculated saturated density will locally be in the lower range or slightly lower than 1,950 kg/m$^3$. However, seen over the whole cross section the density will lie within the acceptable limits for all acceptable deposition holes. It is possible to increase the installed density by active selection of blocks with high density for the parts of the deposition hole where spalling occurs.

# Sammanfattning


Rapporten ingår i en grupp av *Produktionsrapporter* som redovisar hur KBS-3-förvaret är utformat, producerat och kontrollerat. Gruppen av rapporter ingår i säkerhetsredovisningen för KBS-3-förvaret och förvarsanläggningen.

Rapporten redovisar indata om buffertens *initialtillstånd* för analysen av långsiktig säkerhet, **SR-Site**. Initialtillståndet avser egenskaperna hos de tekniska barriärerna då de slutligt satts på plats i slutförvaret och ej hanteras ytterligare inom slutförvarsanläggningen. Dessutom ger rapporten information till driftsäkerhetsredovisningen, **SR-Drift**, om hur bufferten ska hanteras och installeras.

Rapporten redovisar buffertens konstruktionsförutsättningar och referensutformning, och verifierar referensutformningens överensstämmelse med konstruktionsförutsättningarna. Den beskriver också produktionen av bufferten, från brytning och leverans av material till installation i deponeringshålet. Slutligen redovisas buffertens initialtillstånd och dess överensstämmelse med referensutformningen och konstruktionsförutsättningarna.

## Konstruktionsförutsättningar för bufferten

Konstruktionsförutsättningarna för bufferten 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.

I KBS-3-förvaret ska bufferten hindra vattenflöde och skydda kapseln. Om inneslutningen i kapseln skulle brytas ska bufferten förhindra och fördröja transport av radionuklider från kapseln till berget. De egenskaper hos bufferten som har störst betydelse för dess barriärfunktioner är dess hydrauliska konduktivitet, svälltryck och styvhet/hållfasthet. Dessa egenskaper är relaterade till dess montmorillonithalt och densitet. Konstruktionsförutsättningar för acceptabel montmorillonithalt och densitet ges från analysen av långsiktig säkerhet, som också omfattar andra konstruktionsförutsättningar relaterade till buffertens funktioner i KBS-3-förvaret. Bufferten ska också utformas så den överensstämmer med konstruktionsförutsättningar från andra tekniska barriärer, och från produktion och drift av slutförvarsanläggningen. Med hänsyn till teknisk genomförbarhet ger bufferten konstruktionsförutsättningar för deponeringshål.

## Buffertens referensutformning och dess överensstämmelse med konstruktionsförutsättningarna

Det referensmaterial som används för bufferten är bentonitlera med en nominell montmorillonithalt på 80–85 viktsprocent och en acceptabel variation mellan 75–90 %. Dessutom anges maximalt tillåten halt av organiskt kol, sulfit och total svavelhalt för referensmaterialet.

Den installerade bufferten består av kompakta block under och över kapseln och ringformade block runt kapseln. En spalt mellan blocken och deponeringshålets väggar behövs för att rymma hjälputrustning som används vid installationen, för att förhindra vattenmättnad och svällning av bufferten innan återfyllningen i deponeringstunneln har installerats. I referensutformningen fylls spalten med kompakterade buffertpelletar. För att tillåta deponering av kapseln, och för att åstadkomma en jämn bufferttjocklek, ska buffertblockens centrumlinje sammanfalla med deponeringshålets centrumlinje.

Referensutformningens överensstämmelse med konstruktionsförutsättningarna har verifierats genom beräkningar och provning i laboratorium. Referensmaterialsammansättningen överensstämmer med konstruktionsförutsättningarna. Den genomsnittliga installerade densiteten överensstämmer med konstruktionsförutsättningarna för alla acceptabla densiteter på buffertblock och pellets, installerade geometrier och tvärsnitt på deponeringshål. Om extremerna i acceptabla deponeringshåls-geometrier samt block- och pellets-densiteter kombineras kommer dock den beräknade vattenmättade densiteten att lokalt, i de mest ogynnsamma delarna av tvärsnittet, att ligga utanför det accepterade intervallet. I praktiken kan detta endast förekomma om det har varit ett bergutfall och enbart radiell homogenisering över tvärsektionen.

## Produktionen av bufferten

Metoderna för att tillverka buffertkomponenter och kontrollera deras egenskaper är baserade på etablerad teknik från liknande industriella tillämpningar. Referensmetoden för att tillverka buffertblock är enaxiell pressning och referensmetoden att tillverka pelletar är valskompaktering av små briketter. Blocken är installerade genom styrd placering av blocken i deponeringshålen med en bockkran. Under perioden mellan installationen av blocken och pelletarna skyddas blocken av en gummiduk och deponeringshålet dräneras. Pelletarna hälls ned i spalten när hjälputrustningen har tagits bort.

Produktionen av bufferten omfattar huvuddelarna brytning och leverans, tillverkning av block och pelletar samt hantering och installation. Varje huvuddel är indelad i flera steg. Produktion-kontroll scheman som beskriver de processer som genomförs för att förändra och/eller kontrollera buffertens utformningsparametrar i varje steg finns i rapporten.

Erfarenheter och resultat från genomförda materialleveranser, provtillverkning och -installation visar att material, buffertkomponenter och installerad buffert som ligger väl inom de acceptabla variationer som specificerats för referensutformningen kan åstadkommas. För att reducera variationen i blockens och pelletarnas densitet behöver tillverkningen anpassas till det valda materialet.

## Buffertens initialtillstånd

Buffertens initialtillstånd är tillståndet då hjälputrustningen som använts under deponeringen är borttagen och samtliga buffertkomponenter är installerade i deponeringshålet. Initialtillståndet kommer att bero av sammansättningen på buffertmaterialet, storleken och densiteten på de installerade buffertkomponenterna och på deponeringshålets mått. För att beskriva bufferten vid initialtillståndet kombineras den materialsammansättning och de buffertkomponentstorlekar och densiteter som kan förväntas baserat på nuvarande erfarenheter med erfarenheterna från borrning av deponeringshål.

Erfarenheterna visar att material med montmorillonithalt inom det intervall som specificerats för refernsutformningen och med acceptabelt innehåll av organiskt kol, sulfid och total svavelhalt kan levereras och dess sammansättning kontrolleras med tillräcklig noggrannhet. Kontrollmetoderna kommer att vidareutvecklas för att öka noggrannheten.

Måtten på bufferten under och över kapseln kommer enbart att bero av buffertblockens storlek, och variationen från de nominella måtten på 0,5 respektive 1,5 m förväntas bli i storleksordningen enstaka millimeter. Den nominella tjockleken runt kapseln är 35 cm. Tjockleken kommer att bero av deponeringshålets diameter och placeringen av de ringformade blocken i deponeringshålet. Variationen i deponeringshålens diameter förväntas bli i storleksordningen enstaka millimeter, och den maximala icke-centrerade placeringen av blocken på grund av avvikelser i deponeringshålens rakhet har skattats till ±10 mm. Vidare kan större tjocklek förekomma vid bergutfall.

Den installerade densititen kommer huvudsakligen att bero av buffertblockens densitet och storlek och deponeringshålets mått. Den accepterade vattenmättade densiteten är 1 950–2 050 kg/m$^3$. Den beräknade vattenmättade densiteten i sektioner runt, under och över kapseln ligger inom intervallet i alla deponeringshål utan bergutfall. Om spalling förekommer i sektioner runt kapseln, blocken väljs slumpmässigt och djupet på bergutfallet överskrider 40 mm, ligger den beräknade vattenmättade densiteten lokalt i det lägre området eller till och med något under 1 950 kg/m$^3$. Sett över hela tvärsnittet ligger dock densiteten inom det acceptabla intervallet för alla tillåtna deponeringshål. Det är möjligt att öka den installerade densiteten genom aktivt val block med hög densitet för de delar av deponeringshålet där bergutfall förekommer.

# Contents

# 1 Introduction

## 1.1 General basis

### 1.1.1 This report

This report presents the reference design, production and initial state of the buffer 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 used as references within the set 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 the current knowledge, technology and results from research and development.

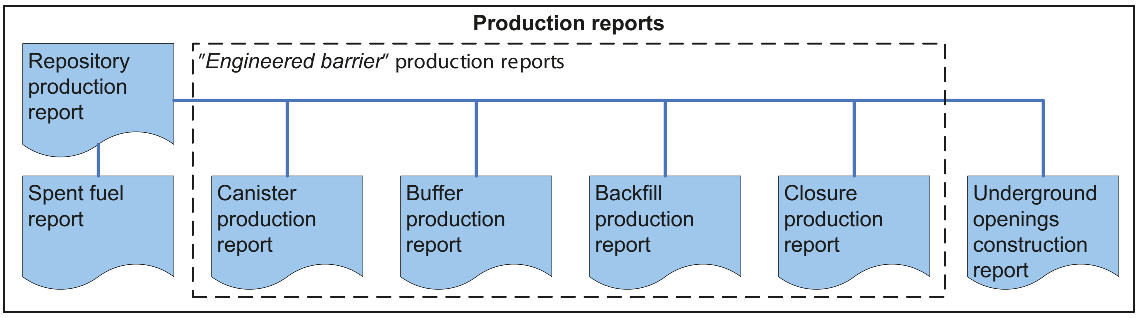



***Figure 1-1.*** *The reports included in the set of reports describing how the KBS-3 repository is designed, produced and inspected. The canister, buffer, backfill and closure reports are commonly referred to as the "Engineered barrier" reports.*

**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 | **Repository production report, 2010.** Design and production of the KBS-3 repository. SKB TR-10-12, Svensk Kärnbränslehantering AB. |
| Design, production and initial state of the canister | Canister production report | **Canister production report, 2010.** Design, production and initial state of the canister. SKB TR-10-14, Svensk Kärnbränslehantering AB. |
| Design, production and initial state of the backfill and plug in deposition tunnels | Backfill production report | **Backfill production report, 2010.** Design, production and initial state of the backfill and plug in deposition tunnels. SKB TR-10-16, Svensk Kärnbränslehantering AB. |
| Design, production and initial state of the closure | Closure production report | **Closure production report, 2010.** Design, production and initial state of the closure. SKB TR-10-17, Svensk Kärnbränslehantering AB. |
| Design, construction and initial state of the underground openings | Underground openings construction report | **Underground openings construction report, 2010.** Design, construction and initial state of the underground openings. SKB TR-10-18, Svensk Kärnbränslehantering AB. |

### 1.1.2 The design of the buffer

The presented design of the buffer 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**.

The reference design of the buffer and the reference methods to produce the buffer presented in this report constitutes a solution that is technically feasible. It is, however, foreseen that the design premises, the design as well as the presented methods for production, test and inspection will be further developed and optimised before the actual construction of the KBS-3 repository facility commences. This particularly concerns properties of the buffer 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 there are 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 buffer

The presented production of the buffer 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 presented handling and installation of the buffer is included in the deposition works in the KBS-3 repository facility. They are based on the deposition and backfill sequences presented in Section 4.1.4 in the **Repository production report**.

## 1.2 Purpose, objectives and delimitations

### 1.2.1 Purpose

The purpose of this report is to describe how the buffer is designed, produced and inspected in a manner related to its importance for the safety of the KBS-3 repository. The report shall provide the information on the design, production and initial state of the buffer required for the long-term safety report, **SR-Site,** as well as the information on how to produce and inspect it required for the operational safety report, **SR-Operation**.

With this report, SKB intends to present the design premises for the buffer and demonstrate how it can be designed, produced and inspected to conform to the stated design premises. The report shall present the reference design and production methods and summarise the research and development efforts that supports that the buffer 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 buffer,
- the reference design of the buffer,
- the conformity of the reference design to the design premises,
- the planned production,
- the initial state of the buffer, 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 **Buffer 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 buffer or the methods to produce them.

The **Buffer production report** also includes the design considerations taken with respect to the application of best available technique with regard to safety and radiation protection. It includes the related design premises for the design and development of methods to produce the buffer. Motivations for the presented reference design and methods as 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 over 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 provide 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 2009/, hereinafter referred to as **Design premises long-term safety.** These design premises constitute a basic input to the design of the buffer.

As stated in Section 1.2 this report shall provide information on the initial state of the buffer for the long-term safety assessment. This report shall also provide data concerning the design of the buffer 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 objectives for the operational safety and radiation protection in the final repository facility and the general description of the facility and its main activities given in Chapters 3 and 5 in **SR-Operation** constitute input to this report.

This report provides information to **SR-operation** on the design of the buffer and the technical systems used to manufacture, handle, install, test and inspect the buffer as well as instructions on where and when inspections shall be performed.

### 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 safety 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, including the integrated process of buffer and backfill installation is provided in the **Repository production report**, Chapter 4. The design premises imposed by the buffer 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 buffer imposes design premises.

## 1.4 Structure and content

### 1.4.1 Overview

The general flow of information in the **Buffer 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, and in Appendix C abbreviations and branch terms used in this report are explained.

### 1.4.2 Design premises

The design premises set out the information required for the design. The design premises for the buffer are presented in Chapter 2 of this report. The chapter is initiated with the definition of the buffer, its purpose and basic design. After that follows a presentation of the barrier functions the buffer 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-tried and reliable technique. Finally, the detailed design premises for the buffer 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 description of the reference design comprises the buffer material and components and the installed buffer. The reference design of the buffer is presented in Chapter 3. The reference design is 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 design. 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. The conformity of the reference buffer to the design premises is presented in Chapter 4.

### 1.4.5 Production of the buffer

The presentation of the production of the buffer is initiated by an overview comprising:

- requirements on the production and design premises for the development of methods to produce, test and inspect the buffer,
- illustration of the main parts and different stages of the production,
- short descriptions of the reference methods for production, test and inspection,
- overview over the design parameters and the corresponding parameters measured in the production to inspect them, and in which stage of the production the design parameters are determined, affected and inspected.

After that follows descriptions of each stage in the production and how the design parameters are processed, affected, tested and inspected within each stage. The current experiences and results from each main part of the production are summarised. The production of the buffer is presented in Chapter 5.

### 1.4.6 Initial state of the buffer

In Chapter 6, 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 the production chapter. Finally, the conformity of the buffer at the initial state to the design premises stated in **Design premises long-term safety** is summarised.

# 2 Design premises for the buffer

In this chapter, the design premises for the buffer are presented. They comprise the barrier functions and properties the buffer 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 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 safety 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. 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 3.4.2 of the **Repository production report** the barrier functions and properties the buffer shall sustain in order to contribute to the functions of the KBS-3 repository are presented. 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 buffer 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 buffer in the KBS-3 repository are based on the results from the latest long-term safety assessment and some subsequent analyses. These design premises for the buffer are provided in **Design premises long-term safety**, and are presented in Section 2.3.1 in this report.

Design premises related to technical feasibility refer to the properties the buffer 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 Section 4.5.2 in the **Repository production report**. In this report, these design premises for the buffer are presented in Section 2.3.2. In Sections 2.4 the design premises the buffer 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 buffer are presented in Sections 2.3.3 in this report. The methodology to substantiate these kinds of design premises is presented in Section 2.5.4 in the **Repository production report**.

### 2.1.2 Definitions, purpose and basic design

The buffer is one of the engineered barriers in the KBS-3 repository. The buffer is a clay containing swelling minerals. The buffer surrounds the canister and fills the space between the canister and the bedrock. The buffer shall prevent flow of water and protect the canister. In case the containment provided by the canister should be breached the buffer shall prevent and retard transport of radioactive substances from the canister to the bedrock.

The buffer blocks installed on top of the canister also serve as radiation protection in the KBS-3 repository facility until the deposition tunnel is backfilled.

The design premises for the buffer are based on that it consists of compacted bentonite clay components to be installed in the deposition hole. Bentonite generally describes clay consisting essentially of montmorillonite, regardless of its origin and occurrence. The design premises are also based on the reference deposition sequence described in Section 4.1.4 in the **Repository production report**.

## 2.2 Barrier functions and design considerations

In this section the barrier functions and design considerations for the buffer 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 that the buffer shall sustain in order for the final repository to maintain its safety (Section 2.2.1) and
- issues that shall be considered when developing a buffer design and methods for manufacturing, installation, testing and inspection (Section 2.2.2.).

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

In order for the KBS-3 repository to contain, prevent or retard the dispersion of radioactive substances, the buffer shall:

- *prevent flow of water (advective transport) in the deposition hole,*
- *keep the canister in its centred position in the deposition hole as long as required with respect to the safety of the final repository.*

To protect the canister and preserve the containment the buffer also shall:

- *have ability to limit microbial activity.*

To contribute to prevent or retard of dispersion of radioactive substances the buffer also shall:

- *prevent that colloids are transported through it.*

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 buffer must:

- *not significantly impair the barrier functions of the other barriers.*

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 barrier system the buffer shall:

- *maintain its barrier functions and be long-term durable in the environment expected in the final repository,*
- *allow the canister to be deposited without causing damages that significantly impair the barrier functions of the canister or buffer.*

The latter is also required with respect to the operational safety of the KBS-3 repository facility.

### 2.2.2 Design considerations

In this section the design considerations that shall be regarded in the design of the buffer and in the development of methods to manufacture, install, test and inspect the buffer and its components are presented. The design considerations mainly affect the development of methods. When a reference design is determined it together with the design considerations form the basis for the detailed requirements on methods to manufacture, install, test and inspect the buffer presented in Section 5.1.1.

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 buffer and methods for manufacturing, installation, test and inspection shall be based on well-tried or tested technique.*

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

- *Buffer with specified properties shall be possible to manufacture and install with high reliability.*
- *The properties of the buffer shall be possible to inspect against specified acceptance criteria.*

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

- *The buffer design and methods for manufacturing, installation, test and inspection shall be cost-effective.*
- *It shall be possible to produce, inspect and install the buffer in the prescribed rate.*

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

## 2.3 Design premises

In this section the design premises for the buffer are given. They constitute a specification for the design of the buffer. The design premises comprise the properties and parameters to be designed and premises for the design 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 based on the barrier functions presented in Section 2.2.1 and the design considerations presented in Section 2.2.2. They are also based on, and constitute a concise summary of, the current results of the design process with its design-safety assessment and design-technical feasibility 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 given as feedback from the technical development are based on the reference designs of the other parts of the KBS-3 repository and the construction, deposition and backfill sequence presented in Section 4.1.4 in the **Repository production report**.

### 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 left hand column of the table the barrier functions which form the basis for the design premises and that were presented in Section 2.2.1 are repeated, the middle column contains the buffer properties and design parameters to be designed and in the right hand column the design premises as stated in **Design premises long-term safety** are given.

The design premises presented in Table 2-1 are based on the presumption that the canister, backfill, deposition holes and tunnels are constructed according to their reference design and conform to the design premises given for them.

**Table 2-1. The barrier functions, the related properties and design parameters to be designed and the design premises for the buffer.**

| Barrier function | Property and design parameters to be designed | Design premises long-term safety |
|---|---|---|
| *The buffer shall prevent flow of water (advective transport) in the deposition hole.* | Properties that affect swelling pressure and hydraulic conductivity.<br>Material composition: *montmorillonite content.*<br>Installed density: *bulk density, water content and dimensions of the installed buffer components.* | *Fulfilled for the densities required with respect to capacity to eliminate microbes and not damage the canister for expected shear movements.*<br>(The conductivity should be less than $10^{-12}$ m/s and the swelling pressure should exceed 1 MPa.) |
| *The buffer shall have ability to limit microbial activity.* | Properties that affect swelling pressure.<br>Material composition: *montmorillonite content.*<br>Installed density: *bulk density, water content and dimensions of the installed buffer components.* | *The initially deposited buffer mass should be such that it corresponds to a saturated buffer density in the volume initially filled with buffer that is higher than 1,950 kg/m$^3$, i.e. sufficiently high to ensure a swelling pressure of 2 MPa with margin for possible loss of material.*<br>*The montmorillonite content of the dry buffer material shall be 75–90% by weight.*<br>(Elimination of microbes will occur at swelling pressures exceeding 2 MPa.) |
| *The buffer shall prevent that colloids are transported through it.* | Properties that affect tortuosity and size of pores.<br>Installed density: *bulk density, water content and dimensions of the installed buffer components.* | *Fulfilled for the densities required with respect to capacity to eliminate microbes and not damage the canister for expected shear movements.*<br>*(*The judgement is that colloid transport in the buffer can be neglected if the density at saturation exceeds 1,650 kg/m$^3$.*)* |
| *The buffer shall keep the canister in its centred position in the deposition hole as long as required with respect to the safety of the final repository.* | Properties that affect swelling pressure.<br>Material composition: *montmorillonite content.*<br>Installed density: *bulk density, water content and dimensions of the installed buffer components.* | *Fulfilled for the densities required with respect to capacity to eliminate microbes and not damage the canister for expected shear movements.*<br>(The swelling pressure shall exceed 0.2 MPa.) |
| *The buffer must not significantly impair the barrier functions of the other barriers.* | Properties that affect swelling pressure and its distribution, stiffness and shear strength.<br>Material composition: *montmorillonite content.*<br>Installed density: *bulk density, water content and dimensions of the installed buffer components.*<br>Installed geometry: *dimensions and position of blocks and width of pellet filled gap.* | *The initially deposited buffer mass should be such that it corresponds to a saturated buffer density in the volume initially filled with buffer that is less than 2,050 kg/m$^3$ to prevent too high shear impact on canister.*<br>*The montmorillonite content of the dry buffer material shall be 75–90% by weight.* |
| | Properties that affect the chemical conditions around the canister.<br>Material composition: *organic carbon, sulphide, total sulphur.* | *The content of organic carbon should be less than 1 wt-%*<br>*The sulphide content should not exceed 0.5 wt-% of the total mass, corresponding to approximately 1% of pyrite.*<br>*The total sulphur content (including the sulphide) should not exceed 1 wt-%.* |
| *The buffer shall maintain its barrier functions and be long-term durable in the environment expected in the repository.* | Properties that affect the ability of the buffer to uphold and maintain the minimum swelling pressure, maximum hydraulic conductivity, acceptable stiffness and shear strength, tortuosity and size of pores and chemical composition.<br>Installed geometry: *dimensions and position of blocks and width of pellet filled gap.* | *The buffer dimensions used as reference dimensions in SR-Can shall be used, in addition to other requirements affecting the buffer and deposition hole geometry* (i.e. initially deposited mass and saturated density). |

| Barrier function | Property and design parameters to be designed | Design premises long-term safety |
|---|---|---|
| | Properties that affect the ability of the buffer to uphold and maintain the minimum swelling pressure, maximum hydraulic conductivity, acceptable stiffness and shear strength, tortuosity and size of pores and chemical composition.<br>Material composition: *montmorillonite content.*<br>Installed density: *the bulk density, water content and dimensions of the installed buffer components.* | *After swelling the buffer should uphold the minimum swelling pressure 2 MPa and the hydraulic conductivity should not exceed $10^{-12}$ m/s independently of dominating cation and for chloride concentrations up to 1 M.*<br>*After swelling the shear strength of the buffer must not exceed the strength used in the verifying analysis of the canisters resistance against shear loads*. |
| | Properties that affect the heat transport through the buffer.<br>Material composition: *montmorillonite content.*<br>Installed density: *the bulk density, water content and dimensions of the installed buffer components.*<br>Installed geometry: *dimensions and position of blocks and width of pellet filled gap.* | *The buffer geometry (e.g. void spaces), water content and distances between deposition holes should be selected such that temperature in the buffer is <100°C.* |

### 2.3.2 Design premises from the other engineered barriers

In this section the design premises on the buffer imposed by the other engineered barriers are given. Only the canister provides design premises for the buffer. This section only comprises design premises related to technical feasibility. Interdependencies between the buffer and other parts of the final repository occurring after the initial state are considered in **Design premises long-term safety**.

From the function that the buffer shall allow the canister to be deposited without causing damages that significantly impair the barrier functions of the canister or buffer follows.

- Required property: *The installed buffer shall contain a hole centred with respect to the vertical centre line of the deposition hole and large enough to allow deposition of the canister without impairing the canister or buffer.*
- Design premises: *The outer dimensions of the reference canister.*

The required function also results in design premises imposed by the buffer on deposition holes, see Section 2.4.1.

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

In this section the design premises for the buffer and its components related to their production and the operation of the KBS-3 repository facility are given. (Design premises for the methods to manufacture, install, test and inspect the components are given in Section 5.1.1). In addition to the design considerations presented in Section 2.2.2, they are based on the current reference sequence for deposition of the canister and installation of the buffer and backfill presented in the **Repository production report,** Section 4.1.4.

The design premises for the buffer and its components related to the production and operation are presented in Table 2-2. In the leftmost column the design considerations from Section 2.2.2, are repeated.

**Table 2-2. Design premises for the buffer and its components related to the production and operation.**

| Design consideration | Required property | Design premises |
|---|---|---|
| *The buffer and methods for manufacturing, installation, test and inspection shall be based on well-tried or tested technique.*<br>*Buffer with specified properties shall be possible to prepare and install with high reliability.* | *The buffer material must be possible to compact to required density.* | – |
| | *The dimensions, weight and water content of the buffer components shall be designed so that manufacturing, handling and installation can be performed with high reliability.* | *The reference sequence for deposition of the canister and installation of the buffer and backfill.*<br>*The reference design of deposition holes.* |

## 2.4 Design premises imposed by the buffer

In this section the design premises imposed by the buffer on the other engineered barriers and the underground openings in order to achieve a technically feasible design and reliable production are presented. The buffer provides design premises for the deposition holes, they are further discussed and verified in the **Underground openings construction report**.

### 2.4.1 Deposition holes

In order to determine the density, dimensions and water content of buffer components required for the buffer to conform to the design premises from long-term safety the geometry of the deposition holes must be known. Further, both to determine density and to achieve a reliable deposition, the variation in deposition hole geometry must be limited and known.

The design considerations stating that: buffer with specified properties shall be possible to install with high reliability and that it shall be based on well-tried or tested technique, together with the current results of the development of the buffer and methods for excavation of deposition holes forms the basis for the design premises presented in Table 2-3.

The design of the part of the deposition hole where the buffer is going to be installed is the result of an iterative design process with the objective to establish a solution where the deposition holes can be constructed and the specified buffer density can be achieved with high reliability and so that mishaps in connection with the nuclear operations are prevented. Since the deposition hole geometry must be known to determine a buffer design and since the buffer is an important engineered barrier in the KBS-3 repository the required geometry of the deposition holes is stated as a design premise from the buffer on the deposition hole, and not vice versa. The resulting design premises imposed on the deposition holes by the buffer are given in Table 2-3 and the resulting nominal geometry and acceptable variations are illustrated in Figure 2-1.

The stated deviations in radii include all possible causes e.g. alignment, straightness, displacements and rock fall out. In Figure 2-1 the maximum deviation in alignment in one direction is illustrated. In practice different causes can be combined and the deviations in radii vary along the deposition hole (see Figure 6-1). The principle is that the minimum and maximum radii of all cross sections projected in the horizontal plane shall lie within the blue circle. In such a projection the radius of the free space is less than 0.925 m and at least 0.84 m in all directions, i.e. the space is sufficient to host the buffer blocks and a gap required for auxiliary equipment.

