KBS-3H — Design, Production and Initial State of the Supercontainer

Posiva Oy

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This work has been carried out under KBS-3H System Design project co-funded by Posiva and SKB.
The report presents the design basis and reference design of the supercontainer and verifies the conformity of the reference design to the design basis. The purpose of the supercontainer is to form a unit that facilitates handling and deposition in the KBS-3H drift. It consists of a canister surrounded by bentonite clay (buffer) and an outer cylindrical perforated metallic shell. The most important design basis is that the supercontainer shell shall not affect the bentonite buffer with respect to its desired long-term performance. Based on the long-term performance/safety aspect titanium has been selected for the supercontainer shell, expected to be the most chemically inert material, also being a material with good mechanical properties, hence selected as the reference material. Verification of the mechanical integrity of the supercontainer under loading are made by modelling and calculations. Several large-scale tests have been performed to verify bentonite buffer swelling in a supercontainer section in dry and wet conditions. The reference methods to manufacture the supercontainer shell components is by conventional means, i.e. cutting of hole patterns and cylindrical forming of titanium plates and welding of the plates. The final assembly of the supercontainer is carried out in a radiation shielded handling cell at the reloading station in SKB’s case. In Posiva’s case the assembly of the supercontainer takes place in the assembly hall in connection with the reloading station using remote control system. Performed deposition tests has, in full-scale, verified that the KBS-3H transport concept with application of water cushion technology for emplacement of supercontainers is technically feasible. The initial state of the supercontainer is defined as the state when the supercontainer is finally deposited in the repository.
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PREFACE

The KBS-3V production line reports (produced by Posiva and SKB, respectively) have formed the basis for the organization’s respective license applications for the construction, possession and operation of the KBS-3H repository.

For the construction of the KBS-3H repository SKB and Posiva have defined a set of production lines:

- the spent nuclear fuel;
- the canister;
- the closure;
- the backfill
- the buffer and filling components;
- the supercontainer;
- the plugs;
- the underground openings.

The latter four production lines are reported in new 3H-specific production reports. The former four are expected to only deviate slightly from their 3V counterparts and are thus left without further adaptation and any significant differences are accounted for in a new 3H-specific repository production report which also presents the common basis for the production line reports.

This set of reports addresses primarily applicable design basis (according to the Posiva VAHA system), reference design, conformity of the reference design to the applicable design basis, production and the initial state for KBS-3H, i.e. the results of the production. Comparison with the SKB design premises is provided in dedicated tables setting forth the differences between the two organizations and repository sites. In parallel with this process an overarching process is underway that is expected to further harmonize the Posiva and SKB requirements.

The preparation of the above-mentioned set of reports has been led and coordinated by Anders Winberg (Conterra AB) with support from Antti Öhberg (Saanio & Riekkola Oy). This report has been authored by Bo Halvarsson (Vattenfall AB) and Peter Sandberg (Vattenfall AB).

The KBS-3H design has been developed jointly by SKB and Posiva since 2002. This report has been prepared within the project phase “KBS-3H - System Design 2011-2016”.
1 INTRODUCTION

KBS-3H is a variant of the KBS-3 method and an alternative to the KBS-3V reference design. KBS-3H is based on horizontal emplacement of several canisters in a series in long deposition drifts whereas KBS-3V calls for vertical emplacement of the canister in individual depositions holes within a deposition tunnel, see Figure 1-1. Horizontal emplacement has been studied in parallel with the development of the KBS-3V reference design since the late 90’s.

(SKB, 2012) is the report presenting the current reference design as well as the reference methods.

The design basis in this report in essence is those given for KBS-3V and they are supplemented with method specific premises/ basis. This has established the reference case for the KBS-3H method as well as the current status in developing design and methods.

In Posiva’s terminology “design basis” refers to the current and future environmentally induced loads and interactions that are taken into account in the design of the disposal system, and, ultimately, to the requirements that the planned disposal system must fulfil in order to achieve the objectives set for safety (i.e. the design premises).

In SKB’s terminology the “design premises” are used as input to the production reports, which present the reference design analysed in the long-term safety assessment SR-Site. The design premises correspond to the design requirements and system specifications in Posiva’s terminology. Design basis is used when referring to the design premise in the following text and in the Summary.

In Posiva’s terminology the “system design premises” comprise the objectives set for the whole system, limitations set by the environment, technology and knowledge and existing operating environment (regulations, responsibilities, organisations, resources). These form the starting point for the definition of the design basis of disposal operations. Design basis (in line with this report) is published in (Posiva 2016a).

Figure 1-1. Schematic drawing of the KBS-3V reference design (left) and KBS-3H (right).
1.1 General basis

1.1.1 This report

This report presents the reference design, production and initial state of the supercontainer in deposition drifts of a KBS-3H repository for spent nuclear fuel. It is part of a set of reports presenting how the KBS-3H 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 1-2. 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-3H repository and repository facility. It is based on the results and review of the most recent long-term safety assessment, the current knowledge, technology and results from research and development.

The reference design of the supercontainer and the reference methods for its production as presented in this report constitutes a solution that is technically feasible. It is, however, foreseen that the design basis, the design as well as the presented methods for production, test and inspection will be further developed and optimized before the actual construction of the KBS-3 repository facility commences.

In this context, it should be mentioned that there are alternative designs that conform with the design basis as well as alternative ways to produce the reference design. In addition, the safety assessments as well as future safety assessments may result in updated Design basis.

The ambition is to continuously develop and improve both the design and production.

Figure 1-2. Reports included in the set of reports describing how the KBS-3H repository is designed, produced, tested and inspected. The “Spent fuel”, “Canister” and “Closure” Production reports are essentially the same for KBS-3H and for KBS-3V and hence adapted reports are not produced for KBS-3H (SKB and Posiva have produced their respective non-generic reports). Repository production report includes some information from other production reports (spent fuel, canister, closure) if there are differences between 3V and 3H.
Table 1-1. The reports within the set of Production reports referred to in this report.

<table>
<thead>
<tr>
<th>Full title</th>
<th>Short name used within the Production reports</th>
<th>Text in reference lists</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and production of the KBS-3H repository</td>
<td>3H Repository production report</td>
<td>Posiva 2016d</td>
</tr>
<tr>
<td>KBS-3H Design, construction and initial state of the underground openings</td>
<td>3H Underground openings construction report</td>
<td>Posiva 2016c</td>
</tr>
<tr>
<td>Design, production report and initial state of the buffer</td>
<td>Buffer and filling components production report</td>
<td>Posiva 2016b</td>
</tr>
<tr>
<td>SKB, Design, production and initial state of the canister</td>
<td>Canister production report</td>
<td>SKB 2010</td>
</tr>
<tr>
<td>Posiva, Canister Production Line 2012 – Design, production and initial state of the canister</td>
<td></td>
<td>Posiva 2012b</td>
</tr>
</tbody>
</table>

1.1.2 The design of the supercontainer

The presented design of the supercontainer in the horizontal deposition drifts presumes a repository based on the KBS-3H reference design, employing the DAWE design alternative, with horizontal deposition of supercontainers.

1.1.3 The production of the supercontainer

The presented production of the supercontainer is based on the condition that there is a system, the KBS-3H system, providing the facilities required to manage the handling of the different components, assembly of the supercontainers and finally their deposition in a KBS-3H repository. The presented handling, assembly and deposition of the supercontainer are key activities in the facilities and transport system of the KBS-3 system. The KBS-3 system and its facilities etc. are presented in more detail in the 3H Repository production report and are illustrated in Figure 1-3.
1.2 Purpose, objectives and limitations

1.2.1 Purpose

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

With this report SKB and Posiva intend to present the design basis for the supercontainer and demonstrate how it can be designed, produced and inspected to conform to the stated design basis. The report shall present the reference design and production methods and summarize the research and development efforts that support that the supercontainer can be produced in conformity to the design basis.

1.2.2 Objectives

Based on the above purpose the objectives of this report are to present:
• the design basis/requirements for the supercontainer,
• the reference design of the supercontainer,
• the conformity of the reference design to the design basis,
• the planned production,
• the initial state of the supercontainer, 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
This report includes present design basis for the supercontainer related to the long-term safety of the KBS-3H repository. The presented reference designs must conform to these design basis and consequently they have in most cases determined the design. Design basis related to other aspects than safety and radiation protection are only included if they have in some way governed the design or the methods for production.

The current report presents SKB’s and Posiva’s reference design and methods. Alternative designs and planned developments of the design and methods are not included.

This report also includes the design considerations taken with respect to the application of best available technology with regard to safety and radiation protection. It includes the related design basis for the design and development of methods to produce them. Motivations of the presented reference design and methods as the best available technology are reported elsewhere.

1.3 Interfaces to other KBS-3H reports and aspects
The role of the Production reports in the safety report is presented 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 report for the long-term safety analysis
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 provides feedback to the design of the engineered barriers and underground openings. The methodology used for deriving design basis from the long-term safety assessment is introduced in the 3H Repository production report.

1.3.2 The design basis report
A thorough description as well as the resulting design basis are given in the report “Design basis” (Posiva 2016a) for a KBS-3H repository, hereinafter referred to as Design basis for long-term safety. This design basis constitutes a basic input to the design of the supercontainer.
The report (SKB 2012) presents the current main reference design as well as the reference methods. The design basis in essence is that given for KBS-3V and they are supplemented with method specific design basis. This has established the reference case for the KBS-3H method as well as the current status in developing design and methods.

1.3.3 Operational safety

No specific operational safety report has been prepared during this project phase. The current report, however, report provides information to the operational safety report on the design of the supercontainer and the technical systems used to construct and inspect them as well as instructions on where and when inspections shall be performed.

1.3.4 The repository production report

The 3H Repository production report (Posiva 2016d) 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 3H Repository production report sets out the laws and regulations and demands from the nuclear power plant owners applicable for the design of a final repository for spent nuclear fuel. In addition, it describes the safety functions of a KBS-3H repository and how safety is provided by the barriers and their functions. The report goes on to describe how design basis 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 basis presented in this report is the barrier functions and design considerations introduced in the 3H Repository production report.

The design and production of the different engineered barriers and underground openings are interrelated. An overview of the design and production interfaces is provided in the 3H Repository production report. The design basis imposed by the supercontainer on the design and production of the other engineered barriers and underground openings are presented in this report. The design basis is repeated and verified in the production reports for the engineered barriers and underground openings on which the supercontainer impose design basis.

1.4 Structure and content

1.4.1 Overview

The general flow of information in the current Supercontainer production report can be described as follows:

- design basis,
- reference design,
- conformity of the reference design to the design basis,
- production,
- assembly, handling, storage and deposition,
- 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 A abbreviations and branch terms used in this report are explained.

### 1.4.2 Design basis/premises

The design basis set out the information required for the design. The Design basis for the supercontainer in deposition drifts are presented in Chapter 2 of this report. The chapter is initiated with the definition of the supercontainer, its purpose and basic design. After that follows a presentation of the barrier functions that the supercontainer shall provide to contribute to the safety of the final repository and including considerations that shall be made in the design with respect to the application of a well-established and reliable techniques. Finally, the detailed design basis for the supercontainer is given. They state the properties the reference design shall have to maintain the functions and to conform to the design considerations.

