Technical Report

TR-14-02

Initial state report for the safety assessment SR-PSU

Svensk Kärnbränslehantering AB

November 2014

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Update notice

The original report, dated November 2014, was found to contain factual errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2015-10

Location	Original text	Corrected text
Page 42, Figure 3-4	Wrong data in figure	Figure updated with correct data
Page 50, last paragraph	...waste type package (SKB 2013b)…	...waste type package (SKB 2013b, SKBdoc 1481419 (Mo-93))…
Page 52, table head	...in the Inventory report (SKB 2013b).	...in the Inventory report (SKB 2013b, SKBdoc 1481419 (Mo-93)).
Page 52, Table 3-16	Wrong data in table	Table updated with correct data
Page 53, Table 3-17	Wrong data in table	Table updated with correct data
Page 100, Section 12.1.6, second sentence	...in the Inventory report (SKB 2013b).	...in the Inventory report (SKB 2013b, SKBdoc 1481419 (Mo-93)).
Page 121, updated reference	1427105 ver 1.0	1427105 ver 4.0
Page 121, new reference		SKBdoc 1481419 ver 1.0. Ny beräkning av Mo-93 i normkolli till PSU 2015-05 (In Swedish.) SKB, 2015

Preface

This report compiles information on the initial state of the waste and repository for the long-term safety of the low-and intermediate level waste repository SFR. It forms part of the SR-PSU safety assessment, which supports the application for a licence to extend SFR repository in Forsmark.

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The report has been reviewed by Claes Johansson, Anders Eriksson, Theresa Millqvist, SKB, Anna Pettersson, Vattenfall Research and Development AB and Ulf Brising, Sweco.

Stockholm, November 2014

Fredrik Vahlund
Project leader SR-PSU

Summary

The final repository for short-lived radioactive waste (SFR) located in Forsmark, Sweden is currently being used for the final disposal of low- and intermediate-level operational waste from Swedish nuclear facilities. SKB plans to extend the repository to host waste from the decommissioning of the nuclear power plants and other nuclear facilities. The SR-PSU assessment of the long-term safety (post-closure safety) of the whole repository is an important part of the application for a licence to build the extension. This report constitutes one of the main references supporting the Main report, which summarises the long-term safety for the SFR repository (SKB 2014e).

The initial state is defined as the expected state of the repository and its environs immediately after closure. The initial state of the repository is based on verified and documented properties of the wastes and the repository components plus an assessment of changes in these properties up to the time of closure. The estimated year of closure is 2075.

This report describes the following, which define and secure an appropriate initial state of SFR:

- Waste types.
- Waste packaging.
- Waste acceptance criteria.
- Design features of each waste vault.
- Allocation of waste packages to the waste vaults.
- Material quantities.
- Radionuclide inventories.
- Main dimensions of the waste vaults.
- Inspection and control processes.

An overview of suggested measures for plugging and closure of SFR is also given. Overall, the report provides input to the assessment of the long-term safety of the SFR repository system.

Finally, the expected properties and condition of each system component at repository closure are described following prescribed lists of variables (parameters).

Sammanfattning

Slutförvaret för kortlivat radioaktivt avfall (SFR) i Forsmark, Sverige används för närvarande för slutlig deponering av låg- och medelaktivt driftavfall från svenska kärntekniska anläggningar. SKB planerar att bygga ut förvaret för att förvara avfall från rivning av kärnkraftverken och andra kärntekniska anläggningar. Analysen av långsiktig säkerhet SR-PSU (säkerhet efter förslutning) för hela förvaret är en viktig del av ansökan om att få bygga ut förvaret. Den här rapporten utgör en av huvudreferenserna till huvudrapporten som summerar analysen av långsiktig säkerhet för SFR (SKB 2014e).

Initialtillståndet är definierat som det förväntade tillståndet för förvaret och dess omgivning direkt efter förslutning. Initialtillståndet för förvaret bygger på kontrollerade och dokumenterade egenskaper hos avfall och förvarskomponenter samt bedömning av förändrade egenskaper under tiden fram till och med förslutning. Tidpunkten för förslutning uppskattas till år 2075.

För att definiera och säkerställa ett ändamålsenligt initialtillstånd för SFR beskrivs följande i rapporten:

- Avfallstyper.
- Avfallsemballage.
- Acceptanskriterier för avfall.
- Bergssalarnas design.
- Fördelning av avfall mellan bergssalarna.
- Materialmängder.
- Radionuklidinventar.
- Bergssalarnas dimensioner.
- Inspektions- och kontrollprocess.

En översikt över föreslagna åtgärder för pluggning och förslutning av SFR ges också. Sammantaget utgör den här rapporten underlag för analysen av den långsiktiga säkerheten av SFR:s förvarssytem.

Slutligen beskrivs de förväntade egenskaperna vid förslutning för varje systemkomponent i förvaret samt deras kondition med hjälp av föreskrivna listor med variabler (parametrar).

Contents

1 Introduction

1.1 Background

The SFR repository includes waste vaults underground together with buildings above ground that include a number of technical installations. The underground part is situated at about 60 metres depth in the rock and is located below the Baltic Sea. The existing facility (SFR 1) comprises five waste vaults with a disposal capacity of approximately 63,000 m^3. The extension (SFR 3[1]) will have a disposal capacity of 108,000 m^3 in five new waste vaults plus one new vault for nine boiling water reactor pressure vessels, see Figure 1-1.

The long-term post closure safety of the whole SFR has been assessed and documented in the SR-PSU Main report (SKB 2014e) with supporting documents, see Section 1.2. The Main report is part of SKB's licence application to extend and continue to operate SFR. The present report is a main reference and describes the SFR repository at the time of closure.

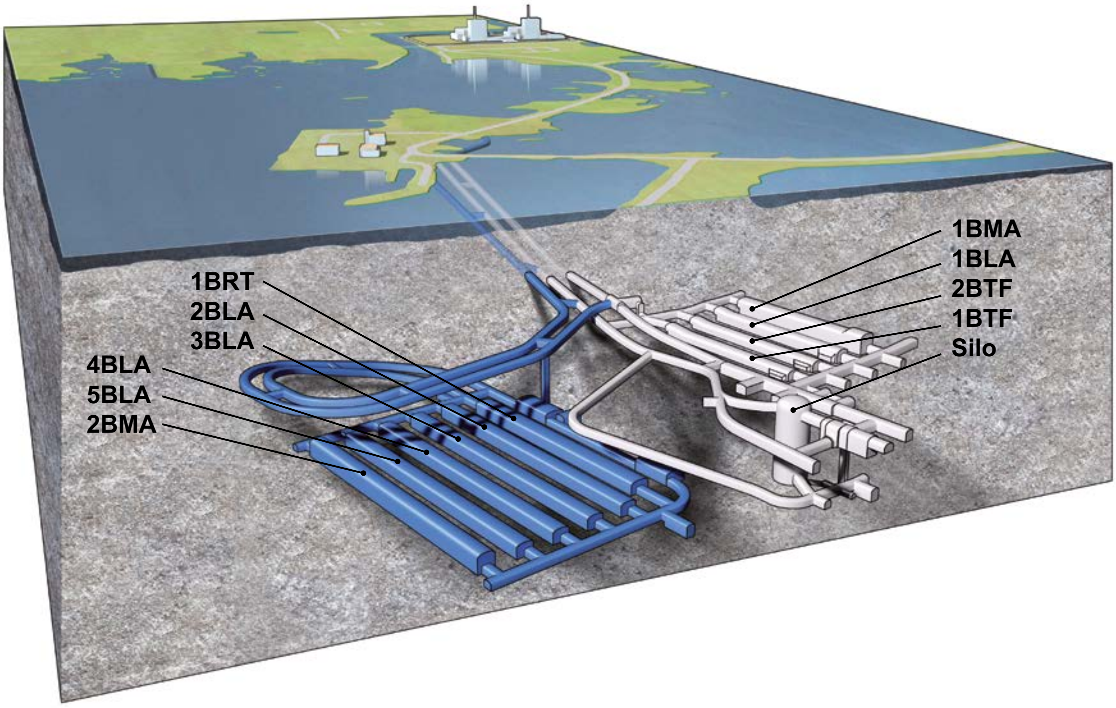

Figure 1-1. *Schematic illustration of SFR. The grey part is the existing repository (SFR 1) and the blue part is the planned extension (SFR 3). The waste vaults in the figure are the silo for intermediate-level waste, 1–2BMA vaults for intermediate-level waste, 1–2BTF vaults for concrete tanks, 1–5BLA vaults for low-level waste and the BRT vault for reactor pressure vessels.*

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[1] The extension is called SFR 3 since the name SFR 2 was used in a previous plan to build vaults adjacent to SFR 1 for disposal of reactor core components and internal parts. The current plan is to dispose of this waste in a separate repository.

1.2 Report hierarchy in the SR-PSU safety assessment

The applied methodology for the long-term safety comprises ten steps and is described in Chapter 2 of the PSU Main report (SKB 2014e). Several of the steps carried out in the safety assessment are described in more detail in supporting documents, so called main references that are of central importance for the conclusions and analyses in the Main report. The full titles of these reports together with the abbreviations by which they are identified in the following text together with short comments on the report contents are given in Table 1-1.

There are also a large number of additional references. The additional references include documents compiled within SR-PSU, but also documents compiled outside of the project, either by SKB or equivalent organisations as well as in the scientific literature.

A schematic illustration of the safety assessment documents is shown in Figure 1-2.

Two important references to this Initial state report are the "Inventory report" (SKB 2013b) and the "Closure plan for SFR" (SKBdoc 1358612), in addition to the following main references; Barrier process report (SKB 2014c), Data report (SKB 2014b), FEP report (SKB 2014d), and Waste process report (SKB 2014f).

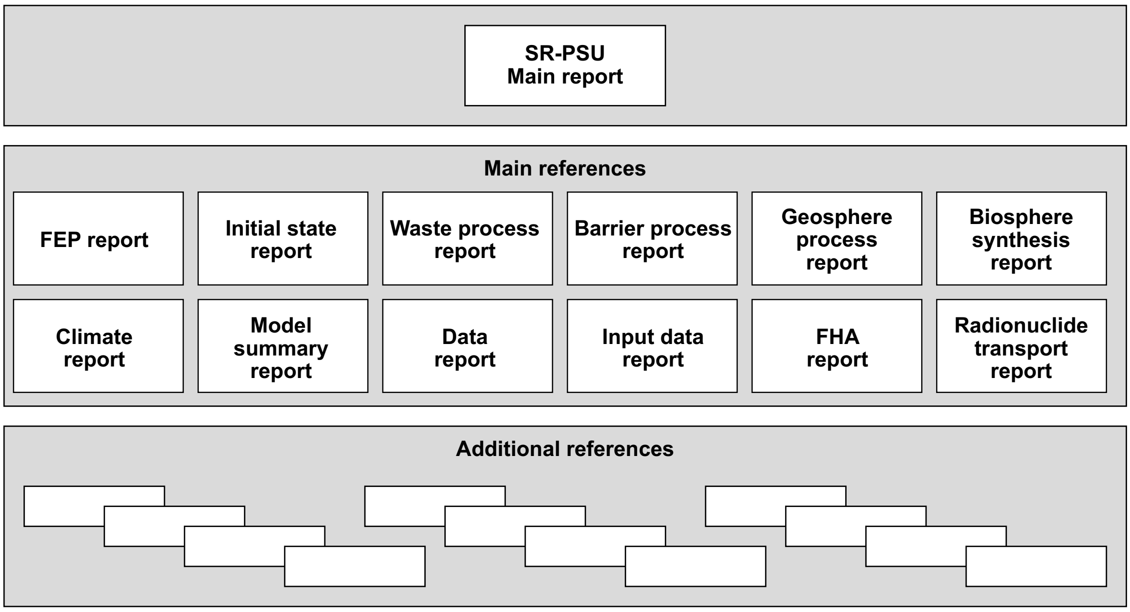

Figure 1-2. The hierarchy of the Main report, main references and additional references in the SR-PSU long-term safety assessment. The additional references either support the Main report or any of the main references.

Table 1-1. Main report and main references in the SR-PSU long term safety assessment. All reports are available at www.skb.se

Abbreviation used when referenced in this report	Reference	Comment on content
Main report	Main report, 2014. Safety analysis for SFR. Long-term safety. Main report for the safety assessment SR-PSU. SKB TR-14-01, Svensk Kärnbränslehantering AB.	This document is the main report of the SR-PSU long-term post-closure safety assessment for SFR. The report is part of SKB´s licence application to extend and continue to operate SFR.
Barriers process report	Engineered barriers process report, 2014. Engineered barrier process report for the safety assessment SR-PSU. SKB TR-14-04, Svensk Kärnbränslehantering AB.	Describes the current scientific understanding of the processes in the engineered barriers that have been identified in the FEP processing as potentially relevant for the long-term safety of the repository. Reasons are given in the process report as to why each process is handled a particular way in the safety assessment.
Biosphere synthesis report	Biosphere synthesis report, 2014. Biosphere synthesis report for the safety assessment SR-PSU. SKB TR-14-06, Svensk Kärnbränslehantering AB.	Describes the handling of the biosphere in the safety assessment. The report summarises site description and landscape evolution, FEP handling, exposure pathway analysis, the radionuclide model for the biosphere, included parameters, biosphere calculation cases and simulation results.
Climate report	Climate report, 2014. Climate and climate-related issues for the safety assessment SR-PSU. SKB TR-13-05, Svensk Kärnbränslehantering AB.	Describes the current scientific understanding of climate and climate-related processes that have been identified in the FEP processing as potentially relevant for the long-term safety of the repository. The report also describes the climate cases that are analysed in the safety assessment.
Data report	Data report, 2014. Data report for the safety assessment SR-PSU. SKB TR-14-10, Svensk Kärnbränslehantering AB.	Qualifies data and describes how data, including uncertainties, that are used in the safety assessment are quality assured.
FEP report	FEP report, 2014. FEP report for the safety assessment SR-PSU. SKB TR-14-07, Svensk Kärnbränslehantering AB.	Describes the establishment of a catalogue of features, events and processes (FEPs) that are of potential importance in assessing the long-term functioning of the repository.
FHA report	FHA report, 2014. Handling of future human actions in the safety assessment SR-PSU. SKB TR-14-08, Svensk Kärnbränslehantering AB.	Describes radiological consequences of future human actions (FHA) that are analysed separately from the main scenario, which is based on the reference evolution and less probable evolutions.
Geosphere process report	Geosphere process report, 2014. Geosphere process report for the safety assessment SR-PSU. SKB TR-14-05, Svensk Kärnbränslehantering AB.	Describes the current scientific understanding of the processes in the geosphere that have been identified in the FEP processing as potentially relevant for the long-term safety of the repository. Reasons are given in the process report as to why each process is handled a particular way in the safety assessment.
Initial state report	Initial state report, 2014. Initial state report for the safety assessment SR-PSU. SKB TR-14-02, Svensk Kärnbränslehantering AB.	Describes the conditions (state) prevailing in SFR after closure. The initial state is based on verified and documented properties of the repository and an assessment of the evolution during the period up to closure.
Input data report	Input data report, 2014. Input data report for the safety assessment SR-PSU. SKB TR-14-12, Svensk Kärnbränslehantering AB.	Describes the activities performed within the SR-PSU safety assessment and the input data used to perform these activities.
Model summary report	Model summary report, 2014. Model summary report for the safety assessment SR-PSU. SKB TR-14-11, Svensk Kärnbränslehantering AB.	Describes the calculation codes used in the assessment.
Radionuclide transport report	Radionuclide transport report, 2014. Radionuclide transport and dose calculations for the safety assessment SR-PSU. SKB TR-14-09, Svensk Kärnbränslehantering AB.	Describes the radionuclide transport calculations carried out for the purpose of demonstrating fulfilment of the criterion regarding radiological risk.
Waste process report	Waste process report, 2014. Waste form and packaging process report for the safety assessment SR-PSU. SKB TR-14-03, Svensk Kärnbränslehantering AB.	Describes the current scientific understanding of the processes in the waste and its packaging that have been identified in the FEP processing as potentially relevant for the long-term safety of the repository. Reasons are given in the process report as to why each process is handled in a particular way in the safety assessment.

1.3 This report

The long-term safety assessment for SFR (SR-PSU) was performed according to a developed methodology including ten steps (see Chapter 2 in the Main Report). This report is part of Step 2 – Description of initial state and it details the initial state of the repository at closure.

This report also describes waste acceptance criteria, reference waste inventory, repository reference design, as well as control and inspection processes used to secure an appropriate initial state of SFR. This information is an important base also for the safety report covering the construction and operation of the SFR facility.

1.3.1 Initial state

The initial state is the starting point for the long-term safety assessment and provides information to several of the subsequent steps in the methodology e.g. Step 4 – Description of processes through the process reports for the waste (SKB 2014f) and the engineered barriers (SKB 2014c) respectively and Step 9 – Analysis of selected scenarios.

The initial state of the repository part in operation (SFR 1) is based on verified and documented properties of the waste and the repository and an assessment of how these will change up to the time of closure, whereas the initial state of the extension (SFR 3) is mainly based on the reference design and present waste prognosis.

The initial state of the repository environment is given in Chapter 4 of the Main report (SKB 2014e).

1.3.2 Reference design

The reference design is a design that is valid from a defined point in time until further notice. The reference design is used for technical development, further design improvements and the analyses of safety, radiation and environmental impact.

The reference design for SFR 1 is mainly based on system descriptions and drawings. The reference design for the extension (SFR 3) and the long-term safety assessment for the SFR repository (SR-PSU), including this report, is based on the repository extension design defined in March 2012, Layout 1.5. However, the preparation of a licence application is an iterative and in time relatively long process and changes have therefore been made to the extension design in the time taken to compile the long-term safety assessment. Therefore, all parts of the application for the extension of SFR, except the long-term safety assessment, are based on the amended design, Layout 2.0. It is therefore important to state the differences between the two designs explicitly, which are:

- Height and width of 2BMA, see Table 5-1.
- Height of walls in 2–5BLA, see Table 9-1.
- Length and height of vault, dimensions of disposal area in BRT, see Table 10-1.