**Table 2-3. Design premises imposed on the deposition holes by the buffer.**

| Required property | Design premises |
|---|---|
| *The diameter and height of the deposition hole shall allow sufficient room to accommodate the buffer and canister.* | *Nominal thickness of the buffer around, below and above the canister (0.35 m; 0.5 m and 1.5 m).*<br>*Nominal dimensions of the canister,* ***Canister production report****, Section 3.2.3.*<br>*Resulting diameter 1.75 m*<br>*Resulting height 6.68 m* |
| *The deposition hole bottom inclination shall with respect to the dimensions of the buffer blocks allow deposition of the canister.* | *The inclination over the part of the cross section where the bottom buffer block is placed shall be less than 1/1,750.* |
| *Variations in deposition hole geometry must not be larger than to allow deposition of buffer according to specification.* | *In that part of the deposition hole where buffer is going to be deposited the maximum area in each horizontal cross section must not exceed the nominal cross section by more than 7%.*<br>*In that part of the deposition hole where buffer is going to be installed the diameter shall be at least 1.745 m. The nominal diameter is 1.75 m.*<br>*From the height of the buffer block on top of the canister to the bottom of the deposition hole the radius from a vertical line in the centre of the deposition hole shall be at least 0.84 m.*<br>*From the height of the buffer block on top of the canister to the bottom of the deposition hole the radius from a vertical line in the centre of the deposition hole must not exceed 0.925 m.* |

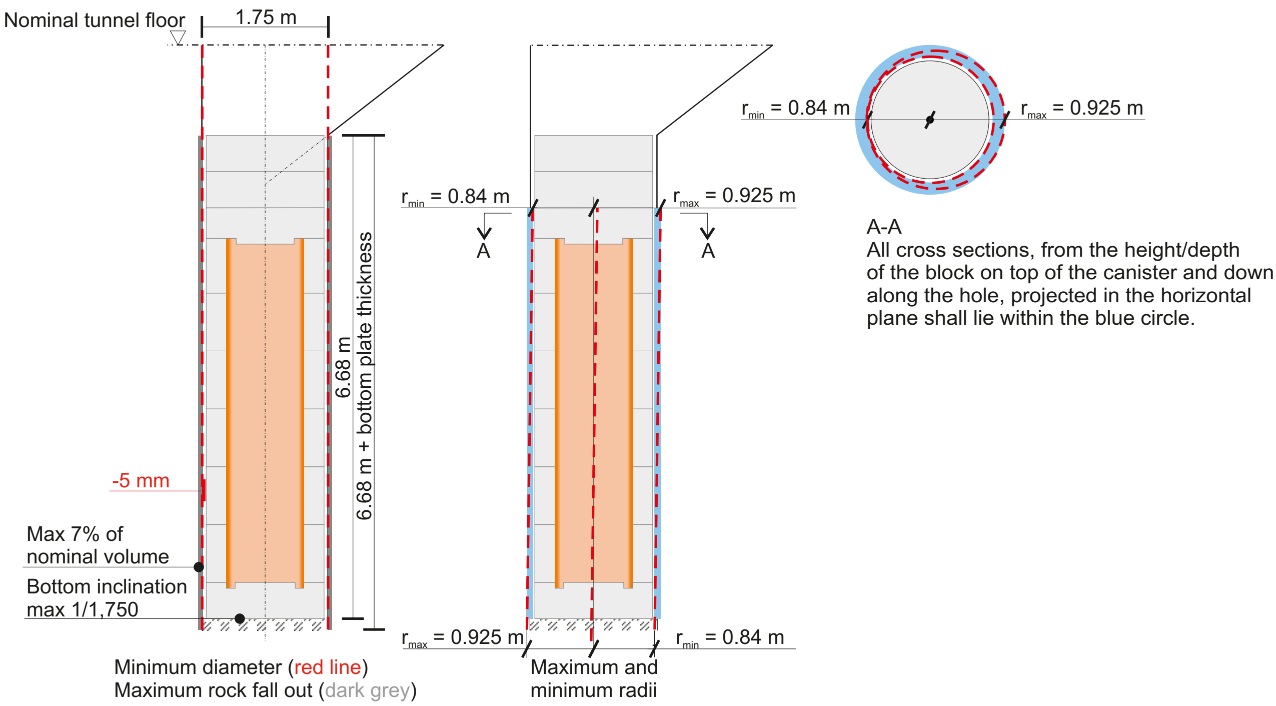



***Figure 2-1.*** *Nominal deposition hole geometry (black thin line) and acceptable deviations in geometry (red dotted line). The scale of the deviations in section A-A is enlarged with a factor of two. The acceptable deviations concern the part of the deposition hole where the buffer is going to be installed. The top of the deposition hole is designed with respect to operational requirements.*

# 3 Reference design of the buffer

The reference design is the currently valid design of the buffer. The reference design shall conform to the design premises presented in Section 2.3 and it shall be technically feasible to produce by applying the methods for preparation and installation described in Chapter 5.

The reference design is described by a set of *design parameters* for which nominal values and acceptable variations are given. In the verification of the reference design it shall be shown that the buffer for the specified values of the design parameters conforms to the design premises. The design parameters shall be inspected in the production to verify that the produced buffer at the initial state conforms to the reference design and to provide an estimation of the actual properties of the buffer at the initial state.

## 3.1 Buffer material and components

### 3.1.1 Material composition

The reference buffer material is a bentonite clay with the material composition specified in Table 3-1. Examples of commercial bentonites with this material composition are MX-80 and Ibeco-RWC (Deponit CA-N) which were analysed in SR-Can.

According to the design premises in Table 2-1 the montmorillonite content in the buffer material must be sufficient for the buffer to provide the required functions in the final repository. The barrier functions of the buffer (see Section 2.2.1 and Table 2-1) are to limit flow of water, have ability to limit microbial activity, prevent colloid transport, keep the canister in place, not significantly impair the barriers and to be long-term durable. The capability of the buffer to maintain these barrier functions will depend on its swelling pressure, hydraulic conductivity, stiffness and content of substances that may be harmful for the barriers.

In **Design premises long-term safety** the montmorillonite content, the amount of organic carbon, the sulphide and total sulphur content are used to specify the buffer material.

High content of swelling mineral will result in high swelling pressure. The swelling mineral of bentonite clays is usually montmorillonite. High-quality commercial bentonites normally contain over 80% of montmorillonite. At a density relevant for the repository, this is expected to give various bentonites similar properties regarding swelling pressure, hydraulic conductivity and to some extent stiffness. The swelling properties and stiffness is also dependant on the magnitude and the position of the layer charge and on the type of charge compensating cation. In the final repository the cation may be exchanged. However, the swelling pressure, hydraulic conductivity and stiffness of the buffer must still conform to the design premises. The montmorillonite content is chosen to specify the bentonite clay since it is the material property of most importance for its swelling pressure and hydraulic conductivity.

**Table 3-1. Reference buffer material.**

| Design parameter | Nominal design (wt-%) | Accepted variation (wt-%) |
|---|---|---|
| Montmorillonite content | 80–85 | 75–90 |
| Sulphide content | Limited | < 0.5 |
| Total sulphur content (including the sulphide) | Limited | < 1 |
| Organic carbon | Limited | < 1 |

Apart from montmorillonite bentonite clays contain accessory minerals. Typical accessory minerals may be other clays, feldspars, quartz, cristobalite, gypsum, calcite and pyrite. Pyrite contains sulphide and sulphur which may cause canister corrosion. Bentonite clays may also contain organic carbon that may impact the radionuclide transport. A bentonite with a high content of accessory minerals with high solubility (e.g. halite), which easily could be transported out from the deposition hole and result in a loss of density, would be unsuitable for the KBS-3 application. However, such minerals have not been found in the investigated bentonites. The identified accessory minerals can generally be considered as "inert". The amount of organic carbon, the sulphide and total sulphur are chosen to specify the quality of the bentonite clay since these substances may facilitate the radionuclide transport or cause canister corrosion.

High grade commercial bentonites generally fulfill the conditions for the content of montmorrillonite, organic carbon, sulphides and total sulphur specified in **Design premises long-term safety** and in Table 3-1.

In the production the content of montmorrillonite, organic carbon, sulphides and total sulphur shall be inspected and their conformity to the reference design at the initial state shall be verified. In addition to these substances the dominant cation and the cation exchange capacity (CEC) are important material parameters. Dominant cation, CEC and content of accessory minerals will vary between different bentonites, in Table 3-2 the content in MX-80 and Ibeco RWC is specified. SKB plans to measure and document these material parameters in the production. However their conformity to the specified contents must not be verified for the initial state.

### 3.1.2 Material ready for compaction

In Table 3-3 the water content of the reference conditioned material ready for compaction is specified and Figure 3-1 shows the granule size distribution of the material ready for compaction.

**Table 3-2. Dominant cation, CEC and accessory minerals for MX-80 and Ibeco-RWC /Karnland et al. 2006/.**

| Parameter | Nominal content MX-80 | Nominal content Ibeco RWC |
|---|---|---|
| Cation (%) | | |
| Na | 72 | 24 |
| Ca | 18 | 46 |
| Mg | 8 | 29 |
| K | 2 | 2 |
| CEC (meq/100g) | 75 | 70 |
| Calcite + Siderite (wt-%) | 0–1 | 10 |
| Quartz (wt-%) | 3 | 1 |
| Cristobalite (wt-%) | 2 | 1 |
| Pyrite (wt-%) | 0.07 | 0.5 |
| Mica (wt-%) | 4 | 0 |
| Gypsum (wt-%) | 0.7 | 1.8 (anhydrite) |
| Albite (wt-%) | 3 | 0 |
| Dolomite (wt-%) | 0 | 3 |

**Table 3-3. Reference processed material ready for compaction (based on MX-80).**

| Design parameter | Nominal design | Accepted variation |
|---|---|---|
| Granule size distribution | See Figure 3-1 | See Figure 3-1 |
| Water content (wt-%) | 17 | ±1 |

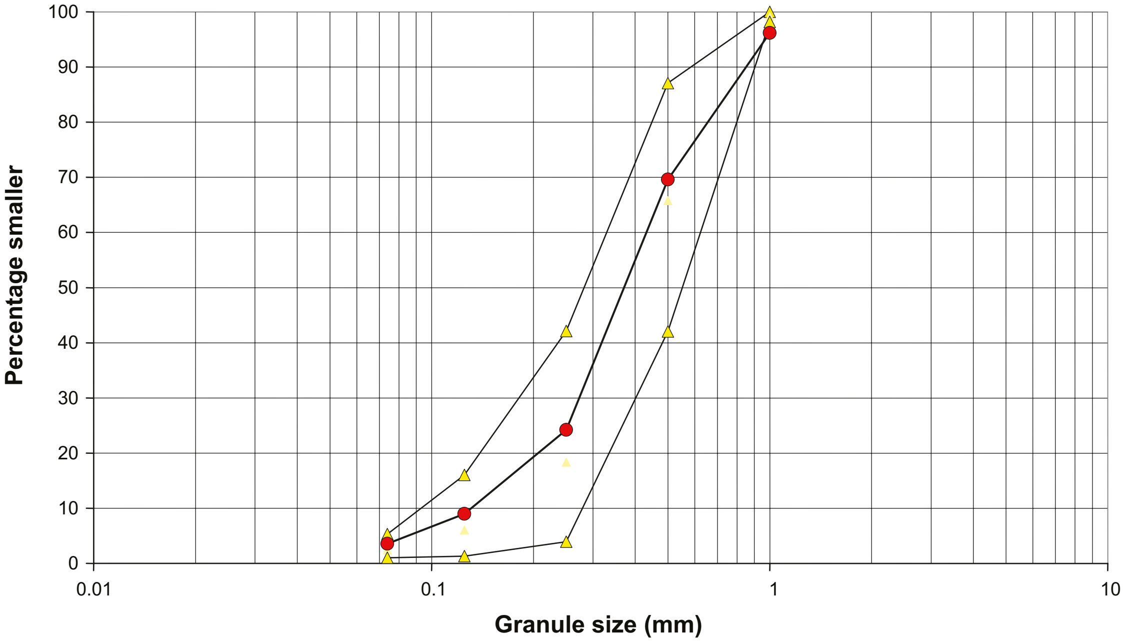



***Figure 3-1.*** *Nominal granule size distribution and acceptable variation (based on MX-80).*

The design premises considered in the specification of the reference material ready for compaction are that it must be possible to compact blocks and pellets to the required density and that the production shall be reliable, see Table 2-2. Further the blocks shall be homogenous and free from cracks and damages. The density and homogeneity of the produced blocks and pellets will depend on the granule size distribution and water content of the material to be compacted and on the compaction pressure. To achieve high reliability in the production the granule size distribution and water content must be specified. The specification of the material ready for compaction will depend on the selected bentonite material. The specification given in Table 3-3 and Figure 3-1 is valid for MX-80, if another material is chosen minor adjustments may be required.

### 3.1.3 Blocks and pellets

The reference design of the blocks and pellets are presented in Table 3-4. The densities are given as bulk densities since it is the bulk densities that are going to be inspected in the production. In **Design premises long-term safety** the saturated density is specified. The relations between bulk, dry and saturated densities are presented in Appendix A. The dry density of a clay, or any soil material, is determined by its grain density and porosity. In practical applications the bulk density and water content of the material are measured. The measured bulk density depends on the water content, grain density and porosity. To determine the final saturated density of an initially unsaturated material the water content, grain density and porosity must be known. For a saturated material the density of the dry material and porosity can be calculated if the water content is known. The saturated densities specified in **Design premises long-term safety** are based on a grain density in the range of 2,750–2,780 kg/m$^3$. This is the grain density of many bentonite clays. A different grain density could require an adjustment of the density interval.

The blocks and pellets are designed to conform to the design premises for installed density and geometry presented in Table 2-1, the design premises from the other barriers presented in Section 2.3.2 and the design premises related to production and operation presented in Table 2-2.

In order to conform to the density interval given in **Design premises long-term safety** (Table 2-1) in all sections of the deposition hole the ring shaped blocks surrounding the canister and the solid blocks must be compacted to different densities. Further the gap between the blocks and the rock surface must be filled with pellets with the specified density of loose filling. The dimensions of the blocks are determined by the dimensions and densities given in **Design premises long-term safety** and by the dimensions of the deposition hole and the space required for auxiliary equipment used

**Table 3-4. Reference design of buffer blocks and pellets.**

| Design parameter | Nominal design | Accepted variation |
|---|---|---|
| **Solid bocks** | | |
| Bulk density (kg/m$^3$) | 2,000 | ±20 |
| Water content | As in the material ready for compaction. | As in the material ready for compaction. |
| Dimensions (mm) | Height: 500 | ±1 |
| | Outer diameter: 1,650 | |
| **Ring shaped blocks** | | |
| Bulk density (kg/m$^3$) | 2,070 | ±20 |
| Water content | As in the material ready for compaction. | As in the material ready for compaction. |
| Dimensions (mm) | Height: 800 | ±1 |
| | Height of top block: 760 | |
| | Outer diameter: 1,650 | |
| | Inner diameter: 1,070 | |
| **Pellets** | | |
| Dimensions (mm) | 16×6×8 | – |
| Bulk density loose filling (kg/m$^3$) | 1,035 | ±40 |
| Water content | As in the material ready for compaction. | As in the material ready for compaction. |

to achieve a reliable installation of the buffer. The dimensions of the ring shaped blocks are also determined by the dimensions of the canister.

The canister lids and bottoms are not flat but contain hollows or edges see the **Canister production report,** Section 3.2.3. These volumes must be filled with bentonite. This is done by specially machined solid blocks according to Figure 3-2. The bottom blocks are machined so the central part of the canister can rest on the upper surface of the bottom block after deposition and the top blocks are machined so they fill the hollow in the lid. Furthermore, the upper most ring shaped block is adjusted in height so that the top solid blocks rest on the ring shaped blocks.

The height of the blocks is limited since it may be difficult to press higher homogenous blocks. Another reason for not making higher blocks is to limit the weight of each block. Less weight makes the blocks easier to handle and the risk of causing large stresses in the blocks during the transportation and installation is reduced.

The dimensions of the pellets shall be such as they can be installed in the gap in a reliable way. The dimensions need to be specified and inspected for the production but regarding the installed density it is sufficient to specify the bulk density of loose filling. The dimensions and density of individual pellets may very well be altered as long as they can be poured into the gap and yield the required bulk density of loose filling.

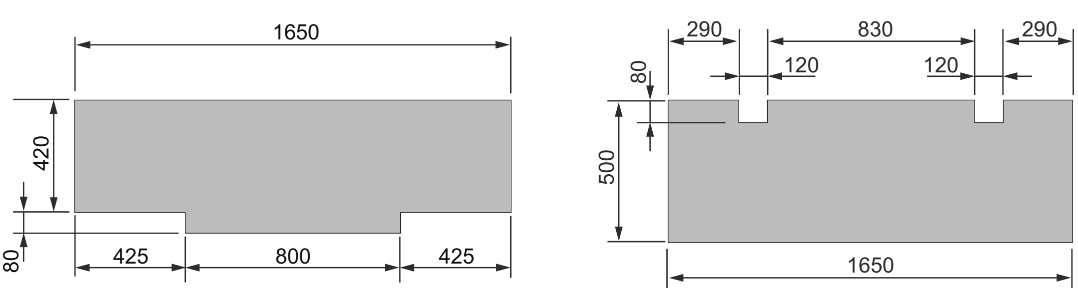



*Figure 3-2. The nominal dimensions of the blocks placed on top (left) and beneath (right) the canister. The accepted deviation is ±1 mm for all specified dimensions.*

## 3.2 Installed buffer

The reference geometry of the installed buffer is illustrated in Figure 3-3. The installed buffer consists of altogether one bottom block, six ring shaped blocks around the canister and three solid blocks on top of the canister. The centre line of the buffer blocks shall coincide with the centre line of the deposition hole. The gap between the blocks and the rock surface of the deposition hole is filled with pellets.

The geometry and density of the installed buffer shall conform to the density interval and dimensions for the saturated buffer given in **Design premises long-term safety**. Further the hole within the ring shaped blocks must be centred in the deposition hole and straight so that the deposition of the canister can be performed in a safe way.

To allow a reliable installation of the buffer there must be a gap between the buffer blocks and the deposition hole walls sufficient for the blocks to be installed without getting damaged. The gap need to be wide enough to hold auxiliary equipment required to keep the blocks dry and pump out water so the buffer does not start to swell and expand until the deposition tunnel is backfilled.

The main reason for using pellets in the outer gap is to ensure that the density after saturation is sufficiently high for the reference geometry of the blocks and deposition hole. If pellets are not used the gaps will have to be narrow to ensure high enough final density of the buffer. Narrow gaps lead to strict limitations of the acceptable variations of the geometry of the deposition holes and high precision of the installation technique. The pellet filling also prevents backfill material from falling into the deposition hole during the backfilling of the deposition tunnel, and may also to some extent, mitigate the impact of thermally induced spalling in the deposition hole.

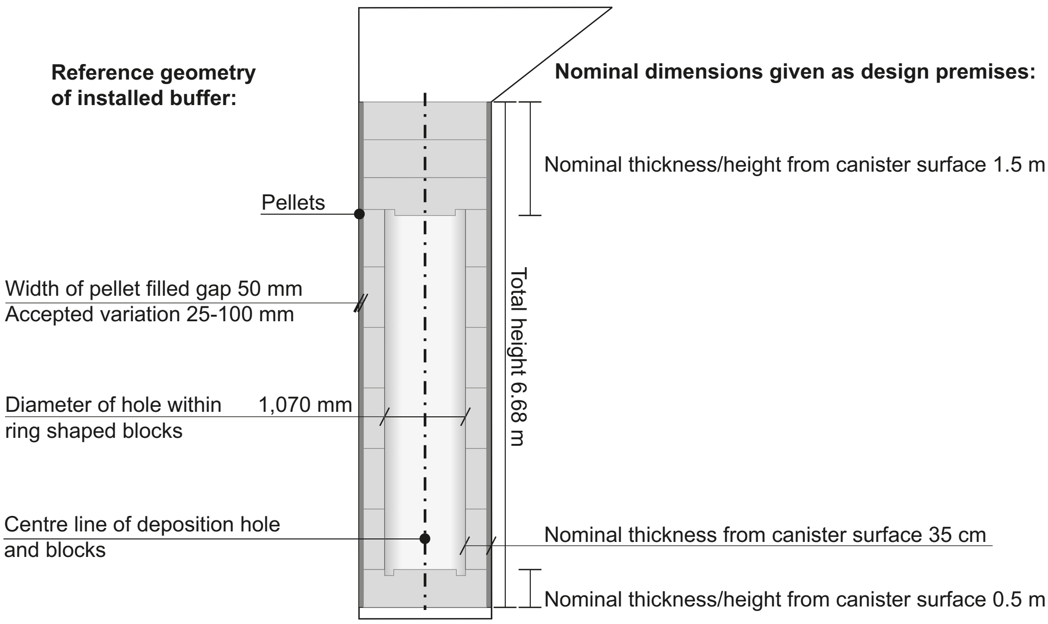



***Figure 3-3.*** *Reference geometry of the installed buffer and the nominal dimensions given as design premises. Note that the installed dimensions and density will depend on the geometry of the deposition hole. (The upper part of the deposition hole is regarded as part of the deposition tunnel and will be backfilled, see Figure 5-13).*

# 4 Conformity of reference design to design premises

The objective of this chapter is to verify that the reference buffer design, i.e. the material composition, the densities, dimensions and water contents presented in Sections 3.1 and 3.2 conform to the design premises presented in Section 2.3. In Section 2.3 the design premises for the buffer are divided into design premises:

- related to the barrier functions in the KBS-3 repository,
- from the other engineered barriers,
- related to the production and operation.

Design premises related to the barrier functions in the KBS-3 repository are stated in **Design premises long-term safety**. In summary the following shall be verified for the reference design with respect to the long-term safety:

- the required montmorillonite content and the contents of organic carbon, sulphide and total sulphur are the specified,
- the initially installed buffer mass corresponds to a saturated density between 1,950 $kg/m^3$ and 2,050 $kg/m^3$,
- the dimensions are the same as in SR-Can,
- the geometry and water content of the buffer will not result in temperature above 100°C in the buffer,
- after saturation the swelling pressure shall be at least 2 MPa and the hydraulic conductivity should not exceed $10^{-12}$ m/s independently of dominating cation and for chloride concentrations up to 1 M,
- after swelling the shear strength of the buffer must not exceed the strength used in the verifying analysis of the canisters resistance against shear loads.

With respect to design premises from the other barriers it shall be verified that:

- the hole within the installed buffer rings is large enough for deposition of the canister.

Finally with respect to the production and operation it shall be verified that:

- it is possible to compact the material to the required density,
- the blocks and pellets are designed so that they can be manufactured, handled and installed with high reliability.

In the following sections verifying analyses for each of these issues are presented. The issues related to the barrier functions are presented in separate sections and the issues related to design premises from other barriers and production and operation are presented commonly in one section.

## 4.1 Material composition

The montmorillonite content and the contents of organic carbon, sulphide and total sulphur specified for the reference design are those stated in **Design premises long-term safety**. In SR-Can it was verified that the specified montmorillonite content is sufficient for the buffer to maintain its barrier functions and that the specified contents of sulphide and total sulphur will not result in unacceptable canister corrosion and the content of organic carbon will not impact the radionuclide transport. No further analyses are provided in this report.

When a bentonite product and supplier is selected it shall be verified that bentonite according to the specification in Table 3-1 can be delivered from the selected deposit. SKB will develop routines for qualification of suppliers as part of a quality assurance programme for the buffer, see Section 5.1.4.

## 4.2 Initially installed mass and density at saturation

It shall be verified that the initially installed buffer mass corresponds to the saturated densities specified in **Design premises long-term safety**, i.e. the saturated density shall be at least 1,950 kg/m$^3$ to prevent bacteria from surviving and below 2,050 kg/m$^3$to prevent too high shear impact on canister. The installed mass depends on the weight of the blocks and pellets and the saturated density depends on:

- the dimensions of the deposition hole, the installed blocks and the canister,
- the densities and water contents of the blocks and the pellets filling.

In the following these parameters are varied and their impact on the saturated buffer density has been calculated. The variations in each horizontal cross section are calculated assuming that no axial swelling of the buffer is taking place. The calculations in each part of the horizontal section are made by assuming the same radius in the whole section. The amount of solid bentonite from pellets and blocks in each section is then determined. Finally, the saturated density is calculated.

### 4.2.1 Variations in deposition hole geometry

Due to variations in the deposition hole geometry the density of the buffer after saturation will vary along the deposition hole. The variation is calculated as described in the previous section, and the results are plotted in Figure 4-1 where the width of the pellets filled outer gap is varied for two different sections of the deposition hole:

- around the canister – yellow line and
- above and under the canister – green line.

The figure shows that with the nominal deposition hole and the nominal dimensions, water content and dry densities of the blocks the average density (blue line) at saturation ($\rho_m$) of the buffer around the canister is 2,010 kg/m$^3$. Corresponding density for the buffer under and above the canister is 2,036 kg/m$^3$.

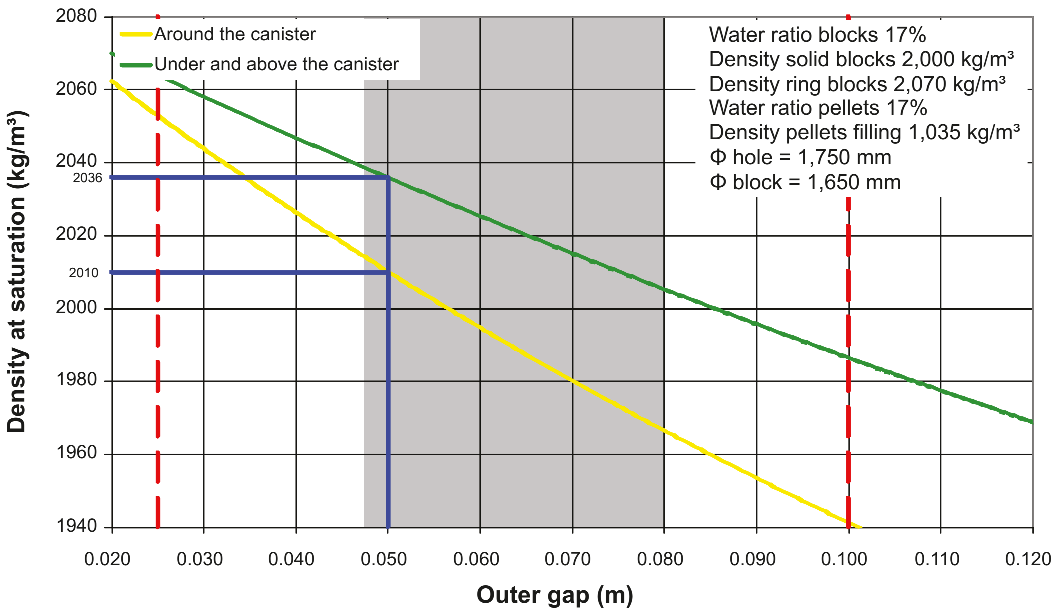



*__Figure 4-1.__ The calculated saturated density of the buffer as function of the width of the pellet filled gap between the bentonite blocks and the wall of the deposition hole. (Blue line: nominal gap. Red dashed lines: acceptable width of gap. Grey shaded area: corresponding to minimum diameter (1,745 mm) and diameter (1,810 mm) of a circle with maximum acceptable area).*

The acceptable variations in the width of the pellet filled gap between the buffer blocks and rock wall is 25–100 mm. The maximum acceptable increase in cross-sectional area in relation to the nominal is 7%. Postulating a circular area this corresponds to a maximum diameter equal to 1,810 mm, which in turn corresponds to a gap width of 80 mm.

The possible causes of variation in gap are illustrated in Figure 4-2. They can be a result of the placement of the blocks within a circular cross section without rock fall out or a result of rock fall out, or a combination of the two. The stack of buffer blocks has to be straight in order to allow deposition of the canister. If the deposition hole is oblique or inclined, the stack of buffer blocks has to be placed un-centred in some sections of the deposition hole. This is illustrated in the leftmost panel in Figure 4-2 for a deposition hole with nominal diameter. The maximum accepted deviation in deposition hole straightness, or buffer block offset, is given by the accepted variation in radius. Another cause of alterations in the width of the pellet filled gap is the occurrence of rock fall out. The possible shape of a rock fall out is illustrated in the right panel of Figure 4-2. The area of such a cross section will always be smaller than the maximum accepted. The maximum accepted radius in connection to rock fall out is 925 mm. For a nominal cross section this corresponds to a local increase of the radius of 50 mm, and a total width of the pellet filled gap of 100 mm.