### 1.4.3 Reference design

The descriptions of the reference design comprise the supercontainer material and components and is presented in Chapter 3. The reference design is specified by a set of variables denominated design parameters. The design parameters shall be inspected in the production and acceptable values for them are given for the reference designs. The design basis and considerations that have determined the design parameters are presented.

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

An important part of this report is the analyses verifying the conformity of the reference design to the design basis. The conformity to each of the design basis given as feedback from the long-term safety assessment as well as the design basis related to technical feasibility, production and operation is analyzed and concluded. The conformity of the reference supercontainer to the design basis is presented in Chapter 4.

### 1.4.5 Manufacturing of the supercontainer

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

- requirements on the production and design basis for the development of methods to produce, test and inspect the supercontainer,
- illustration of the main parts and different stages of the production,
- short descriptions of the reference methods for production, test and inspection,
- overview of 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 affected, tested and inspected within each stage. The current experiences and results from each main part of the production are summarized. An overview of the key issues to be considered in the manufacturing of the supercontainer is provided in Chapter 5.

1.4.6 Assembly, handling, storage and deposition
An overview of delivery of the different supercontainer components, assembly of the supercontainer, handling and deposition of the supercontainer within the KBS-3H system is provided in Chapter 6. The chapter also describes the inspections that shall be performed in the different stages of the assembly, transports, handling, storage and deposition.

1.4.7 Initial state of the supercontainer
In Chapter 7, the initial state of the supercontainer is described, 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 understanding and experiences from the production trials, and they are discussed and justified with respect to the currently available results presented in the production chapter (Chapter 5).
2 DESIGN BASIS FOR THE SUPERCONTAINER

2.1 General basis

In this chapter the design basis for the supercontainer is presented. They comprise the functions and properties the supercontainer shall sustain in the KBS-3H repository and the premises for its design. The required functions and design basis are written in italics.

2.1.1 Identification and documentation of design basis/premises

The methodology to derive, review and document design basis is presented in the 3H Repository production report (SKB 2016d) and is detailed for KBS-3H in (Posiva 2016a).

The design basis is based on:

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

The 3H Repository production report includes a presentation of the laws and regulations applicable for the design of a final repository for spent nuclear fuel. Based on the treaties, laws and regulations SKB has substantiated functions and considerations as a specification of the KBS-3H repository, and as guidelines for the design of its engineered barriers and underground openings. In the 3H Repository production report the functions and properties the supercontainer shall sustain in order to contribute to the functions of the KBS-3H repository are presented. The 3H Repository production report also presents the design considerations to be applied in the design work.

The Design basis related to the functions of the supercontainer in the KBS-3H repository is based on the results from the latest performed long-term safety assessment and some subsequent analyses. The design basis for the supercontainer is presented in Section 2.3 in this report.

Design basis related to technical feasibility refer to the properties the supercontainer 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 basis and the interfaces to the engineered barriers and other parts in the production is presented in the 3H Repository production report.

Finally, design basis related to the operation of the KBS-3H repository facility and the production of the supercontainer are presented in Section 2.3.5.

2.1.2 Definition, purpose and basic design of the supercontainer

The supercontainer is an assembly consisting of a canister surrounded by bentonite clay (buffer)
and an outer cylindrical perforated metallic shell. The purpose of the supercontainer is to form a canister-buffer unit that facilitates/simplifies the handling/transportation/deposition in the KBS-3H horizontal deposition drift. The supercontainer consists of a perforated titanium shell with solid end plates that enfold the ring-shaped bentonite buffer blocks and the cylindrical bentonite buffer end blocks that surrounds the canister. The shell is provided with feet that elevate the container to facilitate handling and transportation of the supercontainer and limit its exposure to water flowing along the drift floor. The supercontainer is depicted in Figure 2-1. Depending of type of canister, the length of the supercontainer may vary but the external diameter is the same.

2.2 Barrier functions and design considerations

In this section barrier functions and design considerations for the supercontainer are presented.

The supercontainer shell has no barrier function related to long-term safety. There is consequently no required safety function of the supercontainer shell and therefore the only assessments that need to be made are related to:

- how the supercontainer shell affects the bentonite with respect to its desired long-term performance.
- issues that shall be considered when developing a supercontainer design and methods for its manufacturing, preparation, installation, test and inspection.
2.2.1 Barrier functions in the KBS-3H repository and functions in the repository facilities

The KBS-3H repository shall accommodate all spent fuel from the currently approved Swedish and Finnish nuclear power programmes, respectively. This means that the supercontainer shall:

- contain the various types of spent fuel (SF) canisters that results from the currently approved Swedish and Finnish nuclear power programme.

In order for the KBS-3 repository to maintain the multi-barrier principle and have several barriers, which individually and in combination contribute to maintain the barrier functions, the supercontainer:

- must not significantly impair the barrier functions.

After the supercontainer is assembled, it shall contain the SF canister and the bentonite buffer and with respect to the safe operation of the KBS-3H system it shall be possible to:

- handle, transport and deposit the supercontainer in a safe way without significantly affecting the properties of importance for the barrier functions of the repository.

2.2.2 Design considerations

This section presents the design considerations that shall be regarded in the design of the supercontainer and in the development of methods to manufacture, install, test and inspect it and its components. The design considerations mainly affect the development of methods.

A determined reference design together with the design considerations form the basis for the detailed design basis for the development of methods to manufacture, install, test and inspect the supercontainer, c.f. Section 5.2.1.

The barrier system of the final repository shall withstand failures and conditions, events and processes that may impair their functions. Hence the following shall be considered in the development of the supercontainer concept.

- The design and methods for preparation, installation, test and inspection shall be based on well-experienced techniques.

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

- The supercontainer with its specified properties shall be possible to manufacture/assemble, handle, transport and deposit with high reliability.
- The properties of the supercontainer shall be possible to test and inspect relative to specified acceptance criteria.
A reliable production is also required with respect to the objective to achieve and ascertain high quality and cost-effectiveness. Regarding cost-effectiveness, the following shall be considered;

- *The design of the supercontainer and methods for manufacturing/assembly, handling, transportation, deposit and inspection shall be cost-effective.*
- *It shall be possible to manufacture/assemble and inspect the supercontainer at 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, assemble and install the supercontainer must also conform to regulations for occupational safety. Design basis related to these aspects can generally be met in alternative ways for supercontainer designs that conform to the safety and radiation protection design basis. Together with design basis related to efficiency and flexibility they are of importance for the design of technical systems and equipment used in the production of the supercontainer.

The design of the technical equipment is not discussed in this report.

### 2.3 Design basis

In this section the design basis for the supercontainer are given. They constitute a specification for the design of the Supercontainer. The design basis comprises 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 the environment or adjacent systems, which form a necessary basis for the design.

The design basis is based on the functions and properties presented in Section 2.2.1 and the design considerations presented in Section 2.2.2.

#### 2.3.1 Design basis related to the barrier functions of the KBS-3H repository

In the longer term, the supercontainer shell will degrade at a rate that depends strongly on the material chosen for its construction, and its degradation products may interact with the buffer. This leads to the following requirements on the supercontainer shell:

- *the properties of the buffer resulting from interaction with the supercontainer shell must be shown to meet the performance targets for the buffer, or, if this is not possible*
- *the region affected by this interaction should extend only to a limited radial distance into the buffer.*
- *volume changes that can occur when the supercontainer shell degrades are not allowed to affect the buffer density.*
2.3.2 Design basis imposed by the buffer

Following artificial watering, the buffer inside the supercontainer must swell and form a tight seal against the drift wall. This leads to the following requirements on the supercontainer shell:

- the configuration of the perforation of the supercontainer shell must be such that the buffer can swell and form a tight seal against the drift wall.

The premises for the design of the supercontainer shell from buffer are compiled in Section 3.3.

2.3.3 Design basis imposed by the SF canister

The supercontainer shall be able to contain various types of SF canisters. The premises for the design of the supercontainer from five types of SF canisters are compiled in Section 3.5.

2.3.4 Design basis imposed by engineered barriers and underground openings

The only design basis imposed on the supercontainer by the other engineered barriers or by the underground openings is related to the geometry of the deposition drift and the void annular space between supercontainer and the drift wall to enable transportation of the supercontainer to its position in the deposition drift.

2.3.5 Design basis related to the production and operation

This section presents the design basis related to the production and operation of the supercontainer. In Chapter 3 the design basis for the supercontainer related to its production are given while the design basis for the production methods are presented in Chapter 5.

The supercontainer with specified properties shall be possible to manufacture/assemble, handle, transport and deposit with high reliability. This leads to the following requirements on properties that affect the handling, transport and deposition of the supercontainer:

- it shall be possible to handle and transport of the supercontainer within the repository facility.
- it shall be possible to deposit the supercontainer in the deposition drift with respect to all events that are expected to occur during deposition sequence.

The properties of the supercontainer shall be possible to inspect and verify relative to specified acceptance criteria.

- the supercontainer shell design shall allow for necessary inspections during supercontainer manufacturing.
• the supercontainer shall be designed to allow for necessary inspections during and after its assembly.

2.4 Design basis imposed by the supercontainer

This section presents the design basis imposed by the supercontainer on:

• the handling of the buffer
• the handling of the canister,
• the other engineered barriers and underground openings, and
• the facilities and transport system of the KBS-3H system.

2.4.1 Requirements on the handling of the buffer

There are no requirements on the handling of the buffer imposed by the supercontainer other than the dimensions of the buffer to allow installation of the buffer inside the supercontainer shell, without causing damages that significantly impair the barrier function of the buffer. Related to technical feasibility the supercontainer only provides design basis for the buffer.

• The dimensions of the reference buffer, see Table 3-3.

2.4.2 Requirements on the handling of the SF canister

There are no requirements on the handling of the canister imposed by the supercontainer other than the positioning of the canister during assembly of the supercontainer which is related to the accuracy of the handling equipment.

• The installed buffer shall contain a hole, centred with respect to the vertical centre line, large enough to allow installation of the SF canister without impairing the canister or buffer. The dimensions of the reference buffer, see Table 3-3.

2.4.3 Design basis imposed on barriers and underground openings

Related to technical feasibility the supercontainer provides design basis for the deposition drift.

• The deposition drift shall be large enough (i.e. minimum diameter) to allow deposition of the supercontainer without impairing the canister or buffer impairing the canister or buffer. The dimensions of the various types of supercontainers are listed in Table 3-5.
2.4.4 Design basis for the facilities and the transportation system of the KBS-3H system

It is stated that the supercontainer shall be apt for deposition for all conditions encountered during normal operation of the facilities and transport system of the KBS-3H system. With respect to this and the requirement that it shall be possible to transport, handle and deposit the supercontainer in a safe way without affecting the properties of importance for the barrier functions in the final repository, the following design premise is stated for the facilities and transport system of the KBS-3 system;

- The supercontainer must not, during normal operation (handling/transportation), be subject to mechanical impact that can result in damage to the buffer that can jeopardize the subsequent deposition and/or significantly impair its barrier functions.