In the description given in this report, all figures are according to Layout 2.0 and dimensions are given for both layouts where they differ.

The highest point of the existing waste vaults is the silo top that is located at 64 m beneath the surface of the sea, Öregrundsgrepen, see Figure 1-3. The planned extension (SFR 3) will connect directly to SFR 1 and the highest point of the six new waste vaults is 117 m beneath the surface of the sea and the lowest point is at about the same level as the lowest point in SFR 1. When the extension is complete, it will be fully incorporated into all auxiliary systems in the existing facility.

When waste deposition in SFR is complete, the operating phase will end and the sealing and closure of vaults and tunnels will begin. After sealing and closure is complete by 2075, no further actions will be needed to support the function of the passive underground repository. An overview of the repository after the planned sealing and closure measures described in the Closure plan for SFR (SKBdoc 1358612) is shown in Figure 1-4.

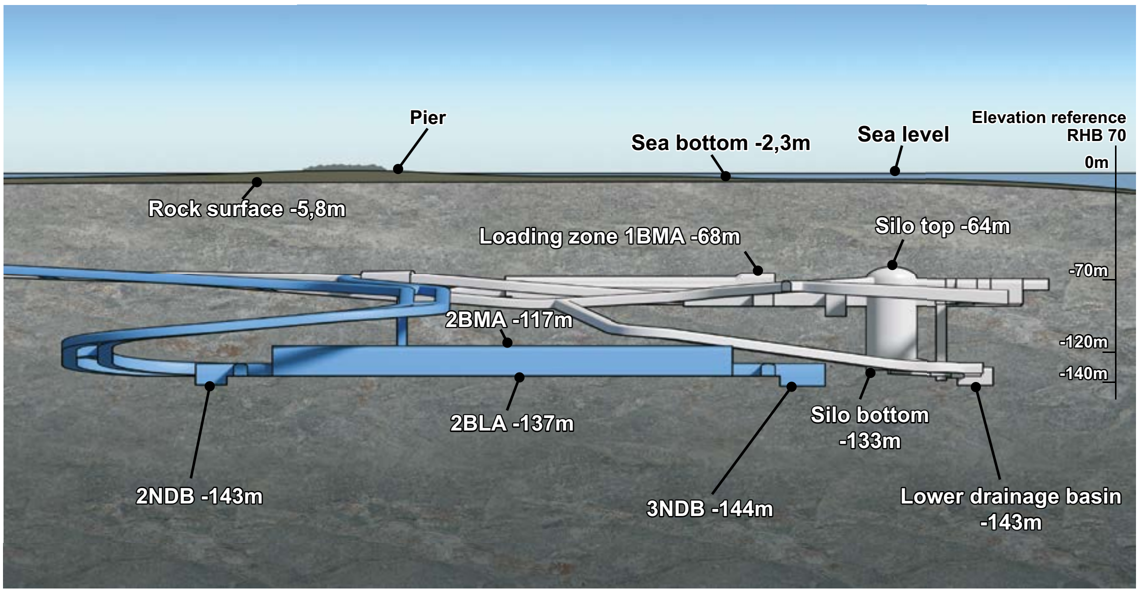

Figure 1-3. *View of SFR with designated levels in RHB 70 (RHB 70 is the Swedish geographical height system). View is towards the NW, approximately perpendicular to the waste vaults. Note that stipulated elevations for the top surface of the rock and the sea floor are to be regarded as approximate since they are point data and vary in the plane above SFR. The grey part is SFR 1 and the blue part is SFR 3.*

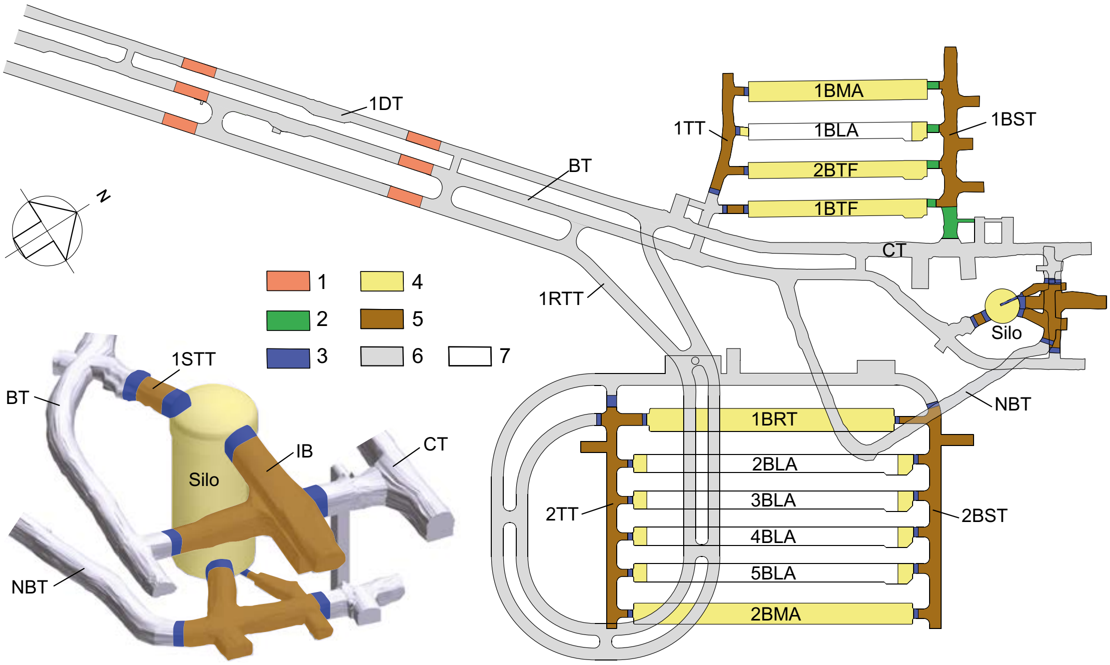

Figure 1-4. *Overview of SFR after closure with detailed view of the silo. Key to numbering: 1) Plugs in access tunnels 2) Transition material 3) Mechanical plug of concrete 4) Backfill material of macadam 5) Hydraulically tight section of bentonite 6) Backfill material in access tunnels and tunnel system 7) Non-backfilled openings. Note that the figure shows Layout 2.0; Layout 1.5 is used in SR-PSU modelling. The difference that can be seen in the figure is that BRT is longer than in Layout 1.5.*

1.3.3 Overview of the report

This report comprises thirteen chapters and an appendix. Following is a brief description of the contents:

Chapter 1 – Introduction. This chapter describes the background and the role of the report. Furthermore, descriptions are given of definitions and abbreviations.

Chapter 2 – General considerations. In this chapter it is explained how different data in the initial state report are obtained and specified.

Chapter 3 – Waste. Waste acceptance criteria, descriptions of waste types and packaging, the allocation of waste packages to waste vaults and material quantities and radionuclide inventory in the waste packages are given in this chapter.

Chapters 4 to 10 – Waste vaults. The waste vaults are the **silo** for intermediate-level waste, **1–2BMA** vaults for intermediate-level waste, **1–2BTF** vaults for concrete tanks, **1–5BLA** vaults for low-level waste and the **BRT** vault for reactor pressure vessels. In these chapters the design and design considerations for the different waste vaults are described. The main dimensions are given in tables.

Chapter 11 – Plugs and other closure components. An overview of suggested measures for plugging and closure of SFR is given in this chapter.

Chapter 12 – Variables at initial state for the system components. The expected condition of the different system components at repository closure are defined by going through the lists of variables (parameters) that are required to describe the properties and condition of each system component.

Chapter 13 – Summary and conclusions.

Appendix A – Detailed information for the waste packages and waste vaults. Information on the number of waste packages in different waste vaults, quantities of different materials in the different compartments as well as material volumes and void including porosity in materials in the waste vaults are given in tables.

1.4 Terms and abbreviations

Terms and abbreviations used in this report are listed in Table 1-2.

Table 1-2. List of terms and abbreviations.

Term or abbreviation	Description
BLA	Vault for low-level waste.
BMA	Vault for intermediate-level waste.
BRT	Vault for reactor pressure vessels.
BST	Waste vault tunnel.
BT	Construction tunnel.
BTF	Vault for concrete tanks.
Clab	Central interim storage for spent fuel.
Clink	Central interim storage and encapsulation plant for spent fuel (Clab is one part of Clink).
Conditioning	Those operations that produce a waste package suitable for handling, transport, storage and/or disposal (IAEA 2007).
Connecting tunnel	General term used for tunnels outside waste vaults, for example BST and TT.
DT	Operational tunnel.
Initial state	The state that exists in SFR and the surroundings after closure.
Layout 1.5	Layout for SFR 3 from March 2012, used in the long-term safety assessment for the SFR repository (SR-PSU).
Layout 2.0	Final Layout for SFR 3 used in the application.
Macadam	Macadam is crushed rock sieved in fractions 2–65 mm. Macadam has no or very little fine material (grain size < 2 mm). The fraction is given as intervals, for example “Macadam 16-32” is crushed rock comprising the fraction 16–32 mm.
Repository system	Broadly defined as the deposited radioactive waste and the surrounding packaging, the engineered barriers surrounding the waste packages, the host rock and the biosphere in the proximity of the repository.
RHB	The Swedish geographical height system.
RPV	Reactor pressure vessel.
SFR	Final repository for short-lived low- and intermediate-level waste.
SFR 1	Existing part of SFR.
SFR 3	Extended part of SFR.
SR-PSU	Current long-term safety assessment (Safety Report – Project SFR Extension).
Silo	Cylindrical vault for intermediate-level waste.
SSM	Swedish Radiation Safety Authority.
System component	A physical component of the repository system, a sub-system.
SKB	Swedish Nuclear Fuel and Waste Management Company.
Transition material	Component in earth dam plug e.g. 30/70 mixture bentonite and crushed rock. The role of the transition material is to hinder bentonite transport out from the hydraulic tight section, to take up the load from bentonite swelling and transfer it to the backfill material.
TT	Transverse tunnel.
Waste form	The physical and chemical form after treatment and/or conditioning. (IAEA 2007)
Waste package	Includes waste form and packaging.
Waste packaging	The outer barrier protecting the waste form. Includes the assembly of components (e.g. absorbant materials, spacing structures, radiation shielding, service equipment, etc. (IAEA 2007).
Waste type	In order to systematically classify the wastes, different waste types have been defined and a code system developed.
Waste vault	Part of repository where waste is stored.

2 General considerations

2.1 General

In this section it is explained how different data in the initial state report were obtained and specified, and the QA measures that were taken to ensure the long-term safety of the repository system.

One part of the repository (SFR 1) already exists today, while the other part (SFR 3) is in the planning stage. Therefore, the description of the initial state of SFR 1 can be given more accurately, based on measurements and observations. The initial state of the extension is based on the proposed design. However, both initial state descriptions are based on certain assumptions. The uncertainties in these assumptions are mainly associated with waste quantities in the repository, the radionuclide inventory and closure measures. For example, future waste quantities are based on forecasts and the technical solutions that will be used at closure have not yet been finalised.

2.2 Laws and regulations

The final repository for low- and intermediate-level radioactive waste shall conform to the requirements of relevant laws and regulations.

The international treaties and national laws and regulations relevant for the design of a final repository for low- and intermediate-level radioactive waste are the following.

International treaty:

- Joint convention on the safety of spent fuel management and on the safety of radioactive waste (IAEA 2006).

National laws:

- Act on Nuclear Activities, KTL (SFS 1984:3).
- Radiation Protection Act, SSL (SFS 1988:220).

Regulations:

- Regulations concerning safety in nuclear facilities (SSMFS 2008:1).
- Regulations concerning physical protection of nuclear facilities (SSMFS 2008:12).
- Regulations concerning safety in connection with the disposal of nuclear material and nuclear waste (SSMFS 2008:21).
- Regulations on the protection of human health and the environment in connection with the final management of spent nuclear fuel and nuclear waste (SSMFS 2008:37).

In addition, the following laws must be followed during design, construction and operation of the repository:

- The Swedish Environmental Code, MB (SFS 1998:808).
- The Planning and Building Act, PBL (SFS 2010:900).
- The Work Environment Act, AML (SFS 1977:1160).

In addition, stakeholder demands are expressed in SKB's guiding principles. These are that safety, efficiency and responsiveness shall be considered in design.

2.3 Repository system

The repository system is broadly defined as the deposited radioactive waste and the surrounding packaging, the engineered barriers surrounding the waste packages, the host rock and the biosphere in the proximity of the repository.

According to the FEP (Feature, Events and Processes) report for the safety assessment SR-PSU (SKB 2014d), the repository can be divided into system components. A system component is a physical component of the repository. This report follows the definition given in the FEP-report, but many other definitions of SFR system components are used elsewhere.

The waste packages are divided into two system components:

- Waste form, i.e. waste including conditioning material
- Waste packaging, e.g. drums, moulds (concrete and steel), concrete tanks, and containers.

The main system components for disposal of waste packages are:

- SFR 1
  - 1BMA
  - 1BTF and 2BTF
  - Silo
  - 1BLA
- SFR 3
  - 2BMA
  - 2BLA, 3BLA, 4BLA and 5BLA
  - BRT.

Each of these main system components consist of several other system components. For example, 1BMA consists of concrete structures, grouting and macadam.

Other system components in the underground facility are:

- Plugs and other closure components (including investigation boreholes).

In addition, the rock surrounding the repository and the surface environment in the repository area are defined as system components in the FEP report (SKB 2014d). The description of the geosphere is given in the site descriptive model for SFR, SDM-PSU (SKB 2013c), the surface environment is described in the Biosphere synthesis report for the safety assessment SR-PSU (SKB 2014a) and the climate is described in the Climate report (SKB 2014g). The initial state for these components is given in the Main report concerning the long-term safety for the SFR repository (SKB 2014e, Chapter 4).

2.4 System components and their functions

The safety in SFR is based on a limited quantity of radioactivity in the waste form and, for some vaults, the retardation of radionuclides by the system components e.g. waste packaging and concrete structures in the repository. Potential aspects that may be considered in the long-term safety assessment for the different system components in some or all of the waste vaults are listed in Table 2-1. The SR-PSU Main report (SKB 2014e, Chapter 5) details the parts of SFR where these safety functions apply to the assessment. It is also important to ensure that there are no negative influences between system components. The system components that are credited as barriers in the long-term safety assessment and their barrier functions are described in the SR-PSU Main report (SKB 2014e, Chapter 11).

Table 2-1. Potential aspects that may be considered in the long-term safety assessment for the different system components in some or all of the waste vaults.

System component	Aspect
Waste form	Level of radioactivity Limited advective transport Mechanical stability Limited dissolution Sorption Favourable water chemistry
Waste packaging	Limited advective transport Mechanical stability Sorption Favourable water chemistry
Grouting surrounding waste packages	Limited advective transport Mechanical stability Sorption Favourable water chemistry
Concrete structures	Limited advective transport Mechanical stability Sorption Favourable water chemistry
Shotcrete	Mechanical stability (during operating phase, together with rock bolts) Sorption Favourable water chemistry
Bentonite and sand/bentonite	Limited advective transport Mechanical stability Sorption
Backfill in waste vaults (crushed rock/ macadam)	Mechanical stability Sorption
Plugs and other closure components (investigation boreholes)	Limited advective transport in the repository Sorption

2.5 Inspection and control

SKB has a quality management system that includes procedures for project management and safety audit. These procedures have served as a basis for framing the control documents, or quality assurance systems, that have governed the work with both SFR 1 and SFR 3. The quality management system meets the requirements in ISO 9001:2000.

Controls performed during the construction, inspection and measurement of conditions in the existing facility SFR 1 are documented. The existing control programme comprises e.g. measurements of groundwater inflows and groundwater chemistry, and inspection of the physical condition of the waste vaults. The purpose of the programme is to examine ongoing changes in the system such as settlement of the silo and the future impacts of blasting during construction of the SFR extension. A special control programme is defined for the silo (Section 7.3), which has the most advanced engineered barrier system.

Methods for testing and inspecting SFR 3 during its construction (tunnels and waste vaults) will be developed and defined during the detailed design phase for the extension. It is foreseen that a special control programme will be defined for 2BMA, due to its new design with unreinforced caissons, see Section 5.3.

3 Waste

3.1 General basis

SKB plans to extend SFR so that it will be able to receive decommissioning waste and additional operational waste resulting from the prolonged planned operating times for the nuclear power plants. The extension of SFR is therefore being designed to receive all additional short-lived low- and intermediate-level operational waste and all short-lived decommissioning waste expected to result from the dismantling of today's nuclear power plants, including waste from the old power plants at Ågesta and Studsvik, and decommissioning waste from the interim storage facility for spent fuel and the planned adjacent encapsulation plant (Clink). In addition, legacy waste from Svafo AB (company that treats nuclear waste and facilities from early Swedish nuclear research) and Studsvik AB (company that treats nuclear waste, which also includes waste from hospitals, research and industry) is also being taken into account in the design of SFR.

The nuclear facilities that generate waste are responsible for conditioning the waste, producing waste packages and the interim storage of the waste. SKB is responsible for the transport to SFR and disposal of the waste. Nevertheless, the waste producers always have the overall responsibility for their waste.

The tools used to ensure that the waste is emplaced in correct packaging and in the correct waste vault in SFR are the Waste handling manual, Waste type descriptions, waste audits and the Waste register. Waste acceptance criteria are given in the Waste handling manual and those valid for the specific waste type are also included in the Waste type descriptions together with information on how they will be fulfilled and verified.