The acceptable variations in gap and deposition hole radii and diameter will result in a variation of the density over the cross section. The maximum variation in width of the gap is plotted with red dotted lines in Figure 4-1. In average over the cross section the density will be between 1,950–2,050 kg/m$^3$ as long as the maximum cross section area conform to the specified (corresponding to a gap width of 80 mm in Figure 4-1). The maximum variation in gap width results in a maximum variation of the saturated buffer density around the canister of $1{,}941 < \rho_m < 2{,}053$ kg/m$^3$, i.e. locally the density will be outside the limits of 1,950–2,050 kg/m$^3$.

### 4.2.2 Density in the upper part of the deposition hole

The upper part of the deposition hole is provided with a bevel to allow that the canister with its radiation protection is turned into upright position over the deposition hole. The connection of the bevel to the deposition hole will extend into the part of the deposition hole where buffer is installed. The cross section of the deposition hole in this upper part of the buffer is illustrated in Figure 4-3.

The density in the part of the deposition hole to which the bevel connects has been calculated for nominal blocks and nominal pellet filling in the triangular-shaped part of the cross section. The average density in the largest cross section at the top of the buffer is 1,979 kg/m$^3$. In this cross section the maximum distance between the bentonite blocks and the lower edge of the triangular-shaped part of the cross section is 412 mm. The maximum distance from the bentonite blocks to the lower edge of the triangular-shaped part of the cross for the density not to locally fall below 1,950 kg/m$^3$ is 143 mm, see Figure 4-3 and Figure 4-4. This means that down to a depth of about 0.36 m from the top of the buffer, where the depth of the wedge exceeds 143 mm, the density will locally be lower than 1,950 kg/m$^3$. In average over each cross section the density will lie within the accepted limits 1,950–2,050 kg/m$^3$.

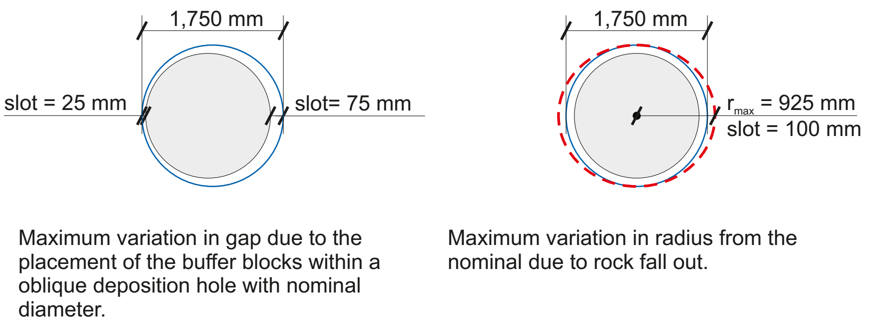



***Figure 4-2.*** *Possible variations in width of the pellet filled gap between bentonite blocks and deposition hole wall due to different causes of deviations in deposition hole geometry. The scale of the deviations is enlarged with a factor of two.*

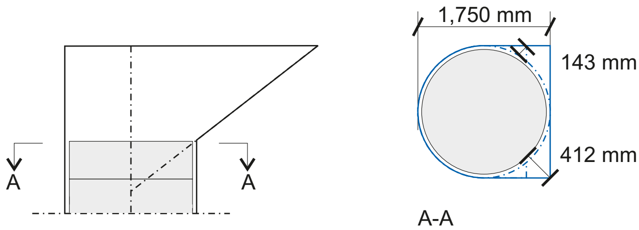



*Figure 4-3. The cross section of the deposition hole in the area where the bevel connects to the hole. As illustrated by the dotted line the bevel will extend into the part of the deposition hole where buffer is installed.*

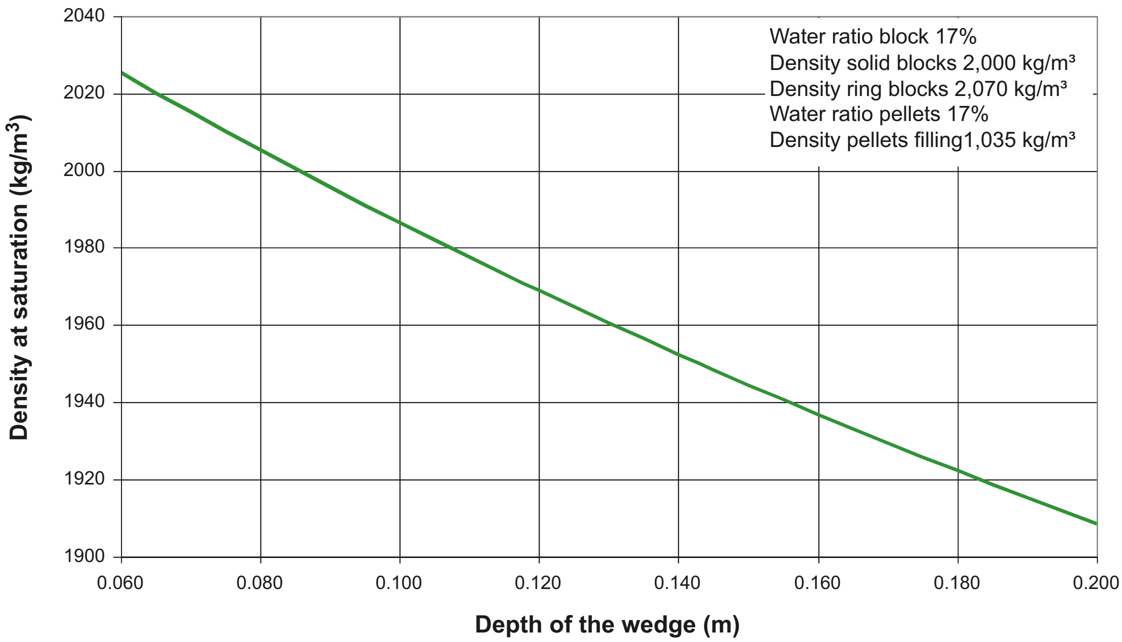



*Figure 4-4. Density of the buffer in the wedge-shaped part of the cross section where the bevel connects to the deposition hole.*

### 4.2.3 Density within the recesses in the canister lid and bottom

The density within the recesses in the canister lid and bottom has been calculated for nominal block densities and nominal dimensions of the blocks according to Figure 3-2. The resulting density within the lifting grip in the canister lid is 1,987 kg/m$^3$. The density in the recess in the bottom of the canister is 2,044 kg/m$^3$. In the ring shaped part of the block outside the canister, the resulting density is 1,979 kg/m$^3$.

### 4.2.4 Variations in block and pellet densities and water content

The saturated density can also vary due to variations in the bulk densities and water contents of the installed blocks and pellets. The variation in the final saturated density of the buffer for the accepted variation in the density of the pellets filling is illustrated with red lines and arrows in Figure 4-5. The acceptable variation of ±40 kg/m$^3$ around the nominal bulk density 1,035 kg/m$^3$ will, for the nominal deposition hole and nominal blocks, not result in a final buffer density at saturation outside the limits $1{,}950 < \rho_m < 2{,}050$ kg/m$^3$.

In Figure 4-6 the final saturated density of the buffer is plotted as function of the density of the blocks. The calculations are made for the nominal deposition hole geometry and nominal pellet density. The arrows on the x-axis represent the acceptable variation in block densities of ±20 kg/m$^3$. The figure shows that for the acceptable variations in installed density of the blocks the saturated density of the buffer will lie within the acceptable limits $1{,}950 < \rho_m < 2{,}050$ kg/m$^3$.

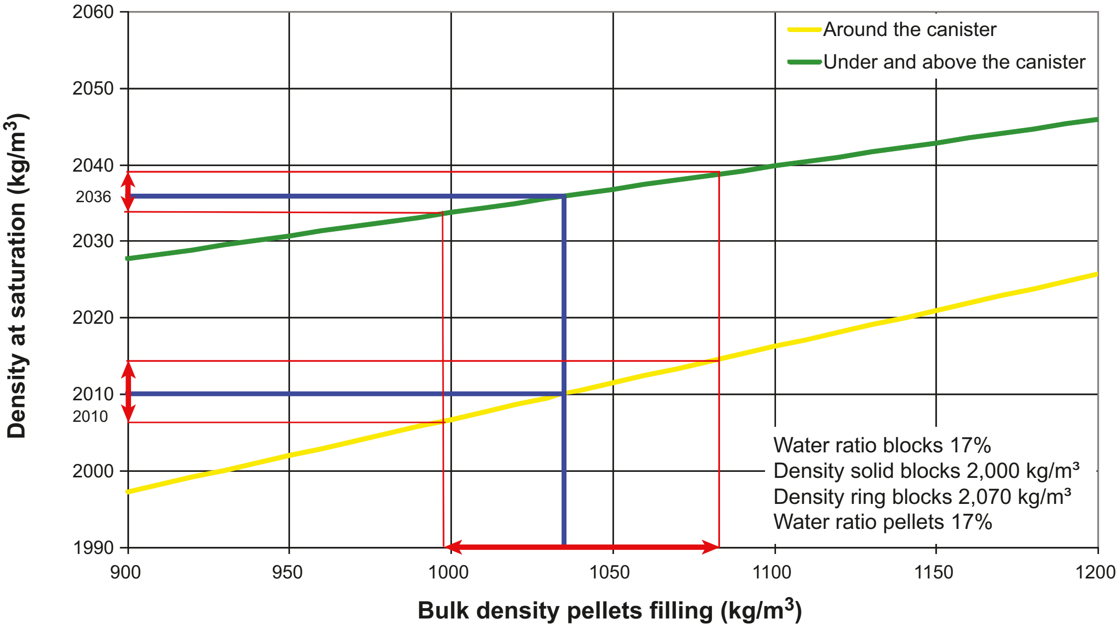



***Figure 4-5.*** *The calculated saturated density of the buffer (red arrows on y-axis) as function of the installed density of the pellets filling. The calculations are based on the nominal geometry of the deposition hole and nominal densities and dimensions of the blocks. (Blue line: nominal density)*

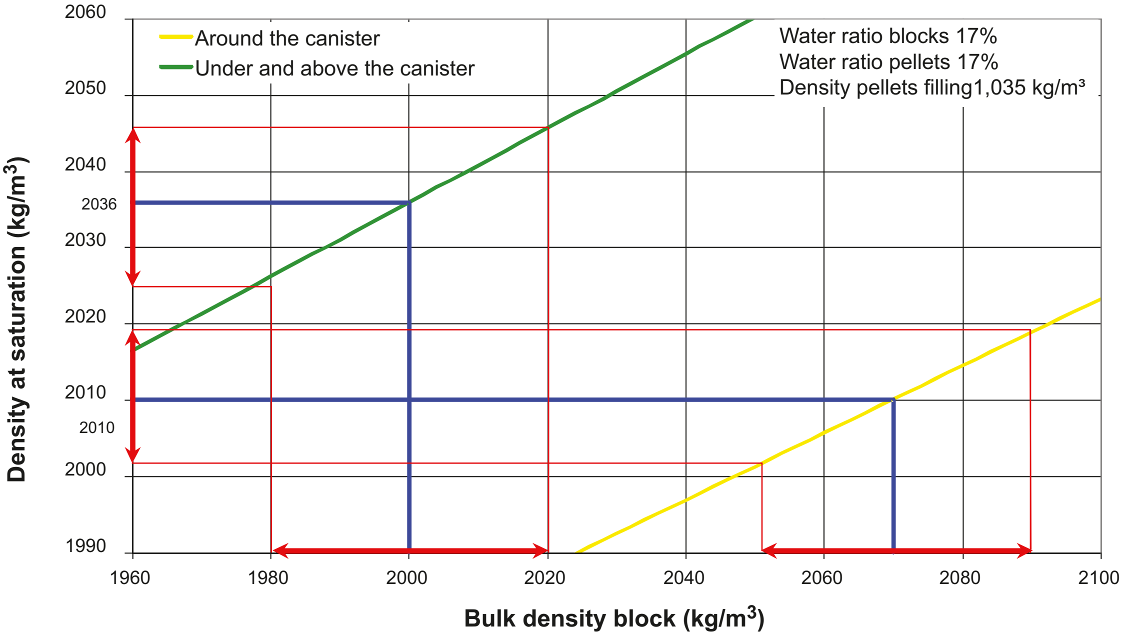



***Figure 4-6.*** *The calculated saturated density of the buffer (red arrows on y-axis) as function of the installed bulk density of the blocks. The calculations are based on the nominal geometry of the deposition hole and nominal density of the pellets. (Blue line: nominal density)*

In Figure 4-7 the final saturated density of the buffer is plotted as function of the water content of the blocks. The calculations are made for nominal deposition hole geometry, nominal block and pellet bulk densities and nominal water content in the pellets. The figure shows that for the acceptable variations in water content of the blocks the saturated density of the buffer will lie within the acceptable limits $1{,}950 < \rho_m < 2{,}050$ kg/m$^3$.

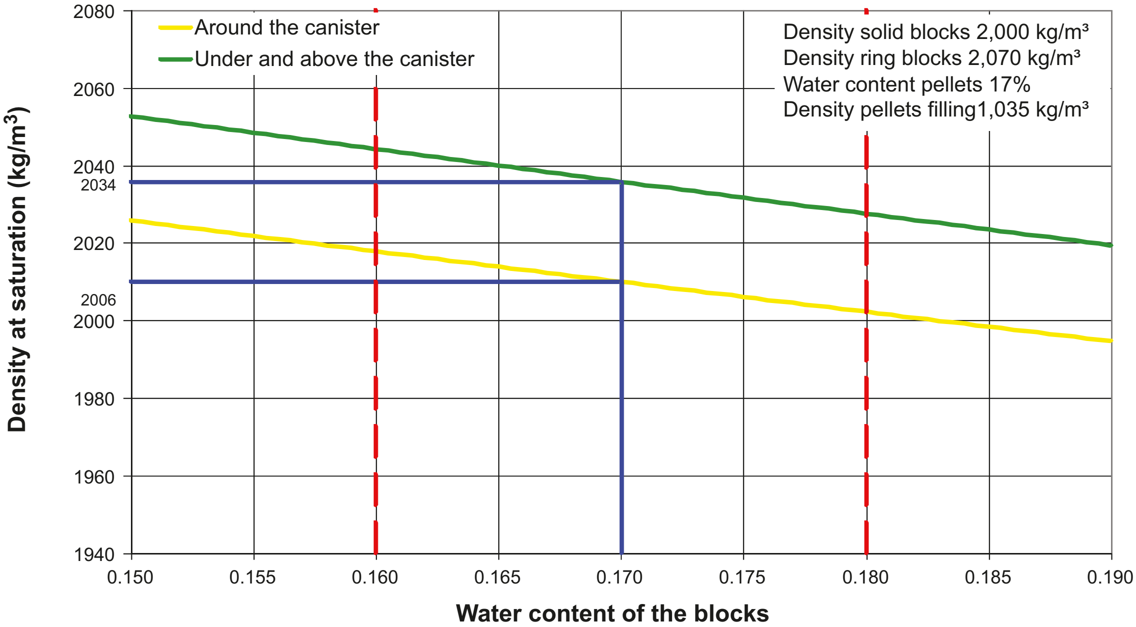



***Figure 4-7.** The calculated saturated density of the buffer as function of the water content of the blocks. The calculations are based on the nominal geometry of the deposition hole, nominal bulk density of the blocks and pellets and nominal water content of the pellets.*

### 4.2.5 Variations in deposition hole geometry and block and pellet densities

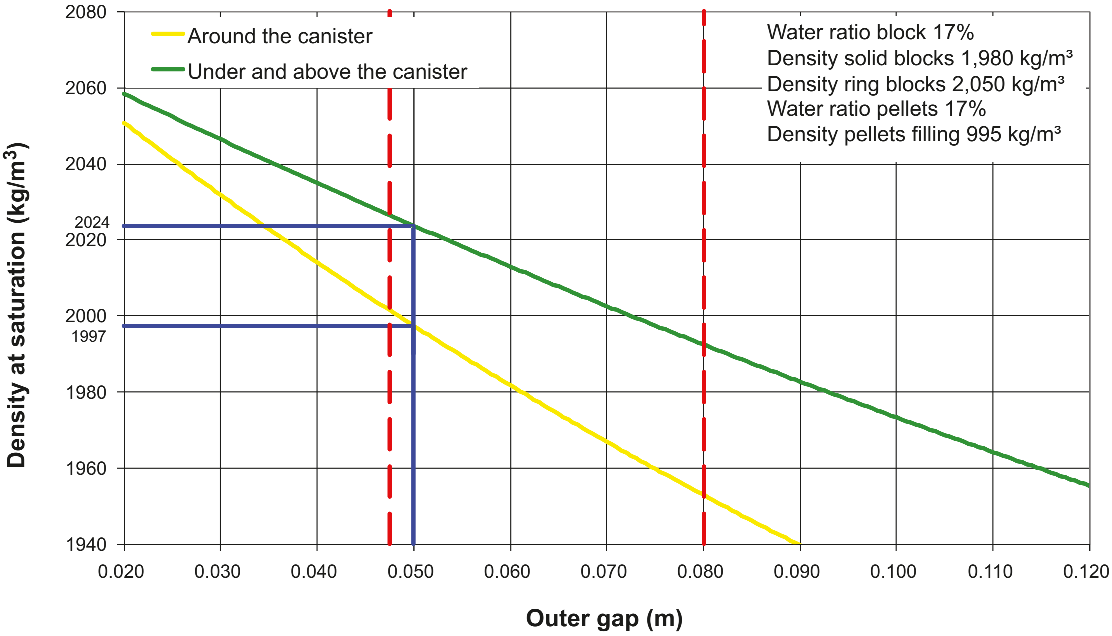
To illustrate the combined effects of the acceptable variations in installed buffer density and deposition hole geometry the saturated density as function of the width of pellet filled gap between the buffer blocks and the wall of the deposition hole are plotted in Figure 4-8. In the upper panel the saturated density is plotted as a function of the width of the gap assuming the minimum accepted block and pellet densities, and in the lower panel the saturated density is plotted for the maximum accepted installed densities. The dotted red lines corresponds to the maximum accepted variation in cross section area, which for a circular area corresponds to a diameter of $1,745 < ø < 1,810$ mm. The figure shows that the average saturated density within any accepted cross section of the deposition hole lies within the limits $1,950 < \rho_m < 2,050$ kg/m$^3$.

However, within a cross section, with respect to the accepted variations of the radius and gap between the blocks and deposition hole walls the density can vary as specified in Table 4-1 and illustrated in Figure 4-2.

The average density of the buffer after saturation in the deposition hole as a whole can be calculated assuming that no axial swelling of the buffer is taking place. Based on the acceptable variation in cross section area the volume of the deposition hole in the part where buffer is installed is 16.0–17.2 m$^3$. In Figure 4-8 this corresponds to a variation in gap between 47.5 and 80 mm, where 80 mm corresponds to a hypothetical deposition hole diameter of 1,810 mm. For the nominal dimensions, water contents and bulk densities of the buffer the accepted variations in deposition hole volume results in an average saturated density of 1,966–2,039 kg/m$^3$, see Figure 4-1.

**Table 4-1. Variations in calculated installed saturated buffer density for the maximum and minimum accepted block and pellet densities and width of the pellet filled gap.**

| Density of blocks and pellets | Installed saturated density (kg/m³) | |
|---|---|---|
| | Gap width 100 mm | Gap width 25 mm |
| Around the canister – minimum densities | 1,927 | 2,041 |
| Around the canister – maximum densities | 1,955 | 2,065 |
| Above and below the canister – minimum densities | 1,973 | 2,052 |
| Above and below the canister – maximum densities | 2,000 | 2,076 |



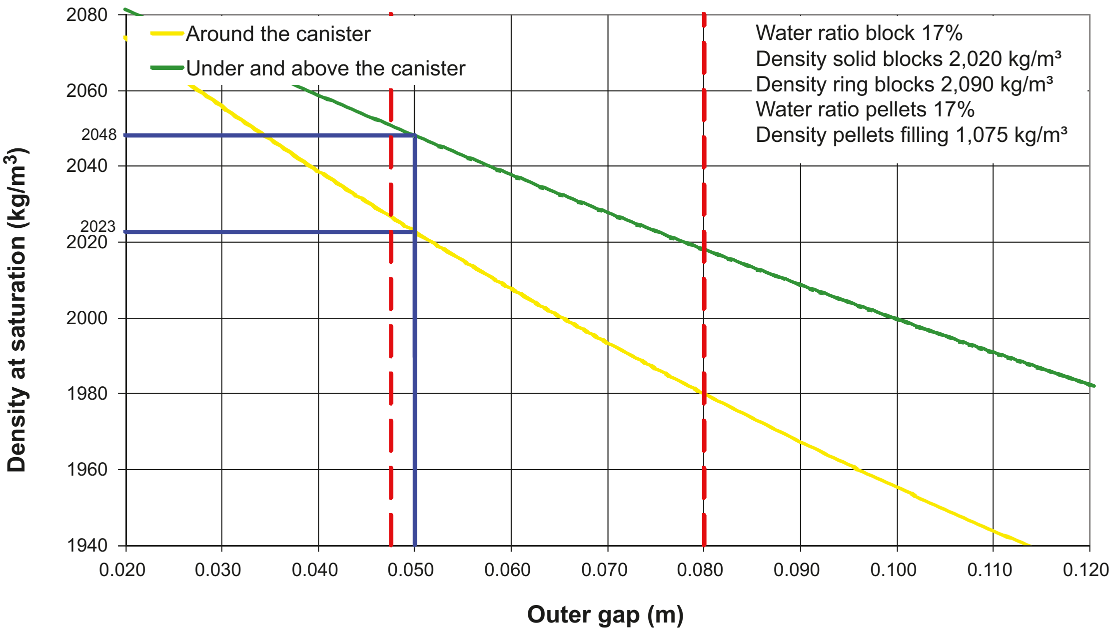




***Figure 4-8.*** *The calculated saturated density of the buffer as function of the width of the pellet filled gap between the bentonite blocks and the wall of the deposition hole. Upper panel: Assuming minimum density of the buffer blocks and pellets. Lower panel: Assuming maximum density of blocks and pellets. (Blue line: nominal gap.) The red dotted lines illustrate the maximum accepted area of the cross section which exceeds the nominal with 7.0%.*

For the minimum and maximum accepted installed densities the average saturated densities will vary between 1,953–2,026 kg/m$^3$ and 1,980–2,050 kg/m$^3$ respectively, see Figure 4-8.

In summary it can be stated that the average saturated buffer density will be $1{,}950 < \rho_m < 2{,}050$ kg/m$^3$ in all possible combinations of acceptable deposition holes and buffer block and pellet densities and geometries. This is true both for the deposition hole as a whole and for all cross sections along the hole. However, based on the accepted geometries and densities the saturated density will vary along the deposition hole depth and locally over a cross section the density may be lower than 1,950 kg/m$^3$ or higher than 2,050 kg/m$^3$. This can only occur if the extremes in accepted deposition hole geometries and block densities are combined, a situation that is stipulated to be unlikely for the actually installed buffer. However, if it is important to warrant that the density design premise for the saturated density is fulfilled everywhere in the deposition hole volume either the installed densities must be adjusted with respect to the actual geometry of the deposition hole or the acceptable variations in deposition hole geometries and/or block densities must be more strict.

## 4.3 The buffer dimensions

It shall be verified the buffer dimensions from SR-Can are used in the reference design. The dimensions from SR-Can are 1.5 m buffer above the canister, 0.5 m below the canister and 35 cm around the canister.

Since SR-Can the depth of the upper part of the deposition hole regarded as a part of the deposition tunnel has been made deeper and provided with a bevel in order to allow a mechanically simpler and more reliable deposition of the canister and decreasing the deposition tunnel height. The buffer thicknesses around, below and above the canister specified for the reference design in Figure 3-3 are the same as in SR-Can.

The dimensions from SR-Can are regarded as nominal. The installed dimensions will depend on the accepted variations in deposition hole geometry according to Figure 2-1, accepted variations in buffer blocks according to Table 3-4 and the installed buffer geometry gap according to Figure 3-3.

Unless the diameter of the deposition hole is less than 1.75 m, i.e. the diameter of the drill, the average buffer thickness in each cross section will always be at least 35 cm. If the canister is placed centred in the deposition hole, the minimum accepted average buffer thickness will be 34.75 cm corresponding to a deposition hole diameter of 1.745 m. The maximum accepted average thickness will be 38.00 cm, corresponding to a circular hole with a cross section area exceeding the nominal with 7.0%.

Assuming that the deposition holes and ring shaped buffer blocks conform to the reference design the minimum accepted distance between the deposition hole wall and the inner surface of the ring shaped blocks is 31.4 cm, the corresponding maximum distance is 39.1 cm. If the canister, which has a nominal diameter of 1,050 mm, is always placed in the centre of the buffer rings, the minimum thickness of the buffer will be 32.45 cm (=25 mm gap+(1,649 mm buffer block–1,050 mm canister)/2). The maximum thickness will be 40.05 cm (=100 mm gap+(1,651 mm buffer block–1,050 mm canister)/2). These thicknesses can only occur locally over a cross section.

Below and above the canister the variation in buffer thickness will depend on the accepted variation of the block height, i.e. below the canister it can deviate from the nominal with 1 mm and above the canister the deviation is 3 mm.

## 4.4 Buffer thermal properties

In **Design premises long-term safety** it is stated that the buffer geometry (e.g. void spaces), water content and distances between deposition holes should be selected such that temperature in the buffer is <100°C. In this section the impact of the heat transport in the buffer on the temperature is investigated. The design premise cannot be verified unless the temperature on the rock surface at the deposition hole is known.

The highest buffer temperatures will occur for low heat conductivity in the buffer, i.e. for a buffer that has not taken up any water and has a gap between the canister and the buffer.

The maximum temperatures will occur on top and below the canister where the buffer is in direct contact with the canister. The total temperature difference between the rock wall at mid-height of the canister and the temperature at the top of the canister can be calculated from the decay power in the canister if the temperature differences at the canister surface and the heat-transport properties of the buffer and the gap between the canister and the buffer are known.

The temperature at the rock wall in the deposition hole depends almost only on the heat conductivity of the rock and the distance between the deposition holes, while the temperature difference between the rock wall at mid-height of the canister and the temperature on top of the canister in principle is independent of the thermal properties of the rock. The maximum temperature in the buffer can thus be calculated by adding the temperature difference over the buffer to the temperature at the rock wall in the deposition hole. The temperature on the rock wall is determined as a part of the rock engineering and site adaptation, see Section 4.2.1 in the **Underground openings construction report**.

The temperature difference between the rock wall at mid-height of the canister and the temperature on the top of the canister depend on the following:

- the thermal conductivity of the bentonite blocks,
- the thermal conductivity of the pellet filling in the gap between the buffer blocks and rock wall,
- the temperature drop over the gap between the buffer and canister,
- the difference in temperature on the canister surface at its top and mid-height,
- the distribution of the heat flux along the canister surface.

In order to evaluate the importance of the heat transport in the buffer calculations to determine the maximum temperature difference between the rock wall and the top of the canister has been preformed /Hökmark et al. 2009/. The total temperature drop ($\Delta T_{tot}$) between the rock surface and top/bottom of the canister was calculated as:

$$\Delta T_{tot}(t) = \Delta T_1(t) + \Delta T_2(t) = 0.02213 \times Q(t)$$

where:

$\Delta T_{tot}$ = Total temperature drop

$\Delta T_1$ = Temperature drop over the buffer blocks and pellets

$\Delta T_2$ = Temperature drop over the canister surface and gap between canister and buffer

Q(t) = The canister power output as function of time

The constant (0.02213) is based on heat conductivity, emission and geometry from both laboratory tests and temperatures measured in the Prototype Repository, deposition hole #6. It was determined for a canister effect of 1,700 W. The temperature drops over the blocks and pellets ($\Delta T_1$) and gap between canister and buffer ($\Delta T_2$) were for the installed buffer geometry calculated from registered heat conductivities and temperatures measured in the Prototype Repository. The total temperature drop ($\Delta T_{tot}$) is direct proportional to the decay power of the encapsulated fuel assemblies and will thus decrease with time as the power decays, see Figure 4-9.