Handling equipment for the supercontainer used in the facilities and the Transport Tube shall be designed to conform to this design premise. This design basis shall also be considered in the instructions for handling the supercontainer in the facilities and during assembly and/or transportation.
3  SUPERCONTAINER REFERENCE DESIGN

3.1  Description of the reference design

The supercontainer consists of the following components:

- Spent fuel (SF) canister (Copper Canister)
- Bentonite buffer
- Titanium shell

The supercontainer is depicted in Figure 3-1, showing the spent fuel canister surrounded by the bentonite buffer and the outer perforated titanium shell.

Detailed design drawings have so far not been developed for the supercontainer in titanium. However, supercontainer full size prototypes were developed for the testing and demonstrations of the deposition machine at the Åspö HRL. The prototypes were designed and manufactured in carbon steel and stainless steel, to be used with a dummy buffer made of concrete in order to verify the transportation technique.

The supercontainer reference design is therefore not necessarily optimised, the design may at a later stage be changed provided that it can be demonstrated that the new design conforms to the design basis.

The verification of the reference design shall demonstrate the conformity of the reference supercontainer to the design basis. The design parameters shall be inspected in the production to verify that the delivered supercontainer conforms to the reference design. If the supercontainers are manufactured, assembled, handled and deposited such that their properties, when deposited, lie within the specification of the reference design, the deposited supercontainers conform to the design basis.

![Figure 3-1. Exploded view of the supercontainer showing its different components.](image)
3.2 Spent fuel canister

The supercontainer shall be designed for the following types of spent fuel canisters:

- SKB PWR
- SKB BWR
- Posiva BWR
- Posiva VVER
- Posiva EPR

The reference geometry of the SKB canister is documented in (SKBdoc 1203875) and the Posiva canister in (Posiva, 2012) is shown in Table 3-1 together with their approximate weights including fuel assemblies.

For Posiva there are two possible alternatives for the copper over pack manufacture, namely cylinder with an integral (flat) bottom, or a tube with a welded bottom end. The latter is made by welding the bottom like the top end lid. In this case the bottom lid will have additional extension on edge area like the top end lid. This makes the welded bottom lid canister variant 75 mm longer than the integrated flat bottom variant. The Table 3-1 shows the dimensions for the integral flat bottom. An illustration of the canister with welded bottom lid is shown in Figure 3-2.

Table 3-1. Dimensions and manufacturing tolerances for canisters.

<table>
<thead>
<tr>
<th></th>
<th>Outer diameter (B)</th>
<th>Total length (A)</th>
<th>Approx. weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKB PWR</td>
<td>$1,050 \pm 1.2$</td>
<td>$4,835 \pm 3.25$</td>
<td>26,500</td>
</tr>
<tr>
<td>SKB BWR</td>
<td>$1,050 \pm 1.2$</td>
<td>$4,835 \pm 3.25$</td>
<td>24,600</td>
</tr>
<tr>
<td>Posiva BWR</td>
<td>$1,050 \pm 1.2$</td>
<td>$4,752 \pm 3.25$</td>
<td>24,500</td>
</tr>
<tr>
<td>Posiva VVER</td>
<td>$1,050 \pm 1.2$</td>
<td>$3,552 \pm 3.25$</td>
<td>18,800</td>
</tr>
<tr>
<td>Posiva EPR</td>
<td>$1,050 \pm 1.2$</td>
<td>$5,223 \pm 3$</td>
<td>29,000</td>
</tr>
</tbody>
</table>

Table 3-2 shows the dimensions of the recesses at the top and bottom of the canister that will affect the shape of the buffer blocks.
Figure 3-2. Schematic figure of the canister showing the top end lid and the welded bottom lid.

Table 3-2. Dimension and manufacturing tolerances for canister recesses.

<table>
<thead>
<tr>
<th>Top</th>
<th>821 ±0.5</th>
<th>85 ±0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom</td>
<td>850 ±0.8</td>
<td>75 ±0.3</td>
</tr>
</tbody>
</table>

3.3 Bentonite buffer

The reference design of the buffer inside the supercontainer consists of altogether four ring-shaped blocks and two solid end blocks. The buffer reference properties are documented in Buffer production report. Table 3-3 shows the geometrical dimensions with tolerances and approximate weights of the components. Schematic drawings of the components are shown in Figure 3-3. The dimensions and manufacturing tolerances for outer and inner diameters have been defined through an iterative process with consideration to the drift dimensions, canister dimensions and installation of the supercontainer in order to reach required buffer densities after saturation.
Table 3-3. Dimensions and manufacturing tolerances for bentonite buffer reference design.

<table>
<thead>
<tr>
<th>Component</th>
<th>Outer diameter [mm]</th>
<th>Inner diameter [mm]</th>
<th>Length [mm]</th>
<th>Approx. weight [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Block</td>
<td>1,740 *1/2</td>
<td>798 *0/2</td>
<td>350 *1/1</td>
<td>1,836</td>
</tr>
<tr>
<td>Bottom block, bottom with recess</td>
<td>1,740 *1/2</td>
<td>828 *0/2</td>
<td>350 *1/1</td>
<td>1,830</td>
</tr>
<tr>
<td>Bottom Block, flat bottom</td>
<td>1,740 *1/2</td>
<td>-</td>
<td>350 *1/1</td>
<td>1,741</td>
</tr>
<tr>
<td>Ring, SKB PWR/BWR</td>
<td>1,740 *1/2</td>
<td>1,058 *1/2</td>
<td>1,211 *1/1</td>
<td>3,722</td>
</tr>
<tr>
<td>Ring, Posiva BWR</td>
<td>1,740 *1/2</td>
<td>1,058 *1/2</td>
<td>1,190 *1/1</td>
<td>3,658</td>
</tr>
<tr>
<td>Ring, Posiva VVER</td>
<td>1,740 *1/2</td>
<td>1,058 *1/2</td>
<td>890 *1/1</td>
<td>2,736</td>
</tr>
<tr>
<td>Ring, Posiva EPR</td>
<td>1,740 *1/2</td>
<td>1,058 *1/2</td>
<td>1,308 *1/1</td>
<td>4,021</td>
</tr>
</tbody>
</table>
Figure 3-3. Schematic drawing of the bentonite buffer. The “bottom block” is for canisters with welded bottom lid and the “bottom block flat” is for Posiva’s canisters with integral (flat) bottom.
3.4 Supercontainer shell

The supercontainer shell is a perforated cylinder with solid circular end plates and provided with five pair of feet. The feet are located under the joints between the bentonite blocks, facing the drift floor.

The thickness of the perforated cylinder and end plates shall be 6 mm. The cylinder is perforated to a degree of approximately 61-62 %. The perforation is made up of holes with a diameter of 100 mm. The hole pattern is shown in Figure 3-4. The shell is in total provided with 49 holes tangentially and 37, 47, 48 resp. 52 holes lengthwise depending of type of SF canister see Table 3-4.

![Figure 3-4. Hole pattern in the supercontainer shell.](image)

**Table 3-4. Shell thickness, holes and degree of perforation.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Thickness [mm]</th>
<th>Holes tangentially</th>
<th>Holes lengthwise</th>
<th>Perforation degree [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKB PWR</td>
<td>6</td>
<td>49</td>
<td>48</td>
<td>62</td>
</tr>
<tr>
<td>SKB BWR</td>
<td>6</td>
<td>49</td>
<td>48</td>
<td>62</td>
</tr>
<tr>
<td>Posiva BWR</td>
<td>6</td>
<td>49</td>
<td>47</td>
<td>61</td>
</tr>
<tr>
<td>Posiva VVER</td>
<td>6</td>
<td>49</td>
<td>37</td>
<td>61</td>
</tr>
<tr>
<td>Posiva EPR</td>
<td>6</td>
<td>49</td>
<td>52</td>
<td>62</td>
</tr>
</tbody>
</table>

With the geometrical requirements set up for the deposition drift, SKB (2012) section 3.4, the maximum allowed diameter of the supercontainer is 1,761 mm. The dimensions of the supercontainer shell with tolerances for the different canisters without end plates and feet are listed in Table 3-5. The total length of the shell is determined by the sum of the length of the buffer blocks and rings plus the thickness of the endplates. Dimension of the end plate with associated tolerances and projected weight are listed in Table 3-6.
Table 3-5. Dimensions, manufacturing tolerances and weight for supercontainer shell.

<table>
<thead>
<tr>
<th></th>
<th>Outer diameter [mm]</th>
<th>Inner diameter [mm]</th>
<th>Length [mm]</th>
<th>Approx. weight [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKB PWR/BWR</td>
<td>1,761 +0/-2</td>
<td>1,749</td>
<td>5,395 +6/-6</td>
<td>305</td>
</tr>
<tr>
<td>Posiva BWR</td>
<td>1,761 +0/-2</td>
<td>1,749</td>
<td>5,387 +6/-6</td>
<td>314</td>
</tr>
<tr>
<td>Posiva VVER</td>
<td>1,761 +0/-2</td>
<td>1,749</td>
<td>4,187 +6/-6</td>
<td>239</td>
</tr>
<tr>
<td>Posiva EPR</td>
<td>1,761 +0/-2</td>
<td>1,749</td>
<td>5,859 +6/-6</td>
<td>332</td>
</tr>
</tbody>
</table>

Table 3-6. Dimension, manufacturing tolerances and weight for supercontainer end plate.

<table>
<thead>
<tr>
<th></th>
<th>Thickness [mm]</th>
<th>Diameter [mm]</th>
<th>Weight [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>All types</td>
<td>6</td>
<td>1747 +0/-1</td>
<td>65</td>
</tr>
</tbody>
</table>

The supercontainer feet shall be 50 mm high and spaced radially 73.5° (centre of feet) to provide a nominal gap of 51.5 mm underneath the container. The gap is to allow for the deposition machine sliding plate/palette, see Section 6.4. The feet shall be 100 mm wide and approximately 560 mm long. The present design is shown in Figure 3-5. The feet are provided with holes that are matching the hole pattern in the shell to allow the bentonite to swell out evenly around the supercontainer. The supercontainer is provided with pair of feet placed close to the joints between the buffer blocks/rings.

Table 3-7. Dimensions for supercontainer feet.

<table>
<thead>
<tr>
<th></th>
<th>Thickness [mm]</th>
<th>Height [mm]</th>
<th>Width [mm]</th>
<th>Length [mm]</th>
<th>Weight [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>All types</td>
<td>app. 10</td>
<td>50</td>
<td>100</td>
<td>560</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Figure 3-5. Supercontainer feet.
3.4.1 Material properties

Based on the long-term performance and the aspect of supercontainer shell – clay interaction, titanium has been selected for the supercontainer shell. The supercontainer (shell, end plates and feet) shall be manufactured in Titanium Grade 3 (ASTM). Titanium Grade 12 has similar mechanical properties and can be chosen depending on availability. Mechanical properties for Titanium Grade 3 and Grade 12 are shown in Table 3-8 below and the corresponding chemical composition is shown in Table 3-9.