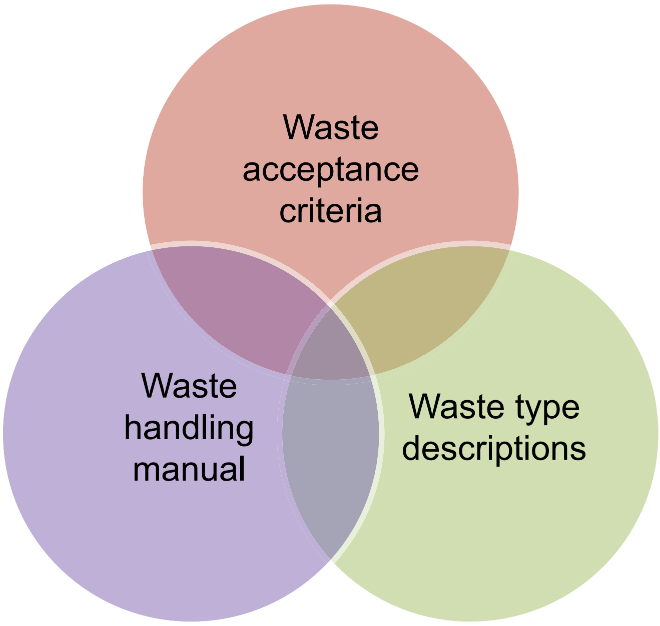

Figure 3-1. Schematic illustration of the interaction between Waste acceptance criteria, Waste handling manual and Waste type description. Waste acceptance criteria are given in the Waste handling manual and those valid for the specific waste type are also included in the Waste type descriptions together with information on how they will be fulfilled and verified.

3.2 Design considerations – Waste acceptance criteria

Waste acceptance criteria can be defined as quantitative or qualitative requirements that must be fulfilled in order for the waste to be accepted for final disposal.

According to the Waste acceptance criteria, the overlying requirement for waste is:

The waste package, i.e. the waste form and packaging, should prevent radionuclide dispersion during handling and delay radionuclide migration during disposal. The waste package should protect workers and the environment from radiation. The waste package should be suitable for handling in the transport and disposal systems. Both the activity and the materials in the waste packages should be selected with regard to the technical barriers of the repository so that the repository is safe after closure. The above principles should be upheld by optimisation from an ALARA perspective and the use of best available technologies (BAT).

Waste acceptance criteria are required according to the SSMFS 2008:1 regulation (Chapter 6 Sections 11–12 (there is no official translation available)):

Acceptance criteria

Section 11 For facilities that handle nuclear material that is no longer intended for use or nuclear waste from other facilities, there must be documented requirements (acceptance criteria) regarding the properties of materials that may be received for storage, disposal or other handling. Acceptance criteria shall, as far as reasonably possible, take account of safety and radiation protection in every step of the further treatment. Acceptance criteria shall be included in the safety analysis report in accordance with Chapter 4, Section 2.

Section 12 In order to receive materials for storage, disposal or handling, written instructions are required on how the received material has been handled earlier in the chain of custody and showing that it meets the acceptance criteria. There should also be documented procedures for handling materials that do not meet the acceptance criteria, either returning them to the sender or correcting the deviations.

These paragraphs were added to SSMFS 2008:1 recently and have been applied since November 2012. The Waste handling manual is the administrative steering document in which the acceptance criteria are given.

The Waste acceptance criteria are summarised in the following subsection.

3.2.1 The SFR Waste acceptance criteria

The Waste acceptance criteria concern general, radiological, chemical and physical as well as mechanical requirements. The Waste acceptance criteria for operational waste in SFR 1 are in use. Preliminary waste acceptance criteria have been defined for the future operational and decommissioning waste (SKBdoc 1368638). A summary of the Waste acceptance criteria is given below, with focus on the criteria that are of importance for long-term safety. The summary is based on the implemented Waste acceptance criteria for operational waste in SFR 1 and major differences between these and the preliminary criteria are pointed out. The description of the waste given in the Initial state report constitutes input to the long-term safety analysis, and the preliminary Waste acceptance criteria are partly based on the results of the long-term safety analysis.

General requirements

The general requirements concern the geometry, dimensions, weight and labelling of waste packages. These requirements are related to the handling and documentation of the waste.

Radiological requirements

The radiological requirements concern the radionuclide inventory, surface dose rate, dose rate at a certain distance, surface contamination, radiation effects on the waste and homogeneity.

Radionuclide inventory

The radionuclide inventory should be known and documented in a register. The inventory of radionuclides should either be obtained by direct measurements or indirect radionuclide-specific measurements and/or calculations.

SFR 1 is currently licensed to hold a total activity of 10^{16} Bq. However, there are also activity limits relating to the disposal of specific radionuclides in each waste vault, see Table 3-1. The overall activity limits set by the license comprise the sum of the activity across all waste packages in a waste vault should be within the limit for the waste vault.

The application for the extension of SFR will contain an updated inventory for both SFR 1 and SFR 3. This forms the basis for defining the Waste acceptance criteria and will be fully implemented after approval from the authority. Both the best estimate inventory and the best estimate including uncertainties are given in Section 3.8.

Table 3-1. Limits for activities in the different waste vaults in SFR 1 [Bq] according to the current license.

Nuclide	Silo	1BMA	1–2BTF	1BLA
H-3	$1.3\cdot10^{14}$	–	–	–
C-14org*	$6.8\cdot10^{11}$	$2.9\cdot10^{10}$	$1.3\cdot10^{10}$	$2.6\cdot10^{8}$
C-14inorg*	$6.1\cdot10^{12}$	$2.6\cdot10^{11}$	$1.2\cdot10^{11}$	$2.3\cdot10^{9}$
Fe-55	$7.1\cdot10^{14}$	$1.0\cdot10^{14}$	$1.7\cdot10^{13}$	$2.3\cdot10^{12}$
Ni-59	$6.8\cdot10^{12}$	$1.0\cdot10^{12}$	$1.5\cdot10^{11}$	$2.3\cdot10^{10}$
Co-60	$1.8\cdot10^{15}$	$2.6\cdot10^{14}$	$4.0\cdot10^{13}$	$5.8\cdot10^{12}$
Ni-63	$6.3\cdot10^{14}$	$8.8\cdot10^{13}$	$1.5\cdot10^{13}$	$1.9\cdot10^{12}$
Sr-90	$2.5\cdot10^{14}$	$6.5\cdot10^{12}$	$2.7\cdot10^{12}$	$7.1\cdot10^{10}$
Nb-94	$6.8\cdot10^{9}$	$1.0\cdot10^{9}$	$1.5\cdot10^{8}$	$2.3\cdot10^{7}$
Tc-99	$3.3\cdot10^{11}$	$8.8\cdot10^{9}$	$3.6\cdot10^{9}$	$1.1\cdot10^{8}$
Ru-106	$6.1\cdot10^{12}$	$1.7\cdot10^{11}$	$6.2\cdot10^{10}$	$2.1\cdot10^{9}$
I-129	$1.9\cdot10^{9}$	$4.7\cdot10^{7}$	$2.2\cdot10^{7}$	$6.4\cdot10^{5}$
Cs-134	$8.1\cdot10^{14}$	$2.2\cdot10^{12}$	$1.1\cdot10^{13}$	$2.6\cdot10^{11}$
Cs-135	$1.9\cdot10^{10}$	$5.3\cdot10^{8}$	$2.2\cdot10^{8}$	$6.4\cdot10^{6}$
Cs-137	$4.9\cdot10^{15}$	$1.3\cdot10^{14}$	$5.3\cdot10^{13}$	$1.4\cdot10^{12}$
Pu-238	$1.2\cdot10^{12}$	$3.1\cdot10^{10}$	$1.7\cdot10^{10}$	$4.7\cdot10^{8}$
Pu-239	$3.8\cdot10^{11}$	$1.2\cdot10^{10}$	$6.9\cdot10^{9}$	$1.9\cdot10^{8}$
Pu-240	$7.8\cdot10^{11}$	$1.9\cdot10^{10}$	$1.1\cdot10^{10}$	$2.9\cdot10^{8}$
Pu-241	$4.2\cdot10^{13}$	$9.4\cdot10^{11}$	$5.4\cdot10^{11}$	$1.5\cdot10^{10}$
Am-241	$1.0\cdot10^{12}$	$2.4\cdot10^{10}$	$1.3\cdot10^{10}$	$3.8\cdot10^{8}$
Cm-244	$1.2\cdot10^{11}$	$2.8\cdot10^{9}$	$1.5\cdot10^{9}$	$4.4\cdot10^{8}$

* C-14 has been divided into organic and inorganic activity.

Surface dose rate

The maximum surface dose rates allowed according to the Waste acceptance criteria for waste packages in the different waste vaults are given in Table 3-2 (implemented for SFR 1 and preliminary for SFR 3 (SKBdoc 1368638)).

Surface contamination

The surface contamination should not exceed 40 kBq/m^2 for beta- and gamma-emitters and 4 kBq/m^2 for alpha-emitters. These are the same as the limits applied in the regulations for clearance of materials (SSMFS 2011:2). There are additional requirements for the waste packages and transport containers relating to transport.

Radiation effects

The integrated dose received by cement or bituminised ion-exchange resins should not exceed 10^6 Gy. Experiments have shown that integrated doses above this level may give rise to swelling as radiolytic cleavage of functional groups from the resins leads to the formation of gaseous products.

Homogeneity

The contents of the waste package should be distributed in a way that does not compromise the radiological safety.

Some waste types have the additional requirement that they must be securely loaded before transport, so that the increase in highest surface dose rate is at the most 20% if the package is dropped.

There are no restrictions regarding the homogeneity of waste allocated to BLA, except for transport-related requirements for some containers.

In the preliminary Waste acceptance criteria (SKBdoc 1368638) it is suggested that no requirements regarding radiological homogeneity of the pressure vessels in BRT are given.

Chemical and physical requirements

The chemical and physical requirements concern composition, structure, homogeneity, hydraulic properties, temperature, liquids, gas formation, fire resistance, chemical reactivity (complexing agents), leaching and environmentally hazardous substances.

Composition and structure

The acceptance criterion regarding the chemical composition and structure of the waste form and waste packaging is that they shall be in accordance with the stated specifications given in the Waste type descriptions. There are guidelines for the quantities of materials allowed in the different waste vaults that should be upheld.

Table 3-2. Maximum surface dose rates for waste packages in the different waste vaults [mSv/h] (implemented for SFR 1 and preliminary for SFR 3 (SKBdoc 1368638)).

Waste vault	Surface dose rate limit (mSv/h)
1BMA	100 (< 30 for 80%, > 30 for 20%)
2BMA	100
1BTF	10 (however the current transport system limits the dose rate to 8 for concrete tanks and 2 for drums)
2BTF	10 (however the current transport system limits the dose rate to 8 for concrete tanks)
Silo	500
1BLA	2 (the current transport system also limits the dose rate to 0.1 at a distance of 2 m)
2–5BLA	2 (the current transport system also limits the dose rate to 0.1 at a distance of 2 m)
BRT	2

Homogeneity

Waste forms that are stabilised with cement or bitumen shall be sufficiently homogeneous to ensure that the physical and chemical properties accounted for in the radiation safety and long-term safety assessments are not compromised.

Hydraulic properties

Waste deposited in the silo or BMA shall be solidified in cement or bitumen or embedded with concrete within the packaging.

Waste deposited in 1BTF and 2BTF shall either be embedded with concrete inside the packaging or the packaging should be a concrete tank.

Containers allocated to BLA should withstand washing and rainfall/snowfall.

In the preliminary Waste acceptance criteria (SKBdoc 1368638), it is suggested that the reactor pressure vessels in BRT should be waterproof.

Temperature

The waste packages should withstand temperatures between 0 and 30°C during storage, and down to –20°C for short time periods, for example during transport.

Liquids

The content of the waste package is not allowed to be liquid. Specifically, the waste shall not contain free or contained liquid.

Gas formation

The rate and extent of gas formation in the waste packages and their contents shall not be sufficient to compromise the safety of the repository during operation or the barriers in the long-term. There are guidelines for the gas-production rates and quantities of specified materials allowed in different waste vaults that should be aimed to be upheld if possible, of primary interest is the quantities of aluminium and zinc. The preliminary Waste acceptance criteria (SKBdoc 1368638) contains limits for gas-production rates and quantities of aluminium and zinc allowed in different waste vaults.

Fire resistance

The waste package must not be subject to self-ignition and it should withstand a short fire without unacceptable dispersion of radionuclides. Explosive substances are not allowed. The design of the packaging shall obstruct the spread of fire. The resistance to fire is explored in studies that are referred to in the Waste type descriptions.

The containers allocated to BLA shall have a total leakage area less than 2 dm^2. This leakage area includes leaks from door joints. No holes from corrosion or physical damage are allowed at disposal. This criterion is set to minimise the risk of an open fire in case of self-ignition inside the container.

Chemical reactivity (complexing agents)

The type and quantity of chemical substances that can form mobile complexes with radionuclides should be known and as far as possible avoided. Substances that are not suitable for deposition in SFR are:

- N-carboxylated diamines, e.g. EDTA.
- N-carboxylated triamines, e.g. DTPA.
- N-carboxylated amino acids, e.g. NTA.
- Tricarboxylic acids, e.g. citric acid.
- α-hydroxi-carboxylic acids, e.g. glycone acid.

The concentration of dicaboxylic acid, e.g. oxalic acid, may not exceed $1 \cdot 10^{-2}$ M in each waste package.

Carbonate may not exceed $1 \cdot 10^{-2}$ M in each waste package.

There are limits for acceptable quantities of cellulose in the waste packages in the different waste vaults. The preliminary Waste acceptance criteria (SKBdoc 1368638) contains updated and new limits for the quantity of cellulose allowed in each waste vault.

Before the introduction of a new substance during waste handling that may give rise to radionuclide complexation, SKB should be consulted for advice on its suitability.

Leaching

Waste allocated to the silo or BMA shall be either solidified with cement or bitumen or embedded with concrete.

Waste allocated to 1BTF and 2BTF shall either be embedded with concrete or the waste packaging shall be a concrete tank.

According to the preliminary Waste acceptance criteria (SKBdoc 1368638) the reactor pressure vessels in BRT shall be filled with grout after disposal.

There are also acceptance criteria related to the leakage of radioactive substances in the case of an accident during transport.

Environmentally hazardous substances

The amount of environmentally hazardous substances shall be kept as low as possible.

Mechanical requirements

The mechanical requirements concern the robustness against external influences, internal stability and corrosion resistance.

Robustness against external influences

Waste packages allocated to the silo shall withstand stacking of 42 moulds or 56 drums grouted with concrete. Waste packages allocated to BMA shall withstand stacking of 6 moulds or 8 drums.Waste packages allocated to 1BTF and 2BTF shall withstand stacking of two concrete tanks with an overload of 30 kN, or 10 laid down drums. Waste packages allocated to BLA shall withstand stacking of 3 full-height or 6 half-height containers.

There are additional requirements for the waste packages and transport containers relating to handling and transport. These requirements are different between different waste types depending on differences in their way from the producers to final disposal. The requirements are given in the Waste type description together with references to supporting studies.

Internal stability

Swelling is assessed per waste type and waste vault.

Corrosion resistance

The waste packaging shall have a corrosion resistance so that the packaging is intact at the time for concrete grouting or closure of repository.

3.2.2 Waste handling manual

The Waste handling manual for low- and intermediate-level waste is the steering document for administrative handling of low- and intermediate-level waste that will be disposed of in SFR.

The Waste handling manual provides guidance about which information and other support that is required in the Waste type description. The used code system is given in the manual.

The manual also gives the Waste acceptance criteria for the waste packages.

3.3 Waste types and Waste type descriptions

3.3.1 Waste types

In order to systematically classify the wastes, different waste types have been defined and a code system developed. The code system is available in the Waste handling manual. The code system is used, for example, when transferring data between the waste producers and SFR. The code system consists of one letter that denominates the producing plant, and two digits giving information on the kind of raw waste, treatment method, geometry and in which part of SFR the waste should be deposited. A complementary number (given after a colon) can also be used to give information about a feature that differentiates this waste from others of the same code.

For example the code R.01:9 means ion-exchange resins from the Ringhals NPP solidified in cement in a 1.2×1.2×1.2 m concrete mould . The waste is meant for disposal in the vault for intermediate level waste (BMA). The ':9' means that it is produced before 1988. The meaning of the complimentary numbers is defined for each waste type, e.g. for B.05:2 the ':2' means that the drums are in a bad condition and have been placed in an extra steel box. The only complementary number with a SFR-wide definition is ':9' which means that the package was made before the operation of SFR started 1988.

In Table 3-3 and Table 3-4 there are explanations of the different abbreviations used for the different waste types.

Table 3-3. Abbreviations in the code system for the nuclear facilities in Sweden.

Abbreviation	Nuclear power plant
B	Barsebäck NPP
C	Clab (central interim storage for spent fuel) in the future Clink (Clab and encapsulation plant)
F	Forsmark NPP
O	Oskarshamn NPP
R	Ringhals NPP
S	Studsvik Research Site or Svafo AB
V*	Svafo AB (decommissioning waste and possibly also future operational waste)
Å*	Ågesta (decommissioning waste)

* Provisional codes for decommissioning waste.

Table 3-4. Abbreviations for the operational waste in the code system for treatment etc.

Abbreviation	Disposal in	Raw waste	Package	Treatment
01	BMA	Ion-exchange resin	Concrete mould	Cement solidified
02	Silo	Ion-exchange resin	Concrete mould	Cement solidified
04	Silo	Ion-exchange resin	Steel drum	Cement solidified
05	BMA	Ion-exchange resin	Steel drum	Bitumen solidified
06	Silo	Ion-exchange resin	Steel drum	Bitumen solidified
07	BTF	Ion-exchange resin	Concrete tank	De-watering
10	BMA	Sludge	Concrete mould	Cement solidified
11	Silo	Sludge and ion-exchange resin	Steel mould	Cement solidified
12	BLA	Trash and scrap metal	ISO-container	None
13	BTF	Ashes	Steel drum	Concrete embedded
14	BLA	Trash and scrap metal	Steel drums in ISO-container	Concrete embedded in drums
15	BMA	Ion-exchange resin	Steel mould	Cement solidified
16	Silo	Ion-exchange resin	Steel mould	Cement solidified
17	BMA	Ion-exchange resin	Steel mould	Bitumen solidified
18	Silo	Ion-exchange resin	Steel mould	Bitumen solidified
20	BLA	Ion-exchange resins	Steel drums in ISO-container	Bitumen solidified in drums
21	BMA	Trash and scrap metal	Steel drum	Concrete embedded
23	BMA	Trash and scrap metal	Concrete/Steel mould	Concrete embedded
24	Silo	Trash and scrap metal	Concrete/Steel mould	Concrete embedded
29	BMA	Evaporator concentrate	Concrete mould	Cement solidified
99	All waste vaults	Odd waste	Differs	Differs

A provisional system is used in the prognosis of decommissioning waste, see Table 3-5. To distinguish between operational and decommissioning waste easily, the letter D (D for Decommissioning) has been added after the number in the code for the decommissioning waste types.