The temperature differences plotted in Figure 4-9 apply to a reference case with dry buffer and nominal geometry. A sensitive analysis where the thermal conductivity of the buffer was varied has been carried out. The analysis shows that the worst case would be low heat conductivity in the buffer combined with high heat conductivity in the rock which has a minor unfavourable impact on the distribution of the heat flux along the canister surface. The calculations show that the maximum temperature increase does not exceed the reference case by more than 3.3°C for the worst case combination. The impact of variations in buffer geometry was not analysed. However the worst case would be a large gap between canister and buffer and low conductivity over the blocks and pellets. With respect to the acceptable variations in dimensions of the ring shaped blocks the gap width cannot exceed 10 mm with more than 0.5 mm as long as the canister is placed in the centre of the hole.

The analysis show that the increase in temperature between the rock wall at mid-height of the canister and the warmest spot in the buffer will be about 37°C, assuming a dry deposition hole and a 10 mm gap between the canister and the buffer. For a worst case regarding heat conductivity the temperature increase is about 40°C.

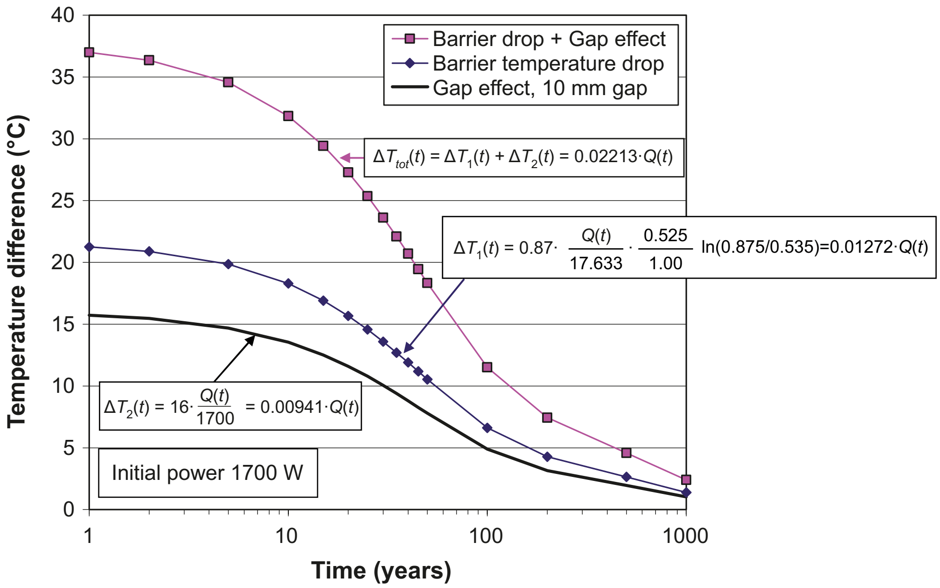



***Figure 4-9.*** *Evolution of the temperature difference $\Delta T_{tot}$ for a reference case with a thermal conductivity of the buffer, $\lambda_{b(eff)}$ = 1.00 W/(m·K), and with gap effect scaled to the Prototype hole #6 /Hökmark et al. 2009/.*

In order to verify that the accepted temperature in the buffer is not exceeded the temperature on the rock wall of the deposition hole must be known. The temperature on the rock wall will depend on the heat conductivity of the rock and the distance between deposition holes. The distances between deposition holes are determined with respect to this, see Section 4.2.1 in the **Underground openings construction report**.

## 4.5 Maintain swelling pressure, hydraulic conductivity and shear strength

In **Design premises long-term safety** it is stated that, the buffer after swelling *should uphold the minimum swelling pressure 2 MPa, and the hydraulic conductivity should not exceed $10^{-12}$ m/s independently of dominating cation and for chloride concentrations up to 1 M*. In addition, the shear strength of the buffer after swelling *must not exceed the strength used in the verifying analysis of the canisters' resistance against shear loads*. Further, in **Design premises long-term safety** it is stated that if the saturated buffer density is 1,950–2,050 kg/m³ the swelling pressure, hydraulic conductivity and shear strength will be maintained.

In Section 4.2 it is verified that the initially installed buffer mass corresponds to an average saturated density between 1,950 and 2,050 kg/m³.

A saturated density between 1,950 and 2,050 kg/m³ corresponds to a dry density of 1,480 kg/m³ < $\rho_d$ < 1,640 kg/m³. /Karnland et al. 2006/ have investigated the relation between dry density and swelling pressure and dry density and hydraulic conductivity for different chloride concentrations. The investigations were made for MX-80, which is an example of a buffer material according to the specification for the reference design. The results are presented in Figure 4-10 and show that the reference material for the specified density interval maintains the minimum swelling pressure and the maximum hydraulic conductivity with a large margin.

The maximum shear strength in the buffer is related to the following design premise for the canister: *The copper corrosion barrier should remain intact after a 5 cm shear movement at a velocity of 1 m/s for buffer material properties of a 2,050 kg/m³ Ca-bentonite, and for all locations and angles of the shearing fracture in the deposition hole. The insert should maintain its pressure-bearing properties to isostatic loads.* The shear strength of the buffer must not exceed the strength used in the analysis of the conformity of the reference canister to this design premise, see Section 4.4 in the **Canister production report**.

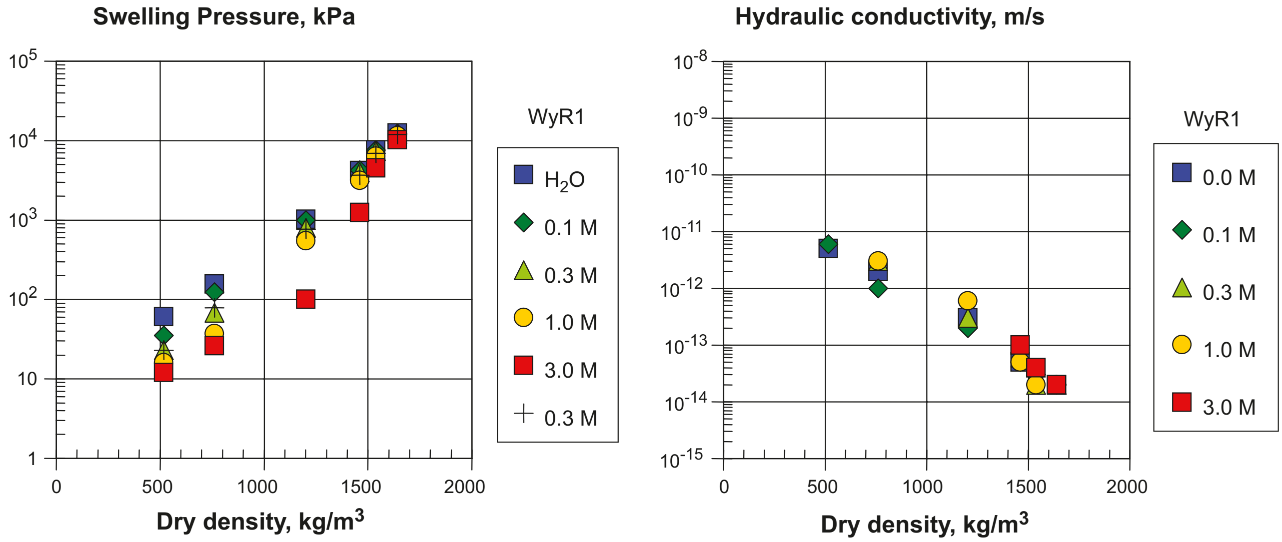



***Figure 4-10.*** *Swelling pressure (left) and hydraulic conductivity (right) as function of dry density for Wyoming MX-80. The measurements are made with different salt concentrations in the test solution (NaCl) /Karnland et al. 2006/*

/Börgesson et al. 2010/ has presented a material model used to calculate the load transferred from the buffer to the canister in connection to shear movements over the deposition hole. The transfer of the displacement depends on the stiffness and shear strength of the buffer. The most severe case, that cannot be exceeded, occurs for high densities and with Ca as dominating cation, i.e. for the reference buffer at a saturated density of 2,050 kg/m³ and Ca as dominating cation. Lower densities and Na as dominating cation causes smaller stresses on the canister in case of displacements over the deposition hole. The strength of the buffer material also depends on the deformation rate. Figure 4-11 shows the stress-strain relation for the buffer applicable for the specified deformation rate and used in the verifying analysis of the shear load case in the **Canister production report**. The model is based on investigations of MX-80 which is a buffer material according to the reference design.

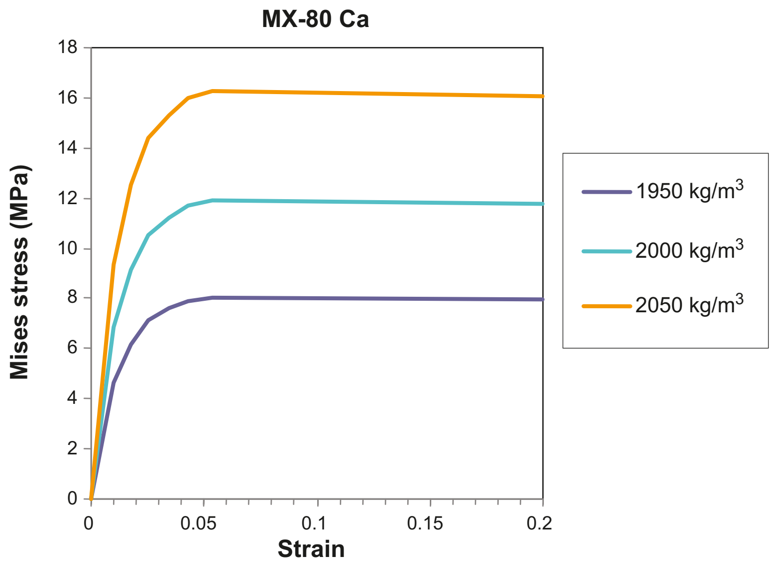



***Figure 4-11.*** *Dimensioning stress-strain relation for the buffer based on MX-80 with Ca as dominating cation. The Mises stress describes the shear stress in three dimensions, the model includes an elastic and a plastic part /Börgesson et al. 2010/.*

## 4.6 Design premises from other barriers, production and operation

### 4.6.1 Deposition of canister

The installed buffer shall contain a hole large enough for deposition of the canister. The inner diameter of the ring shaped blocks is 1,070 mm with an acceptable deviation of ±1 mm. The blocks shall be installed in the deposition hole so that their centre axis coincide, see Section 5.4.4. The diameter of the canister is 1,050 mm. The deposition machine will grip the canister in a flange in the lid and lower it down in its position. It will have steering devices that ensures that the canister is placed centred in the hole, but no parts that stick out. Consequently the hole within the ring shaped blocks is large enough for deposition of the canister.

### 4.6.2 Compactability of the bentonite material

It shall be verified that it is possible to compact the bentonite to the required density. For a specific bentonite material the density achieved at compaction will depend on the granule size distribution and water content of the material ready for compaction and on the compaction pressure. The required granule size distribution, water content and pressure must be adapted to the selected bentonite product, i.e. the reference material ready for compaction presented in Table 3-3 is only valid for MX-80 and must be revised if another material is selected.

When a bentonite product and supplier is selected it shall be verified that it is possible to compact the bentonite from the selected deposit to the required density. Tests in which blocks are pressed from bentonite samples with different granule size distribution and water content will be performed. SKB will develop test programmes for this purpose as a part of the routines for qualification of suppliers, also see Section 5.1.4.

### 4.6.3 Design of blocks and pellets

The buffer blocks and pellets shall be designed so that installation can be performed with high reliability. Details in the block and pellet design that will impact the reliability of the installation are the water content and the dimensions.

Relatively high water content will limit damages caused by the exposure to high relative humidity. Too high water contents (>20%) will increase the risk that mould will grow on the surfaces of the blocks during storage. MX-80 blocks with water content of 17% have been handled without getting damaged or grow of mould on the surfaces, in laboratories and at Äspö Hard Rock Laboratory (HRL).

The blocks must be designed so that they are possible to lift, transport and install with high reliability, preferably by applying well-tried technique and equipment. The dimensions of the blocks are adapted so that their weight will allow the use of conventional lifting equipment and so that high lifts are avoided.

The gap between the deposition hole wall and the blocks shall allow for the installation and removal of auxiliary equipment. This has affected the width of the gap and consequently the outer diameter of the blocks.

The dimensions of the pellets must allow that they can fall down in the gap and fill it to the specified bulk density.

Tests that verify that the water content and dimensions according to the reference design will result in a reliable production have been performed in laboratories and at Äspö HRL. Results and experiences are presented in Section 5.4.8.

## 4.7 Summary of results and conclusions

In this section the conclusions from the analyses of the conformity of the reference design to the design premises from Sections 4.1–4.6 are summarised. For each design premise from **Design premises long-term safety** the buffer properties and design parameters that have been designed with respect to the design premise are presented and the conformity to the design premise concluded.

### 4.7.1 Material composition

In **Design premises long-term safety** the required montmorillonite content and the accepted content of organic carbon, sulphides and total sulphur are stated. The related buffer property and design parameters determined in the design are (see Table 2-1 and Table 3-1):

- buffer property: *material composition,*
- design parameters: *content of montmorillonite, sulphide, total sulphur and organic carbon.*

The montmorillonite content shall be sufficient for the buffer material to have capacity to yield the required hydraulic conductivity and swelling pressure, and for the buffer to have ability to limit microbiological activity. Further it must not result in stiffness and shear strength exposing the canister to larger stresses than assumed for the dimensioning shear load case. The content of sulphides and total sulphur must not cause significant canister corrosion and the content of organic carbon must not impact radionuclide transport. The contents specified for the reference buffer material conform to the contents specified in **Design premises long-term safety**.

### 4.7.2 Initially installed mass and density at saturation

For the specified buffer material the initially installed density shall be sufficient for the buffer to maintain its barrier functions, i.e. to limit flow of water; keep the canister in its centred position in the deposition hole; have ability to limit microbiological activity; prevent transport of colloids and not significantly impair the barrier functions of the engineered barriers or rock. In **Design premises long-term safety** it is stated that the saturated buffer density shall be higher than 1,950 kg/m$^3$, i.e. sufficiently high to ensure a swelling pressure of 2 MPa to limit microbiological activity, and less than 2,050 kg/m$^3$ to prevent too high shear impact on canister. It is also stated that if the saturated density conforms to these conditions then the design premises for hydraulic conductivity, swelling pressure etc required to maintain the other barrier functions are also likely to be met. The related buffer property and design parameters determined in the design are (see Table 2-1, Table 3-4 and Figure 3-3):

- buffer property: *installed density,*
- design parameters: *the water content (in the material ready for compaction) and bulk density of buffer blocks and pellets and the width of the pellet filled gap.*

The installed density will depend on:

- the dimensions of the deposition hole, the installed blocks and the canister,
- the densities and water contents of the blocks and the pellets filling.

In Section 4.2 all these parameters, with exception from the dimensions of the canister, have been varied within their acceptable limits and the resulting saturated density calculated. The conclusion is that in average the saturated density will lie within the acceptable limits for all acceptable cross sections of the deposition hole and buffer block and pellet densities and geometries. However, if the extremes in accepted deposition hole geometries and block and pellet densities are combined the density at saturation will locally, in the most unfavourable part of the cross section, fall outside the accepted interval. Unless the deposition hole is exteemly oblique, or the diameter exceeds the nominal with several centimetres, this can only occur if there has been a rock fall and no homogenisation over the cross section.

If homogenisation shall be neglected and the saturated density shall lie within the interval 1,950 kg/m$^3$–2,050 kg/m$^3$ for all accepted combinations of buffer blocks and deposition hole cross sections then either of the following must be done:

- in the production line of the buffer the installed buffer mass must be adjusted to the actual deposition hole geometry if there has been a rock fall out,
- the accepted variation in width of the pellet filled gap, i.e. the deposition hole geometry, must be reduced,
- the accepted variation in bulk density of blocks and pellets must be reduced.

### 4.7.3 The buffer dimensions

In **Design premises long-term safety** it is stated that the buffer dimensions used as reference dimensions in SR-Can shall be used. The related buffer properties and design parameters determined in the design are (see Table 2-1and Figure 3-3):

- buffer properties: *installed geometry,*
- design parameters: *the dimensions of the buffer blocks, the width of the pellet filled gap and the position of the buffer blocks in the deposition hole.*

In the buffer design the dimensions from SR-Can are regarded as nominal, i.e. to the stated thicknesses of 35 cm around the canister and 0.5 and 1.5 m below and above the canister respectively variations that may occur in the production have been added.

#### *Thickness around the canister*

With respect to the acceptable variations specified for deposition holes and buffer blocks in their reference designs, assuming that the canister is placed centred in the deposition hole and neglecting variations in the canister diameter the minimum average buffer thickness according to the reference design will be 34.75 cm and the maximum average thickness will be 38.25 cm (Section 4.3). Locally over a cross section for the extremes in accepted deposition hole geometries the minimum thickness of the buffer is 32.45 cm and the maximum thickness is 40.05 cm.

If 35 cm should be regarded as a minimum thickness that shall be achieved everywhere around the canister, either the deposition hole diameter must be increased or the accuracy in drilling and placement of the ring shaped blocks must be exact. Exact drilling and placement of the blocks is based on current experiences not possible to achieve.

#### *Thickness above and below the canister*

The thickness of the buffer below and above the canister will only depend on the accepted variations of the height of the buffer blocks. The maximum variations will be ±1 mm and ± 3 mm respectively.

If 0.5 and 1.5 m should be regarded as minimum thicknesses the height of the solid blocks must be increased.

### 4.7.4 Buffer thermal properties

The buffer geometry (e.g. void spaces), water content and distances between deposition holes should be selected such that temperature in the buffer is <100°C. The distances between deposition holes are selected to conform to this design premise see Section 4.2.1 in the **Underground openings construction report.** The buffer is not designed with respect to this design premise. As input to the analyses performed to determine the distances between deposition holes the impact on the heat transport in the buffer on its maximum temperature is analysed.

The highest temperatures in the buffer will occur at the canister top and bottom where the buffer is in contact with the canister. The increase in temperature will be largest for low heat conductivity in the buffer, i.e. for a dry buffer and a gap between canister and buffer. The maximum temperature increase from the temperature at the rock wall at mid-height of the canister, for a dry buffer, has been calculated to 37°C. For a worst case regarding heat conductivity the temperature increase is about 40°C. To confirm that the temperature in the buffer stays below 100°C the temperature at the rock surface at mid-height of the canister shall be added to these temperature increases.

### 4.7.5 Maintain swelling pressure, hydraulic conductivity and shear strength

The buffer shall after swelling uphold the minimum swelling pressure, the accepted hydraulic conductivity and the accepted shear strength independently of dominating cation and for chloride concentrations up to 1 M. The buffer properties to be designed to conform to this design premise are the material composition, i.e. the montmorillonite content, and the density.

Based on laboratory tests of MX-80, which is an example of a bentonite with a montmorillonite content according to the reference design, it is verified that at a saturated density of 1,950–2,050 $kg/m^3$ the hydraulic conductivity will be less than $10^{-12}$ m/s and the swelling pressure will exceed 2 MPa for chloride concentrations up to 1 M (Section 4.5) as specified in **Design premises long-term safety**.

The shear strength will depend on the density and dominating cation. High densities and Ca will result in a more stiff buffer and severe load on the canister. The strength will also depend on the deformation rate. Also based on tests of MX-80, it is verified that a buffer with Ca as dominating cation at a saturated density of 1,950–2,050 $kg/m^3$ will have the shear strength presumed for the shear load case analysed in Section 4.4 in the **Canister production report**.

# 5 Production of the buffer

In this chapter a production line for the buffer is presented. The production line illustrates and explains how the buffer can be produced, installed and inspected applying the current reference methods. The level of detail in the described production provides an overview of the reference methods, solutions and equipments.

## 5.1 Overview

### 5.1.1 Requirements on the production of the buffer

In this section the design premises for the development of methods for production, test and inspection of the buffer are given. *The design premises are written in italics.*

The manufactured blocks and pellets and the installed buffer shall lie within the acceptable limits specified for the reference design in Sections 3.1 and 3.2. In addition the design considerations presented in Section 2.2.2 shall be kept in mind when developing the methods, i.e. systems and processes, for preparation, installation, test and inspection of the buffer. The methods must also be applicable for the current reference sequence for deposition of the canister, buffer and backfill. Further the design premises for the methods are based on SKB's objective to minimise radiation doses during the operation of the KBS-3 repository facility. The reference sequence for deposition is briefly described in Section 4.1.4 in the **Repository production report**. Regarding limitation of radiation doses the objective for the operation of the KBS-3 repository facility is to avoid any handling of the canister above that required for its safe deposition. Mishaps that results in that an individual canister must be brought back to a previous stage in the handling are accepted to occur during the lifetime of the facility. However, events causing retrieval of several deposited canisters should not occur. The resulting design premises for the development of methods for manufacturing, installation, test and inspection are compiled in Table 5-1.

**Table 5-1. Design premises for the development of methods for preparation, installation test and inspection of the buffer.**

| Design consideration | Required capability | Design premise |
|---|---|---|
| *The buffer and methods for preparation, installation, test and inspection shall be based on well-tried or tested technique.* | *The methods for manufacturing, installation, test and inspection of the buffer shall as far as possible be based on experiences and established practice from similar applications.* | – |
| | *If there is a lack of experiences the reliability of the methods shall be tested and demonstrated.* | – |
| *Buffer with specified properties shall be possible to prepare and install with high reliability.* | *Methods used in the manufacturing and installation shall result in buffer with acceptable properties.* | *Reference design according to Sections 3.1 and 3.2 .* |
| | *The rejection frequency of prepared buffer material and components shall be low.* | – |
| | *Methods for inspections shall have an accuracy of measurement that lies within the acceptable variations of the parameter to be inspected.* | *Reference design according to Sections 3.1 and 3.2.* |
| | *The frequency of the event: "Retrieval of installed buffer after completed installation." shall be low.*[1] | *Frequency $10^{-3}$ or less per deposition hole.* |
| *The buffer design and methods for manufacturing, installation, test and inspection shall be cost-effective.*<br>*It shall be possible to produce, inspect and install the buffer in the prescribed rate.* | *The overall buffer installation rate shall be adapted to the specified canister deposition rate.* | *In average blocks and pellets in one deposition hole shall be possible to install per working day. Based on: A canister deposition rate of one per working day or 200 canisters per year during the life time of the repository facility.* |

[1] This capability is also a consequence of SKB's objective to minimise the doses during the operation of the KBS-3 repository facility (also see the **Repository production report**).

### 5.1.2 The production line for the buffer

The production line for the buffer comprises the following three main parts:

- excavation and delivery,
- manufacturing of blocks and pellets,
- handling and installation.

The buffer production line is illustrated in Figure 5-1, from the material delivery (to the left) to the installation in the deposition hole (to the right). The figure also includes a flow chart for the production line with references to the illustrated stages and the sections in which they are presented.

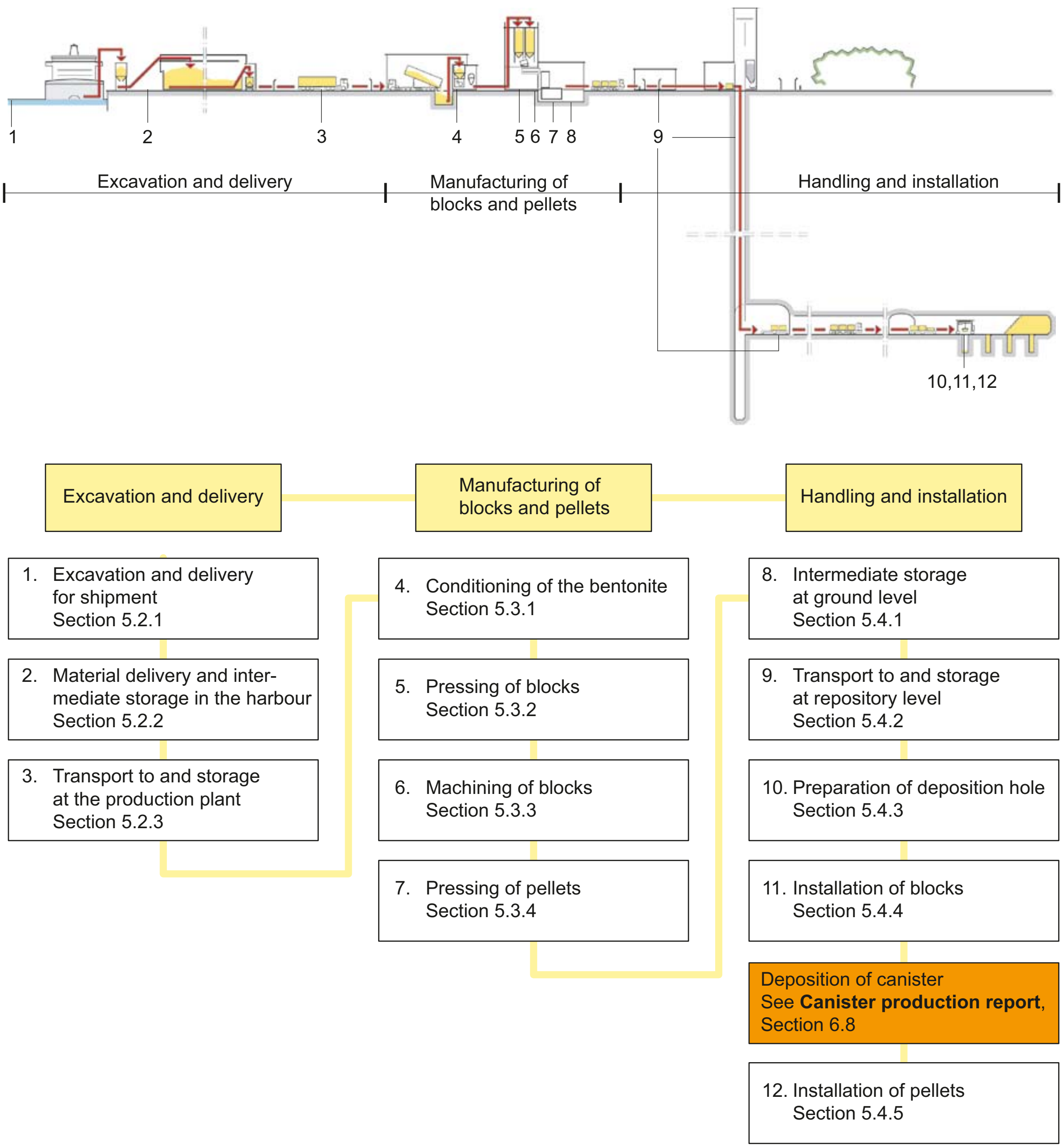



*__Figure 5-1.__ Upper panel: Illustration of the buffer production line from the delivery of the material to the installation in the deposition hole. Lower panel: The main parts of the buffer production line (yellow) and flow chart for all stages, including references to the numbers in the illustration and sections in the text where they are described.*

### 5.1.3 Reference methods for preparation and installation

With respect to the requirements on the production the reference methods for manufacturing of blocks and pellets are based on established technique from similar industrial applications. Conventional methods are adapted to SKB's needs so they result in blocks and pellets according to the reference design. SKB has gained important experience from some large scale experiments at Stripa in the 1980s and at Äspö HRL in the 1990s and 2000s. The methods presented in this report are mainly based results from the Prototype Repository at Äspö HRL /Johannesson 2002/.