Table 3-8. Material properties Titanium Grade 3 and Grade 12.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Density $\rho$ [kg/m$^3$]</th>
<th>Tensile strength Yield $\sigma_y$ [MPa]</th>
<th>Tensile strength Ultimate $\sigma_{UTS}$ [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 3</td>
<td>4500</td>
<td>380</td>
<td>450</td>
</tr>
<tr>
<td>Grade 12</td>
<td>4500 min 345 (typical 480)</td>
<td>min 483 (typical 620)</td>
<td></td>
</tr>
</tbody>
</table>

Table 3-9. Chemical composition for Titanium (Grade 3 and Grade 12).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Content (%)</th>
<th>Ti</th>
<th>N</th>
<th>C</th>
<th>H</th>
<th>Fe</th>
<th>O</th>
<th>Mo</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 3</td>
<td>bal.</td>
<td>0.05</td>
<td>0.08</td>
<td>0.015</td>
<td>0.3</td>
<td>0.35</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Grade 12</td>
<td>bal.</td>
<td>0.03</td>
<td>0.08</td>
<td>0.015</td>
<td>0.3</td>
<td>0.25</td>
<td>0.2-0.4</td>
<td>0.6-0.9</td>
<td></td>
</tr>
</tbody>
</table>

3.5 Supercontainer data

Table 3-10 summarises the overall nominal dimensions of the supercontainer variants and also provides an estimation of the corresponding total weights. All dimensions with tolerances and gaps can be found in Appendix B.

Table 3-10. Summary of overall nominal dimensions and total weights for supercontainer reference designs of the various canisters.

<table>
<thead>
<tr>
<th>Canister Type</th>
<th>Outside diameter [mm]</th>
<th>Length [mm]</th>
<th>Total weight [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKB SC PWR canister</td>
<td>1,761</td>
<td>5,395</td>
<td>44,490</td>
</tr>
<tr>
<td>SKB SC BWR canister</td>
<td>1,761</td>
<td>5,395</td>
<td>42,590</td>
</tr>
<tr>
<td>Posiva SC BWR canister</td>
<td>1,761</td>
<td>5,387</td>
<td>42,760</td>
</tr>
<tr>
<td>Posiva SC VVER canister</td>
<td>1,761</td>
<td>4,187</td>
<td>33,290</td>
</tr>
<tr>
<td>Posiva SC EPR canister</td>
<td>1,761</td>
<td>5,859</td>
<td>52,750</td>
</tr>
</tbody>
</table>
4 CONFORMITY OF THE REFERENCE DESIGN TO THE DESIGN BASIS

This chapter summarizes the performed analyses and measures taken to verify that the reference supercontainer conforms to the design basis, as described in Chapter 2.

4.1 Conditions for the analyses of mechanical loads

Verifying analyses has been carried out based on the reference design described in Sections 3.1 and 3.2 and any exceptions from this are given in conjunction with the specific load case.

4.1.1 Load conditions

The only function the supercontainer shell has is to keep the components together to enable transport of the supercontainer and therefore the supercontainer shell is only designed to carry its own weight and the loads that can arise during transport and handling.

The deposition drift is approximately 300 m long, which indicates that the first supercontainer to be deposited in the deposition drift will be subject to approximately 200 loading cycles during its transportation.

Based on results from performed analysis the supercontainer shall be designed and verified for the following load cases:

- **Normal load case (Load case 1a):** The supercontainer rests against the drift wall on all feet i.e. the load is distributed evenly on all feet.

- **Extreme load case (Load case 4b):** There is a possibility that the deposition drift has a vertical step of 5 mm, which implies that the supercontainer will only rest on the two outermost pairs of feet.

4.1.2 Design Acceptance Criteria

With regards to the load conditions outlined in Section 4.1.1, the following acceptance criteria shall apply for the structural verification.

- The equivalent stress in the titanium shell, end plate and feet should not exceed the minimum tensile yield stress of 380 MPa.
- Stresses in the bentonite must not exceed 1.75 MPa ($=\sigma_1^{\text{d}}$), in tension to prevent crack growth.
- In compression, the magnitude of the stresses in the bentonite must not exceed 17.5 MPa ($=\sigma_3^{\text{d}}$), to prevent crushing.
4.1.3 Modelling and calculations

The program used for the finite element calculations in this study was ANSYS. The model, Figure 4-1, geometry is established with 10-node solid tetrahedrons and 8-node solid brick elements. In total, the model consists of up to 200,000 nodes.

![FE model of the supercontainer.](image)

The model is simplified to one quarter of the supercontainer by the use of two symmetry planes. In the presented analysis, the end plates are perforated and not solid as per the updated reference design. This is however considered not to change the overall result and/or conclusions because notable strains are limited to the area around the feet.

Gaps, contact and friction (used friction coefficients are listed in Table 4-1) between surfaces are modelled by the use of contact elements that are highly non-linear, which leads to extensive calculations with the advantage that contact pressures and deformations are predicted more accurately. The bentonite has the capacity of both cracking and crushing. The shell is modelled as elastic-ideal plastic.

The calculation was made for the two cases listed in section 4.1.1 with the supercontainer standing in the deposition drift.

<table>
<thead>
<tr>
<th>Contact pair</th>
<th>Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper – Bentonite</td>
<td>0.45</td>
</tr>
<tr>
<td>Bentonite – Bentonite</td>
<td>0.65</td>
</tr>
<tr>
<td>Titanium – Bentonite</td>
<td>0.45</td>
</tr>
</tbody>
</table>

**Table 4-1. Friction coefficients.**

**Load Case 1a**

All stresses are below the yield stress limit. The strains in the shell are limited to areas close to the parking feet. There are only small areas in the model e.g. perforations in the
shell (stress raisers) or sharp corners in the parking feet (singularities), where strains can be found.

Figure 4-2. Load Case 1a; Left, von Mises effective stress. Right, Detail of area above foot close to the end plate with maximum stress.

Figure 4-3. Load Case 1a; Left, 1st principal stress, tensile, in the bentonite. Right, 3rd principal stress, compressive, in the bentonite.

Table 4-2. Result load case 1a, maximum values.

<table>
<thead>
<tr>
<th>Material</th>
<th>( \sigma_{\text{max}} ) effective [MPa]</th>
<th>( \sigma_1 ) tensile [MPa]</th>
<th>( \sigma_3 ) compressive [MPa]</th>
<th>( \delta_{\text{max}} ) deflection [mm]</th>
<th>( \varepsilon_{\text{tot}} ) strain [-]</th>
<th>( \varepsilon_{\text{pl}} ) strain [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium – container</td>
<td>100</td>
<td>1</td>
<td>0.001</td>
<td>~0</td>
<td>~0</td>
<td>~0</td>
</tr>
<tr>
<td>Titanium – parking feet</td>
<td>55</td>
<td>0.02</td>
<td>0.0006</td>
<td>~0</td>
<td>~0</td>
<td>~0</td>
</tr>
<tr>
<td>Bentonite</td>
<td>0.1</td>
<td>0.6</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The safety factor against cracking in the bentonite is approximately 17 (given by \( \frac{\sigma_1^d}{\sigma_1} \)), c.f Section 4.1.2.
The safety factor against crushing in the bentonite is approximately 29 (given by $\frac{\sigma_3'}{\sigma_3}$), c.f. Section 4.1.2.

**Load Case 4b**

All stresses are below the yield stress limit. The strains in the shell are limited to areas close to the parking feet.

**Figure 4-4.** Load Case 4b; Left, von Mises effective stress. Right, Detail of area above foot close to the end plate with maximum stress.

**Figure 4-5.** Load Case 4b; Left, 1st principal stress, tensile, in the bentonite. Right, 3rd principal stress, compressive, in the bentonite.

**Table 4-3.** Results of load case 4b, maximum values.

<table>
<thead>
<tr>
<th>Material</th>
<th>$\sigma_{\text{max}}$ effective [MPa]</th>
<th>$\sigma_1$ tensile [MPa]</th>
<th>$\sigma_3$ compressive [MPa]</th>
<th>$\delta_{\text{max}}$ deflection [mm]</th>
<th>$\varepsilon_{\text{tot}}$ strain [-]</th>
<th>$\varepsilon_{\text{pt}}$ strain [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium – container</td>
<td>241</td>
<td></td>
<td></td>
<td></td>
<td>0.003</td>
<td>~0</td>
</tr>
<tr>
<td>Titanium – parking feet</td>
<td>140</td>
<td></td>
<td></td>
<td></td>
<td>0.002</td>
<td>~0</td>
</tr>
<tr>
<td>Bentonite</td>
<td>0.25</td>
<td>1.2</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The safety factor against cracking in the bentonite is approximately 7 (given by $\frac{\sigma_1^d}{\sigma_1}$), c.f. Section 4.1.2.

The safety factor against crushing in the bentonite is approximately 15 (given by $\frac{\sigma_3^d}{\sigma_3}$), c.f. Section 4.1.2.

4.1.4 Cyclic strain-controlled fatigue

The following calculation gives an indication of how the structural integrity of the titanium shell would withstand repeated loading cycles during the deposition phase. It is estimated that the first supercontainer to be loaded into the tunnel will be subject to up to 200 loading cycles. The load is approximated as load case 4b, rounded up for conservatism. The calculation is performed with theoretical values on fatigue, according to (Z. Zhang et al. 2009).

The relationship between strain amplitude $\varepsilon_a$ and fatigue life $N$ is defined as:

$$\varepsilon_a = \frac{\sigma_f^d}{E} (2N_f)^b + \varepsilon_f^d (2N_f)^c$$

Equation 9.4 (Dahlberg and Ekberg, 2002)

Where:

- $\varepsilon_a = 0,01$ Strain amplitude
- $\sigma_f^d = 681$ MPa Fatigue strength coefficient
- $2N_f$ Number of load reversals to failure
- $\varepsilon_f^d = 0,123$ Fatigue ductility coefficient
- $b = -0,1$ Fatigue strength exponent
- $c = -0,404$ Fatigue ductility exponent

The strain amplitude versus load reversal to failure is show in Figure 4-6. Which yields $2N_f \approx 1100$ load reversals to failure.
4.1.5 Summary of analysis of the supercontainer

It is concluded that all calculated stresses, strains and deformations are acceptable. All stresses are below the yield stress limit and no plastic strains are found.

A calculation on the fatigue life of the titanium details indicates that approximately 1,100 loading cycles can be carried out before failure. This gives a good safety margin, as the supercontainer will, at a maximum, be exposed approximately 200 loading cycles whilst loaded into the deposition drift.

A summary of the results is listed in Table 4-4, as a percentage of the dimensioning value. For titanium the dimensioning value is the yield stress limit, for bentonite it is the yield stress limit in tension and the ultimate tensile strength in compression.

Table 4-4. Level of usage, expressed as a percentage of the dimensioning value.