3.3.2 Waste type descriptions

Every waste type that is to be disposed in SFR must have an approved Waste type description that describes the whole handling sequence from production to final disposal of the waste, before disposal starts. Waste type descriptions have been used since the late 1980s with the purpose of documenting the waste disposed in SFR. Waste type descriptions are also used in the safety assessments for both SFR and the nuclear facilities.

Together with the overview of the handling sequence, the Waste type descriptions include detailed descriptions of the waste properties and characteristics, including the waste category, type of packaging and treatment methods etc. In addition, the Waste type description explains how the waste meets the waste acceptance criteria in all steps of the handling sequence. This includes a description of production data, results from investigations and calculations as well as checks that are in place. A description of the controls should be given for packaging, waste form and waste package.

Waste descriptions instead of Waste type descriptions can be used in cases where only a few waste packages are planned to be produced.

Production and review of the Waste type descriptions is an iterative process between the waste producers and SKB. The safety review that is conducted by the waste producers focuses on the production and the further handling until transport to the final disposal site. SKB's safety review focuses on transport and disposal as well as the long-term safety for the final repository. Before waste packages of a specific type are disposed of, SSM must approve the Waste type description and give their consent to permit transport and disposal.

Table 3-5. Abbreviations for provisional codes for decommissioning waste (same as used in the Inventory report (SKB 2013b)).

Abbreviation	Disposal in	Raw waste	Package	Treatment
02:D	Silo	Ion-exchange resin	Steel mould	Cement solidified
12:D	BLA	Trash and scrap metal	ISO-container	None
12A:D	BLA	Asphalt, gravel, soil	ISO-container	None
12C:D	BLA	Concrete	ISO-container	None
12S:D	BLA	Sand	ISO-container	None
16:D	Silo	Ion-exchange resin	Steel mould	Cement solidified
18:D	Silo	Ion-exchange resin	Steel mould	Bitumen solidified
23:D	BMA	Trash and scrap metal	Concrete/Steel mould	Concrete embedded
4K23:D	BMA	Trash and scrap metal	Tetramould	Concrete embedded
4K23C:D	BMA	Concrete	Tetramould	Concrete embedded
4K23S:D	BMA	Sand	Tetramould	Concrete embedded
25:D	BMA	Ashes	Steel drum	Concrete embedded
BWR:D	BRT	Reactor pressure vessel	None	None

3.4 Handling and control of waste

The handling of the waste comprises the following steps:

Production of the waste package

The production of the waste package is performed according to the Waste type description. The Waste type description also includes other instructions such as the prescription for stabilisation or how wastes are sorted according to their dose rate.

Interim storage

The Waste type descriptions give details of the interim storage plans. They may also give instructions on, for example, transport to the interim storage site.

Transport

Before transport, a transport message (TRAM) and a waste data file are produced. SFR reviews the waste data file to ensure that the acceptance criteria are fulfilled and that the specified waste codes are approved for disposal.

Disposal and registering in Triumf

When the waste package is lifted out of the transport packaging at SFR, the ID-number is checked against the number given in the transport message (TRAM) and in the waste data file. After disposal, the exact disposal position of the waste package is registered in the Waste register, i.e. the database Triumf. The information in the waste data file is also registered in the database.

3.4.1 Handling and control at the waste producer

The waste producer is responsible for:

- waste conditioning and producing waste packages,
- documenting production data,
- measuring the activity of waste samples and/or measuring the surface activity of the waste package,
- assigning a unique identity to the waste package marked on the waste packaging,
- documentation in the shipping document.

The Waste type descriptions include details on the quality control procedures for the packaging, waste form and waste package. The waste producers are required to ensure that the producer of the packaging has a satisfactory programme for quality control. The quality of the waste form is primarily controlled by the surveillance of production, including both technical and administrative routines that influence the properties of the waste form. The producer must ensure that the activity content and dose rates of the final waste package are measured and are within the specified limits.

3.4.2 Waste audits

SKB performs a quality audit of the waste handling at each nuclear facility every four years.

Every nuclear facility is required to have routines and instructions for the sorting and emplacement of waste. It must be clear which waste will be placed in which packaging. There are prescribed processes for stabilisation treatments that should be followed.

The aims of the audits are to judge whether:

- the valid Waste type descriptions are used,
- the producers follow their own routines and instructions for assessing whether the acceptance criteria are fulfilled,
- the producer is in control of the steering, management and documentation of the waste process, including routines for safety review.

The audit is performed in accordance with an audit plan and results in an audit report that includes any deviations or observations. The audited facility returns the audit report, together with an action plan in the case of deviations, to the facility manager at SFR. If anything else is prescribed the audit result is followed-up at the next ordinary audit.

3.4.3 Handling and control in the SFR facility

The activity content of a waste package is a crucial factor when determining the optimum position for the package in SFR. Also, as the activity content influences the surface dose rate, it affects the routines needed for handling the package.

All waste packages are transported in special transport packaging, except ISO-containers for BLA and drums destined for BTF. Packages are transported at the facility using a terminal vehicle.

The receiving control/inspection of the waste at SFR comprises:

- determination of identity and inspection of the shipping document,
- measurement of surface dose rate,
- measurement/control of surface contamination,
- evaluation of mechanical damage.

When underground, the waste packages are transported to the different waste vaults depending on their activity and geometry. The waste packages are placed in the loading zone of the relevant waste vault using the terminal vehicle. When the transport packaging is discharged, it is monitored for surface contamination inside and out. If there is no contamination, it can be prepared to leave. If the packaging is contaminated, it is cleaned. The loading zone is also checked for contamination after each deposition campaign and cleaned if necessary.

The waste packages in the silo, 1BMA and 2BMA are loaded using remote control, and this is monitored by TV cameras. The handling is controlled and monitored from the operation room in the underground facility and could also be monitored from the operational building at the surface.

The underground disposal facility also uses forklift trucks. Waste packages in BLA and BTF are loaded manually by the forklift truck driver.

The reactor pressure vessels will be transported with a special vehicle that is constructed to withstand heavy load with a good manoeuvrability.

After disposal the register in the Triumf database is updated.

3.4.4 Waste register

After disposal, the exact disposal position of the waste package is registered in the Triumf database. The information from the waste data file from the waste producers is also stored in the Waste register. Table 3-6 shows the type of information that is stored in the Waste register.

Table 3-6. Information stored in the Waste register.

Information
Waste package ID
Waste Type
Package type code
Waste category code
Package weight
Date of production
Nuclide content and total activity
Surface dose-rate
Dose-rate at 1 metre
Measuring date
Special information from the producer
Position in SFR after disposal

3.5 Future waste

The tools used to ensure that the waste is emplaced in the correct packaging and in the correct waste vault in SFR are the Waste handling manual, Waste type descriptions, waste audits and the Waste register.

The Waste handling manual, including the acceptance criteria and waste codes, is a living document that is updated so that it always remains valid. The document is updated gradually and when necessary expanded with new waste codes for operational waste and decommissioning waste, as well as new acceptance criteria for waste that will be disposed in SFR 3.

The existing Waste type descriptions will be used as far as possible and new Waste type descriptions will be produced for the new waste types.

The waste audits at the waste producers are planned to continue as before.

The Waste register will continue to be used by the waste producers and SKB. The computer program may be updated, but the same data will be registered and existing data will be preserved.

3.6 Waste packaging

The main types of waste packaging used or intended to be used in SFR are described in this section, including details of their geometries and material quantities. The types of waste packaging are illustrated in Figure 3-2 and consist of:

- Concrete moulds.
- Steel moulds.
- Steel drums.
- Concrete tanks.
- ISO-containers.
- Tetramoulds of steel (intended to be used for decommissioning waste, but may also be used for operational waste).
- Other packaging.

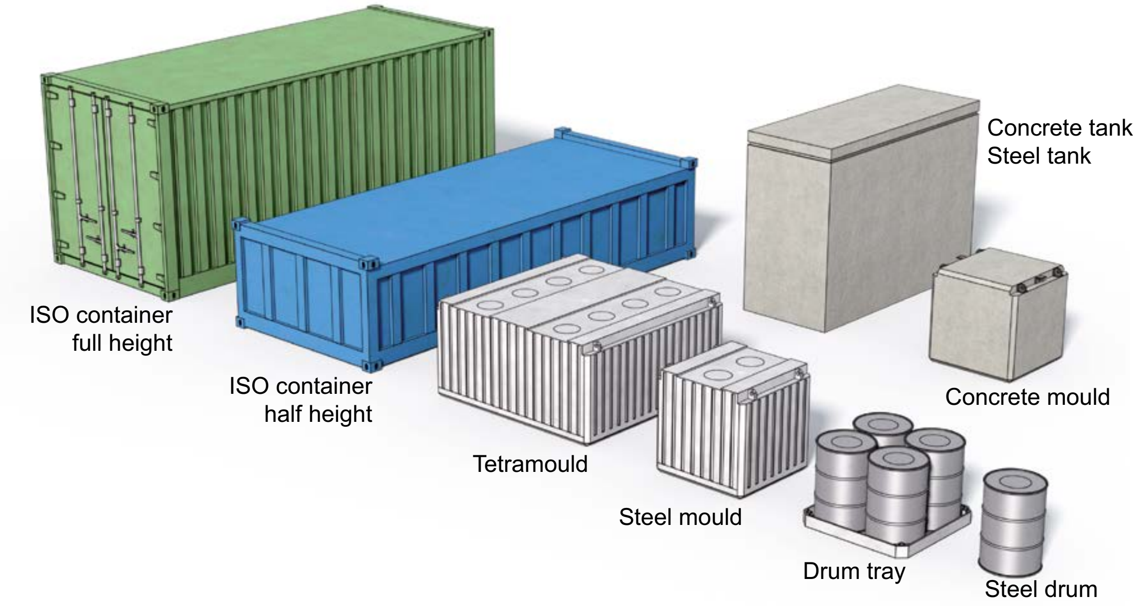

Figure 3-2. *Schematic illustration of waste packaging used or intended to be used in SFR. Note that the steel tanks only are used for intermediate storage of long-lived radioactive waste.*

3.6.1 Concrete moulds

The concrete moulds are cubic boxes made of reinforced concrete. The dimensions of the moulds are 1.2×1.2×1.2 m. The walls are normally 10 cm thick but can, in some exceptional cases, be 25 cm thick. In most cases, the lid is made by grouting concrete on the top of the mould and is at least 10 cm thick.

The concrete moulds are mainly used as packaging for waste mainly ion-exchange resins, solidified with cement. In addition, concrete moulds are used for solid waste embedded in concrete.

For waste solidified with cement, a stirrer made of carbon steel is included in the waste package. It weighs 16 kg and has an estimated surface area of 1 m^2. To avoid cracking of the 10-cm thick moulds, due to expansion of the concrete matrix, a lining of compactable material (polyethene) is placed inside each mould. The lining has a thickness of 20 mm and a total weight of 10 kg. A plate made of steel is placed on top of the waste to prevent splashing during stirring. This cover plate is left in the mould.

Solid waste is either packaged directly in the mould or in a steel drum, which is then placed in the mould. Both the waste and the steel drums are embedded in concrete. In some cases, a drum basket is used to centre the waste inside the drums.

In Table 3-7, representative data are given for the most common type of concrete mould and internal packaging for solidified waste and solid waste. The Inventory report (SKB 2013b) shows that different concrete moulds are used for some waste types.

Table 3-7. Representative data for a concrete mould.

	Value	Reference/Comment
Packaging		
Height (m)	1.2	Inventory report (SKB 2013b)
Width (m)	1.2	Inventory report (SKB 2013b)
Length (m)	1.2	Inventory report (SKB 2013b)
Thickness of walls (m)	0.1	Inventory report (SKB 2013b)
Outer volume (m^3)	1.728	Calculated from dimensions above
Inner volume (m^3)	1.0	Calculated from dimensions above
Disposal volume (m^3)	1.728	Disposal volume is equal to outer volume
Outer surface area (m^2)	8.64	Calculated from dimensions above
Inner surface area (m^2)	6.0	Calculated from dimensions above
Concrete, volume (m^3)	0.728	Calculated from dimensions above
Concrete, weight (kg)	1,840	Whereof 500 kg lid, Inventory report (SKB 2013b)
Reinforcement, weight (kg)	274	Inventory report (SKB 2013b)
Reinforcement, area (m^2)	11.8	Inventory report (SKB 2013b)
Reinforcement, diameter (m)	0.012	Inventory report (SKB 2013b)
Inside packaging with cement solidified waste		
Stirrer, weight (kg)	16	Inventory report (SKB 2013b)
Stirrer, area (m^2)	1	Inventory report (SKB 2013b)
Stirrer, thickness (m)	0.005	Inventory report (SKB 2013b)
Expansion cassette, weight (kg)	10	Inventory report (SKB 2013b)
Expansion cassette, thickness (m)	0.02	Inventory report (SKB 2013b)
Inside packaging solid waste		
Steel packaging, weight (kg)	420	Only waste types C.24 and O.24, Inventory report (SKB 2013b)
Steel packaging, area (m^2)	21.4	Only waste types C.24 and O.24, Inventory report (SKB 2013b)
Steel packaging, thickness (m)	0.005	Only waste types C.24 and O.24, Inventory report (SKB 2013b)

3.6.2 Steel moulds

Steel moulds are cubes with the same outer dimensions as the concrete moulds, but with 5 or 6 mm thick walls. Although the thickness of the walls shows only minor variation, the weight of the empty steel moulds can differ significantly due to differences in the amount of reinforcement and corrugation. This allows the stability of the mould to be optimised for the weight of the waste.

The steel moulds are used for waste solidified with cement or bitumen. In addition, steel moulds are used for solid waste grouted with concrete.

For waste solidified with cement, a stirrer made of carbon steel is included in the waste package. It weighs 25 kg and has an estimated surface area of 3 m^2. A plate made of steel is placed on top of the waste to prevent splashing during stirring. This cover plate is left in the mould. The lid is either made of steel or, for most waste types, concrete grout placed directly on top of the waste.

Stirrers and cover plates are not required for waste solidified in bitumen, since the mixing of waste and bitumen is performed before emplacement in the steel moulds. The lid for waste solidified in bitumen is made of steel.

Solid waste is often compacted using a steel plate that is left in the mould. The lid is either made of steel or concrete grout placed directly on top of the waste.

In Table 3-8, representative data are given for the most common type of steel mould and the associated inside packaging for cement-solidified waste. The Inventory report (SKB 2013b) shows that different steel moulds are used for some waste types.

Table 3-8. Representative data for a steel mould.

	Value	Reference/Comment
Height (m)	1.2	Inventory report (SKB 2013b)
Width (m)	1.2	Inventory report (SKB 2013b)
Length (m)	1.2	Inventory report (SKB 2013b)
Thickness of walls (m)	0.005	Bottom is 0.006 up to 0.008 m, Inventory report (SKB 2013b)
Outer volume (m^3)	1.728	Calculated from dimensions above
Inner volume (m^3)	1.7	Calculated from dimensions above
Disposal volume (m^3)	1.728	Disposal volume is equal to outer volume
Outer surface area (m^2)	7.2/8.65*	Inventory report (SKB 2013b), half of total surface area 14.4–20.7 m^2
Inner surface area (m^2)	7.2/8.65*	Same as outer surface area chosen
Steel weight (kg)	400/550*	Inventory report (SKB 2013b), 400 kg up to about 600 kg
Inside packaging with cement solidified waste		
Stirrer, weight (kg)	25	Inventory report (SKB 2013b)
Stirrer, area (m^2)	3	Inventory report (SKB 2013b)
Stirrer, thickness (m)	0.005	Inventory report (SKB 2013b)
Cover plate, area (m^2)	2.6	Inventory report (SKB 2013b)

* The lower value is for moulds with concrete lids used mainly for cement-solidified waste, the higher value is for moulds with steel lids used for most solid waste and bituminised waste.

3.6.3 Steel drums

The steel drums are standard 200-litre drums. The measurements differ slightly, but the drums are approximately 90 cm high and have a diameter of 60 cm. There are also packages that consist of waste in a 100-litre drum which is placed inside a 200-litre drum and grouted with concrete.

For waste solidified with cement, a stirrer made of carbon steel is included in the waste package. It weighs 10 kg and has an estimated surface area of 0.5 m^2.

The drums in the silo and BMA are mostly stored on trays with four drums on each, but some are stored in steel boxes. Drums containing bituminised waste will expand in the future and, to avoid damage to the concrete structure of the silo, expansion boxes are placed in the middle of the four drums on a tray. The drums in 1BTF are not stored in trays or boxes.

In Table 3-9, representative data are given for the most common type of steel drum and extra accessories that are used for different waste types, such as 100-litre inner drums and stirrers in cement-solidified waste. The inventory report (SKB 2013b) shows that slightly different steel drums are used for some waste types.

Table 3-9. Representative data for a steel drum.