Handling such as transport and storage of blocks and pellets are performed by applying conventional technique. The installation of blocks and pellets has been developed and tested by SKB.

The buffer design is based on stacking bentonite blocks and rings in the deposition hole and filling the gap between the blocks and the rock with bentonite pellets.

The reference method for preparation of buffer blocks is uniaxial compression of individual blocks. The reference method for manufacturing of pellets is roller compaction of small briquettes.

The reference method for installation of blocks is to place each block with a gantry crane. The installed blocks are protected by a rubber sheet and the deposition hole is drained until the gap between the installed blocks and the rock is filled with pellets. Before the gap is filled with pellets the rubber sheet is removed. The reference method for installation of the pellets is to pour them into the gap.

### 5.1.4 Reference strategy and methods for test and inspection

With respect to the requirements on the production the purpose of the tests and inspections performed at the different stages of the production line are to:

- warrant that the production result in buffer with acceptable properties,
- achieve a reliable and cost-effective production with low rejection frequency.

The tests and inspections to be performed, the number of inspections and the spatial distribution of the sampling depend on a number of factors. Examples of such factors are:

- the selected supplier and the character of the bentonite deposit,
- the properties to be inspected,
- the accuracy of measurement and reliability of the applied methods,
- required information e.g. mean or extreme values or variation in time or space,
- the purpose of the test, e.g. input to control a process stage or final inspection of a property,
- available information and experiences, e.g. reliability of the supplier, results from previous deliveries or process stage,
- the available time to perform the inspections with respect to the desired production capacity.

These factors need to be considered when developing a plan for inspections the buffer. Such a plan shall comprise the parameters to be inspected, the methods to be applied, a strategy for sampling including the number and volume of samples and their distribution in time and space. SKB intend to develop such plan for inspections as a part of the quality assurance of the buffer. The reliability of the test results will depend on this programme as a whole. At this stage of development the parameters to be measured, the reference methods to be applied in each stage of the production and their accuracy of measurement are presented. Further, the sampling strategy for each stage of the production is discussed.

The methods for test and inspection are based on established technique from similar industrial applications. Their accuracy of measurement shall lie within the acceptable variations of the property to be inspected. Generally conventional technique and equipment with sufficient accuracy of measurement is available.

### 5.1.5 The design parameters and production-inspection schemes

The design parameters are the parameters that in Section 3.1 (Table 3-1, Table 3-3, Table 3-4, Figure 3-1, Figure 3-2 and Figure 3-3) were used to specify the reference design of the buffer. These parameters shall, directly or indirectly, be inspected during the production of the buffer to verify that the produced buffer conform to the reference design. The outcome of the design parameters need to be known for the initial state. The properties required with respect to the long-term safety and the production (Section 2.3), the design parameters and the parameters inspected in the production and their relations are presented in Table 5-2.

To give an overview of the production, *production-inspection schemes* illustrating the main parts of the production and their included stages are established. For each illustrated stage the design parameters and the processes performed to alter and/or inspect them are presented. Details about the production processes are given in the text about each stage. The text about each stage also includes a presentation of the inspections performed within the stage. The methods for test and inspection are presented separately for each main part of the production. The production-inspection schemes for the excavation and delivery and manufacturing of blocks and pellets are shown in Figure 5-2 and the production-inspection scheme for the handling and installation of the buffer is given in Figure 5-3.

**Table 5-2. Buffer – required properties and related design parameters and parameters inspected in the production.**

| Required property | Design parameter | Parameter inspected in the production |
|---|---|---|
| Material composition | Montmorillonite content | X-ray diffraction pattern |
| | Sulphide content | Combustion gases |
| | Total sulphur content (including the sulphide) | Combustion gases |
| | Organic carbon | Combustion gases |
| Compaction properties of material ready for compaction | Granule size distribution | Sieving curve |
| | Water content | Weight before and after drying |
| Density and dimensions of blocks | Bulk density | Weight and dimensions |
| | Dimensions | Height<br>Diameter (outer)<br>Hole diameter (ring shaped blocks)<br>Details according to Figure 3-2 |
| Density and dimensions of pellets | Bulk density separate pellets | Weight and dimensions of individual pellets |
| | Dimensions | Thickness of individual pellet<br>Width of individual pellet<br>Length of individual pellet |
| | Bulk density loose filling | Weight and volume of loose material |
| Installed density | Bulk density of blocks | Weight and dimensions of installed blocks |
| | Bulk density of pellet filling | Weight and volume of installed pellets |
| | Width of pellet filled gap | Geometry of deposition hole[1]<br>Position of installed blocks in the deposition hole |
| Installed geometry | Buffer thickness | Dimensions of deposition hole[1]<br>Dimensions of installed blocks<br>Positions of installed blocks in the deposition hole |
| | Width of pellet filled gap | Dimensions of deposition hole[1]<br>Dimensions of installed blocks<br>Positions of installed blocks in the deposition hole |
| | Diameter of hole within the installed blocks | Dimensions of installed blocks<br>Positions of installed blocks in the deposition hole |

[1] From the **Underground openings construction report**.

In the production-inspection schemes stages where the design parameters are processed are marked with blue colour. Light blue is used for any processing of design parameters and darker blue is used for processes that finally determine one or several design parameters. Determining a parameter means that the parameter is determined within the stage and that no active efforts are, or can be, made to alter it in the following stages of the production.

For the tests and inspections orange colour is used. Lighter colour is used for any inspections of the design parameters during the production and darker orange is used for final test and inspections. After final inspection no further inspections are possible to perform.

Stages where the design parameters are not processed but can be affected are marked with grey colour. Grey colour is also used for inspections of conditions that may impact the design parameters.

| | | **4.2 Excavation and delivery** | | | **4.3 Manufacturing of blocks and pellets** | | |
|---|---|---|---|---|---|---|---|
| **Property** | **Design parameter** | **Excavation and delivery for shipment** | **Material delivery and intermediate storage** | **Transport to and storage at production plant** | **Conditioning of the bentonite** | **Pressing of blocks / Pressing of pellets** | **Machining of blocks** |
| Material composition | Montmorillonite | Excavation | | | | | |
| | | (By supplier) | X-ray diffractation | – | – | X-ray diffractation | |
| | Organic carbon | Excavation | | | | | |
| | | (By supplier) | Heating in furnace | – | – | Heating in furnace | |
| | Sulphide | Excavation | | | | | |
| | | (By supplier) | Heating in furnace | – | – | Heating in furnace | |
| | Total sulphur | Excavation | | | | | |
| | | (By supplier) | Heating in furnace | – | – | Heating in furnace | |
| Compaction properties | Granule size distribution | Grinding | – | – | Grinding | | |
| | | (By supplier) | Sieving | – | Sieving | | |
| | Water content | Drying | Storage | Transport and storage | Mixing | | |
| | | (By supplier) | Drying in micro wave oven | – | Drying in oven | Drying in micro wave oven | |
| Density and dimensions of blocks | Bulk density | – | – | – | – | Pressing | |
| | | – | – | – | – | Weighing and calliper | Weighing |
| | Dimensions | – | – | – | – | Pressing | Machining |
| | | – | – | – | – | Calliper | Calliper |
| Density and dimension of pellets | Bulk density separate pellets | – | – | – | – | Pressing | |
| | | – | – | – | – | Weighing and calliper | – |
| | Dimensions | – | – | – | – | Pressing | |
| | | – | – | – | – | Calliper | |
| | Bulk density loose filling | – | – | – | – | Pressing | |
| | | – | – | – | – | Weighing of defined volume | – |

***Figure 5-2.*** *Production-inspection scheme for the excavation and delivery and manufacturing of blocks and pellets. Blue colour is used for processing of the design parameter and orange for inspection, darker colour illustrate final processing or inspection. Grey colour show stages where the design parameters may be affected but no processing occurs (also see explanation to the colours is given in text above).*

| | | 4.4 Handling and installation | | | | |
|---|---|---|---|---|---|---|
| **Property** | **Design parameter** | **Intermediate storage** | **Transport to and intermediate storage at repository level** | **Preparation of deposition hole** | **Installation of blocks** | **Installation of pellets** |
| Installed density | Bulk density of blocks | Storage | Storage | – | Installation | |
| | | Visual inspection of cover and if required weighing | Visual inspection of cover and if required weighing | Visual inspection and functional test of protective sheet and drainage system | – | |
| | Bulk density of pellet filling | Storage | Storage | – | – | Installation |
| | | Visual inspection of cover and if required weighing | Visual inspection of cover and if required weighing | – | – | Weighing and volume |
| | Width of pellet filled gap | – | – | – | Installation | |
| | | – | – | Measuring in of deposition hole geometry[1] | Position of installed blocks | |
| Installed geometry | Buffer thickness | – | – | – | Installation | |
| | | – | – | – | Position of installed blocks | |
| | Width of pellet filled gap | – | – | – | Installation | |
| | | – | – | – | Position of installed blocks | |
| | Diameter of hole within the installed blocks | – | – | – | Installation | |
| | | – | – | – | Position of installed blocks | |

[1] From **Underground openings construction report**.

***Figure 5-3.*** *Production-inspection scheme for the handling and installation of finished blocks and pellets. Blue colour is used for processing of the design parameter and orange for inspection, darker colour illustrate final processing or inspection. Grey colour show stages where the design parameters may be affected but no processing occurs (also see explanation to the colours is given in text above).*

## 5.2 Excavation and delivery

### 5.2.1 Excavation and delivery for shipment

#### *The process*

In this stage the montmorillonite, sulphide, total sulphur and organic carbon content are finally determined. The bentonite material can be mixed and the content homogenised in later stages but no active efforts to alter the material composition are performed.

Bentonite deposits exist at many places around the world and excavation and delivery can be made by alternative companies. The bentonite supplier is approved by SKB. The material is specified by SKB at ordering, most probably by selecting a commercial product defined by the supplier.

The bentonite is excavated from open pits. Exactly how the excavation is performed depends on the deposit. The procedure described in this report is based on Wyoming type bentonite supplied by the American Colloid Company. It is similar for other suppliers.

Before excavation soil layers are removed and the bentonite deposit is fully exposed. Samples are taken from different parts of the deposit to specify the composition of the clay. The clay is excavated and hauled to a processing plant. At the plant the bentonite is segregated by various quality attributes and put into stockpiles. Quality inspectors direct the building and use of these stockpiles to ensure that each specific material is kept separate and free of contamination. The bentonite is collected from the stockpiles and mixed, ground and dried so it conforms to the specification given in the order.

### *Inspections*

SKB will develop a routine for qualification of suppliers. This will comprise inspection of the quality assurance measures and systems applied by the supplier as well as laboratory tests of bentonite samples. The tests comprise measurements of material composition as well as investigations of material properties. The bentonite supplier must have a well documented quality management system.

Before each delivery the bentonite is inspected by the supplier. The inspections comprise a set of parameters specified by SKB and are performed applying specific methods. The supplier is also responsible for the inspection of the cargo area before loading, as well as any necessary cleaning of the cargo space.

## 5.2.2 Material delivery and intermediate storage in the harbour

### *The process*

The bentonite is delivered from self-unloading ships to a harbour close to the repository site. The bentonite is primarily inspected and if it is accepted it is unloaded and transported to a storage building. In the storage building the temperature is kept above 0°C and the humidity is regulated so condensation is avoided. In connection to the unloading the material is weighed. After unloading samples are taken from different parts of the load to inspect that the quality is even. There shall be enough delivered material available not to interrupt the process even if a delivery is not accepted.

### *Inspections*

Each shipment of bentonite is followed by a protocol from the supplier that describes the actual composition of the delivered material. The delivered material is inspected by SKB as a basis for the acceptance of the delivery. Inspections for the production comprise measurement of water content and granule size distribution of the delivered material and measurement of its total weight. Inspections of design parameters of importance for the barrier functions of the buffer comprise mineralogical composition of the buffer material.

Samples collected from different parts of the delivery are analysed with respect to mineral composition, water content and to the specific character of the swelling mineral. The tests aim at inspecting that material according to specification is delivered, to estimate the variation in material composition and water content in the cargo and to determine the grain size distribution as an input to the following process stages. The number of samples depends on the size of the cargo and on the supplier, i.e. the deposit, the methods applied by the supplier and experiences from previous deliveries.

## 5.2.3 Transport to and storage at the production plant

### *The process*

The desired weight of buffer material called for from the production plant is transported by trucks from the storage building in the harbour to the receiving building of the production plant. To avoid wetting and with respect to working conditions the loading area should be indoors and provided with controlled ventilation. The storage can be in buildings or silos. An example of a store with automatic discharge is illustrated in Figure 5-4.

### *Inspections*

Only the material flow is inspected in this stage and for this purpose vehicle weighing equipments are placed in the harbour and in the receiving building. It is foreseen that all vehicles are weighed once.

*Figure 5-4. Store with scraper for automatic discharge (Minelco AB, Luleå).*

### 5.2.4 Methods for test and inspection of material composition

#### X-ray diffraction – montmorillonite content

The mineral identification and quantification is based on X-ray diffraction of samples prepared as random powders. The method is based on exposing the sample to very short-wave electromagnetic radiation and analysing the set of interplanar lattice spacings, which are characteristic to each mineral species. The diffraction pattern is analysed by applying computer-based procedures where observed patterns are fit to known lattice parameters of smectite and other minerals in the mixture. The method is described by /Karnland et al. 2006/.

The result from the X-ray diffraction analyses is a list of minerals present in the sample and the contents in weight percent. The accuracy of measurement differs between minerals and also depends on the character of the sample. /Karnland et al. 2006/ have evaluated the montorillonite content in six samples taken from a small volume from the same delivery of Wyoming bentonite. Statistical analysis of the recorded montmorillonite contents shows a mean value of 83.5% with a standard deviation of 1.7%. Since the samples were taken from a confined volume the results can be regarded as an estimation of the uncertainty in the used method. To express a more precise value of the uncertainties of the test method more data are required. A test programme specifically designed for the evaluation of the accuracy of the X-ray diffraction method must be carried out.

#### Determination of organic carbon, sulphide and sulphur

The content of organic carbon, sulphide and total sulphur is determined by heating samples in a furnace and analysing the combustion gases. The samples are heated to different defined temperatures for detection of carbon, sulphide and sulphur. Special furnaces and analysing devices are available /Karnland et al. 2006/. During the heating the temperature is recorded and combustion gases are detected by IR-detectors. The content of organic carbon is determined by measuring the amount of $CO_2$. The amount of sulphate is determined by heating one sample. The total sulphur is analysed by burning all sulphur to $SO_3$ in another sample. The amount of sulphide can then be calculated by subtracting the determined sulphate content from the total amount of sulphur.

From four determinations of organic carbon from samples taken from a small volume from the same delivery of Wyoming bentonite the recorded average content was 0.24 wt-% and the corresponding standard deviation was 0.04%. Five determinations of sulphide also taken from a small volume from the same delivery resulted in a recorded average content of 0.13 wt-% of the total mass and a standard deviation of 0.05%. As for the tests of the X-ray diffraction, since the samples were taken from a confined volume of bentonite, this can be regarded as an estimation of the uncertainty in the used method. Also as for the tests of the X-ray diffraction, the data are not sufficient to express the accuracy of the method and a test programme must be specially designed and carried out for this purpose.

#### *Other applied methods*

In addition to the inspections of the montmorillonite, organic carbon, sulphide and total sulphur content SKB tests the main element distribution, the cation exchange capacity (CEC), free swelling volume and liquid limit of the material. These tests are made as a part of the quality control programme of the material to achieve a reliable production. The results of these tests are not directly used for inspection of the design parameters for the initial state but they contribute to reducing the variability of the produced buffer.

The main element distribution is determined by use of Atomic Emission Spectroscopy from an Induced Coupled Plasma (ICP/EAS). The method is described by /Karnland et al. 2006/. The results are used for comparison with a calculated composition based on the mineral composition determined by X-ray diffraction.

The cation exchange capacity (CEC), free swelling volume and liquid limit of the material are indicators of important material properties e.g. swelling ability, hydraulic conductivity and the compaction properties of the material. As these properties depend on the montmorillonite content, and also on the dominant cation, they are used to indirectly inspect the montmorillonite content and dominant cation.

The CEC is determined by use of the Cu-trien method. This is a conventional method which SKB has adapted for the use on bentonite as described in /Karnland et al. 2006/.

The free swelling volume is determined by applying the following conventional procedure. A graduated measuring glass is filled with a defined volume of de-ionised water. A defined amount of clay is poured into the water so that it sinks down as individual grains. The measuring glass is left for the clay to swell and the altered volume of the expanded sample is then registered.

The liquid limit is determined by dropping a cone into a mixture of clay and water and investigating the depth to which the cone penetrates the sample. The method is established and described in Laboratory manual series of the /Swedish Geotechnical Society 1988/. The method is adapted to bentonite by adding the time from mixing of the test paste. This addition is made since the physical properties of bentonite are determined by interaction between the montmorillonite component and water and the kinetics of the reaction is significant.

The data from the free swelling and the liquid limit tests are indicators of the montmorillonite content and dominant cation of the material. It is not used as absolute values of the material composition but as tests for detecting relative variation of the material within a delivery.

### 5.2.5 Methods for test and inspection of granule size distribution and water content

The granule size of the material is inspected by sieving through a set of nested sieves. This is a standard procedure to determine the distribution of particles down to a particle size of 75 µm. The accuracy of measurement is sufficient for the purpose.

The water content of the material is inspected by drying samples in an oven at a temperature of 105°C for 24 h and gravimetric determination of the weight loss of the sample. This is a well established and commonly applied method. In order to assure that the water content lies within the acceptable variation it should be possible to determine with an accuracy of ± 0.05%.

If fast answers are required, e.g. before unloading of the ship, the drying is performed by heating the sample in an ordinary micro wave oven for 5 minutes. As for drying in an oven the water content is determined by weighing the sample.

### 5.2.6 Experiences and results

Bentonite is a product used in many industrial applications. Excavation and delivery of bentonite with specified properties are well known and tested techniques and procedures. SKB regards the conventional methods and procedures as reliable.

The composition of the commercial bentonite product MX-80 supplied by American Colloid Company has been tested by SKB over the last decades, see Figure 5-5. The tests show that the composition of the bentonite varies very little between different deliveries. The natural variation in montmorillonite content can be described by a mean value of 81.4 wt-% and a standard deviation of 1.9% /Karnland et al. 2006/. Based on the current experiences the variations in the content of organic carbon, sulphides and total sulphur are limited. The range in organic carbon can be estimated to 0.25–0.40 wt-% of the total dry mass, the sulphide content can be estimated to 0.05–0.20 wt-% and the total sulphur can be estimated to 0.10–0.40 wt-% of the total dry mass.

The montmorillonite contents presented in Figure 5-5 depend on the actual variation in mineral composition, the sampling and on the accuracy of measurement in the applied methods. The analyses techniques for the test of mineralogical composition has been used by SKB on several investigated bentonites /Karnland et al. 2006/. Based on the current experiences the accuracy in measurement of the montmorillonite content can be estimated to about 2%, and the accuracy in measurement of organic carbon, sulphide and total sulphur can be estimated to about 0.05%, see Section 5.2.4. The accuracy of measurement is used as an input when determining a sampling strategy.

In this stage of the production the water content is inspected for economical reasons to confirm that the delivered mass does not consist of too much water. Generally the water content lies between 8–12%.

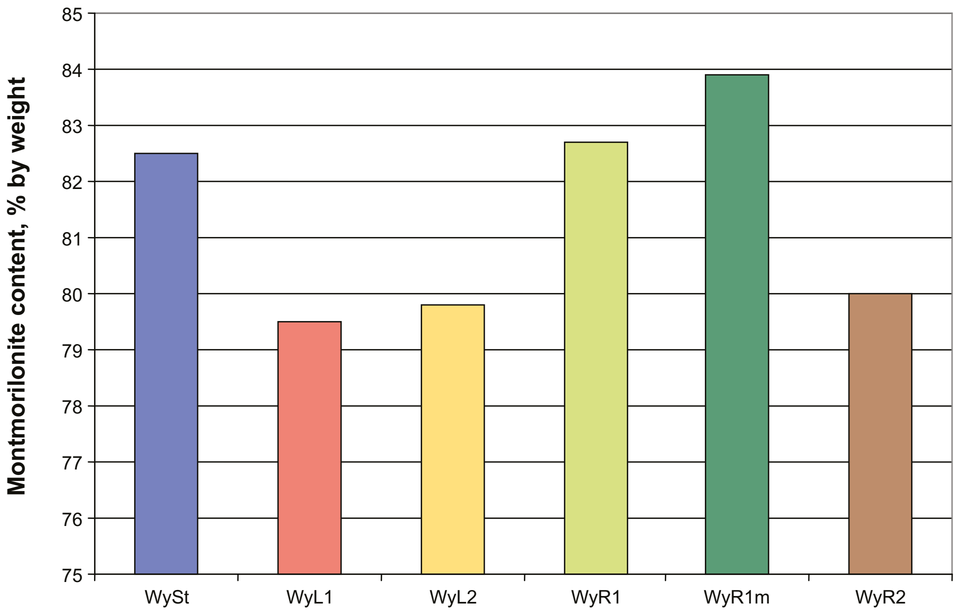



***Figure 5-5.*** *Results of X-ray diffractation inspections and analysis of diffractation patterns showing the montmorillonite content in the five consignments representing over 20 years of production of MX-80 bentonite /Karnland et al. 2006/. The Stripa (WySt) material represents material delivered around 1980, and the others were delivered 1995 (WyL1), 1999 (WyL2), and 2001 (WyR1 and WyR2).*

## 5.3 Manufacturing of blocks and pellets

### 5.3.1 Conditioning of the bentonite

***The process***

In this stage the delivered material is processed to the material specific granule size distribution and water content suitable for pressing blocks and pellets. The granule size distribution and water content of the material ready for compaction are finally determined.

The conditioning of the material comprises the following activities:

1. drying to a water content suitable for grinding,
2. grinding to a granule size suitable for compaction,
3. storage of ground material,
4. wetting of ground material to a water content suitable for compaction,
5. storage of material ready for compaction.

The water content measured at delivery is used to determine whether the material needs to be dried to a moister content suitable for grinding. The drying is made in a dryer with a high capacity, an example of a dryer is shown in Figure 5-6.

After drying the material is transported to a mill and ground to the required granule size. The grinding is made with a hammer mill (see Figure 5-6). After the grinding the ground material is transported to a silo where it is stored.

In order to get the water content required for pressing of blocks and pellets the ground material is mixed with water in a mixer. The adjustment of the water content of the bentonite is made with high efficient mixers, an example is given in Figure 5-6. A specified amount of ground bentonite material is filled into the mixer, its water content is measured and the amount of water needed to reach the specified water content is calculated. Water is added to the bentonite in the mixer through a spray nozzle. In order to reach the required density and water content when pressing blocks and pellets it is important that the bentonite after the mixing is homogeneous, free from lumps, and that the variation in the water content is less than ±1%.

After the mixing the batch of material ready for compaction is stored in a smaller silo close to the pressing equipments used for manufacturing the blocks or pellets. The storage capacity of the silo is adapted to the required buffer block and pellet production rate.

The whole conditioning process, excluding the inspections, is automatic from the storage of raw material to the delivery of material ready for compaction to the silo in connection to the pressing devices. The press operator calls for material when needed.

***Inspections***

The water content of the delivered raw material is inspected before and after drying to yield a level suitable for grinding.

The water content and granule size distribution of the material ready for compaction is finally inspected in connection to the mixing. The inspection of the granule size distribution is made before the mixing. The water content is inspected before the mixing to determine the amount of water to be added. The amount of water added is measured and finally the water content of the mixed material ready for compaction is inspected. Samples are taken from each mixing of material.

The water content and grain size distribution are inspected for each mixed batch transferred to the silo in connection to the pressing devices. The inspections are performed by drying in micro wave oven. The number of samples shall be sufficient to determine the average water content.

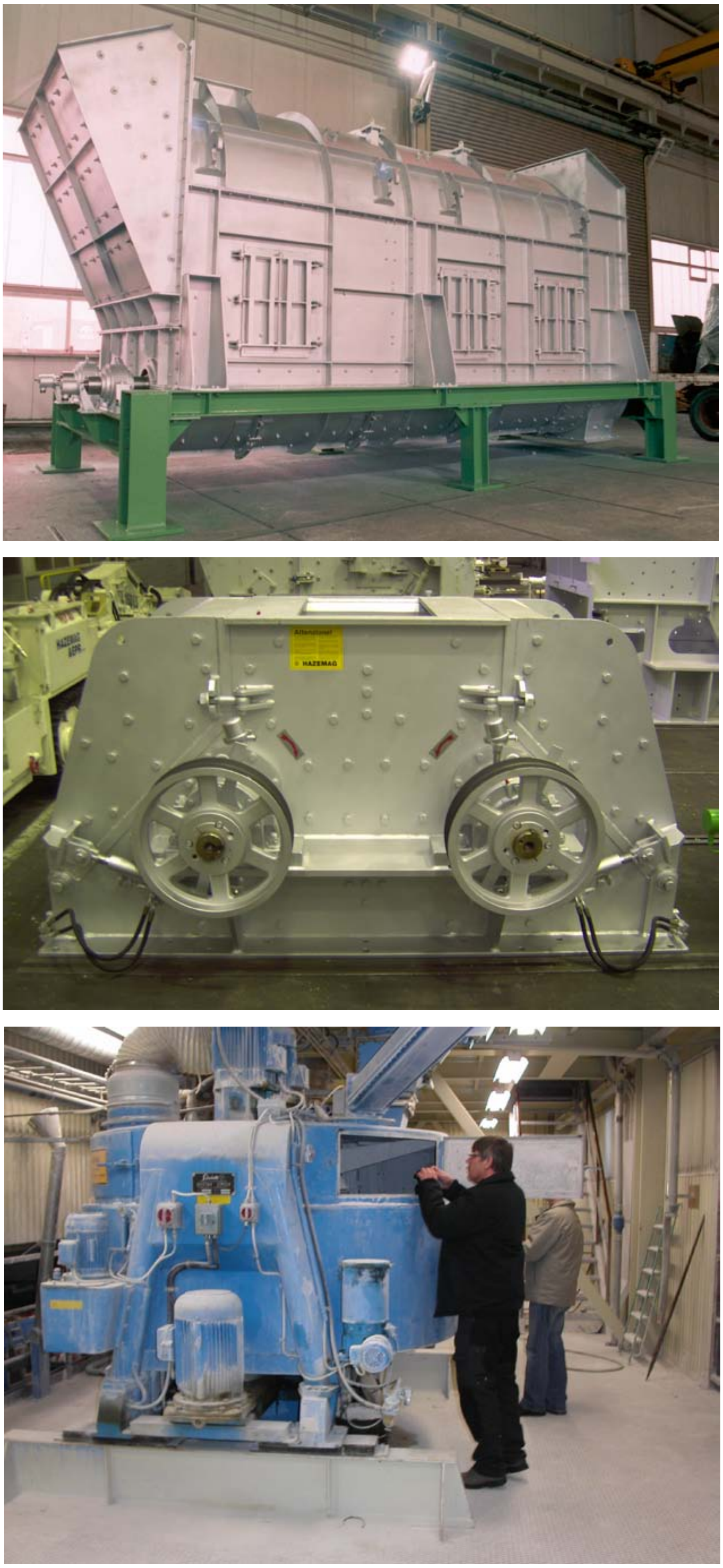


***Figure 5-6.*** *Examples of equipment for conditioning the bentonite a) drying oven from Hazemag b) a hammer mill from Hazemag c) a mixer from Eirich.*

### 5.3.2 Pressing of blocks

***The process***

In this stage the dry density of the blocks is finally determined. The pressing process is controlled to yield the specified density.