<table>
<thead>
<tr>
<th></th>
<th>Shell</th>
<th>Parking Feet</th>
<th>Bentonite - Tension</th>
<th>Bentonite - Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1a</td>
<td>26 %</td>
<td>15 %</td>
<td>6 %</td>
<td>3 %</td>
</tr>
<tr>
<td>Case 4b</td>
<td>63 %</td>
<td>37 %</td>
<td>14 %</td>
<td>7 %</td>
</tr>
</tbody>
</table>

4.2 Supercontainer shell material

As stated in Section 2.3.1 the supercontainer material shall be selected on the basis of:

- the properties of the buffer are affected by interaction with the supercontainer shell and must be shown to meet the performance targets for the buffer, or, if this is not possible;
• the region affected by this interaction should be shown to extend only to a limited radial distance into the buffer.
• volume changes that can occur when the supercontainer shell degrades are not allowed to affect the buffer density.

Titanium is expected to be the most inert material, having the lowest corrosion rate and lowest rate of production of hydrogen and is a stronger material with good mechanical properties and has therefore been selected as the reference material.

According to studies (Posiva, 2018) titanium forms an insoluble TiO₂ passive corrosion layer on its surface under both oxic and anoxic conditions and over a wide pH range. Thus, metallic titanium will corrode and release titanium cations to the bentonite buffer only at an extremely slow rate (i.e. 1 nm corrosion per year or lower) the chemical passivity will be maintained throughout the evolution of the repository. However, the limited studies that have been performed so far indicate that titanium will not affect the bulk properties of the bentonite buffer. The chemical speciation of titanium transferred to the clay by corrosion is, however, difficult to determine. This while significant amounts of titanium are naturally present in bentonite, e.g. in form of small TiO₂ particles or incorporated in the clay structure (MX-80).

4.3 Supercontainer shell perforation

As stated in Section 2.3.2;

• the perforation of the supercontainer shell must be such that the buffer can swell and form a tight seal against the drift wall.

Several large-scale tests, Big Berta (BB), have been performed to verify the bentonite buffer swelling in a supercontainer section in both dry and wet conditions. The tests and results are described in the Buffer Production Report.

The main conclusions from the BB test 2 (BB2) and test 3 (BB3) are listed in brief below. Only the artificially filled water was available to contribute to the swelling pressure build up.

The tests were performed to investigate the swelling behaviour at extreme conditions in the short term, without access to additional water. The tests have shown that there will be a certain pressure build up against the rock walls also at these conditions which is considered to be favourable in order to prevent thermal spalling of the rock wall. The radial pressure against the rock around the supercontainer will vary depending on the swelling behaviour where bentonite is extruded through the perforated steel shell (development of “muffins”) resulting in large density variations. Between the “muffins” there will be some empty voids close to the supercontainer shell but there will probably be bentonite covering almost all rock surfaces, see Figure 4-7 from the dismantling of the BB2 test.
Figure 4-7. Picture from the dismantling of the BB2 test.

The supercontainer was standing on feet (steel tubes welded to the supercontainer shell just over a perforated hole). The sampling showed that all feet were filled with bentonite and that the density was slightly higher inside a foot than outside. This depends on the fact that the bentonite had been extruded into a closed volume with no possibility to expand in radial direction.

The two tests had been running for 230 (BB2) and 218 (BB3) days, respectively. The registered radial pressures were still slowly increasing in all measuring points. This shows that the homogenisation process was still ongoing, but very slowly. The tests simulate dry conditions where there is no access to additional water and it is difficult to predict the further swelling pressure development. In a real repository there probably will be access to some additional water also in “dry” drifts and this will of course improve the situation.

The main conclusions from the BB test 4 (BB4), where the bentonite had after the artificially filled water access to additional saline water from the simulated rock matrix available that contributed to the swelling pressure build up, are listed in brief below.

The BB4 test was performed as a short-term test to investigate the early evolution of the buffer. This because the buffer block in the BB4 test has a density and water content which is in the same range as in full scale. This means, depending on geometrical effects, that after a complete homogenization of the buffer, the average density will be lower than what is targeted in the full scale. The BB 4 test was running for 6 months.

The test has shown that the SC-rock gap will be filled with swelling bentonite rather soon after installation, see Figure 4-8. The variation in density of this material will, however, be great and consequently also the swelling pressure acting on the rock.

The BB4 test is considered to have given important information regarding the swelling behaviour and swelling pressure development around a supercontainer when there is access to additional water from the rock.
Figure 4-8. Picture from the dismantling of the BB4 test. As shown in the photo there are no empty voids present in the SC-rock gap. The gap is completely filled with bentonite.

Ongoing test BB5, which is planned to run until the buffer has been fully saturated, indicates that the radial swelling pressure increases by time in all measured points. The BB5 test has as the BB4 test after the artificially filled water access to additional saline water.
5 MANUFACTURING OF SUPERCONTAINER SHELL

This chapter describes the manufacturing of the supercontainer shell and includes activities in conventional industrial plants in which the supercontainer shell is manufactured, see Figure 5-1. The assembly of the supercontainer, its transportation, handling and deposition of are presented in Chapter 6.

5.1 Overview

The purpose of the chapter is to describe the production system for supercontainer shells and to verify that it delivers shells that conform with the specifications for the reference supercontainer shells. The chapter describes all stages in the manufacturing of the supercontainer shells and the associated inspections to be performed. The inspection work includes self-inspections, which are conducted at different stages of the manufacturing in order to guarantee a reliable product. It also includes final inspections that are carried out to verify the conformity to the reference design. The descriptions and data given in this chapter for the supercontainer production are based on the technical development completed by 2014/2015. The presented production and inspection methods will/may be further developed and optimized before the construction of the KBS-3H repository commences.

The production system for the manufacturing of supercontainers comprises a network of suppliers who manufacture the supercontainer shell and an assembly facility (reloading station) that is to be run by SKB/Posiva where the assembly and final inspections will be carried out.

Manufacturing of a titanium supercontainer shell has not been carried out yet. So far only two prototype containers have been manufactured for the testing/demonstrations of the deposition machine, one in carbon steel and one in stainless steel. The performed manufacturing has however verified that it is possible to manufacture supercontainer shells within specified tolerances.

5.2 Manufacturing of supercontainer shell

The manufacturing of the supercontainer shell is made in an external workshop. The shell is manufactured from titanium plates where the manufacturing consists of the following steps:

- Cutting of hole pattern
- Forming of the cylindrical shell
- Welding of shell
- Welding of end plate
- Welding of feet

The first manufacturing step is cutting of the hole pattern in the shell plates. To minimize or eliminate the heat affected zone (HAZ) around the holes shall water cutting, laser cutting or fine beam plasma cutting be used for cutting. All cut edges
around the holes shall be grinded. Preparation of weld joints is made before the next step.

The second step is rolling of plates to the cylindrical shape and welding of the longitudinal joints. To ensure that the minimum tolerances are met, it is proposed to use a fixture on the inside of the shell. The preferred and the widely-used process for joining titanium is TIG welding. Because of the high reactivity of titanium and titanium alloys at temperatures above 550°C, additional precautions must be applied to shield the weldment from contact with air. The environment for the welds can be prepared by either shielding from the torch side as well as the back side or welding could be performed in a chamber with a controlled inert gas environment.

After welding and before removal of the fixture the shell shall be provided with stiffening plates tack-welded on the outside of the shell to ensure that the cylindrical shape is maintained.

Each shell consists of several cylinders, depending of plate size, that are welded together with transverse weld joints. When the cylinders are welded together the longitudinal welds shall be displaced.

The stiffening plates on the outside also ensure that the cylindrical shape is kept during transport and assembly, see Figure 5-1.

![Figure 5-1. Pictures from the manufacturing of the supercontainer shell made of stainless steel originally made for the deposition machine tests performed at the -220 level of the SKB Äspö HRL.](image)

The “bottom” end plate is welded to the shell. The other end plate is welded during the assembly of the supercontainer in the reloading station.

The final step before verification and possible adjustment of geometrical shape and tolerances is that the feet are welded to the shell. The feet will be made of titanium casting or titanium plates that are welded together.
5.2.1 Manufacturing inspection and documentation

The inspection plan for the supercontainer shell will as a minimum include the inspections listed in Table 5-1.

Table 5-1. Inspection parameters for the supercontainer shell manufacturing.

<table>
<thead>
<tr>
<th>Property</th>
<th>Design parameter</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material properties</td>
<td>Ultimate tensile strength ($R_m$)</td>
<td>Material certificate</td>
</tr>
<tr>
<td></td>
<td>Yield strength ($R_p$)</td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>Diameter, inner</td>
<td>Inspection protocol</td>
</tr>
<tr>
<td></td>
<td>Length</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bevel (weld) preparation</td>
<td></td>
</tr>
<tr>
<td>Shape</td>
<td>Roundness</td>
<td>Inspection protocol</td>
</tr>
<tr>
<td></td>
<td>Straightness</td>
<td></td>
</tr>
<tr>
<td>Welds</td>
<td>Visually form/shape (100 %)</td>
<td>Inspection protocol</td>
</tr>
<tr>
<td></td>
<td>NDE (general 20 %)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NDE (welds around feet 100 %)</td>
<td></td>
</tr>
</tbody>
</table>
6 ASSEMBLY, TRANSPORTATION, HANDLING AND DEPOSITION

The assembly of the supercontainer will be carried out in a radiation shielded handling cell at the reloading station. The reloading station will be equipped with necessary lift arrangements for handling of the different components.

6.1 Transportation of components

6.1.1 Canister

Posiva Approach

The canister will be transported down to a canister storage area, located at the lower floor in the reloading station, at repository depth in the canister shaft. The canister will be stored in vertical position. From the storage area the canister will be transported to the reloading station, by a canister truck, where the canister can be lifted and placed inside the supercontainer, see Section 6.2.

SKB Approach

The canister is transported in a transport cask provided with shock absorbers from the parking bays in the terminal building to the reloading station at repository depth with the aid of a ramp vehicle. Handling at this stage of the process takes place in accordance with the operating instructions of the final repository facility. After removal of the cask shock absorbers, the transport cask is raised by the overhead crane in the reloading station to a vertical position and subsequently lowered into the trench outside the shielded handling cell.

6.1.2 Supercontainer shell

Posiva Approach

The supercontainer shell will be transported from the intermediate storage at ground level down to the repository level with the skip and placed in the storage (facility/room). Handling and transport are facilitated by conventional overhead cranes, grapple units and load carriers. From the storage, the supercontainer will be transported to the reloading station where the shell is lifted and moved to the handling cell.

SKB Approach

The supercontainer shell will transported from the storage area in the terminal building to the reloading station at repository depth by a truck/lorry. The shell is lifted from the truck/lorry by an overhead crane.

6.1.3 Bentonite buffer

Posiva Approach

The bentonite buffer that is placed in sealed containers will be transported down to the storage area at the upper floor of the reloading station at repository depth in the canister shaft. From the storage the buffer containers will be transported to the reloading station where the container will be opened for assembly of the supercontainer.
**SKB Approach**

The bentonite buffer (rings and blocks) will be transported from the intermediate storage at ground level down to the repository level with the skip. The buffer is placed in sealed containers in the storage (facility/room). Handling and transport are facilitated by conventional overhead cranes, grapple units and load carriers. From the storage the buffer containers will be transported to the reloading station where the container will be opened and the buffer components are lifted and moved to the handling cell.