	Value	Reference/Comment
200 l drums		
Height (m)	0.88	Inventory report (SKB 2013b) 0.84–0.88 m
Diameter (m)	0.59	Inventory report (SKB 2013b) 0.57–0.6 m
Thickness of walls (m)	0.0012	Inventory report (SKB 2013b) up to 0.003 m
Outer volume (m^3)	0.241	Calculated from dimensions above
Inner volume (m^3)	0.238	Calculated from dimensions above
Disposal volume (m^3)	0.324	Inventory report (SKB 2013b) if stored on tray
Outer surface area (m^2)	2.2	Inventory report (SKB 2013b), half of total surface area 4–4.5 m^2
Inner surface area (m^2)	2.2	Inventory report (SKB 2013b), same as outer surface area chosen
Steel weight (kg)	21	Inventory report (SKB 2013b), 20–60 kg
100 l drums		
100 l drum, weight (kg)/drum	10	Inventory report (SKB 2013b)
100 l drum, area (m^2)/drum	2.7	Inventory report (SKB 2013b)
100 l, wall thickness (m)	0.001	Inventory report (SKB 2013b)
Stirrer in cement-solidified waste		
Stirrer, weight (kg)	10	Inventory report (SKB 2013b)
Stirrer, area (m^2)	0.5	Inventory report (SKB 2013b)
Stirrer, thickness (m)	0.005	Inventory report (SKB 2013b)
Tray for 4 drums		
Tray, weight (kg)/drum	16.6	Inventory report (SKB 2013b), 16.2–17.5 kg
Tray, area (m^2)/drum	0.7	Inventory report (SKB 2013b)
Tray, thickness (m)	0.005	Inventory report (SKB 2013b), 0.004–0.005 m
Between packages with bitumen solidified waste in the silo		
Expansion box, weight (kg)/drum	5	Inventory report (SKB 2013b)
Expansion box, area (m^2)/drum	0.3	Inventory report (SKB 2013b)
Expansion box, wall thickness (m)	0.001	Inventory report (SKB 2013b)

3.6.4 Concrete tanks

The concrete tanks have a length of 3.3 m, width of 1.3 m and height of 2.3 m. The walls are 15 cm thick. The tanks are lined with 2 mm thick butyl rubber on the inside. The lining weighs 50 kg. The concrete tanks have a drainage system. Steel lids are placed on the opening in the top of the concrete tanks.

In Table 3-10, representative data for concrete tanks are given. The variations between packages are minimal.

Table 3-10. Representative data for a concrete tank.

	Value	Reference/Comment
Height (m)	2.3	Inventory report (SKB 2013b)
Width (m)	1.3	Inventory report (SKB 2013b)
Length (m)	3.3	Inventory report (SKB 2013b)
Thickness of walls (m)	0.15	Inventory report (SKB 2013b)
Outer volume (m^3)	9.867	Calculated from dimensions above
Inner volume (m^3)	6	Calculated from dimensions above
Disposal volume	9.867	Disposal volume is equal to outer volume. Inventory report (SKB 2013b) gives disposal volume of 10 m^3
Outer surface area (m^2)	29.74	Calculated from dimensions above
Inner surface area (m^2)	22	Calculated from dimensions above
Concrete, volume (m^3)	3.867	Calculated from dimensions above
Concrete, weight (kg)	10,350	Inventory report (SKB 2013b)
Reinforcement, weight (kg)	647	Inventory report (SKB 2013b)
Reinforcement, area (m^2)	40	Inventory report (SKB 2013b)
Reinforcement, diameter (m)	0.008	Inventory report (SKB 2013b)
Steel lid, weight (kg)	1,686	Inventory report (SKB 2013b)*
Steel lid, area (m^2)	9	Inventory report (SKB 2013b)*
Steel lid, thickness (m)	0.05	Inventory report (SKB 2013b)
Butyl rubber liner, weight (kg)	50	Inventory report (SKB 2013b)
Butyl rubber liner, thickness (m)	0.002	Inventory report (SKB 2013b)

* According to the Inventory report (SKB 2013b) these lids weigh 1,700 kg. However, it has been concluded that the lid only covers the opening and not the whole tank. The area and weight given in the table are hence too large.

3.6.5 ISO-containers

The dimensions of the Standard ISO-containers are usually 6.1×2.5×1.3 m (20-foot half-height) or 6.1×2.5×2.6 m (20-foot full-height). Other dimensions can also be used for example 3.0×2.4×2.6 m (10-foot full-height) and 3.0×2.4×1.3 m (10-foot half-height).

The containers can hold drums, boxes or bales. They can also hold unpackaged scrap metal.

Table 3-11. Representative data for ISO-containers.

	20-foot full-height	20-foot half-height	10-foot full-height	10-foot half-height	Reference/Comment
Height (m)	2.6	1.3	2.6	1.3	Inventory report (SKB 2013b)
Width (m)	2.5	2.5	2.4	2.4	Inventory report (SKB 2013b)
Length (m)	6.1	6.1	3.0	3.0	Inventory report (SKB 2013b)
Thickness of walls (m)	0.0015	0.0015	0.0015	0.0015	Inventory report (SKB 2013b)
Outer volume (m^3)	30.28	15.24	15.24	7.74	Inner volume + calculated volume of steel from steel weight and density 7,860 kg/m^3.
Inner volume (m^3)	30	15	15	7.5	Inventory report (SKB 2013b)
Disposal volume (m^3)	40	20	20	10	Inventory report (SKB 2013b)
Outer surface area (m^2)	75	52.5	52.5	*	Inventory report (SKB 2013b), half of total surface area.
Inner surface area (m^2)	75	52.5	52.5	*	Inventory report (SKB 2013b), same as outer surface area chosen.
Steel weight (kg)	2,200	1,900	1,900	*	Inventory report (SKB 2013b)

* The Inventory report uses the same data as for a 10-foot full-height container.

3.6.6 Tetramoulds

A tetramould is the size of four normal steel moulds and is intended for decommissioning waste, but may also be used for operational waste. Representative data for a tetramould are given in Table 3-12.

Table 3-12. Representative data for a tetramould.

	Value	Reference/Comment
Height (m)	1.2	Inventory report (SKB 2013b)
Width (m)	2.4	Inventory report (SKB 2013b)
Length (m)	2.4	Inventory report (SKB 2013b)
Thickness of walls (m)	0.005	Inventory report (SKB 2013b), walls 0.005 m, bottom 0.008 m
Outer volume (m^3)	6.912	Calculated from dimensions above
Inner volume (m^3)	6.8	Calculated from dimensions above
Disposal volume (m^3)	6.912	Disposal volume is equal to outer volume
Outer surface area (m^2)	23	Inventory report (SKB 2013b), half of total surface area 46 m^2
Inner surface area (m^2)	23	same as outer surface area chosen
Steel weight (kg)	1,722	Inventory report (SKB 2013b)

3.6.7 Other packaging

In addition to the packaging listed above, there are certain other odd containers and in some cases large items of waste (components) that are emplaced in SFR without packaging. Data for these are available in the Inventory report (SKB 2013b).

3.7 Waste in different parts of the repository

In this section, the waste types, waste volumes and material quantities allocated to different waste vaults are given.

The information is based on waste produced by the end of 2012 and future prognoses from the Inventory report (SKB 2013b).

Volumes of waste in different vaults

The waste allocated to different waste vaults is shown in Figure 3-3. The amount of secondary decommissioning waste (wastes that arise during decommissioning, mostly materials that have been brought into a classified area, used, contaminated and discarded) is very uncertain and has therefore been shown separately in red in the figure.

Operational waste

Most of the waste in SFR 1 comes from the Swedish nuclear power plants. Radioactive waste is formed during nuclear fission in the reactor core. This produces fission products such as Cs-137 and I-131, and neutrons. The neutrons can cause further fission or activate the uranium in the fuel. Neutron absorption and subsequent rapid radioactive decay result in the formation of transuranic elements such as plutonium and americium. As with the fission products, these transuranics form in the fuel itself and will only contaminate the reactor water if the fuel cladding is damaged.

In the reactor water, the greatest activities result from the activation of substances outside the fuel rods. These substances may already be dissolved or dispersed in the reactor water, following corrosion of material surfaces, but they may also be activated on surfaces near the core and then dissolve in the reactor water.

The reactor water in the primary circuit undergoes continuous cleanup to remove radioactive substances. The reactor water is purified in the reactor's cleanup circuits by means of ion-exchange resins that absorb radionuclides that are present as ions in the reactor water. The ion-exchange resins also remove "crud", dispersed particles consisting of oxides/hydroxides of engineering materials.

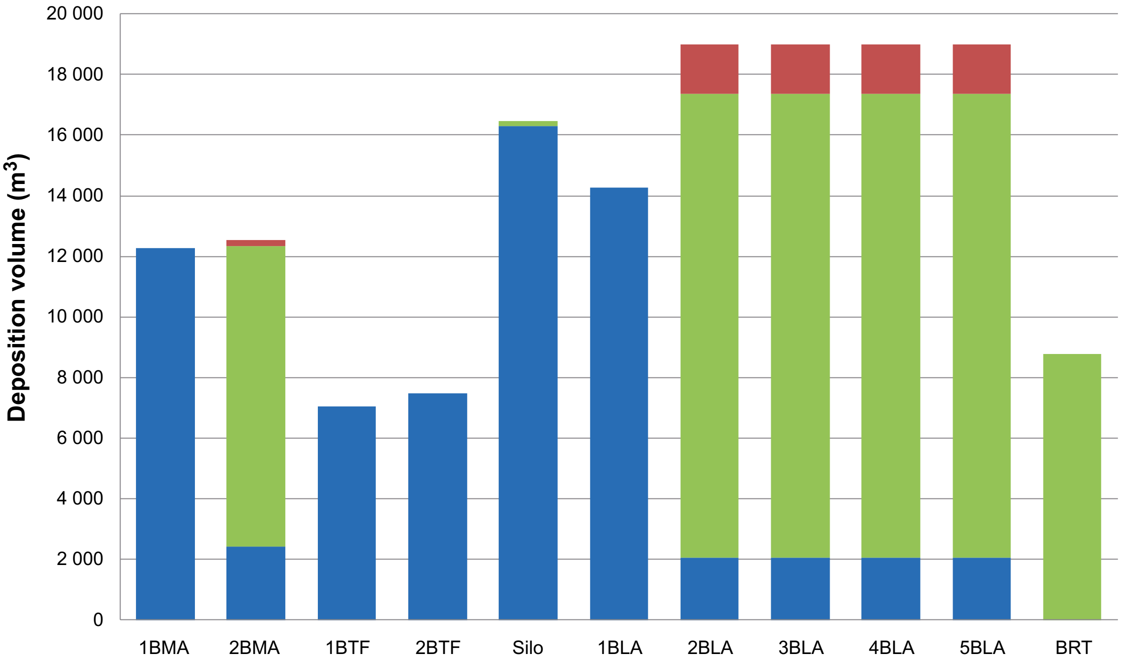

Figure 3-3. *Volume of waste allocated to different waste vaults. Operational waste is shown in blue, decommissioning waste in green and secondary decommissioning waste in red.*

Even though most of the radionuclides that have left the core are isolated in the cleanup system, small amounts spread to other systems. Relatively large volumes of ion-exchange resins and mechanical filter resins are used in the boiling water reactors for cleanup of the water that condenses in the condenser. Due to the fact that small quantities of radioactive substances are carried from the reactor to the turbines, this water and its filter resins become weakly radioactive. Pressurised water reactors have a closed system and hence no radioactivity reaches the turbines, and smaller volumes of ion-exchanges resins are used.

Additional waste consisting of ion-exchange resin, mechanical filter resin and precipitation sludge arises in the water cleanup system.

Some radioactive substances have also been released from the spent fuel stored in the storage ponds at the nuclear power plants and at the interim storage Clab. These ponds also have cleanup systems with ion-exchange resins that are used in roughly the same way as in the reactor water cleanup systems.

Low and intermediate level solid waste is also generated at nuclear facilities. Compared with the wet waste, its activity is often much lower. The solid waste consists of components of the primary system or other active systems, but mostly consists of material that has been brought into a classified area, used, contaminated and discarded.

Material types

Much of the activity in SFR 1 is present in the wet waste. The wet waste consists, for the most part, of bead resin, powder resin, mechanical filter aids and precipitation sludge. The ion-exchange resins consist of organic polymers with acidic or basic groups, making them capable of cation or anion exchange.

A large portion of the waste volume in SFR 1 consists of metals, above all carbon steel and stainless steel. Scrap metal arises mainly from maintenance outages when equipment is discarded, modified or renovated.

The largest volume of raw waste consists of combustible solid waste. However, since a part of this is incinerated at Studsvik or disposed of locally at the plant, the volume remaining for disposal in SFR 1 is comparatively small. The waste consists mainly of cellulose (paper, cotton and wood) and plastics (e.g. polystyrene, PVC, polyethylene, polypropylene, etc).

Other materials occurring in the waste include mineral wool (used for insulation), concrete and brick. Various additional materials are also included in smaller quantities.

In addition, there are similar wastes from other industries, research and medical care.

Decommissioning waste

Large quantities of scrap metal and concrete are generated when nuclear power plants are dismantled. Like operational waste, most of this waste is low and intermediate-level. Some decommissioning wastes that have been close to the core, such as control rods and other core components, are classified as long-lived and allocated to the repository for long-lived low- and intermediate level waste, SFL. Equally, systems containing more than 10^{10} Bq C-14 are allocated to SFL. The decommissioning waste allocated to SFR will mainly be stored in SFR 3.The exception to this is ion-exchange resins from system decontamination, which are allocated to the silo.

The pressure vessels from the BWR reactors are allocated to SFR, whereas vessels from PWR are not.

The source of the radioactivity in the waste is both due to nuclear fission and activation. The pressure vessels, in particular, contain induced activity.

During decommissioning, wastes will be decontaminated to enable clearance. This will generate decontamination solutions that will be cleaned using ion-exchange resins.

In addition to the building material, secondary waste will be produced that consists mostly of material that has been brought into a classified area, used, contaminated and discarded.

Material types

The decommissioning waste materials mainly arise from the power plant buildings, i.e. metals and concrete. Large volumes of concrete also arise from the biological shield, and there is the sand used in blast-cleaning and in sand-bed filters in the gas treatment systems.

Secondary waste consists mainly of cellulose (paper, cotton and wood) and plastics (e.g. polystyrene, PVC, polyethylene, polypropylene, etc) but also includes metals and sludge. There are large uncertainties in the prognosis of the volume of secondary waste, which partly arises from uncertainties in the extent to which the wastes will be combusted.

3.7.1 Distribution of waste packages between the different SFR vaults

The distribution of waste packages between different types of vaults in SFR is given in the Inventory report (SKB 2013b). The distribution between 1BTF and 2BTF, 1BMA and 2BMA and 1BLA and 2–5BLA is described below. In the following sections the waste allocated to different vaults will be described together with details on the emplacement in each vault. The distribution follows the strategy for allocation of different wastes (SKBdoc 1434623).

The resulting distribution of waste packages between the different SFR vaults is shown in Table A-1 in Appendix A.

Distribution of waste between 1BTF and 2BTF

As previously, the distribution of waste packages between 1BTF and 2BTF involves the disposal of drums with ashes, concrete moulds and concrete tanks in 1BTF, and concrete tanks in 2BTF.

Distribution of waste between 1BLA and 2–5BLA

Operational waste intended for BLA will be deposited in 1BLA until it is full, then disposal will continue in 2–5BLA. All decommissioning waste will be deposited in 2–5BLA.

Distribution of waste between 1BMA and 2BMA

The distribution of future waste between 1BMA and 2BMA is based on the following strategy:

- Cellulose. To minimise the effect of the cellulose degradation product ISA on radionuclide sorption, the amount of cellulose in future waste packages will be restricted by new waste acceptance criteria. This should be fully implemented by 2018-01-01. All waste produced before this date is assumed to be emplaced in 1BMA.
- Bitumen. All bituminised waste will be deposited in 1BMA. This avoids the potentially negative influence of swelling on the concrete barriers in 2BMA, which will not be reinforced.
- Microbial activity. Microbial activity will be minimised if the pH is high. To obtain a high pH in compartments with bituminised waste, the bituminised waste will be placed in all open 1BMA compartments and sufficient space will be left for concrete grout backfill.
- Mechanical stability. Two rows of concrete moulds (144 moulds) are required in each large compartment in 1BMA to support the prefabricated lids that are placed on top of the waste. Low activity moulds are selected that do not contain cellulose.

Selection of waste packages for disposal in 1BMA

The selection of waste packages for disposal in 1BMA is carried out in the following stepwise manner:

1) All operational BMA-waste that is foreseen to be produced before 2018-01-01 will be emplaced in 1BMA.
2) All future bituminised waste, i.e. all F.17, will be emplaced in 1BMA.
3) The number of concrete moulds must fulfil the requirement of two rows (144 moulds) per large compartment. This means that an additional 420 of the moulds produced after 2018-01-01 are needed. Five waste types are available, C.23, O.23, R.10, R.29 and S.23. The choice is based on the disposal strategy "low activity". The activities of some important radionuclides are shown in Figure 3-4. R.10 was selected first, due to the lowest radioactivity of Pu-239/240. Thereafter, R.29 was chosen and there will be a sufficient number of these to meet the requirements for 1BMA.

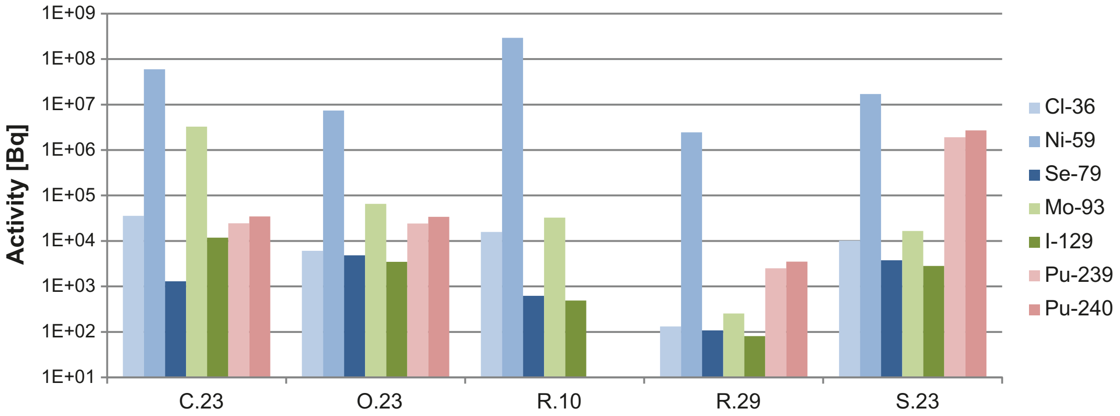

***Figure 3-4.** Activity (Bq) in concrete moulds that are candidates for emplacement in 1BMA.*

The remaining space is left "empty" to make it possible to have more grout in the compartments that contain bituminised waste. More concrete increases the pH and thus reduces the potential microbial activity. In addition, more concrete reduces the negative effects from sulphate containing evaporator concentrates on the concrete structure. This is based on the assumption that sulphate released from the waste will form ettringite inside the compartments prior to forming ettringite in the concrete structures, see the Main report (SKB 2014e, Section 6.3.7).