The density of the blocks depends on the grain size distribution and water content of the material to be compressed and on the compaction pressure. The reference method for pressing of blocks is uniaxial compaction. At uniaxial compaction the bentonite is filled in a rigid mould and compacted in axial direction. The compaction is made either with one piston or with an upper and a lower piston. If two pistons are used the thickness of the blocks can be increased while maintaining homogeneity. To get a homogeneous block lubricant is used on the mould (bentonite contaminated with lubricant will be machined off, see Section 5.3.3). Further the mould is slightly conical in order to facilitate the removal of the block. The mould used for the blocks to the Prototype Repository experiment at Äspö HRL is shown in Figure 5-7.

The pressing of blocks comprises three steps:

- cleaning and lubrication of the mould,
- filling the mould with bentonite,
- compaction and removal of the block from the mould.

Before the mould is filled it is cleaned from bentonite and lubricants from the previous pressing. The cleaning is made by hand and the mould is visually inspected. Then the cylinders (inner and outer) are lubricated and a clean filter is placed on the bottom plate. The lubricant shall withstand high pressures and is applied by a brush or spraying. The same amount of lubricant is used for each pressed block. The lubrication is important for the results of the pressing. Too little lubricant cause friction between the bentonite and the mould and may result in damaged or inhomogeneous blocks. Too much lubricant may cause upward movements of the outer cylinder during the compaction which might damage the mould. By using the same amount of lubricant for each block the variation in density between the blocks is reduced.

The conditioned material to be filled in the mould is transported to a balance and weighed. The mass must be accurate in order to minimise the variation of block height. In order to get homogeneous blocks it is important that the bentonite is equally distributed in the mould. This is done by vibrating the bentonite in the mould. If required, samples for inspections of material composition and water content are taken from the bentonite poured into the mould.


***Figure 5-7.*** *The mould used for making ring shaped blocks for the Prototype Repository.*

The mould filled with bentonite is transported to the press. Cleaned filters are placed in the piston. The piston is placed on top of the bentonite in the mould. A vacuum pump is connected to the filters on the bottom plate of the mould and on the piston. The air in the bentonite is evacuated through the filters and the mould is then placed in the press.

The block is compacted in one step. The compaction pressure is increased to the required load, the required load is acting on the block and the pressure is then unloaded. To control the resulting density the pressure is registered. After the compaction the block is removed from the mould with the use of the press. When a ring-shaped block is compacted the inner cylinder is removed from the block with an overhead crane. The block is given a unique identity and is lifted from the bottom plate of the mould and placed on a special designed pallet. At the same time the block is weighed. An example of combined lifting and weighing is shown in Figure 5-8.

In order to reach the desired capacity it is necessary to use several moulds. Currently the use of three moulds circulating between the three process steps, cleaning, filling and compaction is suggested.

### *Inspections*

The water content in the material ready for compaction and the material composition and dry density of the pressed blocks are finally inspected in this stage.

To minimise the friction between the mould and the bentonite during the compaction it is important that the surface of the mould is shining and free from scratches and other damages. The mould is visually inspected before it is filled. The mould is lubricated and the amount of lubricant is weighed to get an even density of the pressed blocks and also as an input to the machining of the blocks.

***Figure 5-8.*** *A bentonite block lifted with the vacuum oak used at the production of the blocks of the Prototype Repository. Note the weighing machine hanging in the over head crane.*

Samples for which the material composition and water content is determined is taken from the bentonite before pressing of the blocks. The samples are saved as reference for the compacted blocks. The number of samples depends on the number of inspections previously performed from the same delivery and their results. A sampling strategy will be developed as part of a control programme, see Section 5.1.4. Both material composition and water content of the blocks are finally inspected.

The weight and dimensions (height and diameter/s) of each block are inspected. The dry density of the block is calculated from the recorded water content, weight and dimensions. This test is performed to inspect that the compaction has resulted in the desired bulk and dry densities. The blocks are given a unique identity and the bulk and dry densities, weight and dimensions are registered.

Before the blocks are transported to machining they are visually inspected for fractures and damages. If there are no indications of density loss or fractures that may reduce the strength of the blocks they are transported to machining.

### 5.3.3 Machining of blocks

***The process***

In this stage the blocks are machined to the dimensions specified in Table 3-4. The machining process also assure the evenness of the blocks required in order to achieve a strait stack of blocks in the deposition hole and the required installed bulk density. To fit the bottom and top of the canister the bottom block on which the canister is standing and the block placed on top of the canister are machined to the dimensions illustrated in Figure 3-2.

The need for machining of the vertical surfaces of the blocks depends on the results from the pressing. Factors that impact the need for machining are the use of lubricant and how far it is spread into the block, and to which extent the blocks need to be conical to facilitate the removal of the block from the mould.

The machining of the blocks is made with a turning lathe. The lathe has to be enclosed and supplied with equipment for preventing spreading of dust. The spreading of dust must be limited in order to get a good working environment. The material machined off the block is collected and must not be mixed with material used in the production.

After the machining the blocks are placed on a pallet provided with a plastic cover so that their moisture content is maintained during storage and the transport to the repository level. An example of a pallet with a buffer ring and plastic cover is shown in Figure 5-9.

***Inspections***

The bulk density, i.e. the weight and dimensions, of the blocks are finally inspected in this stage.

After the machining the blocks are visually inspected for fractures and damages. If there are no indications of density loss or fractures that may reduce the strength of the blocks they are approved and their weight and dimensions, i.e. height, diameter/s and specially designed details, are inspected. All approved blocks are measured and weighed, and the bulk density is calculated. The inspected and calculated data are registered for each uniquely identity marked block.

### 5.3.4 Pressing of pellets

***The process***

The reference method to manufacture pellets is to compact the conditioned material to small briquettes. The pellets can be made in different sizes an example is shown in Figure 5-11. The machine pressing the pellets consists of a screw and two rolls, see Figure 5-10. Conditioned material for one batch to be pressed to pellets is transported to the pressing machine. The material is compressed by the screw while the rolls rotate. The right roll rotates clockwise and the left anti-clockwise. It is possible to vary the roll speed and the pressure from the screw to change the density of the pellets. After pressing the pellets are placed in special designed containers which are transported to intermediate storage.

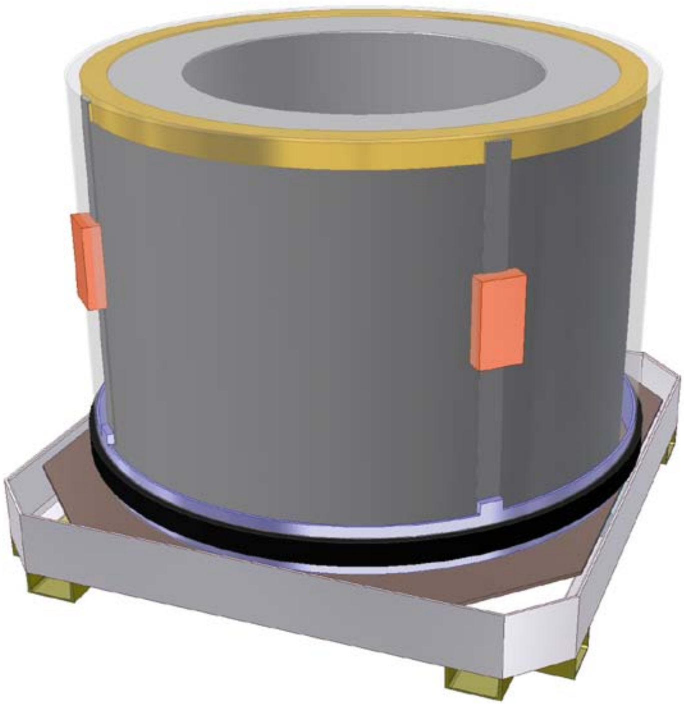


*Figure 5-9. Bentonite block on the transfer pallet with locking device and a transparent protection cover.*

*Figure 5-10. A machine for pressing of briquette shaped pellets (BEPEX test equipment).*

### Inspections

The water content in the material ready for compaction, the material composition and the dimensions of the pressed pellets are finally inspected in this stage.

Samples are taken of the bentonite from each batch of conditioned material to be pressed to pellets. The material composition and the water content of the samples are inspected. The samples are saved as a reference for each batch of pellets. The number of samples depends on the number of tests previously performed from the same delivery and their results. A sampling strategy will be developed as part of a control programme, see Section 5.1.4.

***Figure 5-11.*** *Pellets made by the briquette pressing machine used for the Prototype Repository.*

The dimensions of the pellets are inspected by measuring a number of pellets with a calliper. The number of pellets to be inspected depends on available data from the pressing of pellets from the same raw material delivery and batch of material ready for compaction. If recorded process data indicate that there may be pellets that do not have the required dimension the number of inspected pellets are increased.

The weight of a loose filling of the pellets is inspected by weighing a filled container with known weight and volume. The bulk density of the loose filling is calculated from the volume and the recorded weight. This test is done for all produced pellet batches.

### 5.3.5 Methods for test and inspection of material composition

The same methods for test and inspection of the material composition as for the excavation and delivery are applied. The methods and their accuracy in measurement are presented in Section 5.2.4.

### 5.3.6 Methods for test and inspection of granule size distribution and water content

The same methods for test and inspection of granule size distribution and water content as for the excavation and delivery are applied. The methods and their accuracy in measurement are presented in Section 5.2.5.

### 5.3.7 Methods for test and inspection of weight, dimensions and density

Different kinds of weighing machines are used for inspection of the weight of the pellets and blocks. The weighing machines are calibrated to the required accuracy by applying conventional procedures. In order to verify that the bulk density lies within the acceptable limits the weight of the blocks should be measured with an accuracy of ± 2 kg. The bulk density of the pellets is directly determined by weighing a defined volume of loose filling. Measuring of weight of objects with a mass of pellets and blocks with the required accuracy is established and well known technique.

The measurements of the height, diameters and specially designed details of the blocks are made with a calliper. The dimensions of the blocks are measured with an accuracy of ±1 mm. Measuring of dimensions of objects of the size of the blocks with the required accuracy is established and well known technique from various similar applications.

The dimensions of the pellets are also determined with a calliper. The required accuracy is similar as for the blocks and as for the blocks the method is based on well known and established technique.

The bulk density is calculated from the recorded weights and dimensions. The accuracy of the calculated density depends on the accuracy of measurements of the weights and dimensions. The accepted variation in bulk density is about ±1%. Assuming that the weight of the blocks can be measured with an accuracy of ± 2 kg and the dimensions measured with an accuracy of ± 0.1 mm the density can be determined with an accuracy of about ± 0.15%.

### 5.3.8 Experiences and results

All the suggested equipments for conditioning of the bentonite are available and can be purchased from alternative suppliers. The used materials for the large scale tests at the Äspö HRL were dried and ground to the specified granule size distribution by the supplier. The water content of the ground material was adjusted with the use of a large mixer with good result /Johannesson 2002/. This indicates that the drying and the grinding process described above are feasible.

Experiences and equipment for uniaxial compaction of blocks is available from similar industrial applications. It has been used by SKB for the production of the blocks for the large scale tests at Äspö HRL, all together more than 130 blocks /Johannesson 2002/. The tests show that it is possible to manufacture blocks according to the reference design if the blocks are pressed and then machined to remove the lubricant from the surface of the blocks and adjust their dimensions. The produced blocks had a height of 500 mm while the height of the ring shaped blocks in the reference design is 800 mm. Other investigations have indicated that it is possible to compact blocks to a height in the same range as the block diameter /Johannesson et al. 1995 Section 4.2.3/ without getting inhomogeneous blocks, which justifies the choice of the reference design.

Recorded data of the blocks for the Prototype Repository are presented in /Birgersson and Johannesson 2006/. The data are presented as dry densities while the densities of the reference blocks are given as bulk densities. For the defined water content a bulk density of 2,000 kg/m$^3$ corresponds to a dry density of about 1,710 kg/m$^3$, and a bulk density of 2,070 kg/m$^3$ corresponds to a dry density of about 1,770 kg/m$^3$.

The average dry densities for the two types of blocks placed in the six deposition holes in the Prototype Repository are given in Table 5-3. The mean dry densities of the compacted blocks lie within the accepted variation for the reference design. However, if all the manufactured blocks are considered, the 95% confidence interval observed is larger than the accepted variation for the reference design. This is true both for ring shaped and solid blocks. The larger than desired variation in dry density of the blocks is attributed to the different occasions when they were manufactured and that the source materials came from different deliveries of bentonite. In the test production there were limited possibilities to adapt the water content and grain size of the material ready for compaction, as well as the pressing process, to the delivered material. The variation within the deliveries for each deposition hole lies within the acceptable limits for all holes except one.

**Table 5-3. Calculated dry density based on measurements of the blocks compacted for the Prototype Repository /Birgersson and Johannesson 2006/.**

| | Dry density of ring shaped blocks (kg/m$^3$) | | | | Dry density of solid blocks(kg/m$^3$) | | | |
|---|---|---|---|---|---|---|---|---|
| Hole No. | mean | std | 95% C.I. | | mean | std | 95% C.I. | |
| DA3587G05 | 1,788 | 7.6 | 1,773 | 1,803 | 1,711 | 5.1 | 1,701 | 1,721 |
| DA3581G01 | 1,783 | 8.8 | 1,766 | 1,800 | 1,704 | 12.5 | 1,679 | 1,728 |
| DA3575G01 | 1,786 | 8.2 | 1,770 | 1,802 | 1,717 | 6.3 | 1,705 | 1,730 |
| DA3569G02 | 1,793 | 6.8 | 1,780 | 1,806 | 1,713 | 3.9 | 1,705 | 1,720 |
| DA3551G01 | 1,756 | 14.8 | 1,727 | 1,785 | 1,703 | 11.1 | 1,682 | 1,725 |
| DA3545G01 | 1,758 | 8.4 | 1,742 | 1,775 | 1,701 | 7.6 | 1,686 | 1,716 |
| All Holes | 1,777 | 17.4 | 1,743 | 1,811 | 1,708 | 11.4 | 1,686 | 1,731 |

The technique for machining of blocks has been tested on blocks with a diameter of 800 mm at Ifö Ceramics AB factory in Bromölla. The same technique is used by Ifö Ceramics in their normal production. Tests where full size bentonite blocks, diameter 1,630 mm, are machined have not been performed yet. Experiences from machining the bentonite blocks with a diameter of 800 mm indicate that machining can be made with a variation in diameter of less than 1 mm. In Table 5-4 the results from measurements of the diameter of seven machined bentonite blocks are given. The blocks were machined in a standard turning lathe and the diameters of the blocks were measured afterwards. The table shows that the mean value of the diameter is 800.5 mm with a standard deviation of 0.4 mm. This shows that conventional technique can be applied to machine the blocks to the specified dimensions with a variation of ±1 mm.

The technique for pressing of pellets has been tested at two suppliers of equipment for this type of production. The technique is well known from other industrial applications and has been used for production of pellets for the large scale tests at Äspö HRL.

Laboratory tests made for evaluating the density of a filling of pellets show that a dry density below 1,000 $kg/m^3$ is achieved for a number of investigated clay materials /Sandén et al. 2008/, see Table 5-5.

## 5.4 Handling and installation

The installation of the buffer is included in the deposition works in the KBS-3 repository facility. The deposition works comprise a deposition sequence and a backfill sequence. Some stages of the installation of the buffer are included in the deposition sequence and some in the backfill sequence. An overview of the deposition works and the deposition and backfill sequences is given in the **Repository production report,** Section 4.1.4.

**Table 5-4. Measurements of the diameter at two positions of the compacted bentonite blocks.**

| Block No | Diameter 1 (mm) | Diameter 2 (mm) |
|---|---|---|
| 1 | 800.9 | 800.5 |
| 2 | 800.6 | 800.6 |
| 3 | 801.0 | 801.0 |
| 4 | 800.0 | 800.0 |
| 5 | 800.3 | 800.2 |
| 6 | 800.3 | 800.3 |
| 7 | 800.8 | 800.6 |
| | mean: | 800.5 |
| | std: | 0.4 |

**Table 5-5. Bulk density of loose pellets filling of investigated buffer materials /Sandén et al. 2008/.**

| Sample | Water ratio (%) | Bulk density of filling ($kg/m^3$) |
|---|---|---|
| MX-80 pellets (typical value) | 11.3 | 1,038 |
| Minelco (big bags at Äspö HRL) | 18.8 | 1,159 |
| CEBOGEL QSE | 18.9 | 1,121 |
| Friedland granules | 7.1 | 1,118 |

### 5.4.1 Intermediate storage at ground level

#### *The process*

A stock of buffer blocks and pellets at the ground level is needed to avoid interruptions in the installation of the buffer in the final repository in case of breakdowns in the production. It is important that the water content of the blocks and pellets is not changed during the storage. For this purpose the blocks are placed on special designed pallets equipped with an air tight hood. The pellets are placed in containers placed on the same type of pallets. The hood is transparent in order to facilitate inspection of the blocks and pellets. Stores are planned to be placed in the industrial area of the final repository facility and also within the protected area of the nuclear facility. Handling and transports are made by conventional overhead cranes, grapple units and load carriers.

#### *Inspections*

Before the pallets are transported from the storage to repository depth the identity, covers, blocks and pellets are visually inspected. If the covers are damaged or there are any visible damages on the blocks or pellets, they are either discarded or the inspections of their weight and dimensions are repeated.

### 5.4.2 Transport to and storage at repository level

#### *The process*

The buffer blocks and pellets are transported to repository level with the skip. A small stock of blocks and pellets at the repository level is needed to avoid interruptions in the installation of the buffer in case of breakdowns or temporary capacity shortages of the skip. The blocks and pellets are transported and stored on the covered pallets described in Section 5.4.1 and the same type of equipment and stores as above ground are used.

#### *Inspections*

At delivery to the store the same inspections as for the interim storage on ground level described in Section 5.4.1 are performed. To confirm that no water-uptake or other alterations of the blocks have occurred during the handling and storage, a number of blocks can be selected for weighing and measuring.

### 5.4.3 Preparation of deposition hole

#### *The process*

The installation of the buffer is based on that deposition holes according to specification are provided from the underground openings construction line. The preparation and approval of deposition holes for deposition is described in the **Underground openings construction report,** Section 5.3.6 and comprises:

- removing of water and cleaning of the deposition hole,
- inspection of inflow to the deposition hole,
- inspection of fractures intersecting the deposition hole,
- installation and inspection of the bottom plate,
- inspection of deposition hole dimensions, i.e. radii and cross section as a function of depth, bottom inclination and total volume and measuring in of centre line.

To protect the buffer from taking up water from the moist in the air and from drying if the deposition hole is dry, a protection sheet is placed in the deposition hole before installation of the blocks. The protection sheet is made of thick, elastic, durable and watertight rubber. The sheet is attached to the bottom plate. The bottom plate consists of a copper plate with a border and a centred hole resting on a concrete foundation. The sheet is attached to the border of the copper plate, see Figure 5-12.

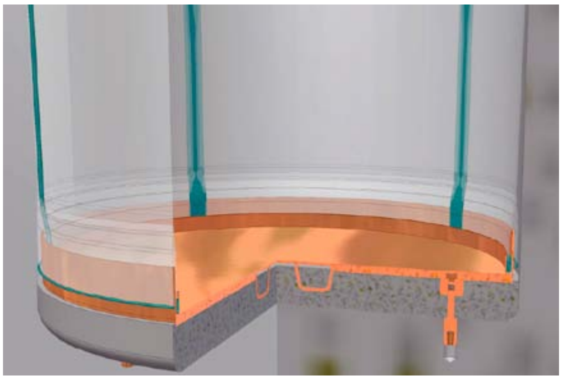


*__Figure 5-12.__ The protection sheet installed in a deposition hole. The sheet is attached to the border of the copper plate in the bottom of the deposition hole.*

A drainage system is placed between the sheet and the wall of the deposition hole. The system consists of a pipe, an ejection pump and an alarm system. The pipe is placed at the bottom of the hole and the ejection pump is placed at the tunnel floor. The alarm system alarms for high water level in the deposition hole. The pumping and water lifting capacity of the pump is adapted to the accepted inflow and depth of the deposition holes. The space between the border of the copper plate and the deposition hole wall forms a water store. The storage capacity of this store together with the maximum pumping capacity will determine the design of the drainage system. The detailed configuration of the pumps and drainage system remains to be determined.

#### *Inspections*

Before installation of the protection sheet and drainage system the deposition hole is visually inspected. If there is lose material or much water in the deposition hole or any other indications of that the deposition hole does not conform to the reference design a renewed inspection and scanning of the dimensions of the deposition hole is made.

Before installation of the buffer the function of the alarm system included in the drainage system is inspected.

### 5.4.4 Installation of blocks

#### *The process*

In this stage the position of the blocks in the deposition hole, the thickness of the buffer around, below and above the canister and the diameter of the hole within the ring shaped blocks are determined. The position and weight of the blocks together with the deposition hole dimensions and the weight of the later installed pellets determine the bulk density of the installed buffer.

The buffer consists of altogether one solid bottom block, six ring shaped blocks around the canister and three solid blocks on top of the canister, see Figure 3-3. The buffer ends and the backfill commences at the top of the third block on top of the canister, see Figure 5-13.

To avoid handling of both backfill and buffer material in the manufacturing of blocks, and to facilitate the installation, the two top blocks in the part of the deposition hole regarded as part of the deposition tunnel are made of the same material and installed at the same time as the buffer.

Before the installation of the block commences the gantry crane that shall install the blocks is positioned above the deposition hole and a gamma gate is placed on top of the hole. The gantry crane is positioned with respect to the determined average centre line of the deposition hole. The function and position of the gantry crane are inspected to confirm that it can perform the installation correctly. The gantry crane and its lifting tool are shown in Figure 5-14.

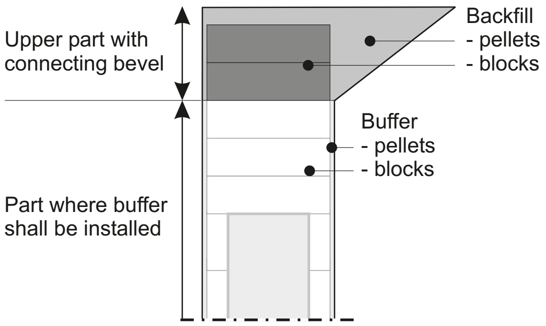



***Figure 5-13.*** *The upper part of the buffer and the connection to the backfill in the deposition tunnel. The two dark grey blocks are made of buffer material but are regarded as a part of the backfill. The upper part of the deposition hole down to the level where the buffer is installed is regarded as a part of the deposition tunnel.*

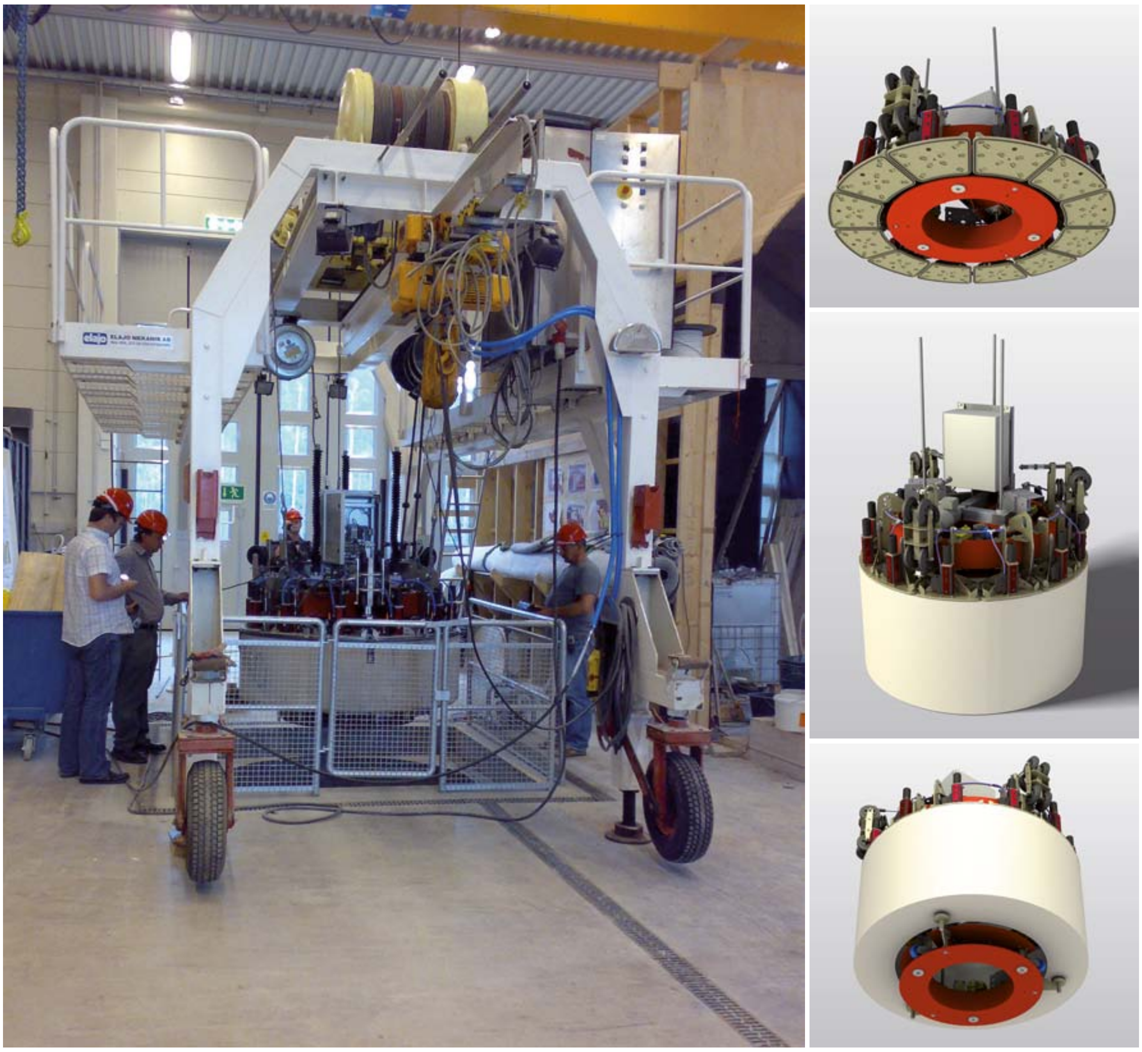


***Figure 5-14.*** *The gantry crane and the lifting tool for buffer blocks. The solid blocks are lifted with vacuum only but the rings are also supported from below during the installation.*

The bottom block is installed and centred with respect to the average centre line of the deposition hole. The protocol from the measuring in of the deposition hole is used to calculate the position of the block. The position is fed into transmitters controlling servo-engines that position the lifting tool in the correct position and the block is then lowered into the hole.

The first ring shaped block is installed in the same way as the bottom block. The installed ring shaped block is used to guide the installation of the next ring shaped block so that they are positioned in the same horizontal position on top of each other with a straight and centred hole for deposition of the canister in the middle. After installation of the top ring shaped block the hole within the blocks is inspected, the gamma gate is closed and the gantry crane removed. The canister is then deposited as described in the **Canister production report,** Section 6.8**.**

When the canister has been deposited and the gamma gate closed the gantry crane is repositioned above the deposition hole. The gamma gate is then opened and the three top buffer blocks and the two blocks considered as a part of the backfill are installed. The blocks are positioned in the same way as the bottom block. This part of the buffer installation is performed remotely. The stack of blocks is visually inspected and sensors for measuring of the temperature and moisture are placed inside the protection sheet. The protection sheet is then pulled over the blocks and closed. The gantry crane and the gamma gate are removed and a protective lid is placed on top of the deposition hole.

#### *Inspections*

In this stage the positions of each of the blocks installed in the deposition hole are finally inspected.

Prior to installation the identities of the blocks to be deposited in the specific deposition hole are inspected and registered. The position of each installed block within the deposition hole is recorded by the control system for the servo-engines of the gantry crane during the installation. The coordinates of the installed blocks are calculated from the measuring in protocol of the deposition hole and the recorded positions of the lifting tool.