### 6.2 Supercontainer assembly

As stated above, the assembly of the supercontainer will be carried out in the reloading station at repository depth, further described below. The assembly is performed with the supercontainer in a vertical position.

To enable lifting and tilting from vertical to horizontal position and transport of the supercontainer after assembly, the supercontainer is placed in a so called transport tube. The transport tube is provided with detachable gamma gates, see Section 6.3.

The assembly of the supercontainer consists of the following main steps and illustrated in Figure 6-1 below.

0. The transport tube gamma gate is placed in assembly position
1. The supercontainer shell with stiffening plates is placed on the gamma gate
2. The buffer end block and the four buffer rings are placed inside the supercontainer shell
3. The stiffening plates on the supercontainer shell are removed
4. The transport tube is placed over the supercontainer and attached to the gamma gate
5. The canister is lifted and placed inside the supercontainer.
6. The top buffer block and the upper end plate are lifted and placed on top of the supercontainer and the end plate is welded to the supercontainer shell.
7. The upper gamma gate is mounted to the transport tube
8. The transport tube is lifted and placed on a transport frame and tilted to horizontal position

The transport tube with the supercontainer placed on the transport frame can now be transported to an interim storage area or to the deposition site with the aid of a heavy load transport vehicle.
Figure 6-1. Illustration of the supercontainer assembly.

**Posiva Approach**

The principal design of the Posiva reloading station is shown in Fig. 2.

The transport vehicle with the transport tube for the supercontainer enters the upper floor in the reloading station. The transport tube is handled with the overhead crane in the reloading station. The transport tube is lifted and tilted to vertical position. The assembly of the supercontainer starts when the complete but empty transport tube with gamma gates is placed in the assembly position located on the lower floor in the reloading station.

The next step is to disconnect the “tube” with the upper gamma gate of the transport tube from the gamma gate at the bottom and thereafter lift and place it on the transport support on the upper floor in the reloading station.

Figure 6-2. 3D illustration of the reloading station and the canister storage.
The assembly of the supercontainer can now start by placing the empty supercontainer shell with stiffeners on top of the gamma gate that is placed in assembly position. The buffer (blocks and rings) can now be placed inside the supercontainer shell using the overhead crane in the reloading station. The handling of the buffer units can be done with the same type of tools as for the KBS-3V concept. When all the rings are placed inside the supercontainer shell, careful measurement and quality control of the buffer is done, especially the height of the buffer rings after emplacement is of importance. The buffer rings must have the correct height and they must also be placed in a way not obstructing the subsequent emplacement of the canister inside the pile of bentonite rings. When installation is approved the stiffeners can be removed from the shell and the “tube” without the upper gamma gate can be placed over the supercontainer and bolted to the bottom gamma gate.

The next step is to bring the canister from the storage at the lower floor in the reloading station. The canister is lifted with the overhead crane and placed inside the supercontainer. With the canister in place, the top buffer block can be placed in the supercontainer followed by placing the top end plate that will be remotely welded to the shell of the supercontainer. After completion of the weld and approval of the weld the upper gamma gate of the transport tube is bolted to the tube.

The transport tube with the loaded supercontainer can now be lifted with the overhead crane in the reloading station to the transport support for transport with the transport vehicle to the deposition area, followed by disposal of the supercontainer inside the active deposition drift.

**SKB Approach**

The principal design of the SKB reloading station with the shielded handling cell is shown in Figure 6-3 and Figure 6-4.

The transport vehicle for the cask with canister enters to reloading station from the left and the transport vehicle for the transport tube from the right side. The transfer of the canister from the transport cask to the supercontainer/Transport Tube takes place inside the shielded handling cell.
Figure 6-3. This is a plan view of the reloading station vault with the Shielded Handling Cell in the centre of the reloading station. The vehicle for transport cask for the canister enters the reloading station on the left of the shielded handling cell and the transport vehicle for the transport tube to the right side.

Figure 6-4. This is cross section through the reloading station with the shielded handling cell. The illustration show for instance the transfer of the canister from the transport cask into the supercontainer prepared with a pile of buffer rings. This is done inside the shielded handling cell that gives required radiation protection during the transfer.

The handling of the transport cask will in principal be identical with that used by the KBS-3V concept with an unloading pit for the cask. However, in the KBS-3H application the transport cask will be placed in a trench outside the shielded handling cell and transferred inside the shielded handling cell on a motorised wagon. In the shielded handling cell the removal of the transport cask lid will be done in the same way as for KBS-3V.

The assembly of the supercontainer starts when the complete but empty transport tube with gamma gates is placed on a motorised wagon in a separate trench so that the transport tube can be transported in and out of the shielded handling cell.

The next step is to disconnect the “tube” with the upper gamma gate of the transport tube from the gamma gate at the bottom and place it at its storage location in the reloading station.

The assembly of the supercontainer can now start by placing an empty supercontainer shell with stiffeners on the gamma gate. The buffer (blocks and rings) can now be
placed inside the supercontainer shell. The handling of the buffer units can be done with the same type of tools as for the KBS-3V concept. When all the rings are placed inside the supercontainer, careful measurement and quality control of the buffer is done, especially the height of the buffer rings after emplacement is of importance. The buffer rings must have the correct height and they must also be placed in a way not obstructing the subsequent emplacement of the canister inside the pile of bentonite rings. If the installation of the buffer is approved also the top bentonite block is placed inside the supercontainer and also the top cover is placed inside the transport tube. The stiffeners can now be removed from the shell. After inspection, the “tube” with the upper gamma gate now can be placed over the supercontainer and bolted to the bottom gamma gate.

The transport tube with the supercontainer, including all the buffer material is now ready for transfer inside the shielded handling cell with the motorised wagon. With the transport tube inside the shielded handling cell the shielding gate for the trench is closed. The upper gamma gate is disconnected and placed inside the shielded handling cell and the supercontainer top plate and the top buffer block are removed. When this is successfully done the transport cask with the SF canister can enter the shielded handling cell.

The transport cask can now be opened and the canister is transferred from the transport cask into the open pile of bentonite rings inside the supercontainer. This will be done with a separate overhead crane inside the shielded handling cell. With the canister in place, the top buffer block can be placed in the supercontainer followed by placing the top end plate that will be remotely welded to the shell of the supercontainer. After completion of the weld and approval of the weld the upper gamma gate of the transport tube can be bolted to the tube. The transport tube is now ready to be transferred out of the shielded handling cell following opening of the shielding gate.

Subsequently, the transport tube with the supercontainer can be lifted with the overhead crane in the reloading station to the transport support for transport with the transport vehicle to storage area or to the deposition area, followed by disposal of the supercontainer inside the active deposition drift.

### 6.2.1 Inspection and documentation

The following inspections shall be performed during the supercontainer assembly and documented in inspection protocols:

- Inspection regarding positioning of supercontainer shell on the gamma gate (visual)
- Inspection regarding shape/form of the supercontainer shell (visual)
- Inspection regarding cleanliness (visual)
- Inspection of buffer after placement (visual)
- Inspection of shell after removal of stiffeners (visual)
- Inspection of bolting transport tube/gamma gate (measurement of torque)
- Inspection regarding cleanliness before placement of canister (visual)
- Inspection of buffer after placement of top block (visual)
- Inspection of weld (visual and with PT)
- Inspection of bolting transport tube/gamma gate (measurement of torque)

6.3 Transport tube (including gamma gates)

The transport tube enables handling/transportation of the supercontainer and forms the radiation protection outside the deposition drift.

The Transport Tube is designed to allow for handling of supercontainers in both vertical and horizontal positions and is therefore provided with trunnions allowing the transport tube to be lifted with a specialized lifting device. The supercontainer, which is assembled in a vertical position, as described in Section 6.2, is placed inside the transport tube and tilted to a horizontal position on the transport support with help of an overhead crane, see Figure 6-5.

Figure 6-2. Tilting of the transport tube. Only the lower gamma gate is mounted to the transport tube at this time.

The transport tube is provided with detachable (bolted) gamma gates. The gates are of the type “sliding” gates and are provided with a hydraulic operated rack and pinion drive.

The Transport Tube is on the transport support resting on a movable cradle to allow for docking of the transport tube to the drift entrance. The movable cradle is supported on the transport support and manoeuvred with help of hydraulic actuators.

The transport tube with gamma gates resting on the transport support is shown in Figure 6-6.
Figure 6-3. 3-D illustration of transport tube with gamma gates resting on the transport support.

6.4 Deposition equipment

The deposition machine is presented in (SKB, 2008) (c.f. Sections 4.1 and 4.2 therein) and is described in brief below.

Figure 6-7 shows 3D illustration of the set-up of the equipment manufactured for the deposition tests performed at the -220 m level at the SKB Åspö HRL during 2007 to verify in full-scale that the KBS-3H transport concept with application of water cushion technology is technically feasible for emplacement of supercontainers.

Figure 6-4. 3D Lay-out of Deposition Equipment.
The deposition equipment design is based on a transport principle where the supercontainer is moved stepwise inside the drift. The process is repeated continuously until the supercontainer is in the correct position in the deposition drift. The supercontainer, which is provided with feet, is moved with help of a lifting cushion pallet and a slide plate placed in the space between the feet underneath the supercontainer.

The transport principle is chosen to reduce required forces needed to move the supercontainer, which will minimise the risk for damage of the bentonite buffer and the surrounding shell. The transport principle is described in Figure 6.8.
Step 1
The supercontainer is resting on its support feet (indicated with red arrows). The lifting palette/slide plate located between the supercontainer feet is inactivated.

Step 2
When the lifting cushions on the palette are activated (indicated with red arrows) the supercontainer is lifted. The supercontainer floats on a thin film of water.

Step 3
Floating on the water film the supercontainer is moved forward one stroke (1.5 metres) on the slide plate. After fulfilled stroke the lifting cushions are inactivated and the supercontainer is lowered for support on the feet and the slide plate is moved forward to prepare for the next cycle.

*Figure 6-5. Schematic illustration of the chosen transport/deposition principle.*
7 Initial State of the Supercontainer

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 supercontainer is the state when it is finally deposited and standing on its feet in the deposition drift.

The conformity of the reference design to the design basis is verified in Chapter 4. In this chapter the initial state of the supercontainer and its conformity to the reference design are presented.

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

- the conformity of the reference supercontainer to the design basis,
- the conformity of the deposited supercontainer to the reference design.

7.1 Initial state and conformity to the reference design

In this section, the initial state of the supercontainer is presented and the conformity of the manufactured and deposited supercontainer to the specification given for the reference design is discussed. The section includes initial state values for the design parameters of importance for the conformity to the design basis. The other design parameters specified for the reference design are presumed to conform to the specified values. The conformity of these parameters to the reference design can generally be verified by applying conventional techniques and procedures.