Number of waste packages in 1BMA and 2BMA

The number of waste packages to be disposed in 1BMA and 2BMA of different waste types and corresponding mould units is shown in Table 3-13.

3.7.2 1BMA

1BMA is designed to store intermediate level waste that has a lower dose rate or waste that is not suitable for deposition in the silo. The maximum surface dose rate allowed is 100 mSv/h. The waste contains solidified (bitumen or cement) ion-exchange resins and stabilised scrap metal and refuse. Small amounts of sludges and evaporator concentrates are also stored in 1BMA. All waste in 1BMA is handled in concrete or steel moulds or drums on steel plates or steel boxes. The distribution between different wastes, matrices and packaging is shown in Figure 3-5.

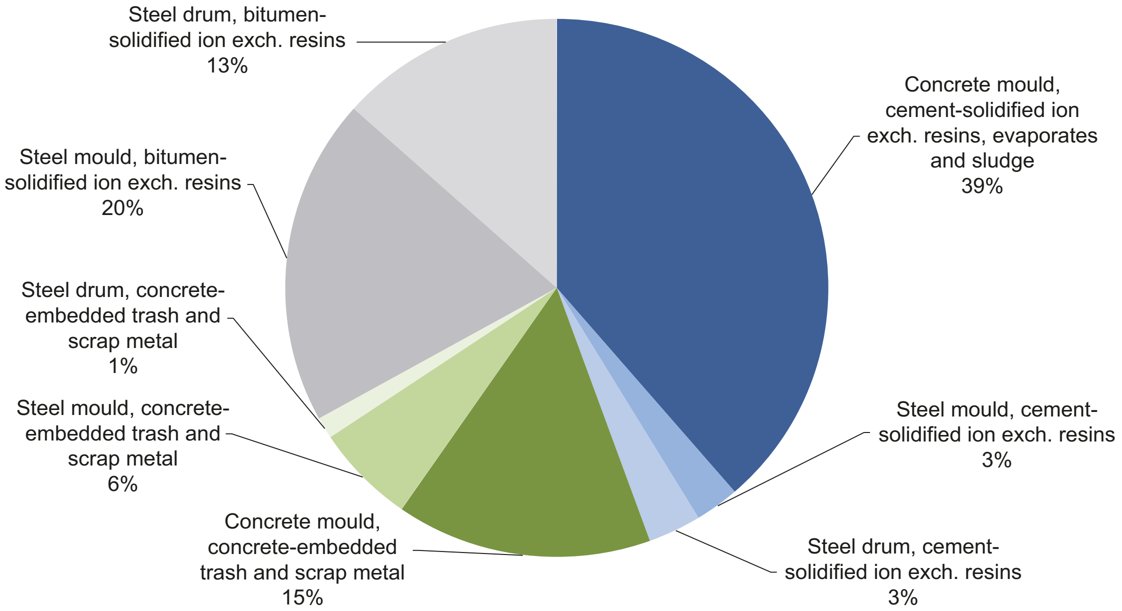

***Figure 3-5.** Distribution between different packaging and conditioning of waste in 1 BMA (vol%).*

Table 3-13. Number of waste packages in 1BMA and 2BMA of different waste types.

Waste type	Packaging	Bitumen	Number of packages					Number of mould units [a]	
			2012-12-31		Until 2018	Year 2075		Year 2075	
			Disposed in 1BMA	Interim storage	Produced operational waste	1BMA	2BMA	1BMA	2BMA
B.05/B.05:9	Drums on tray	x	3,360	0	3,360	3,360	0	630	0
B.05:2	Drums in box	x	892	0	892	892	0	224	0
B.23	Steel mould		0	25	33	33	0	33	0
B.23:D	Steel mould		0	0	0	0	608	0	608
C.01:9	Concrete mould		7	0	7	7	0	7	0
C.01:9–30 [b]	Concrete mould		61	0	61	61	0	61	0
C.23	Concrete mould		43	15	63	63	98	63	98
C.4K23:D	Tetramould		0	0	0	0	3	0	12
F.05:1/F.05:2	Drums on tray	x	1,712	0	1,712	1,712	0	321	0
F.15	Steel mould		11	0	11	11	0	11	0
F.17/F.17:1	Steel mould	x	252	185	757	1,187	0	1,187	0
F.17cellulose [c]	Steel mould	x	195	0	0	195	0	195	0
F.23C [d]	Concrete mould		57	0	57	57	0	57	0
F.23	Steel mould		151	19	220	220	250	220	250
F.4K23:D	Tetramould		0	0	0	0	237	0	948
F.4K23C:D	Tetramould		0	0	0	0	70	0	280
F.99:1	Steel mould		2	0	2	2	0	2	0
O.01:9	Concrete mould		392	5	397	397	0	397	0
O.01:9–30 [b]	Concrete mould		278	0	278	278	0	278	0
O.23/O.23:9	Concrete mould		455	29	509	509	100	509	100
O.4K23:D	Tetramould		0	0	0	0	198	0	792
O.4K23C:D	Tetramould		0	0	0	0	82	0	328
O.4K23S:D	Tetramould		0	0	0	0	15	0	60
R.01/R.01:9	Concrete mould		1,686	3	1,689	1,689	0	1,689	0
R.10	Concrete mould		84	5	94	121	0	121	0
R.15	Steel mould		124	50	186	186	68	186	68
R.23C [d]	Concrete mould		338	0	338	338	0	338	0
R.23	Steel mould		96	54	172	172	96	172	96
R.23:D	Steel mould		0	0	0	0	153	0	153
R.4K23:D	Tetramould		0	0	0	0	314	0	1,256
R.4K23C:D	Tetramould		0	0	0	0	149	0	596
R.29	Concrete mould		0	0	80	188	192	188	192
S.21	Drums on tray		0	488	488	488	0	91.5	0
S.23	Concrete mould		0	0	113	113	605	113	605
S.23:D	Concrete mould		0	0	0	0	164	0	164
S.25:D	Drums on tray		0	0	0	0	2,384	0	447
Å.4K23:D	Tetramould		0	0	0	0	45	0	180
Å.4K23C:D	Tetramould		0	0	0	0	5	0	20
Total			10,196	878	11,519	12,279	5,836	7,093.5	7,253

[a] As the packages are not equal in volume "mould unit" is used to normalise the packages.
[b] The packaging of waste types C.01:9–30/O.01:9–30 contains cellulose, while C.01:9/O.01:9 don't.
[c] The waste in F.17cellulose contains cellulosic filteraids.
[d] F.23C, R.23C are used in this table to identify the concrete moulds.

Waste emplacement

In the 13 large compartments, it is possible to store twelve moulds in width, six in height and eight in length, which results in a maximum of 576 moulds in each compartment. The maximum number of drums that can be placed in a compartment if the drums are stored on steel plates, with two rows of moulds (144 moulds) in the middle supporting the prefabricated lids that are emplaced on top of the waste. In this case, the steel plates, each holding 4 drums, are stored on either side of the moulds, five plates in width, eight in height and eight in length, which results in a maximum of 2,560 drums. The maximum number of moulds in the two smaller compartments is 144 (six in width, six in height and four in length) and the maximum number of drums is 768, if stored on steel plates.

The emplacement in 1BMA today (December 2012) is given in the Inventory report (SKB 2013b). Compartments 1–5, 7 and 9 are filled and closed. Compartments 6 and 8 are almost filled, 10–12 are partly filled and 11, 13–15 are empty. Compartments 2, 3, 5, 6 and 10 contain bituminised waste.

The prognosis of the emplacement at closure is based on the emplacement of today, the predicted number of future waste packages given in the Inventory report (SKB 2013b) and the distribution of future waste between 1BMA and 2BMA according to Table 3-14. The future waste has been distributed between the compartments based on the following assumptions.

Since compartment 1–9 are totally filled or almost filled already, no additional waste is emplaced in those compartments.

The packages of different waste types will be distributed between the compartments in 1BMA to obtain an activity distribution that is as equal as possible, after taking into account:

1) Bituminised waste, F.17, is distributed equally between the open compartments.
2) Concrete moulds are emplaced to fulfil the criteria of 144 concrete moulds per large compartment.
3) The remaining packages are distributed as equally as possible between the open compartments. Special concern is taken to the amount of cellulose in each compartment.

The resulting emplacement in 1BMA at closure is given in Table 3-14.

3.7.3 2BMA

2BMA is designed to store mainly intermediate level decommissioning waste. The maximum surface dose rate allowed is 100 mSv/h. The distribution between different wastes, matrices and packaging is shown in Figure 3-6.

Waste emplacement

In the 14 caissons it is possible to store twelve moulds in width, six in height and twelve in length, which results in a maximum of 864 moulds in each caisson. The maximum number of drums in a caisson is obtained if the drums are stored on steel plates. Steel plates with drums are stored twelve in width, eight in height and twelve in length, which results in a maximum of 1,152 steel plates with drums or 4,608 drums.

The waste types are assumed to be equally distributed between the caissons. The number of waste packages that will be deposited in 2BMA according to Table 3-13 implies that theoretically 8.4 caissons will be filled (864 moulds per compartment, a total of 7,253 "mould units").

Table 3-14. Prognosis of waste in the different compartments in 1BMA at closure (number of packages). The definitions of the waste types are given in Section 3.3.1. Compartments including bituminised waste are marked with grey.

Waste type	Packaging	Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
B.05/B.05:9	Drums on tray	Bitumen	0	0	1,168	0	2,000	192	0	0	0	0	0	0	0	0	0	3,360
B.05:2	Drums in box	Bitumen	0	382	270	0	96	144	0	0	0	0	0	0	0	0	0	892
B.23	Steel mould	Concrete	0	0	0	0	0	0	0	0	0	0	7	8	8	5	5	33
C.01:9	Concrete mould	Cement	0	0	0	0	0	0	2	0	0	5	0	0	0	0	0	7
C.01:9–30[a]	Concrete mould	Cement	0	0	0	20	0	0	10	1	21	9	0	0	0	0	0	61
C.23	Concrete mould	Concrete	0	0	0	1	0	0	0	12	30	0	7	6	7	0	0	63
F.05:1	Drums on tray	Bitumen	0	1,454	0	0	0	0	0	0	0	0	0	0	0	0	0	1,454
F.05:2	Drums on tray	Bitumen	0	258	0	0	0	0	0	0	0	0	0	0	0	0	0	258
F.15	Steel mould	Cement	0	0	0	8	0	3	0	0	0	0	0	0	0	0	0	11
F.17	Steel mould	Bitumen	0	0	144	0	8	247	0	0	0	211	211	211	212	53	53	1,350
F.17:1	Steel mould	Bitumen	0	0	0	0	20	12	0	0	0	0	0	0	0	0	0	32
F.23C[b]	Concrete mould	Concrete	0	0	0	49	0	0	2	4	0	2	0	0	0	0	0	57
F.23	Steel mould	Concrete	0	0	0	15	0	0	10	88	0	38	21	21	21	3	3	220
F.99:1	Steel mould	–	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2
O.01:9	Concrete mould	Cement	0	0	0	11	0	0	209	10	28	134	2	1	2	0	0	397
O.01:9–30[a]	Concrete mould	Cement	0	0	0	45	0	0	43	19	156	15	0	0	0	0	0	278
O.23/O.23:9	Concrete mould	Concrete	0	0	0	35	0	0	36	134	137	113	18	18	18	0	0	509
R.01/R.01:9	Concrete mould	Cement	576	148	144	144	144	144	144	146	88	0	2	8	1	0	0	1,689
R.10	Concrete mould	Cement	0	0	0	0	0	0	0	36	48	0	12	12	13	0	0	121
R.15	Steel mould	Cement	0	0	0	124	0	0	0	0	0	0	14	14	14	10	10	186
R.23C[b]	Concrete mould	Concrete	0	0	0	124	0	0	120	38	52	0	0	4	0	0	0	338
R.23	Steel mould	Concrete	0	0	0	0	0	0	0	80	16	0	17	18	17	12	12	172
R.29	Concrete mould	Cement	0	0	0	0	0	0	0	0	0	0	64	60	64	0	0	188
S.21	Drums on tray	Concrete	0	0	0	0	0	0	0	0	0	0	110	110	110	79	79	488
S.23	Concrete mould	Concrete	0	0	0	0	0	0	0	0	0	0	39	35	39	0	0	113
Total			576	2,242	1,726	576	2,268	744	576	568	576	527	524	526	526	162	162	12,279

[a] The packaging of waste types C.01:9–30/O.01:9–30 contains cellulose, while C.01:9/O.01:9 do not.

[b] F.23C, R.23C are used in this table to identify the concrete moulds.

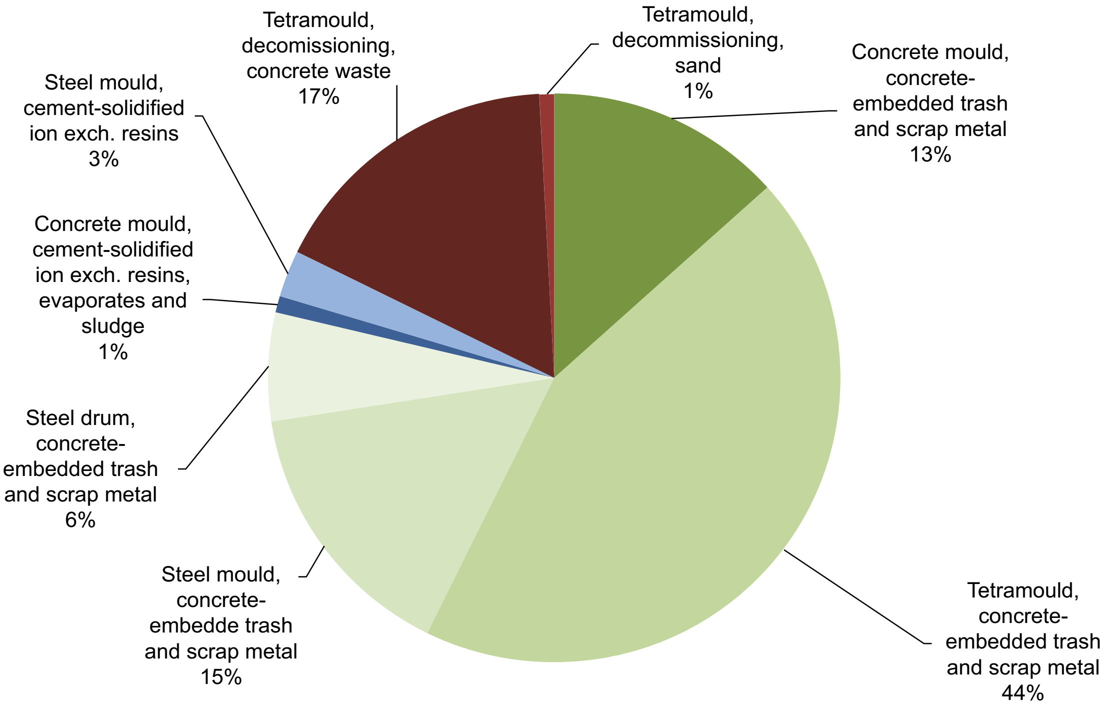

Figure 3-6. *Distribution between different packaging and conditioning of waste in 2BMA (vol%).*

3.7.4 1BTF

1BTF is designed mainly to contain de-watered ion-exchange resins, but cement-solidified resins and ashes will also be present. The maximum allowed surface dose rate is 10 mSv/h, however the current transport system limits the dose rate to 8 mSv/h for concrete tanks and 2 mSv/h for drums. All waste in 1BTF is handled in concrete tanks, moulds or drums. The distribution between different wastes, matrices and packaging is shown in Figure 3-8.

Waste emplacement

When the drums containing ash are placed in 1BTF, stabilising walls are necessary, see Figure 3-7. Concrete tanks are placed alongside the rock walls. The drums are then piled lying down on their side between the concrete tanks. When six rows of drums have been piled, concrete moulds are placed across the vault. A wall of concrete moulds is made up of nine in width and four in height. A section between two rows of concrete moulds contains 1,110 drums. The walls alongside the rock comprise of 8 concrete tanks in total per section of drums. The prognosis of the number of drums given in the Inventory report is 8,546 (SKB 2013b), which is equivalent to 8 sections with drums.

Concrete tanks, excepting the ones used as walls in the drum section, are stored four in width and two in height, see the upper detail in Figure 6-2.

3.7.5 2BTF

2BTF is designed mainly to contain de-watered ion-exchange resins. The maximum surface dose rate allowed is 10 mSv/h, however the current transport system limits the dose rate to 8 mSv/h for concrete tanks. Almost all waste in 2BTF is stored in concrete tanks. The distribution between different wastes, matrices and packaging is shown in Figure 3-9.

Waste emplacement

Concrete tanks are stored four in width and two in height, see Figure 6-2.