From the dimensions of the blocks and their positions the buffer thickness and block filled part of the deposition hole volume are calculated. The positions and dimensions of the ring shaped blocks determine the diameter of the hole within the blocks, and if the canister is placed centred in the hole, also the thickness of the buffer around the canister. The thickness, or height, of the buffer above and below the canister is determined by the dimensions of the installed solid blocks. The deposition hole dimensions and the positions and dimensions of the blocks determine the width of the gap between the blocks and the rock surface. Together with the weights of the blocks and pellets these data are used as input to calculate the bulk density of the installed buffer and its variation in the deposition hole.

The water level in the gap between the buffer and the rock is inspected by the alarm system included in the drainage system (also see Section 5.4.3). The sensors placed inside the protection sheet continuously record the temperature and moisture. High moisture content would be an indication that the buffer protection sheet may be defect. If the installed blocks are exposed to water they may start to swell which may result in that the protection sheet cannot be removed and/or enough volume of pellets cannot be installed. If so the buffer, and as a consequence also the canister, may need to be retrieved. Criteria for acceptable moisture content remain to be determined.

### 5.4.5 Filling of pellets

#### *The process*

In this stage the weight and volume of the installed pellets are determined. Together with the position, weight and volume of the blocks this determine the bulk density of the installed buffer and its variation in the deposition hole.

The buffer pellet filling ends in level with the third buffer block on top of the canister, see Figure 5-13.

The installation of the pellets commences when the backfilling of the deposition tunnel has reached the section of the deposition hole. Before the installation of the pellets the drainage system, the protection sheet and the sensors placed within the sheet are removed. The pellets to be installed are weighed and placed in a container. The pellets are filled into the gap by placing a conical hood on top of the last installed bentonite block and pouring the pellets into the deposition hole. As soon as the gap has been filled with pellets the backfilling of the deposition tunnel continues so that the backfill prevents swelling and expansion of the buffer caused by a fast water uptake of the pellets filling.

***Inspections***

To determine the weight and volume of the pellets installed in the deposition hole, the weight and volume of pellets filled into the container are measured before and after the installation. The weight and volume that has been filled into the gap are recorded.

### 5.4.6 Methods for test and inspection of weight, dimensions and density of blocks and pellets

The same methods as described for the manufacturing of blocks and pellets in Section 5.3.7 are used to determine weight, dimensions and density during the handling and installation of the buffer blocks and pellets.

### 5.4.7 Methods for test and inspection of installed buffer geometry and density

The installed buffer thickness and density and their variation in the deposition hole volume are calculated from:

- the deposition hole volume (provided from the **Underground openings construction report**),
- the deposition hole radii and cross section area along its centre axis (provided from the **Underground openings construction report**),
- the weight, dimensions and positions of the installed blocks,
- the weight and volume of the installed pellets.

The positions of the blocks within the deposition hole are determined from the measuring in protocol of the deposition hole, the recorded positions of the lifting tool and the measured positions of the fixed points on the installed blocks. The calculations of the installed buffer thickness and density are made with software to which the measured deposition hole geometry, the block dimensions and data recorded during and after the installation are automatically fed and interpreted.

The bottom ring shaped block guide the placement of the following ring shaped blocks. If the bottom ring shaped block is placed in an incorrect position with respect to the centre axis the deviation may propagate along the deposition hole. Inclining surfaces of the blocks and the bottom plate may also result in propagating deviations.

The accuracy in the placement of the solid blocks and the first ring shaped block depends on the accuracy of the system with transmitters controlling the servo-engines positioning the lifting tool. To inspect the resulting position and ensure that no debris or other objects have resulted in an inclined surface the position of the blocks are measured after the installation.

The accuracy of the calculated variations of installed dimensions and densities along the deposition holes depends on the accuracy of the recorded positions, masses and volumes. The positioning system has neither been constructed nor tested yet and no data are available to estimate its accuracy.

The accuracy of measurement of the average density in the deposition hole is estimated from the accuracy of the measurement of the deposition hole volume, the accuracy of the bulk densities and dimensions of the blocks and the accuracy in the measurement of the weight and volume of installed pellets.

### 5.4.8 Experiences and results

The techniques for loading, transportation and storage of the buffer blocks and pellets are well known from similar industrial applications. SKB has own experiences from the Äspö HRL. Blocks have been stored placed on pallets with an air tight hood for several months without showing any changes of dimensions /Johannesson 2002, Johannesson et al. 2004/. The transport system has not been tested in full scale but the technique is well known and established.

The function of the protection sheet placed in the deposition hole before installation of the buffer has been tested at Äspö HRL. During the installation of the buffer in the six deposition holes in the Prototype Repository a simple type of protection sheet made of plastic was tested with good results /Johannesson 2002, Johannesson et al. 2004/. The bottom slab of these deposition holes did not have the same design as in the reference design. The plates were not of low pH concrete and were levelled with simple tools after the casting. Full scale tests with protection sheets made of rubber have also been performed at the Äspö HRL. Both the installation and the removal of the sheet were carried out with good results /Wimelius and Pusch 2008/. The drainage system including the alarm system has also been tested with good results /Wimelius and Pusch 2008/.

The installation of the buffer in the large scale projects at Äspö HRL was in principle carried out as described above /Johannesson 2002, Johannesson et al. 2004/. The gantry crane was developed for the installation of the buffer for the Canister Retrieval Tests and the Prototype Repository at Äspö HRL. It was not provided with any positioning system and the horizontal positioning of the blocks was manually controlled. The technique to fill the outer gap with pellets has been used in several large scale tests at Äspö HRL with good results. The gantry crane, the lifting tool as well as the pellet filling machine will be subject for further development and testing.

All tests at Äspö HRL were performed in deposition holes without a connecting bevel. Further, no gamma gate was placed over the deposition holes in the tests.

A statistical analysis of the installed bulk density of the buffer in the six deposition holes in the Prototype Repository has been made /Birgersson and Johannesson 2006/. The variation in dimensions of the deposition holes, the variations in the density of the compacted blocks and the density of the pellet filling were taken into account when determining the installed densities. The calculations were made with the assumption that no vertical swelling of the buffer had occurred in the deposition holes. In Table 5-6 the calculated average dry densities of the installed pellets filling are presented, data for the blocks are given in Table 5-3 (Section 5.3.8) and the resulting calculated installed densities are given in Table 5-7.

The mean dry density of the pellet filling for all six holes is 1,100 kg/m$^3$, which for a water content of 10% correspond to a bulk density of about 1,200 kg/m$^3$. This value is above the limit for the reference design. Other tests made for evaluating the density of a filling of pellets show however lower dry density than those achieved in Prototype Repository, a dry density of about 1,000 kg/m$^3$ /Sandén et al. 2008/.

Due to the different water content in blocks and pellets their dry densities were used when calculating the average installed density. The 95% confidence interval is presented as the resulting saturated density.

**Table 5-6. The average dry density of the installed pellets filling in the Prototype Repository /Birgersson and Johannesson 2006/.**

| Hole No. | Hole diameter (m) | Block diameter (m) | Weight of installed pellets (kg/m$^3$) | Dry density of installed pellets (kg/m$^3$) |
|---|---|---|---|---|
| DA3587G05 | 1.760 | 1.637 | 364 | 1,113 |
| DA3581G01 | 1.760 | 1.638 | 374 | 1,147 |
| DA3575G01 | 1.761 | 1.638 | 340 | 1,032 |
| DA3569G02 | 1.761 | 1.638 | 361 | 1,103 |
| DA3551G01 | 1.760 | 1.638 | 373 | 1,143 |
| DA3545G01 | 1.759 | 1.638 | 357 | 1,104 |
| | | | Average | 1,107 |

**Table 5-7. Results of calculations of the mean dry density and corresponding saturated density in the six deposition holes in Prototype Repository /Birgersson and Johannesson 2006/.**

| | Section around the canister | | | | Section above and below the canister | | | |
|---|---|---|---|---|---|---|---|---|
| | Dry density, $\rho_d$ (kg/m³) | | Resulting saturated density, $\rho_m$ (kg/m³) | | Dry density, $\rho_d$ (kg/m³) | | Resulting saturated density, $\rho_m$ (kg/m³) | |
| Hole no. | mean | std | 95% C.I. | | mean | std | 95% C.I. | |
| DA3587G05 | 1,605 | 7.5 | 2,018 | 2,037 | 1,636 | 5.6 | 2,041 | 2,055 |
| DA3581G01 | 1,610 | 7.6 | 2,021 | 2,040 | 1,636 | 10.2 | 2,035 | 2,060 |
| DA3575G01 | 1,589 | 7.0 | 2,009 | 2,026 | 1,630 | 5.5 | 2,037 | 2,051 |
| DA3569G02 | 1,608 | 7.4 | 2,021 | 2,039 | 1,635 | 15.0 | 2,028 | 2,066 |
| DA3551G01 | 1,587 | 11.4 | 2,002 | 2,030 | 1,634 | 11.1 | 2,032 | 2,060 |
| DA3545G01 | 1,581 | 9.2 | 2,000 | 2,023 | 1,626 | 8.0 | 2,031 | 2,051 |
| All Holes | 1,597 | 14.9 | 2,003 | 2,041 | 1,633 | 10.1 | 2,033 | 2,058 |

Two type sections of the installed buffer can be recognised, one around the canister and one above and below the canister. In order to get similar densities in the two type sections the ring shaped and solid blocks must be compacted to different densities, see Section 3.1.3. As can be seen from the 95% confidence interval presented in Table 5-7, the highest installed bulk density was obtained in the sections above and under the canister i.e. for the solid blocks. The upper limit of the 95% confidence interval is 2,066 kg/m³ in the hole with the largest variation in density and 2,058 kg/m³ for all holes, i.e. it exceeds the acceptable maximum density 2,050 kg/m³ specified for the reference design. This is due to that the solid blocks were pressed to too high density. However, the variation around the mean value is ±12.5 kg/m³ in comparison to the accepted variation of ± 50 kg/m³. This indicates that blocks with specified densities can be manufactured with sufficient reliability in the production and that the production process needs to be adapted to the selected material. For ring shaped blocks the installed density lies within the accepted according to the reference design and the maximum variation around a mean value is about ±20 kg/m³.

In Table 5-8 the calculated average saturated density of the installed buffer in the six deposition holes, i.e. for the full volume excluding the canisters, from the Prototype Repository is presented. The 95% confidence interval for the mean density lies within the limits according to the reference design $1{,}950 < \rho_m < 2{,}050$ kg/m³ and the variation around the mean value is ±7 kg/m³.

The thickness of the installed buffer around the canister depends on the dimensions of the deposition hole, the position of the ring shaped blocks within the deposition hole, the inner diameter of the ring shaped blocks and the position of the canister within the ring shaped blocks and also on the diameter of the canister. Neither the positions of the buffer blocks nor the canisters have been registered in SKB's full scale tests. However if it is assumed that the canister is positioned centred in the deposition hole and have a diameter of 1,050 mm the minimum, maximum and average thicknesses achieved in the Prototype Repository can be calculated from the deposition hole geometries presented in the **Underground openings construction report,** Section 5.3.2 and Appendix B. The resulting average thicknesses of the buffer around the canister and its variation is 355 ± 0.5 mm.

The thickness of the buffer above and below the canister depends only on the variation in height of the solid buffer blocks.

**Table 5-8. Results from calculation of average installed buffer density in a deposition hole /Birgersson and Johannesson 2006/.**

| Deposition holes in the Prototype Repository | | | | |
|---|---|---|---|---|
| Dry density, $\rho_d$ (kg/m³) | | Resulting saturated zdensity, $\rho_m$ (kg/m³) | | |
| mean | std | mean | 95% C.I. | |
| 1,610 | 5.8 | 2,031 | 2,024 | 2,038 |

# 6 Initial state of the buffer

The initial state refers to the properties of the engineered barriers once they have been finally placed in the final repository and will not be further handled within the repository facility. The initial state of the buffer is the state when the auxiliary equipment used during installation is removed and all buffer components are installed in the deposition hole. Inflow of groundwater to the deposition hole and its impact on the buffer is not accounted for in the initial state.

For the assessment of the long-term safety it shall be confirmed that the buffer at the initial state conform to the design premises related to the barrier functions in the final repository. The confirmation shall be made through verification of:

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

The conformity of the reference design to the design premises was verified in Chapter 4 and the results are summarised in Section 4.7. In this chapter the initial state of the buffer and its conformity to the reference design is presented. This chapter also comprise conclusions regarding the conformity of the installed buffer to the design premises stated in **Design premises long-term safety**.

## 6.1 Initial state and conformity to the reference design

In this section the initial state of the buffer is presented and the conformity of the manufactured buffer components and installed buffer to the specification given for the reference design is discussed.

### 6.1.1 Initial state

At this stage of development, the presented initial state of the buffer is the outcome of the design parameters that can be expected based on the experiences and results from the test production presented in Chapter 5 (Sections 5.2.6, 5.3.8 and 5.4.8).

In Table 6-1 initial state values for the design parameters that in Sections 3.1 and 3.2 were identified as important for the conformity to the design premises stated in **Design premises long-term safety** are presented. For each design parameter reference design and initial state values are given. The table also include references to the sections where the experiences from the production are compiled and sections where the presented initial state values are discussed and justified.

The conformity of the design parameters stated in Table 6-1 to the reference design shall be verified for the initial state. In addition to the material parameters included in Table 6-1 dominant cation, CEC and content of accessory minerals are measured and documented in the production. The values of these parameters will depend on the selected bentonite product, at this stage the values given in Table 3-2 provides an estimation of the range at the initial state.

The total mass and volume of buffer material, water and air in the deposition hole are input to some analyses included in the long-term safety assessment. They have been calculated for nominal buffer blocks and pellets and nominal dimensions of the deposition hole and are given in Table 6-2. In the calculations the solid density is set to 2,780 kg/m$^3$ /Karnland 2010/. The table also includes comments to how deviations from the nominal values at the initial state can be estimated. In addition, the saturated density in the deposition hole as a whole, i.e. averaged around, above and below the canister, has been calculated to 2,019 kg/m$^3$ for nominal densities of the buffer blocks and pellets and nominal volume of the deposition hole.

For the assessment of the long-term safety a set of physical variables have been selected to allow an adequate description of the long-term evolution of the buffer /SKB 2006a/. The initial state for these variables is presented in Appendix B.

**Table 6-1. The buffer design parameters at the initial state and summary of the experiences that supports the conformity of the produced buffer to the reference design.**

| Design parameter | Reference design | Initilal state | Reference to relevant sections |
|---|---|---|---|
| **Material composition** | | | |
| Montmorillonite content | 75–90 wt-% | 75–90 wt-% | See Section 5.2.6 and 6.1.2 |
| Organic carbon | <1 wt-% | 0.25–0.40 wt-%[a] | |
| Sulphide content | <0.5 wt-% | 0.05–0.20 wt-%[a] | |
| Total sulphur content (including the sulphide) | <1 wt-% | 0.10–0.40 wt-%[a] | |
| **Density of blocks and pellets** | | | |
| Bulk density of ring shaped blocks | 2,070±20 kg/m$^3$ | 2,070±5.81 kg/m$^3$<br>2,050–2,089 kg/m$^3$ with a 99.9% C.I. | See Section 5.3.8 and 6.1.3 |
| Bulk density of solid blocks | 2,000±20 kg/m$^3$ | 1,998±5.79 kg/m$^3$<br>1,978–2,017 kg/m$^3$ with a 99.9% C.I. | |
| Bulk density of loose pellet filling | 1,035±40 kg/m$^3$ | 1,035 kg/m$^3$ | |
| **Installed density[b]** | | | |
| Saturated density around the canister[c] | 2,000±50 kg/m$^3$ | With respect to variations in buffer components and deposition hole, if no spalling occurs:<br>2,000–2,020 kg/m$^3$ with a 99.9% C.I.<br>With respect to deposition hole straightness if no spalling occurs:<br>1,986–2,035 kg/m$^3$ with a 99.9% C.I.<br>With respect to variations in buffer components if spalling occurs:<br>Spalling of 10 mm:<br>1,986–2,003 kg/m$^3$ with a 99.9% C.I.<br>Spalling of 20 mm:<br>1,972–1,988 kg/m$^3$ with a 99.9% C.I.<br>Spalling of 30 mm:<br>1,959–1,974 kg/m$^3$ with a 99.9% C.I.<br>Spalling of 40 mm:<br>1,946–1,961 kg/m$^3$ with a 99.9% C.I.<br>Spalling of 50 mm:<br>1,933–1,948 kg/m$^3$ with a 99.9% C.I. | See Section 5.3.8, 5.4.8 and 6.1.4 |
| Saturated density above and below the canister[c] | 2,000±50 kg/m$^3$ | 2,025–2,045 kg/m$^3$ with a 99.9% C.I. | |
| **Installed dimensions[b] and geometrical configuration** | | | |
| Buffer thickness around the canister[d] | 35 cm | 34.7–35.3 cm with a 99.9% C.I. | See Section 5.4.8 and 6.1.5 |
| Buffer thickness below the canister | 0.5 m | 0.5 m ±1 mm | |
| Buffer thickness above the canister | 1.5 m | 1.5 m ±3 mm | |
| Width of pellet filled gap | Nominal: 50 mm<br>Accepted variation[e]: 25–100 mm | In holes with no spalling:<br>50±10 mm | |
| Diameter of hole within the installed blocks | 1,070±1 mm | As for the reference design | |

[a] Based on experiences from MX-80.

[b] Will in addition to the properties of the installed buffer depend on the initial state of the deposition holes, see **Underground openings construction report**, Section 5.3.2 and Appendix B.

[c] The value stated in the column for the reference design refers to the calculated average saturated density for acceptable densities of buffer blocks and pellets and deposition hole volumes.

[d] Assuming that the canister has a diameter of 1,050 mm and is placed centred in the deposition hole, i.e. the deposition hole is straight.

[e] Note that the smallest and largest acceptable width of the gap can only occur locally over a cross section. The smallest gap may occur if the stack of buffer blocks is placed un-centred due to deviations in the straightness of the deposition hole. The largest gap occur if there has been a rock fall out.

**Table 6-2. Installed total mass and volume buffer material, water and air in a deposition hole, assuming nominal blocks and pellets and nominal dimensions of the deposition hole (see Figure 3-3).**

| Parameter | Nominal value<br>Mass (ton) | <br>Volume ($m^3$) | Range at the initial state |
|---|---|---|---|
| Buffer bulk material | | | Can be calculated from the variations in block densities stated in Table 6-1. |
| – ring shaped blocks | 12.21 | 5.90 | |
| – solid blocks | 8.21 | 4.12 | |
| – pellets | 1.85 | 1.78 | |
| **Total** | 22.27 | 11.80 | |
| Buffer solid part | | | Can be calculated from the variations in block densities stated in Table 6-1. |
| – ring shaped blocks | 10.43 | 3.75 | |
| – solid blocks | 7.04 | 2.53 | |
| – pellets | 1.58 | 0.57 | |
| **Total** | 19.05 | 6.85 | |
| Water | | | Can be calculated from the variations in block densities stated in Table 6-1. |
| – ring shaped blocks | 1.77 | 1.77 | |
| – solid blocks | 1.20 | 1.20 | |
| – pellets | 0.27 | 0.27 | |
| **Total** | 3.24 | 3.24 | |
| Air | | | Can be calculated from the variations in block densities and the variations in geometries stated in Table 6-1, i.e. the variation of the buffer diameter assuming a total height of the buffer of 6.68 m. |
| – ring shaped blocks | – | 0.37 | |
| – solid blocks | – | 0.39 | |
| – pellets | – | 0.95 | |
| **Total** | – | 1.71 | |

### 6.1.2 Material composition

SKB's experiences from excavation and delivery of bentonite clay indicate that a potential supplier can deliver bentonite with a montmorillonite content according to the reference design, i.e. 80–85%, and a limited content of organic carbon, sulphides and total sulphur (Section 5.2.6). To confirm that a bentonite according to specification can be delivered the supplier should be qualified according to approved routines.

#### *Montmorillonite content*

The X-ray diffractation method SKB intend to apply to inspect the montmorillonite content of the delivered material have based on current experiences an accuracy of measurement described by a standard deviation of about 1.7%, Section 5.2.4. By applying this method to measure the montmorillonite content in the five consignments representing over 20 years of production of MX-80 a standard deviation of 1.9% was derived. This supports SKB's experience that application of conventional industrial procedures for qualification of suppliers together with the described inspection method will yield satisfactory mineral composition of the material used in the production of buffer components.

Strict specifications of the content of montmorillonite, as well as for the method used by the supplier for determining the content, will be provided when ordering bentonite for the buffer. The inspection method applied by SKB will be further developed to enhance the accuracy. Based on the current experiences the montmorillonite content at the initial state is expected to lie within the limits specified for the reference design.

#### *Content of organic carbon, sulphides and total sulphur*

The methods SKB intend to apply to inspect the contents of organic carbon, sulphides and total sulphur in the delivered material have based on current experiences an accuracy of about 0.05%. This is sufficient with respect to the acceptable contents of organic carbon, sulphides and total sulphur, i.e. less than 1, 0.5 and 1 wt-% for organic carbon, sulphides and total sulphur respectively. To verify that the actual contents of organic carbon, sulphides and total sulphur are acceptable the same actions as for the montmorillonite content must be taken.

As for the montmorillonite content SKB's experiences supports that conventional methods can be customised and applied with satisfactory results.

Based on the current experiences the content of organic carbon, sulphides and total sulphur at the initial state can be estimated to 0.25–0.40 wt-%, 0.05–0.20 wt-% and 0.10–0.40 wt-% respectively. This is based on experiences from delivery of MX-80 with a nominal content of 0.25 wt-% organic carbon, 0.12 wt-% sulphide and 0.34 wt-% total sulphur. The available data are not sufficient to estimate actual distributions of the contents of organic carbon, sulphides and total sulphur at the initial state.

### 6.1.3 Blocks and pellets

SKB's experiences from pressing of blocks and pellets show that it is possible to achieve the required densities with sufficient accuracy (Section 5.3.8). However, both the achieved mean densities and the variation in resulting densities were, in spite of small variations in the material composition, affected by the fact that the blocks were made from material from different deliveries applying the same procedure when compacting the blocks. To reduce the variation the water content and grain size distribution of the material ready for compaction and the pressing process must be adapted to the delivered raw material.

The experiences from machining of blocks shows that conventional technique can be applied with satisfactory results.

Measurements of weight and dimensions can be performed with conventional equipment with sufficient accuracy to identify blocks and pellet filling with too high or low density. The accuracy of the recorded densities will depend on the accuracy of measurements of the weights and dimensions. Based on available technique and current experiences the accuracy in recorded densities is estimated to ± 0.15% which can be compared to the accepted variation in bulk density of about ±1% (Section 5.3.7).

In summary SKB conclude that the pressing of blocks and pellets must be adapted to the selected material to improve the reliability of the processes. Furthermore, it is important to inspect the density of each block and batch of pellets so that blocks and pellets with too high or low density can be discarded. The density of the blocks and pellets will be measured in connection to the manufacturing. This warrants that the probability that blocks and pellets with unacceptable density will be installed will be very small. Conventional techniques and approaches can be customised to meet SKB's needs.

A statistical evaluation of the blocks manufactured for the Prototype Repository shows that the block densities are normally distributed /Birgersson and Johannesson 2006/. As an estimation of the density distribution resulting from a manufacturing process adapted to the selected material the density of totally 25 blocks (10 ring-shaped and 15 solid blocks) made from the same delivery of bentonite and compacted at the same occasion has been analysed. The resulting densities are given in Table 6-3. The densities given in Table 6-3 are, based on current experiences, the variation in block densities that can be expected from a manufacturing process adapted to the delivered material.

**Table 6-3. Expected bulk densities of blocks based on measurements of blocks made from the same delivery of bentonite and compacted at the same occasion. The total number of blocks used in the evaluation is 25, 10 ring shaped blocks and 15 solid blocks.**

| Bulk density of ring shaped blocks (kg/m$^3$) | | | | Bulk density of solid blocks (kg/m$^3$) | | | |
|---|---|---|---|---|---|---|---|
| mean | std | 99.9% C.I. | | mean | std | 99.9% C.I. | |
| 2,070 | 5.81 | 2,050 | 2,089 | 1,998 | 5.79 | 1,978 | 2,017 |

### 6.1.4 Installed buffer density

Experiences from the Prototype Repository show that the 95% confidence interval for the saturated density was ±12.5 kg/m$^3$ for the sections above and below the canister and less than ± 20 kg/m$^3$ in the sections around the canister, i.e. well within the accepted variation of ± 50 kg/m$^3$. In general the average resulting saturated densities achieved in the Prototype Repository are higher than 2,000 kg/m$^3$ which would be desirable with respect to the accepted interval 1,950–2,050 kg/m$^3$. This has been considered in the reference design by altering the density and water content of the pellets filling.

The installed buffer density will depend on the density and dimensions of the installed blocks and pellets, i.e. the installed buffer mass, and the volume of the deposition hole and canister. The impact of the variations of volume of the canister and dimensions of the blocks on the installed buffer density can be neglected. The important parameters are the density of the blocks and pellets and the volume of the deposition hole. Over a random cross section of the deposition hole the installed density will vary due to:

- variations of the diameter of the deposition hole,
- the placement of the buffer blocks with respect to the centre line of the deposition hole,
- the occurrence of spalling.

In the following the impact of these parameters on the saturated buffer density is investigated assuming no loss of material during saturation and that no homogenisation over the cross sections occurs.

#### *Variation in deposition hole diameter*

The impact on the variation in deposition hole diameter on the installed and corresponding saturated density can be determined assuming that the canister and ring shaped blocks are placed centred in each cross section. This will be the case if the centre points of each cross section coincide with a vertical line, i.e. the drilling is straight.

Experiences from the Prototype Repository show that the diameter of the deposition hole is normally distributed. Based on three measurements of the diameter on each level with an equidistance of 0.4 m in depth the average diameter was determined to 1.760 m with a standard deviation of 2.02 mm. In the Prototype Repository the configuration of the drilling equipment was set to a larger nominal diameter than 1.750 m. When describing the statistic distribution of a deposition hole drilled in the final repository it is therefore reasonable to assume a mean value of the diameter of 1.750 m and, based on the current experiences, assume a standard deviation 2.02 mm.

Installing the blocks according to Table 6-3 in a deposition hole with an average diameter of 1.750 m and standard deviation 2.02 mm results in the calculated installed density given in Table 6-4. In the calculations the variations in water content and bulk density of the pellet filling are neglected. The bulk density of the pellets is set to 1,035 kg/m$^3$ and the water content in blocks and pellets is set to 17%.

#### *Variation in placement of buffer blocks*

If the deposition hole is not straight the centre point of each individual cross section will not coincide with the average vertical centre line of the hole see Figure 6-1. As a result buffer blocks will not be placed centred in each individual cross section and the width of the pellet filled gap will vary over the cross section.