7.1.1 Initial state

At this stage of development, the presented initial state of the supercontainer is the outcome of the design parameters that can be expected based on the basis of previous experiences and results from tests. Initial state values for the material composition, material properties and dimensions are given in Table 7-1, Table 7-2 and Table 7-3.

For each design parameter, the reference design and initial state values are given. The initial state values are for many of the design parameters equal to the reference design. The reason is that the reference design is based on the specifications that the suppliers follow during test manufacturing and the material properties specified for the reference design are based on data from the limited number of test samples collected during test manufacturing. Hence, supercontainer dimensions will conform to the reference supercontainer at initial state.
**Table 7-1. Material composition at initial state.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Design parameter</th>
<th>Reference design</th>
<th>Initial state value</th>
<th>Comment and references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell/end plate/feet</td>
<td>Carbon content (%)</td>
<td>0.08</td>
<td>0.08</td>
<td>Section 3.4.1</td>
</tr>
<tr>
<td></td>
<td>Hydrogen content (%)</td>
<td>0.015</td>
<td>0.015</td>
<td>Section 3.4.1</td>
</tr>
<tr>
<td></td>
<td>Iron content (%)</td>
<td>0.3</td>
<td>0.3</td>
<td>Section 3.4.1</td>
</tr>
<tr>
<td></td>
<td>Oxygen content (%)</td>
<td>0.25-0.35</td>
<td>0.25-0.35</td>
<td>Section 3.4.1</td>
</tr>
<tr>
<td></td>
<td>Molybdenum content (%)</td>
<td>0.2-0.4</td>
<td>0.2-0.4</td>
<td>Section 3.4.1</td>
</tr>
<tr>
<td></td>
<td>Nickel content (%)</td>
<td>0.6-0.9</td>
<td>0.6-0.9</td>
<td>Section 3.4.1</td>
</tr>
</tbody>
</table>

**Table 7-2. The material properties at the initial state.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Design parameter</th>
<th>Reference design</th>
<th>Initial state value</th>
<th>Comment and references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell/end plate/feet</td>
<td>Tensile yield strength (MPa)</td>
<td>&gt;380</td>
<td>&gt;380</td>
<td>Section 3.4.1</td>
</tr>
<tr>
<td></td>
<td>Tensile strength ultimate (MPa)</td>
<td>&gt;450</td>
<td>&gt;450</td>
<td>Section 3.4.1</td>
</tr>
<tr>
<td>Bentonite</td>
<td>Tensile strength (MPa)</td>
<td>&gt;0.1</td>
<td>&gt;0.1</td>
<td>xx</td>
</tr>
<tr>
<td></td>
<td>Compression strength (MPa)</td>
<td>&gt;0.6</td>
<td>&gt;0.6</td>
<td>xx</td>
</tr>
</tbody>
</table>
Table 7-3. Dimensions at initial state.

<table>
<thead>
<tr>
<th>Component</th>
<th>Design parameter</th>
<th>Reference design</th>
<th>Initial state value</th>
<th>Comment and references</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKB SC PWR canister</td>
<td>Outside diameter</td>
<td>1,761+0/2</td>
<td>1,761+0/2</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Length (mm)</td>
<td>5,395+6/-6</td>
<td>5,395+6/-6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Shell thickness</td>
<td>6</td>
<td>6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td>SKB SC BWR canister</td>
<td>Outside diameter</td>
<td>1,761+0/2</td>
<td>1,761+0/2</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Length (mm)</td>
<td>5,395+6/-6</td>
<td>5,395+6/-6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Shell thickness</td>
<td>6</td>
<td>6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td>Posiva SC BWR canister</td>
<td>Outside diameter</td>
<td>1,761+0/2</td>
<td>1,761+0/2</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Length (mm)</td>
<td>5,387+6/-6</td>
<td>5,387+6/-6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Shell thickness</td>
<td>6</td>
<td>6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td>Posiva SC VVER canister</td>
<td>Outside diameter</td>
<td>1,761+0/2</td>
<td>1,761+0/2</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Length (mm)</td>
<td>4,187+6/-6</td>
<td>4,187+6/-6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Shell thickness</td>
<td>6</td>
<td>6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td>Posiva SC EPR canister</td>
<td>Outside diameter</td>
<td>1,761+0/2</td>
<td>1,761+0/2</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Length (mm)</td>
<td>5,859+6/-6</td>
<td>5,859+6/-6</td>
<td>Section 3.5</td>
</tr>
<tr>
<td></td>
<td>Shell thickness</td>
<td>6</td>
<td>6</td>
<td>Section 3.5</td>
</tr>
</tbody>
</table>

7.2 Handling and transportation of the supercontainer

The fact that the supercontainer can withstand the loads from handling/transportation, as analyzed in Section 4.1, has also been verified during the transportations that were carried out for the Multi Purpose Test (MPT) performed at the -220 m level at the SKB Åspö HRL. However, the shell was for this test made of carbon steel instead of titanium but is still considered to be a representative verification of the transport technique.

Material properties
Manufacturing inspections of the supercontainer will verify that the material properties conform to the specified values needed to withstand the handling/transportation loads. The proposed materials are in accordance with the ASTM standard, hence the property variations are small.

Dimensions
Manufacturing inspections of the supercontainer will verify that dimensions conform to the specified values. Supercontainers manufactured for tests of the KBS-3H deposition equipment carried out during 2007 have verified that it is possible to manufacture supercontainer shells within specified tolerances (shells were made of carbon steel and stainless steel).
7.3 Conformity to design basis long-term safety at the initial state

This section summarizes the conformity to the design basis related to long-term safety.

The supercontainer has no required long-term safety function. However, the supercontainer shell material is selected to minimize or avoid effects on the buffer long-term performance. Studies regarding titanium-clay interactions show that titanium is the most suitable material. Material certificates produced during manufacturing of the supercontainer will verify that the material properties conform to the specified values.
8 SUMMARY

This report is part of a set of KBS-3H specific production reports, presenting how the KBS-3H repository is to be designed, produced and inspected. The set of reports will form the basis for the safety reports for the KBS-3H repository and repository facility.

The current report provides input for the initial state of the supercontainer, to serve the assessment of the long-term safety. The initial state refers to the properties of the engineered barriers once they have been finally placed in the KBS-3H repository and will not be further handled within the repository facility. In addition, the report provides input to operational safety, i.e. how the supercontainers shall be handled and disposed.

The report also presents the design basis and reference design of the supercontainer and verifies the conformity of the reference design to the design basis. The production methods and the ability to produce a supercontainer according to the reference design are described. Finally, the initial state of the supercontainer and its conformity to the reference design and design basis are presented.

8.1 Design basis for the supercontainer

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

The purpose of the supercontainer is to form a canister-buffer unit that facilitates/simplifies the handling/transportation/deposition in the KBS-3H horizontal deposition drift.

The supercontainer is an assembly consisting of a spent fuel canister surrounded by bentonite clay (buffer) and an outer cylindrical perforated metallic shell. The shell is provided with feet that elevate the container to facilitate handling and transportation of the supercontainer and also limits its exposure to water flowing along the drift floor.

The supercontainer shell has no barrier function related to long-term safety, hence there is no required safety function.

The design basis of primary importance for the design is that the supercontainer shell shall not affect the bentonite buffer with respect to its desired long-term performance. Furthermore, the perforation of the supercontainer shell must be such that the buffer can swell and form a tight seal against the drift wall. The only design basis imposed on the supercontainer by the other engineered barriers or by the underground openings, is related to the geometry of the deposition drift and the void annular space between supercontainer and the drift wall, this to enable transportation of the supercontainer to its position in the deposition drift. The supercontainer shall also conform to design basis related to technical feasibility and production.
8.2 Reference design of the supercontainer and conformity to design basis

The supercontainer shell is a perforated cylinder with solid circular end plates and is provided with five pair of feet. The thickness of the perforated cylinder and end plates shall be 6 mm. The cylinder is perforated to a degree of approximately 60 %. The perforation is made up of holes with a diameter of 100 mm. The reference supercontainer comprises four different shells designed for the various types of spent fuel canisters that results from the currently approved Swedish and Finnish nuclear power programmes, i.e. SKB PWR/BWR, Posiva BWR, Posiva VVER and Posiva EPR. The only difference between the shells is their length.

Based on the long-term performance/safety aspect, due to supercontainer shell – clay interaction, titanium has been selected for the supercontainer shell. Studies has shown that titanium is expected to be the most chemically inert material, having the lowest corrosion rate and lowest rate of production of hydrogen and is a strong material with good mechanical properties and has therefore been selected as the reference material.

The verifications of the mechanical integrity of the supercontainer under loading conditions are made by modelling and various calculations. Several large-scale tests have also been performed to verify the bentonite buffer swelling in a supercontainer section subject to both dry and wet conditions.

8.3 Production, assembly, transportation, handling and deposition of the supercontainer

The production system for the manufacturing of supercontainers comprises a network of suppliers who manufacture the supercontainer shell and an assembly facility (reloading station) that is to be run by the respective organization, where the assembly and final inspections will be carried out.

The reference method to manufacture the supercontainer shell components is by conventional means, i.e. cutting of hole patterns and cylindrical forming of titanium plates and welding of the plates. In Posiva’s case the assembly is performed in the reloading station without employing a radiation shielded handling cell, whereas the final assembly of the supercontainer in the case of SKB will be carried out in a radiation shielded handling cell at the reloading station.

The supercontainer shell components and welds are inspected to ensure conformity to the specifications of the reference design. This is done in accordance with established standards.

The inspections comprise non-destructive testing (NDT), materials analysis and dimension inspections.

Manufacturing of a titanium supercontainer shell has not been carried out thus far. Experiences and results from performed manufacturing of prototype containers made in carbon steel and in stainless steel have however verified that it is possible to manufacture supercontainer shells within specified tolerances. Performed assembly of
the prototype supercontainers has also shown the assembly to be feasible and manageable.

Performed deposition tests have in full-scale have verified that the KBS-3H transport concept, with application of water cushion technology, is technically feasible for emplacement of supercontainers. The transport principle is chosen to reduce required forces needed to move the supercontainer, which will minimise the risk of damage of the bentonite buffer and the surrounding shell.

8.4 Initial state of the supercontainer

The initial state of the supercontainer is defined as the state when the supercontainer is finally deposited in the repository. The presented initial state is based on the current experiences and results from the trial manufacturing of supercontainers. The initial state values are for many of the design parameters equal to those of the reference design. The reason being that the reference design is based on the specifications that the suppliers follow during test manufacturing and the material properties specified for the reference design are based on data from the limited number of test samples collected during test manufacturing. Hence, supercontainer dimensions will conform to the reference supercontainer at initial state.
9 REFERENCES


Posiva 2012b. Design, production and initial state of the canister, Posiva 2012-16, Posiva Oy.


Posiva 2016c. KBS-3H - Design, construction and initial state of the underground openings, Posiva Oy, Posiva 2016-09, Posiva Oy.

Posiva 2016d. Design and production of the KBS-3H repository, Posiva Oy, Posiva 2016-10.