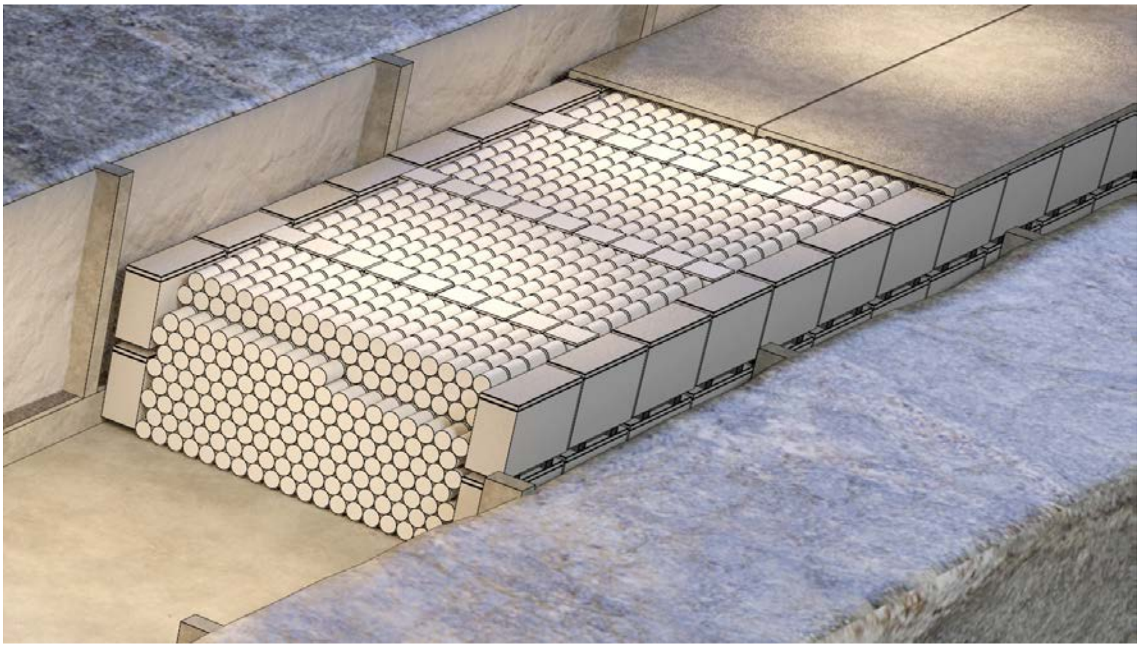

Figure 3-7. *Detail of sections with drums in 1BTF.*

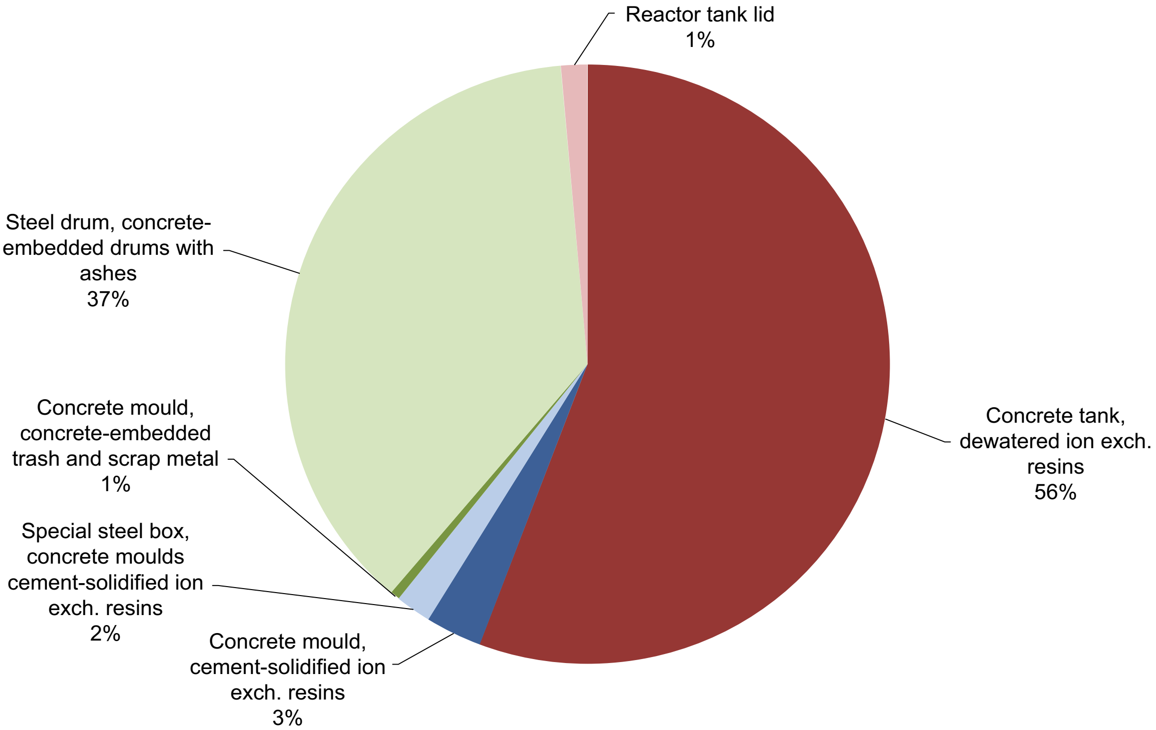

Figure 3-8. *Distribution between different packaging and conditioning of waste in 1BTF (vol%).*

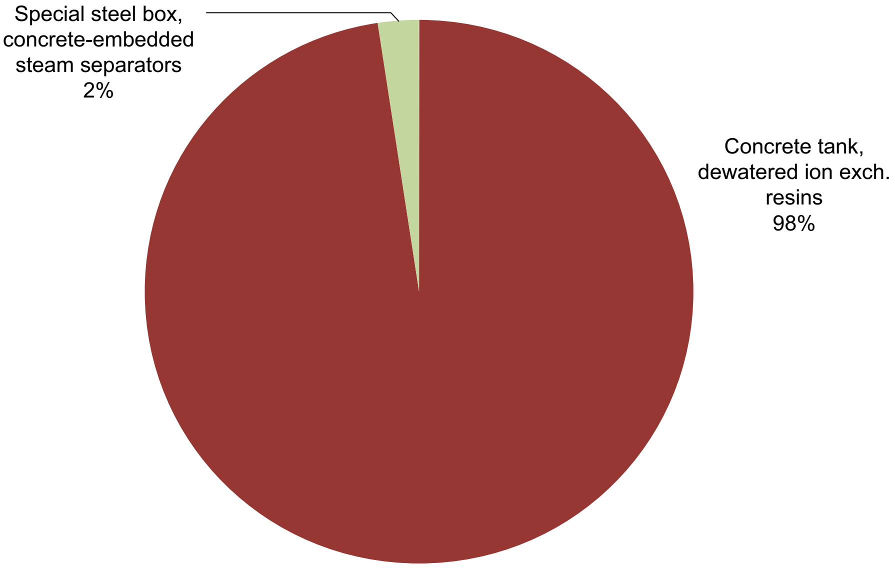

***Figure 3-9.** Distribution between different packaging and conditioning of waste in 2BTF (vol%).*

3.7.6 Silo

Intermediate-level waste is stored in the silo. The maximum allowed surface dose rate is 500 mSv/h. The waste contains solidified (bitumen or cement) ion-exchange resins and a small amount of concrete grouted trash and scrap metal. All waste in the silo is handled in moulds or steel plates each with four drums. The distribution between different wastes, matrices and packaging is shown in Figure 3-10.

Waste emplacement

In the majority of shafts, 42 layers of concrete/steel moulds or 56 layers of drums on plates can be emplaced. Each layer holds four moulds or steel plates with drums. This results in 168 moulds or 896 steel drums per shaft. In the half-size shafts (denoted B, C and D in Figure 7-2), two moulds or steel plates with drums can be emplaced in each layer resulting in 84 moulds or 448 steel drums. The shafts denoted E, F and G in Figure 7-2 may be used for odd waste. In the nine central shafts of the silo, bitumen solidified waste is emplaced, see Figure 7-2.

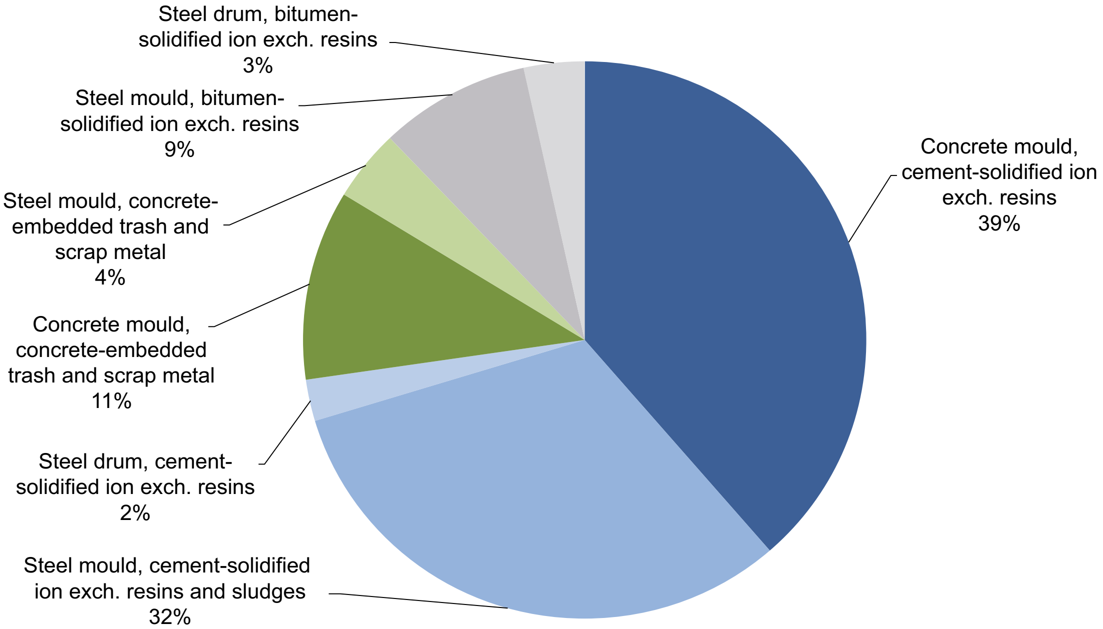

***Figure 3-10.** Distribution between different packaging and conditioning of waste in the silo (vol%).*

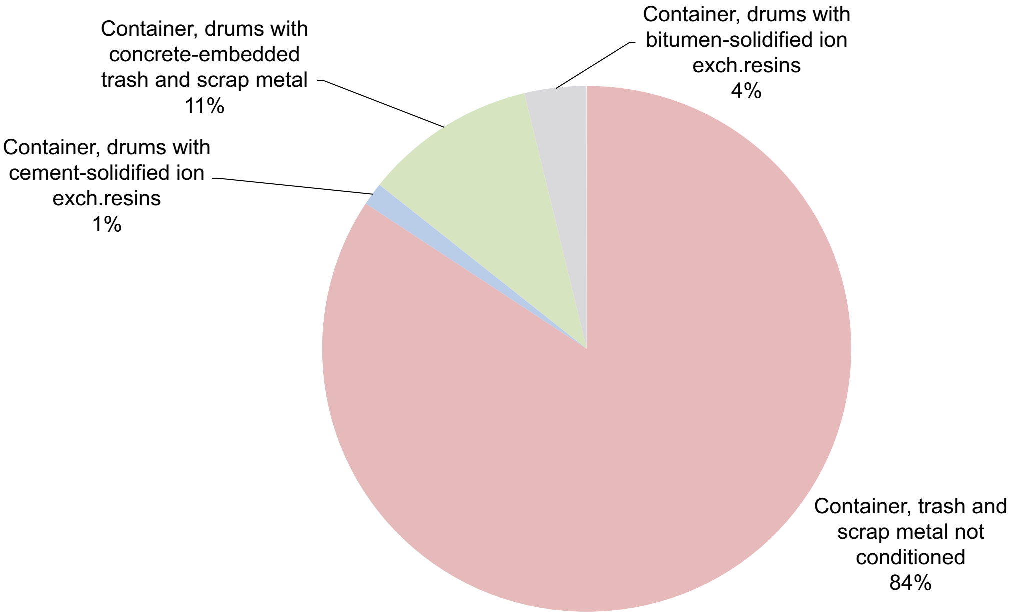

***Figure 3-11.** Distribution between different packaging and conditioning of waste in 1BLA (vol%).*

3.7.7 1BLA

BLA is designed mainly to contain low level trash and scrap metal. All waste in BLA is stored in ISO-containers. The maximum allowed surface dose rate is 2 mSv/h. The 20 foot half-height containers constitute 53% of the total number of containers and the remainder are 20 foot full-height containers. The containers can hold different smaller packages like drums, boxes and bales. The distribution between different wastes is shown Figure 3-11.

Waste emplacement

Containers (20-foot full-height) are stored two in width and three in height and half height six on height.

3.7.8 2–5BLA

2–5BLA is designed mainly to contain low level decommissioning waste. All waste in 2–5BLA is planned to be stored in ISO-containers. The maximum allowed surface dose rate is 2 mSv/h. The containers can hold different smaller packages like drums, boxes and bales. The distribution between different wastes is shown in Figure 3-12.

Waste emplacement

Containers (20-foot half-height) are stored two in width and six in height. After 3 rows of containers an extra space is left before emplacement of the next 3 rows of containers. In total, 90 rows of containers are stored in each of the 2–5BLA vaults. This corresponds to a total of 1,080 containers (20-foot half-height) in each vault.

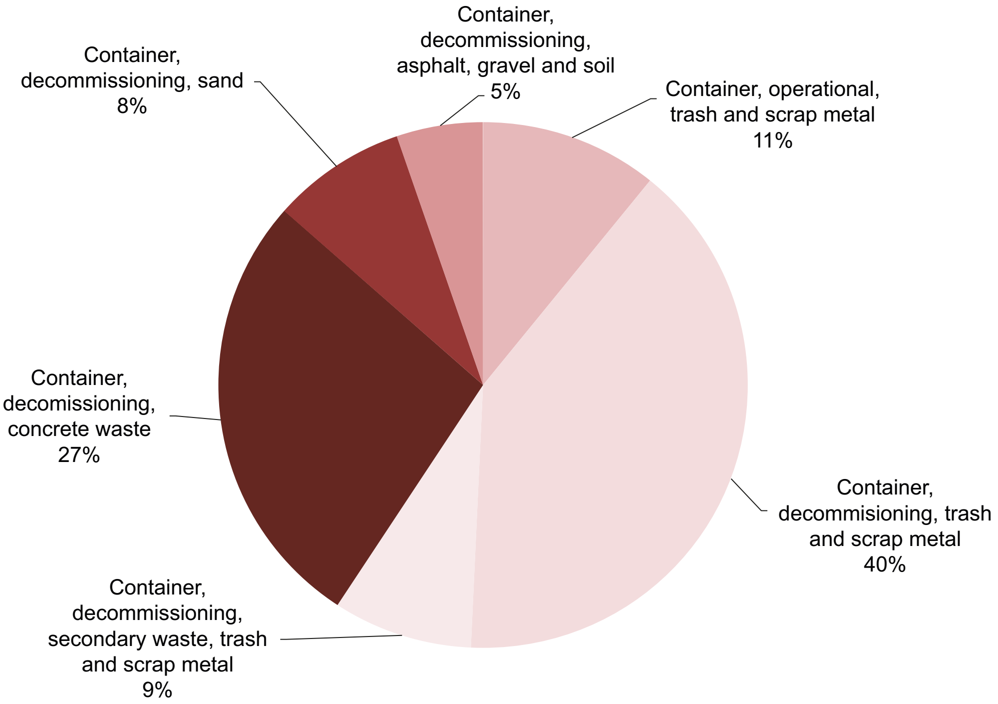

Figure 3-12. *Distribution between different wastes in 2–5BLA (vol%). None of the waste in 2–5BLA is conditioned.*

3.7.9 BRT

The waste in BRT comprises of the nine reactor pressure vessels from Barsebäck (B1, B2), Forsmark (F1, F2, F3), Oskarshamn (O1, O2, O3) and Ringhals (R1).

Waste emplacement

The pressure vessels will be stored in one row with a space of about 2 m between each reactor pressure vessel.

3.8 Material quantities and radioactivity

A summary of the material quantities in the waste packages in the different waste vaults is given in Table 3-15. The material quantities are calculated from the number of waste packages (Appendix A, Table A-1) and the current prognosis of the average quantities for different waste types given in the Inventory report (SKB 2013b). The amounts of cellulose and aluminium/zinc are expected to be overestimated in the prognosis, in particular.

Since the waste comprises a large variety of materials, foreign materials and stray materials that are present in the repository are foreseen to be of negligible importance for the safety. According to the regulations, SSMFS 2008:37, chemotoxic materials are not part of the long-term safety analysis for a final repository for nuclear waste.

A radionuclide inventory that is a best estimate, given Table 3-16, is calculated from the average inventory in each waste type package (SKB 2013b, SKBdoc 1481419) and the number of waste packages of each waste type in the waste vaults (Appendix A, Table A-1). A radionuclide inventory calculated from the best estimate inventory including uncertainties (95th percentile) (SKBdoc 1427105) is given in Table 3-17.

Table 3-15. Quantities of different materials in the waste packages (waste + matrix + packaging) in SFR at closure plus corrosion surface areas and void (calculated from number of waste packages (Appendix A, Table A-1) and the average quantities for different waste types given in the Inventory report (SKB 2013b).