**Table 6-4. Results of calculations of installed buffer density for different sections in a deposition hole.**

| Section around the canister | | | | Section above and below the canister | | | |
|---|---|---|---|---|---|---|---|
| Dry density, $\rho_d$ (kg/m$^3$) | | Resulting saturated density, $\rho_m$ (kg/m$^3$) | | Dry density, $\rho_d$ (kg/m$^3$) | | Resulting saturated density, $\rho_m$ (kg/m$^3$) | |
| mean | std | 99.9% C.I. | | mean | std | 99.9% C.I. | |
| 1,577 | 4.72 | 2,000 | 2,020 | 1,616 | 4.73 | 2,025 | 2,045 |

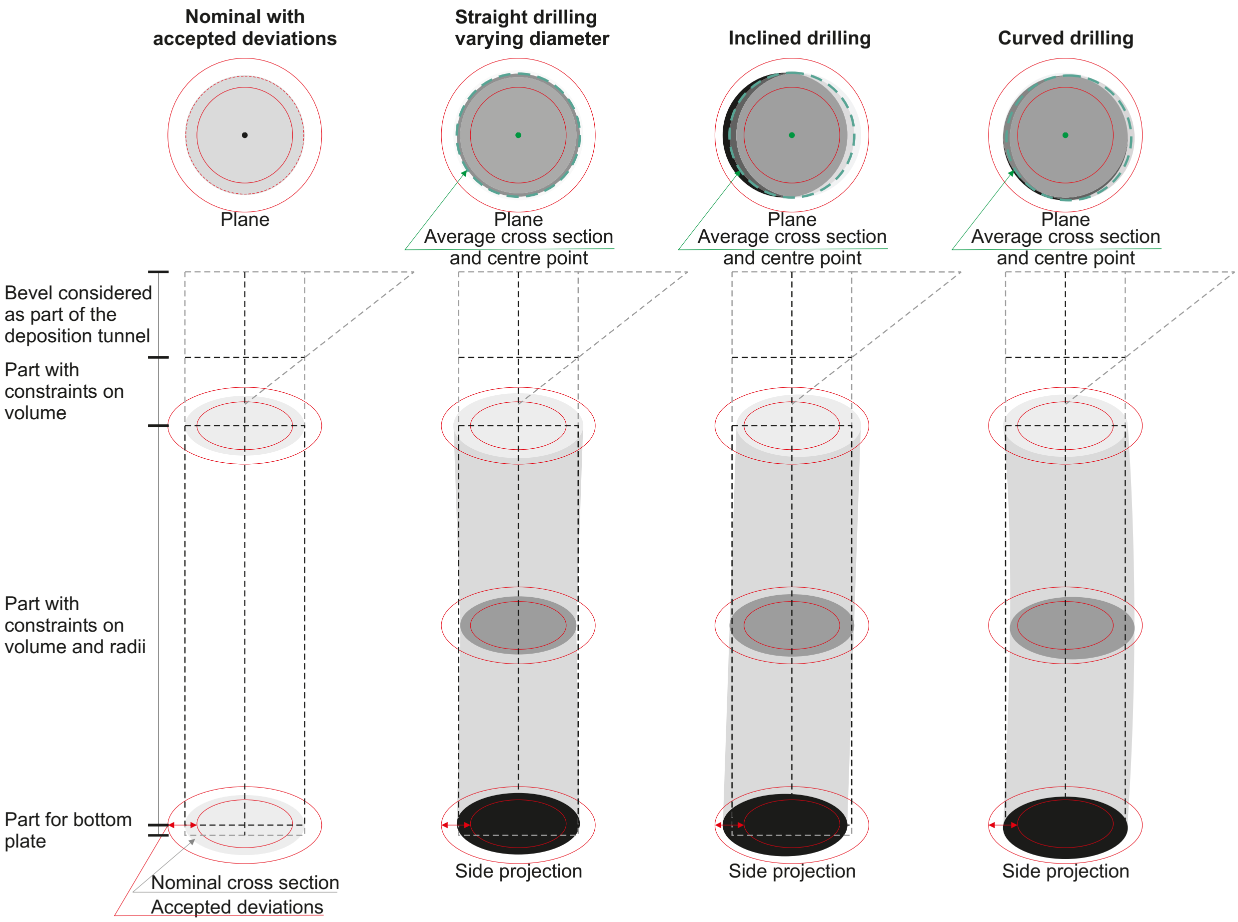



***Figure 6-1.*** *Some possible causes of deviations in the geometry in a deposition hole without rock fall out. All kinds of deviations can occur in the same deposition hole. The deviations are exaggerated in scale.*

At Äspö HRL the deviation between the centre points of the cross section measured every 0.4 m and a line connecting the centre points of the section in the tunnel floor and bottom of the deposition hole has been measured. The deviation is in the order ±10 mm, see Appendix B in the **Underground openings construction report**. This can be regarded as an estimation of the straightness of the holes and the corresponding variation in width of the pellet filled gap.

The impact on the installed density resulting from an increase of the width of the pellet filled gap with 10 mm, has been calculated assuming that the increase is due to a rock fall out, see Table 6-6. The corresponding local decrease of the installed density will be the same independently of the cause of the variation of the width of the pellet filled gap. The local increase of the installed density on the opposite side of the installed ring shaped buffer blocks has for the block densities given in Table 6-3 and a gap width of 40 mm been calculated to 2,017–2,035 kg/m$^3$ with a 99% confidence interval.

### *Occurrence of spalling*

Spalling will result in a local increase in the deposition hole radius as illustrated in Figure 6-2.

By assuming different density of the ring shaped blocks it is possible to calculate the accepted width of the pellet filled gap to reach the minimum accepted buffer density at saturation, 1,950 kg/m$^3$. Such calculations are shown in Figure 6-3 for five different bulk densities of the blocks. The variation in saturated density is calculated as a function of the width of the pellet filled gap. The accepted width of the gap in order to reach a saturated density of 1,950 kg/m$^3$ is marked with the intersection between the calculated density curves and the horizontal dotted line. The accepted widths are also given in Table 6-5. The densities 2,070 kg/m$^3$, 2,050 kg/m$^3$ and 2,089 kg/m$^3$ corresponds to the average block density and the lower and upper limits for the 99.9% block density confidence interval, see Table 6-3 Bulk density of ring shaped blocks.

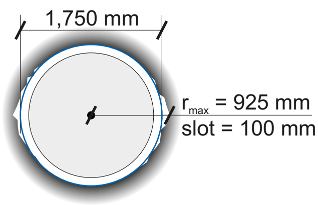



*Figure 6-2. Increase in deposition hole radius due to spalling and rock fall out in a deposition hole with nominal diameter.*

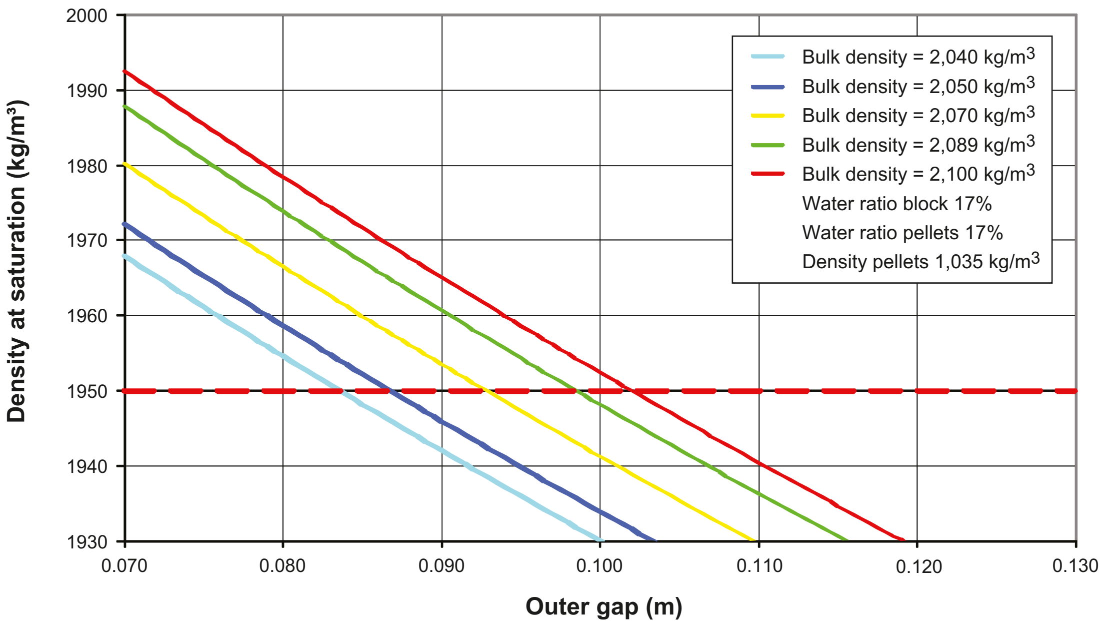



*Figure 6-3. The density at saturation for the buffer at the level of the canister as function of the width of the pellets filled outer gap. The calculations are made assuming different bulk densities on the ring shaped blocks.*

The occurrence of spalling at the Forsmark site have been analysed in Section 4.3 in the **Underground openings construction report**. The number of deposition holes where the spalling reaches different depths is illustrated in Figure 6-4.

The maximum accepted width of the pellet filled gap to reach a saturated density of 1,950 kg/m³ is illustrated in Figure 6-3. In a straight deposition hole with nominal diameter the width of the pellet filled gap is 0.05 m. The accepted depth of spalling in such a deposition hole and the number of deposition holes in which this depth of spalling may occur according to Section 4.3 in the **Underground openings construction report** is given in Table 6-5. If the diameter deviates from the nominal the accepted spalling is altered accordingly. If the deposition hole is not straight the accepted spalling decreases accordingly.

**Table 6-5. Results of calculations of the numbers of holes which have to be rejected in order to obtain the minimum density at saturation for the buffer of 1,950 kg/m³.**

| Block bulk density (kg/m³) | Maximum outer gap to obtain the buffer density of 1,950 kg/m³ (m) | Allowed depth of spalling in a nominal deposition hole (m) | Number of deposition holes out of 6,000 with unacceptable depth of spalling |
|---|---|---|---|
| 2,050 | 0.087 | 0.037 | ~250 |
| 2,070 | 0.093 | 0.043 | ~200 |
| 2,089 | 0.099 | 0.049 | ~150 |
| 2,100 | 0.102 | 0.052 | ~100 |

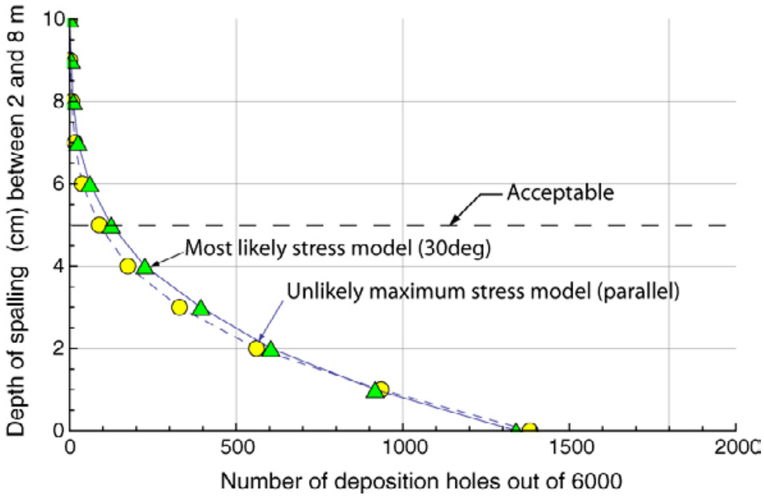



***Figure 6-4.*** *The number of deposition holes where the spalling reaches different depths for the "most likely" stress model with the deposition tunnel at 30 degrees to the maximum horizontal stress and the "Unlikely maximum" stress model with the deposition tunnel parallel to the maximum horizontal stress, see Section 4.3 in the* ***Underground openings construction report****.*

Based on the distribution in block densities given in Table 6-3 the variation in saturated density can be calculated for accepted increases in width of the pellet filled gap, or deposition hole radius, from the nominal. Results from such calculations are given in Table 6-6. For a straight deposition hole with nominal diameter the increase in width of the pellet filled gap corresponds to the maximum accepted depth of spalling. The number of deposition holes where this depth of spalling may occur according to Section 4.3 in the **Underground openings construction report** is also given in Table 6-6. If the diameter deviates from the nominal the accepted depth of spalling is altered accordingly. If the deposition hole is not straight the accepted spalling decreases accordingly.

### 6.1.5 Buffer geometry

#### *Thickness around the canister*

The thickness around the canister will for the installed buffer deviate from the nominal thickness, i.e. 35 cm. The installed buffer thickness will depend on the diameter of the deposition hole and its variation along the hole and on the position of the ring shaped blocks within it. The buffer thickness will also be affected by the position of the canister within the ring shaped blocks and the diameter of the canister. The canister will be guided so it is placed centred within the buffer rings. The impact of the variation in canister placement and canister diameter on the buffer thickness can be neglected. The variation in buffer thickness will, in similarity to the installed density, mainly depend on:

- variations of the diameter of the deposition hole,
- the placement of the buffer blocks with respect to the centre line of the deposition hole,
- the occurrence of spalling.

**Table 6-6. Results of calculations of the saturated buffer density at the canister sections for accepted increases in width of the pellet filled gap from the nominal.**

| Allowed increase in widht of pellet filled gap (mm) | Number of deposition holes out of 6,000 with corresponding depth of spalling | 99.9% confidence interval for the buffer density at saturation (kg/m³) | (kg/m³) |
|---|---|---|---|
| 0.050 | 150 | 1,933 | 1,948 |
| 0.040 | 200 | 1,946 | 1,961 |
| 0.030 | 400 | 1,959 | 1,974 |
| 0.020 | 600 | 1,972 | 1,988 |
| 0.010 | 950 | 1,986 | 2,003 |

The actual deposition hole diameter will deviate from the nominal. Analyses of measurements of diameters from the Prototype Repository shows that the variation is 2.02 mm, also see Section 6.1.4. The 99.9% confidence interval of the deposition hole diameter is $1.743 < ø < 1.757$ m. Assuming that the canister is placed in the centre of the deposition hole and there is no spalling results in a 99.9% confidence interval for the buffer thickness of $34.7 <$ buffer thickness $< 35.3$ cm.

However, since the deposition holes will not be absolutely straight the buffer blocks, and canister, cannot always be centred in the hole but will be placed with an offset with respect to the centre point of some cross sections along the hole. The size of the offset will depend on the straightness of the deposition hole which has been estimated to ±10 mm in Section 5.3.2 and Appendix B in the **Underground openings construction report** (also see Section 6.1.4).

The occurrence of spalling will result in a local increase of the buffer thickness. The number of affected deposition holes and the size of the increase in relation to the nominal deposition hole diameter are given in Table 6-5.

#### *Buffer thickness below and above the canister*

The thickness of the buffer above and below the canister will depend on the height of the solid blocks. SKB´s experiences show that the blocks can be machined so that the deviation in height is ±1 mm. This means that the maximum deviation from the nominal thickness will be ±1 mm below the canister and ± 3 mm above the canister.

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

In this section the conformity of the buffer at the initial state to the design premises stated in **Design premises long-term safety** is summarised.

### 6.2.1 Material composition

In **Design premises long-term safety** it is stated that the montmorillonite content shall be 75–90 wt-% in order for the buffer to maintain its barrier functions in the final repository. Further, it is stated that the content of organic carbon shall be less than 1 wt-%, the content of sulphides less than 0.5 wt-% and the total content of sulphur less than 1 wt-%.

SKB’s experiences from deliveries of bentonite show that the material composition of commercial bentonite products generally conforms to the specification provided by the supplier. Both regarding approval of bentonite suppliers and inspection of delivered material conventional procedures and methods can be customised to meet SKB’s needs. The probability that the buffer at the intial state will not conform to the material composition stated in **Design premises long-term safety** can based on current experiences be deemed as insignificant.

### 6.2.2 Installed density

In **Design premises long-term safety** it is stated that the initially deposited buffer mass should be such that it corresponds to a saturated buffer density of 1,950–2,050 kg/m$^3$. In Chapter 4, see Sections 4.2 and 4.7.2, it was concluded that the average installed density conforms to the design premises for all accepted variations in geometries and densities. Locally higher or lower densities may occur in connection to rock fall out if the extremes in acceptable deposition hole cross sections and block/pellet densities are combined.

In Section 6.1.4 the probability for locally unacceptable densities to actually occur was investigated. The parameters of most importance for the installed density are the density of the buffer blocks and the radius of the deposition hole. In Section 6.1.4 the installed density was calculated from the density distribution of the blocks, and the deposition hole geometries, that can be expected based on the results from the tests SKB has performed. The results shows that if the blocks are randomly selected and placed centred in the deposition hole densities below 1,950 kg/m$^3$ may locally occur if there has been a rock fall out. Note that in average over each cross section along the deposition hole the installed buffer mass will always correspond to a saturated density of 1,950–2,050 kg/m$^3$.

Densities below 1,950 kg/m$^3$ can only occur locally and if there has been a rock fall out resulting in an increase of the pellet filled gap of at least 30 mm to in total 80 mm. Based on current results this can be expected in about 400 deposition holes out of 6,000. However, there are alternative ways to warrant the conformity of the installed density in all parts of the cross section to the design premises even if there has been a rock fall out, these are:

- to adjust the installed buffer mass to the actual deposition hole geometry by selecting or manufacturing blocks with high density for the sections where the rock fall out occurs,
- to reduce the variation in width of the pellet filled gap by adjusting the placement of the buffer blocks in deposition holes where rock fall out occurs.

If these kind of correction actions are judged to be unfeasible either the acceptable variations in deposition hole geometry or in bulk density of blocks and pellets must be reduced.

In summary it can be concluded that the initially deposited buffer mass most probably will correspond to a saturated buffer density of 1,950–2,050 kg/m$^3$. However, to warrant this the buffer blocks cannot be randomly selected in deposition holes with rock fall out.

### 6.2.3 Buffer geometry

In **Design premises long-term safety** it is stated that the buffer geometry shall be the same as in SR-Can /SKB 2006b/, i.e. the thickness around the canister shall be 35 cm, below the canister 0.5 m, and above the canister 1.5 m. All dimensions are regarded as nominal. The resulting thickness around the canister will depend on the geometry of the deposition holes and the placement of the blocks within the deposition holes and has been estimated to 34.7 < buffer thickness < 35.3 cm (see Section 6.1.5). The thickness below and above the canister will depend on the height of the solid buffer blocks and its accepted variation. This results in an estimated deviation of the thickness from the nominal of ±1 mm below the canister and ± 3 mm above the canister.

### 6.2.4 Buffer thermal properties

The temperature in the buffer must not exceed 100°C. There are no design premises for the thermal properties of the buffer. The highest temperature increase from the rock surface at mid-height of the canister to the canister top and bottom where the highest temperatures in the buffer will occur has been calculated to 40°C (see Section 4.7.4). This increase will occur for low heat conductivity in the buffer, i.e. for a dry buffer and a gap between canister and buffer, the thermal properties of the buffer as well as the other premises for the calculations are presented in /Hökmark et al. 2009/.

### 6.2.5 Maintain swelling pressure, hydraulic conductivity and shear strength

In **Design premises long-term safety** it is stated that the buffer after swelling shall uphold the minimum swelling pressure, the accepted hydraulic conductivity and the accepted shear strength independently of dominating cation and for chloride concentrations up to 1 M. At the initial state the buffer will not be saturated since the inflow of groundwater to the deposition hole and its impact on the buffer is not accounted for in the initial state. However, the installed density at the initial state corresponds to a saturated density within the acceptable interval, and the required functions are maintained for these densities and the specified conditions, see Section 4.5.

# 7 References

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**Closure production report, SKB 2010.** Design, production and initial state of the closure. SKB TR-10-17, Svensk Kärnbränslehantering AB.

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**SKB, 2006a.** Buffer and backfill process report for the safety assessment SR-Can. SKB TR-06-18, Svensk Kärnbränslehantering AB.

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

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# Appendix A

## Definitions used for describing clay materials

To be able to describe the conditions of a bentonite material, several parameters and definitions are used in this report. Bentonite materials consist of solid particles and voids which can be partly filled with water (see Figure A-1). The volume of the material can be divided into the volume of the porous system ($V_p = V_w + V_g$) and the volume of the solid particles ($V_s$) and corresponding masses, $m_w$ and $m_s$. From these definitions several other parameters describing the condition of the material can bed defined. Some of the most common are listed in Table A-1 below.

**Table A-1. Some definitions used for describing the buffer material.**

| Parameter | Definition | Notes |
|---|---|---|
| Water content | $w = \frac{m_w}{m_s}$ | Describes the amount of water in the bentonite. |
| Density of solid particles | $\rho_s = \frac{m_s}{V_s}$ | This parameter varies with the type of soils. For bentonite this density is normally around 2,780 kg/m$^3$. |
| Density of the water | $\rho_w = \frac{m_w}{V_w}$ | Normally is $\rho_w$ = 1,000 kg/m$^3$. |
| Dry density | $\rho_d = \frac{m_s}{V}$ | Describes the density of the bentonite when all the voids are filled with gas. |
| Bulk density | $\rho = \frac{(m_w + m_s)}{V}$ | |
| Density at saturation | $\rho_m = \frac{(\rho_w \times V_p + m_s)}{V}$ | The density when the bentonite is fully saturated. |
| Degree of saturation | $S_r = \frac{V_w}{V_p}$ | Describes the amount of the total pore volume which is filled with water. |
| Void ratio | $e = \frac{V_p}{V_s}$ | The pore volume divided with the volume of the solid particles. |
| Porosity | $n = \frac{V_p}{V}$ | The pore volume divided with the total volume of the sample. |

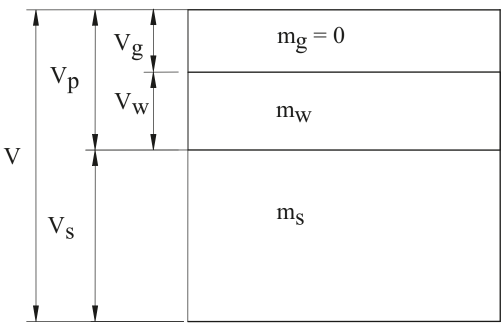


*Figure A-1. A schematic drawing of the components of a sample of bentonite material.*

## Appendix B

# Variables for description of the long-term evolution at the initial state

For the assessment of the long-term safety a set of physical variables have been selected to allow an adequate description of the long-term evolution of the buffer /SKB 2006a/. Initial state values for these variables can generally be derived from the designed and inspected buffer properties given in Table 6-1, or other information recorded during the production of the buffer. However, for some of the variables initial state values must be derived from other sources. In Table B-1 the variables and corresponding designed and inspected buffer properties or other sources from which initial state values of the variables can be derived are presented.

**Table B-1. Relation between the designed buffer properties and the variables used in the safety assessment. References to where, or how, initial state values of the variables not related designed buffer properties can be found or derived.**

| Variable | Buffer property | Initial state values |
|---|---|---|
| Water content | Material composition | |
| Gas content | | |
| Bentonite composition | | |
| Montmorillonite composition | | |
| Pore water composition | | |
| Hydrovariables (pressure and flows) | Material composition | |
| Stress state | Installed density | |
| Pore geometry | Installed density | |
| Buffer geometry | Installed dimensions and geometrical configuration | |
| Radiation intensity | – | Calculated<br>Radiation intensity on canister surface **Spent fuel report**, Section 6.6. |
| Temperature | – | Calculated |
| Structural and stray materials | – | Bottom plate material and dimensions according to the reference design **Underground openings construction report** Figure 5-3. |

The following comments to the variables and corresponding designed buffer properties can be made:

- Water content:
  For the initial state this is the water content of the installed blocks and pellets. This is described in Section 6.1.4. The water content of the material is defined as the mass of the water divided with the mass of the solid particles, see Appendix A.
- Gas content:
  For the initial state this is the gas content of the installed blocks and pellets. The gas content of the blocks and pellets is related to the degree of saturation ($S_r$). The degree of saturation is defined as the volume of the water divided with the volume of the total pore volume of the material, see Appendix A. In order to be able to calculate the gas content the density of the solid particles is required. The degree of saturation at the initial state is for the solid blocks 0.75, for the ring shaped blocks 0.82 and for the pellets 0.15.
- Hydrovariables:
  These parameters are describing the flow and pressures of water and gas as a function of time and space in the buffer The parameters of importance for the hydraulic properties of the unsaturated buffer material are the intrinsic permeability, the relative permeability, the vapour diffusion coefficient and the retention properties. These parameters depend on the type of bentonite, the density and the degree of saturation. The parameters are used to describe the thermo hydro

mechanical properties of the buffer and their values and relation to the designed buffer properties are described in /Åkesson et al. 2010/. The parameter of importance for the hydraulic properties of the saturated buffer is the hydraulic conductivity. This parameter, among other things, depends on the bentonite type, the density, the temperature and the chemical composition of the pore water. The hydraulic conductivity and its relation to the designed buffer properties is described in /Åkesson et al. 2010/.

- Bentonite composition:
  The composition of bentonite clays with the material composition specified in Table 3-1 are described in detail in /Karnland 2010/ and involves the chemical composition, the density of the grains and the granule and grain size distribution. At this stage of development when a supplier has not yet been selected and no results from the production are available the variations in dominant cation, CEC and accessory minerals can be described by the specifications given in Table 3-2. The mean chemical compositions of MX-80 expressed as oxides can be set to: 57% $SiO_2$, 18.5% $Al_2O_3$, 3.6% $Fe_2O_3$, 2.3% MgO, 1.3% CaO, 2.0% $Na_2O$, 0.5% $K_2O$, 0.2% $TiO_2$, 0.3% total carbon, 0.3% total sulfur, and 13.7% loss of ignition and for Ibeco-RWC can be set to 48% $SiO_2$, 15.7% $Al_2O_3$, 4.56% $Fe_2O_3$, 2.92% MgO, 5.4% CaO, 0.7% $Na_2O$, 0.8% $K_2O$, 0.7% $TiO_2$, 1.0% total carbon, 0.7% total sulfur, and 20% loss of ignition /Karnland et al. 2006/.

- Montmorilonite composition:
  The montmorilonite composition can be analysed by extracting the clay fraction of the bentonite, and then investigate and describe the structural formula of the montmorilonite component, the layer charge and the cation exchange capacity. The analyses and relations between the designed buffer properties and these parameters are described in /Karnland 2010/.

- Pore water composition:
  The pore water in the bentonite may change during and after the saturation. The composition of the pore water is depending on the bentonite and the water composition in the surrounding rock. The relations between the designed buffer properties and the pore water composition are described in /Karnland 2010/.

- Pore geometry:
  The pore geometry is related to the installed density. This is described in Section 6.1.4. From the bulk density, water ratio and the density of the solid particles ($\rho_s$) it is possible to calculate the volume of the pores in the buffer. The pore volume of the buffer is normally described as the void ratio (e) which is defined as the pore volume divided with the volume of the solid particles or as the porosity (n) which is defined as the pore volume divided with the total volume of the sample, see Appendix A. The void ratio for a buffer with a saturetad density of 1,950–2,050 kg/m$^3$ is 0.87–0.69 and the porosity is 0.46–0.41.

- Stress state:
  These parmeters are describing the stresses and the strength as function of time and space in the buffer. The parameters are important for determining the thermo hydro mechanical behaviour of the buffer both for the unsaturated and the saturated state. The parameters are depending on the bentonite type, the density, the temperature and the chemical composition of the pore water. Examples of important parameters are the swelling pressure, shear strength, tensile strength, elastic properties and plastic properties. The parameters and their relation to the designed buffer properties are described in /Åkesson et al. 2010/. The swelling pressure is also described in /Karnland 2010/.

- Buffer geometry:
  The geometry of the buffer in the radial direction depends on the geometry of the deposition hole and the canister. For the axial direction the geometry depends on the height of the installed buffer blocks. This is described in Section 6.1.5.

## Glossary of abbreviations and branch terms

The glossary is intended to explain acronyms, SKB-specific terms, and technical terms that occur in this report. It is not intended to contain all technical terms found in the report. Chemical formulae and units are usually not included in the glossary.

| | |
|---|---|
| CEC | Cation exchange capacity. |
| granule | Aggregations of finer clay materials that are produced through mining and processing of raw clay. |
| MX-80 | Sodium bentonite from Wyoming. |
| SR-Can | Report on long-term safety of the final repository (published by SKB in November 2008). |
| SR-Site | Report on long-term safety of the final repository. |
| X-ray diffraction | Method to determine mineral composition of clay materials. |
| Äspö HRL | Äspö Hard Rock Laboratory. |