SKB, 2008. KBS-3H Horizontal emplacement technique of supercontainer and distance blocks. Test evaluation report, SKB R-08-43, Svensk Kärnbränslehantering AB.

SKB 2010. Design, production and initial state of the canister. SKB TR-10-14, Svensk Kärnbränslehantering AB.

SKB, 2012. KBS-3H Complementary studies, 2008-2010. TR-12-01, Svensk Kärnbränslehantering AB.


Unpublished documents

<table>
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<tr>
<th>SKBdoc id version</th>
<th>Title</th>
<th>Issuer, year</th>
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<td>1203875 ver 1.0</td>
<td>Ritningsförteckning för kapselkomponenter (Compilation</td>
<td>SKB, 2009</td>
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<td>of drawings of canister components).</td>
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# APPENDIX A - GLOSSARY OF ABBREVIATIONS AND SPECIALISED TERMS USED

The glossary is intended to explain all acronyms, SKB-specific terms, and technical terms that occur often 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.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier</td>
<td>Engineered or natural barrier used for achieving long-term safety functions.</td>
</tr>
<tr>
<td>Barrier function</td>
<td>The way a barrier functions to contribute to contain the radioactive substances or to prevent or retard their dispersion. Also includes the capability of a barrier to preserve the function of other barriers. See also “safety function”, which is the corresponding term used by Posiva.</td>
</tr>
<tr>
<td>BWR</td>
<td>Boiling water reactor.</td>
</tr>
<tr>
<td>DAWE</td>
<td>Drainage, Artificial Watering and air Evacuation. The SKB-3H reference design alternative.</td>
</tr>
<tr>
<td>Design parameter</td>
<td>The designs of the engineered barriers and underground openings are defined by a set of design parameters which are related to the properties that shall provide the required functions.</td>
</tr>
<tr>
<td>Design basis</td>
<td>In Posiva’s terminology “design basis” refers to the current and future environment-induced loads and interactions that are taken into account in the design of the repository system, and, ultimately, to the requirements that the planned repository system must fulfil in order to achieve the objectives set for safety and other factors.</td>
</tr>
<tr>
<td>Deposition drift</td>
<td>A 100–300 m long horizontal hole with a circular crosssection, 1.85 m in diameter, where the supercontainers are emplaced consecutively.</td>
</tr>
<tr>
<td>Deposition equipment</td>
<td>Includes all equipment needed for the emplacement of supercontainers and installation of compacted bentonite blocks.</td>
</tr>
<tr>
<td>Deposition machine</td>
<td>The machine used in the deposition drift for emplacement of supercontainers and compacted bentonite blocks.</td>
</tr>
<tr>
<td>End plate</td>
<td>Unperforated end plate of the supercontainer shell.</td>
</tr>
<tr>
<td>Gamma gate</td>
<td>Sliding radiation protection gate located either on the transport tube or at the entrance of the deposition drift.</td>
</tr>
<tr>
<td>Handling cell</td>
<td>A radiation shielded cell for handling of the spent fuel canister constituting part of the design for the reloading station (in SKB’s design).</td>
</tr>
<tr>
<td>Handling equipment</td>
<td>Equipment for handling of the transport container for the spent fuel canister within the reloading station or the spent fuel canister inside the handling cell (in SKB’s design).</td>
</tr>
</tbody>
</table>
Initial state

The state when direct control over a specific part of the system ceases and only limited information can be obtained on the subsequent development of conditions in that part of the system or its near-field.

For surface environment, initial state is defined as the present conditions.

KBS-3

An abbreviation of the Swedish word *kärnbränslesäkerhet* (nuclear fuel safety) version 3. The KBS-3 method for implementing the spent nuclear fuel disposal concept is based on multiple barriers (as required in Sweden and in Finland).

KBS-3H

(*Kärnbränslesäkerhet* 3-Horizontal). Design alternative of the KBS-3 method in which several spent nuclear fuel canisters are emplaced horizontally and consecutively in a deposition drift.

KBS-3V

(*Kärnbränslesäkerhet* 3-Vertical). The reference design alternative of the KBS-3 method, in which the spent nuclear fuel canisters are emplaced in individual vertical deposition holes.

KTB

Transport cask for encapsulated spent fuel. (Kapseltransportbehållare).

MPT

Multi-purpose test. Multi Purpose Test. The test is part of the KBS-3H project phase “System Design 2011-2016” but also part of the LucoeX-project. It was designed to address several issues within the KBS-3H design and bring the knowledge of the system behaviour to a higher level. Performance of the task will also demonstrate the ability to properly install the system to fulfil the quality demands.

NDT

Non-destructive testing.

PSAR


PWR

Pressurised Water Reactor.

SF

Spent Fuel.

SF canister

Copper canister with spent fuel emplaced in a cast iron insert.

Parking feet

Feet on the supercontainer, distance blocks, filling blocks, transition blocks and the filling component at the far end of the drift in order to avoid direct contact with groundwater.

Reference design

A design that is valid from a defined point in time until further notice. The established reference design shall be used as a premise for technical development, further design and the analysis of safety, radiation protection and environmental impact. A reference design may be either general or site specific.

Reloading station

Station at repository level where the spent fuel canister is transferred from the canister storage to the supercontainer (Posiva). Station at repository level where the spent fuel canister is transferred from the transport cask to the supercontainer (SKB).
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supercontainer</td>
<td>Assembly consisting of a canister surrounded by bentonite clay and a perforated titanium shell.</td>
</tr>
<tr>
<td>Supercontainer shell</td>
<td>Perforated titanium shell that holds together the canister and the bentonite buffer surrounding it.</td>
</tr>
<tr>
<td>Transport (shielding) tube</td>
<td>Tube for the handling of the supercontainer.</td>
</tr>
<tr>
<td>Transport support</td>
<td>Frame for the transport tube to allow transportation.</td>
</tr>
<tr>
<td>Transport vehicle</td>
<td>Vehicle for transportation of deposition equipment and components.</td>
</tr>
</tbody>
</table>
APPENDIX B - SUPERCONTAINER DIMENSIONS, TOLERANCES AND GAPS

SKB BWR/PWR canisters

Posiva BWR/VVER/EPR canisters
<table>
<thead>
<tr>
<th>Measure</th>
<th>SKB canisters</th>
<th>Posiva canisters</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BWR/PWR</td>
<td>BWR</td>
<td>VVER</td>
</tr>
<tr>
<td>I1</td>
<td>5395 (+8/6)</td>
<td>5387 (+6/6)</td>
<td>4187 (+6/6)</td>
</tr>
<tr>
<td>I2</td>
<td>4835 +3.2%/2.75</td>
<td>4752 +3.2%/2.75</td>
<td>3552 +3.2%/2.75</td>
</tr>
<tr>
<td>I3</td>
<td>1192 +1%/1</td>
<td>1190 +1%/1</td>
<td>890 +1%/1</td>
</tr>
<tr>
<td>I4</td>
<td>350 +1%/1</td>
<td>350 +1%/1</td>
<td>350 +1%/1</td>
</tr>
<tr>
<td>I5</td>
<td>350 +1%/1</td>
<td>350 +1%/1</td>
<td>350 +1%/1</td>
</tr>
<tr>
<td>I6</td>
<td>85 +1%/1</td>
<td>85 +1%/1</td>
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<tr>
<td>I7</td>
<td>77 +1%/1</td>
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<td>-</td>
</tr>
<tr>
<td>t1</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>t2</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>d1</td>
<td>828 +0/2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>d2</td>
<td>850 +0.9/0.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>d3</td>
<td>1050 +1.2%/1.2</td>
<td>1050 +1.2%/1.2</td>
<td>1050 +1.2%/1.2</td>
</tr>
<tr>
<td>d4</td>
<td>1058 +1%/1</td>
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</tr>
<tr>
<td>d5</td>
<td>1740 +1%/2</td>
<td>1740 +1%/2</td>
<td>1740 +1%/2</td>
</tr>
<tr>
<td>d6</td>
<td>1749 (+0/2)</td>
<td>1749 (+0/2)</td>
<td>1749 (+0/2)</td>
</tr>
<tr>
<td>d7</td>
<td>1761 +0/2</td>
<td>1761 +0/2</td>
<td>1761 +0/2</td>
</tr>
<tr>
<td>d8</td>
<td>798 +0/2</td>
<td>798 +0/2</td>
<td>798 +0/2</td>
</tr>
<tr>
<td>d9</td>
<td>821 +0/0.5</td>
<td>821 +0/0.5</td>
<td>821 +0/0.5</td>
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<tr>
<td>g1</td>
<td>8 (+8.4%/8.95)</td>
<td>8 (+8.4%/8.95)</td>
<td>8 (+8.4%/8.95)</td>
</tr>
<tr>
<td>g2</td>
<td>8 (+6.7%/7.25)</td>
<td>8 (+6.7%/7.25)</td>
<td>8 (+6.7%/7.25)</td>
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<tr>
<td>g3</td>
<td>2 (+1.3%/2.3)</td>
<td>-</td>
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<tr>
<td>g4*</td>
<td>11.5 (+1%/0.25)</td>
<td>11.5 (+1%/0.25)</td>
<td>11.5 (+1%/0.25)</td>
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<td>g5*</td>
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<td>4 (+1%/1.1)</td>
<td>4 (+1%/1.1)</td>
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<td>g7*</td>
<td>4.5 (+1%/1.5)</td>
<td>4.5 (+1%/1.5)</td>
<td>4.5 (+1%/1.5)</td>
</tr>
</tbody>
</table>

*) Radial gaps with all components centred
| POSIVA 2016-01                                                                 | Simplified transport modelling of a disposal system and doses using probabilistic methods  
                                        | *Pekka Kupiainen & Olli Nummi (Fortum Power and Heat Oy)*  
| POSIVA 2016-02                                                                 | Safety Evaluation for a KBS-3H spent nuclear fuel repository at Olkiluoto – Performance Assessment  
                                        | *Posiva Oy*  
| POSIVA 2016-03                                                                 | Safety Evaluation for a KBS-3H spent nuclear fuel repository at Olkiluoto – Features, events and processes  
                                        | *Posiva Oy*  
| POSIVA 2016-04                                                                 | Safety Evaluation for a KBS-3H spent nuclear fuel repository at Olkiluoto - Description of the disposal system  
                                        | *Posiva Oy*  
                                        | ISBN: 978-951-652-251-0 |
| POSIVA 2016-05                                                                 | Safety Evaluation for a KBS-3H spent nuclear fuel repository at Olkiluoto – Design Basis  
                                        | *Posiva Oy*  
| POSIVA 2016-06                                                                 | KBS-3H – Design, production and initial state of buffer and filling components  
                                        | *Posiva Oy*  
| POSIVA 2016-07                                                                 | KBS-3H – Design, production and initial state of the compartment and Drift Plug  
                                        | *Posiva Oy*  
| POSIVA 2016-08                                                                 | KBS-3H – Design, production and initial state of the supercontainer  
                                        | *Posiva Oy*  