Material	Weight [kg]								
	Silo	BRT	1BMA	2BMA	1BTF	2BTF	1BLA	2–5BLA	Total
Aluminium/zinc*	$8.26\cdot10^{3}$	0	$7.13\cdot10^{3}$	$2.06\cdot10^{4}$	$5.28\cdot10^{4}$	0	$6.30\cdot10^{4}$	$6.98\cdot10^{4}$	$2.21\cdot10^{5}$
Asphalt, gravel, soil	0	0	0	0	0	0	0	$3.60\cdot10^{6}$	$3.60\cdot10^{6}$
Ashes	0	0	0	$1.53\cdot10^{5}$	$5.19\cdot10^{5}$	0	0	0	$6.72\cdot10^{5}$
Concrete	$1.17\cdot10^{7}$	0	$8.52\cdot10^{6}$	$1.73\cdot10^{7}$	$6.52\cdot10^{6}$	$7.89\cdot10^{6}$	$2.43\cdot10^{5}$	$1.79\cdot10^{7}$	$7.00\cdot10^{7}$
Bitumen	$1.06\cdot10^{6}$	0	$1.93\cdot10^{6}$	0	0	0	1.1810^{5}	0	$3.10\cdot10^{6}$
Cellulose*	$1.80\cdot10^{4}$	0	$7.95\cdot10^{4}$	$7.06\cdot10^{4}$	$1.07\cdot10^{3}$	0	$3.05\cdot10^{5}$	$3.61\cdot10^{5}$	$8.35\cdot10^{5}$
Cement	$1.22\cdot10^{7}$	0	$4.39\cdot10^{6}$	$4.50\cdot10^{5}$	$2.37\cdot10^{5}$	0	$7.50\cdot10^{4}$	0	$1.73\cdot10^{7}$
Filter aids	$1.01\cdot10^{4}$	0	$8.34\cdot10^{4}$	$1.63\cdot10^{2}$	$7.23\cdot10^{4}$	$1.32\cdot10^{5}$	0	0	$2.98\cdot10^{5}$
Evaporator concentrates	0	0	$2.99\cdot10^{5}$	$1.34\cdot10^{5}$	0	0	$2.70\cdot10^{2}$	0	$4.34\cdot10^{5}$
Ion-exchange resins	$3.31\cdot10^{6}$	0	$2.08\cdot10^{6}$	$4.76\cdot10^{4}$	$4.39\cdot10^{5}$	$8.12\cdot10^{5}$	$9.74\cdot10^{4}$	0	$6.78\cdot10^{6}$
Iron/steel	$4.94\cdot10^{6}$	$5.55\cdot10^{6}$	$2.65\cdot10^{6}$	$9.48\cdot10^{6}$	$1.32\cdot10^{6}$	$1.79\cdot10^{6}$	$3.77\cdot10^{6}$	$3.52\cdot10^{7}$	$6.47\cdot10^{7}$
Sand	0	0	0	$1.06\cdot10^{5}$	0	0	0	$5.26\cdot10^{6}$	$5.37\cdot10^{6}$
Sludge	$3.53\cdot10^{4}$	0	$8.61\cdot10^{4}$	$1.73\cdot10^{4}$	$2.53\cdot10^{4}$	$4.37\cdot10^{4}$	$7.25\cdot10^{2}$	0	$2.08\cdot10^{5}$
Other inorganic	$1.07\cdot10^{6}$	0	$2.88\cdot10^{4}$	$8.77\cdot10^{4}$	0	0	$1.84\cdot10^{5}$	$2.51\cdot10^{5}$	$1.62\cdot10^{6}$
Other organic	$5.31\cdot10^{4}$	0	$2.06\cdot10^{5}$	$1.49\cdot10^{5}$	$4.77\cdot10^{4}$	$8.46\cdot10^{4}$	$1.47\cdot10^{6}$	$2.03\cdot10^{6}$	$4.04\cdot10^{6}$
Aluminium/zinc [m^2]*	$1.24\cdot10^{3}$	0	$1.01\cdot10^{3}$	$3.15\cdot10^{3}$	$7.79\cdot10^{3}$	0	$9.33\cdot10^{3}$	$1.04\cdot10^{4}$	$3.29\cdot10^{4}$
Iron/steel [m^2]	$2.21\cdot10^{5}$	$7.24\cdot10^{3}$	$1.15\cdot10^{5}$	$4.38\cdot10^{5}$	$7.74\cdot10^{4}$	$3.94\cdot10^{4}$	$2.29\cdot10^{5}$	$1.84\cdot10^{6}$	$2.96\cdot10^{6}$
Void [m^3]	$2.14\cdot10^{3}$	$4.67\cdot10^{3}$	$1.83\cdot10^{3}$	$2.51\cdot10^{3}$	$5.23\cdot10^{2}$	$6.31\cdot10^{2}$	$4.50\cdot10^{3}$	$3.47\cdot10^{4}$	$5.15\cdot10^{4}$

* Initial estimate from the prognosis in the Inventory report (SKB 2013b). The safety analysis shows the necessity to limit the amounts of cellulose and aluminium/zinc in some waste vaults. These limits have been implemented in the preliminary waste acceptance criteria for future operational and decommissioning waste (SKBdoc 1368638).

Table 3-16. Best estimate radionuclide inventory [Bq] at year 2075 (calculated from number of waste packages (Table A-1) and the average activity for different waste types given in the Inventory report (SKB 2013b, SKBdoc 1481419 (Mo-93)).

Nuclide	1BMA	2BMA	1BTF	2BTF	Silo	1BLA	2-5BLA	BRT	Total
H-3	8.09E+08	3.31E+12	6.82E+07	1.07E+08	8.97E+09	2.00E+08	1.94E+11		3.52E+12
Be-10	2.21E+05	2.19E+04	1.37E+04	2.48E+04	9.89E+05	6.53E+02	1.26E+03		1.27E+06
C-14 org*	1.47E+11	3.96E+09	9.84E+09	6.07E+09	7.56E+11	7.91E+07	2.25E+08		9.23E+11
C-14 oorg*	1.90E+12	1.44E+10	1.89E+11	2.69E+11	2.72E+12	4.03E+09	9.27E+08		5.10E+12
C-14 ind*		5.09E+09					1.19E+09	1.02E+10	1.65E+10
Cl-36	3.34E+08	2.02E+08	1.44E+07	1.66E+07	8.94E+08	2.17E+07	4.60E+07	7.21E+06	1.54E+09
Ca-41		1.56E+10					3.91E+09		1.95E+10
Fe-55	5.35E+10	1.05E+11	8.33E+07	1.14E+08	2.73E+12	8.78E+06	4.45E+08	1.49E+10	2.91E+12
Co-60	4.08E+11	1.99E+12	1.67E+10	2.36E+10	1.29E+13	1.03E+09	2.59E+10	1.93E+11	1.55E+13
Ni-59	2.10E+12	9.50E+11	3.31E+10	3.83E+10	6.85E+12	3.99E+09	1.15E+10	1.60E+11	1.01E+13
Ni-63	1.47E+14	9.23E+13	2.04E+12	2.27E+12	5.48E+14	3.04E+11	1.12E+12	1.44E+13	8.07E+14
Se-79	2.10E+08	7.29E+06	1.57E+07	1.54E+07	1.05E+09	4.00E+05	5.94E+06		1.31E+09
Sr-90	5.49E+11	3.60E+11	3.48E+10	5.76E+10	3.61E+12	7.42E+08	2.40E+10	2.32E+10	4.66E+12
Zr-93	3.68E+08	1.06E+09	2.29E+07	4.14E+07	4.48E+09	1.09E+06	2.95E+07	1.84E+08	6.19E+09
Nb-93m	1.73E+10	1.31E+13	1.44E+09	2.35E+09	9.33E+12	7.68E+07	1.34E+11	1.06E+12	2.36E+13
Nb-94	3.67E+09	9.12E+10	2.53E+08	4.13E+08	8.67E+10	3.14E+07	9.81E+08	7.94E+09	1.91E+11
Mo-93	1.46E+09	4.52E+09	2.56E+08	2.36E+08	1.96E+10	1.01E+08	9.01E+07	3.00E+09	2.93E+10
Tc-99	6.22E+09	1.42E+09	2.30E+09	5.45E+08	5.00E+10	1.85E+09	4.98E+08	4.49E+08	6.32E+10
Pd-107	5.25E+07	2.55E+09	3.92E+06	3.86E+06	2.75E+08	1.00E+05	1.72E+06		2.89E+09
Ag-108m	1.95E+10	4.06E+10	1.51E+09	2.21E+09	2.30E+11	1.94E+08	1.53E+09	1.62E+09	2.97E+11
Cd-113m	7.98E+08	9.32E+07	7.67E+07	6.34E+07	9.58E+09	1.96E+06	6.13E+06		1.06E+10
In-115		3.13E+05							3.13E+05
Sn-126	2.62E+07	1.75E+07	1.96E+06	1.93E+06	2.05E+08	5.00E+04	7.93E+06	7.53E+05	2.62E+08
Sb-125	4.37E+07	2.62E+08	7.47E+06	1.04E+07	1.32E+11	4.74E+05	4.46E+06	1.34E+07	1.32E+11
I-129	1.46E+08	7.67E+06	2.27E+07	1.02E+07	9.84E+08	4.35E+05	1.94E+06		1.17E+09
Cs-134	1.45E+08	2.26E+08	7.10E+04	8.86E+04	2.20E+11	1.58E+04	1.39E+06		2.20E+11
Cs-135	8.41E+08	5.33E+07	1.03E+08	1.85E+07	4.47E+09	3.07E+06	1.75E+08		5.67E+09
Cs-137	8.15E+12	8.95E+11	7.12E+11	6.22E+11	5.97E+13	1.84E+10	4.95E+11		7.05E+13
Ba-133	4.89E+07	1.43E+08	4.03E+06	6.19E+06	6.16E+08	2.20E+05	1.26E+07		8.31E+08
Pm-147	3.71E+08	4.06E+08	3.84E+06	4.57E+06	3.59E+11	3.02E+05	1.19E+06	1.37E+06	3.60E+11
Sm-151	8.26E+10	3.55E+10	6.51E+09	6.13E+09	4.63E+11	1.68E+08	5.88E+09	3.42E+08	6.00E+11
Eu-152	9.47E+07	1.33E+11	6.19E+07	6.54E+06	8.64E+08	1.02E+08	1.73E+10	5.41E+05	1.52E+11
Eu-154	2.33E+10	6.83E+09	1.98E+09	1.80E+09	5.24E+11	4.01E+07	2.67E+08	9.27E+07	5.59E+11
Eu-155	1.02E+09	3.74E+08	4.96E+07	5.83E+07	9.96E+10	1.54E+06	1.16E+07	2.40E+06	1.01E+11
Ho-166m	1.41E+09	5.22E+08	8.79E+07	1.59E+08	6.83E+09	4.18E+06	9.03E+07	7.99E+03	9.10E+09
U-232	8.85E+04	1.46E+05	1.62E+04	6.73E+03	6.20E+05	2.34E+03	9.35E+03	6.86E+03	8.96E+05
U-234	6.66E+06	3.04E+06	9.86E+05	4.55E+05	3.58E+07	1.33E+05	4.38E+05		4.75E+07
U-235	3.00E+06	7.82E+04	1.84E+07	1.12E+05	1.42E+07	2.98E+08	3.23E+08	1.49E+01	6.57E+08
U-236	2.64E+06	6.00E+06	4.02E+05	3.55E+05	1.58E+07	3.99E+04	2.06E+05	3.92E+05	2.59E+07
U-238	5.95E+06	1.23E+06	8.55E+05	8.75E+05	3.28E+07	7.33E+08	1.77E+08		9.52E+08
Np-237	2.73E+07	7.68E+06	1.07E+06	1.98E+06	5.36E+08	6.75E+04	2.61E+05	4.70E+05	5.75E+08
Pu-238	7.52E+09	4.42E+10	2.09E+09	4.56E+08	7.29E+10	3.47E+08	1.52E+09	2.72E+09	1.32E+11
Pu-239	2.77E+09	6.78E+09	4.68E+08	1.89E+08	1.70E+10	6.60E+07	2.77E+08	4.16E+08	2.80E+10
Pu-240	3.87E+09	9.21E+09	5.20E+08	2.65E+08	2.39E+10	6.74E+07	2.95E+08	5.92E+08	3.87E+10
Pu-241	2.40E+10	1.66E+11	7.30E+09	2.42E+09	3.07E+11	1.29E+09	5.74E+09	9.05E+09	5.23E+11
Pu-242	2.00E+07	5.02E+07	2.96E+06	1.37E+06	1.23E+08	3.99E+05	1.71E+06	3.11E+06	2.03E+08
Am-241	2.91E+10	4.12E+10	6.14E+09	1.83E+09	2.32E+13	5.23E+08	1.94E+09	1.99E+09	2.32E+13
Am-242m	4.46E+07	1.83E+08	7.34E+06	3.21E+06	3.22E+08	1.02E+06	4.84E+06	1.32E+07	5.79E+08
Am-243	2.02E+08	6.62E+08	3.25E+07	1.78E+07	1.60E+09	4.00E+06	1.86E+07	4.14E+07	2.57E+09
Cm-243	1.85E+07	1.03E+08	3.82E+06	4.15E+05	1.89E+08	7.58E+05	3.40E+06	6.38E+06	3.25E+08
Cm-244	6.73E+08	1.07E+10	2.68E+08	2.84E+07	9.26E+09	5.39E+07	2.80E+08	6.76E+08	2.19E+10
Cm-245	1.99E+06	1.01E+07	2.95E+05	1.36E+05	1.49E+07	3.97E+04	2.18E+05	6.83E+05	2.84E+07
Cm-246	5.27E+05	3.34E+06	7.82E+04	3.60E+04	4.29E+06	1.05E+04	6.61E+04	2.24E+05	8.58E+06
Total	1.60E+14	1.14E+14	3.06E+12	3.30E+12	6.72E+14	3.39E+11	2.05E+12	1.59E+13	9.71E+14

* C-14 has been divided into organic, inorganic and induced activity.

Table 3-17. High radionuclide inventory [Bq] at year 2075 (calculated from the best estimate inventory including uncertainties (95th percentile) (SKBdoc 1427105)).

Nuclide	1BMA	2BMA	1BTF	2BTF	Silo	1BLA	2-5BLA	BRT	Total	Ratio**
H-3	4.06E+10	2.02E+13	3.41E+09	5.38E+09	4.57E+11	1.01E+10	5.43E+11		2.12E+13	6.04
Be-10	1.11E+07	9.85E+05	6.88E+05	1.24E+06	4.98E+07	3.42E+04	2.49E+04		6.38E+07	50.2
C-14 org*	2.01E+11	7.49E+09	1.35E+10	8.31E+09	1.04E+12	1.08E+08	1.21E+09		1.27E+12	1.38
C-14 oorg*	2.60E+12	2.63E+10	2.58E+11	3.67E+11	3.75E+12	5.51E+09	4.98E+09		7.01E+12	1.37
C-14 ind*		1.76E+10					6.41E+09	1.85E+10	4.26E+10	2.59
Cl-36	6.67E+08	8.00E+08	4.81E+07	4.06E+07	3.91E+09	2.88E+07	1.13E+08	1.31E+07	5.63E+09	3.66
Ca-41		6.07E+10					1.01E+10		7.08E+10	3.63
Fe-55	2.72E+11	4.65E+11	4.17E+08	5.71E+08	1.52E+13	5.05E+07	2.64E+09	2.72E+10	1.59E+13	5.48
Co-60	4.74E+11	3.74E+12	1.71E+10	2.41E+10	2.40E+13	2.01E+09	1.66E+11	3.51E+11	2.88E+13	1.85
Ni-59	6.30E+12	2.12E+12	1.03E+11	1.16E+11	2.09E+13	1.27E+10	6.62E+10	2.91E+11	2.99E+13	2.95
Ni-63	4.40E+14	2.02E+14	6.43E+12	6.88E+12	1.67E+15	9.57E+11	6.57E+12	2.62E+13	2.36E+15	2.93
Se-79	1.05E+10	3.77E+08	7.86E+08	7.71E+08	5.30E+10	2.06E+07	5.84E+07		6.55E+10	50.2
Sr-90	7.27E+11	8.68E+11	5.14E+10	1.29E+11	5.16E+12	2.92E+09	1.80E+11	4.23E+10	7.16E+12	1.54
Zr-93	1.84E+10	3.87E+09	1.15E+09	2.07E+09	1.00E+11	5.69E+07	2.09E+08	3.36E+08	1.26E+11	20.4
Nb-93m	3.46E+11	2.50E+13	2.88E+10	4.70E+10	4.00E+13	1.66E+09	8.69E+11	1.92E+12	6.81E+13	2.88
Nb-94	1.84E+10	1.80E+11	1.27E+09	2.07E+09	3.61E+11	1.95E+08	6.15E+09	1.45E+10	5.84E+11	3.05
Mo-93	2.00E+09	8.65E+09	3.50E+08	3.22E+08	4.23E+10	1.39E+08	3.09E+08	5.46E+09	5.95E+10	2.03
Tc-99	1.22E+10	5.01E+09	8.47E+09	7.54E+08	1.97E+11	6.66E+09	3.06E+09	8.19E+08	2.34E+11	3.71
Pd-107	2.10E+09	4.72E+09	1.57E+08	1.54E+08	1.07E+10	4.14E+06	1.39E+07		1.79E+10	6.19
Ag-108m	9.74E+11	1.73E+11	7.56E+10	1.11E+11	5.09E+12	9.85E+09	8.46E+09	2.96E+09	6.44E+12	21.7
Cd-113m	4.00E+10	4.15E+09	3.85E+09	3.17E+09	5.03E+11	1.04E+08	1.79E+08		5.55E+11	52.2
In-115		8.28E+05							8.28E+05	2.65
Sn-126	1.05E+09	7.45E+07	7.87E+07	7.72E+07	5.91E+09	2.07E+06	5.58E+07	1.37E+06	7.25E+09	27.7
Sb-125	4.61E+08	1.27E+09	7.47E+07	1.04E+08	1.54E+12	5.55E+06	3.03E+07	2.45E+07	1.54E+12	11.6
I-129	3.05E+08	4.50E+07	9.17E+07	1.40E+07	3.29E+09	1.38E+06	1.45E+07		3.76E+09	3.20
Cs-134	1.93E+08	3.30E+08	8.54E+04	1.06E+05	5.85E+11	4.05E+04	9.24E+06		5.86E+11	2.66
Cs-135	1.28E+09	3.22E+08	2.46E+08	2.53E+07	9.94E+09	6.38E+06	1.21E+09		1.30E+10	2.30
Cs-137	8.35E+12	4.58E+12	8.05E+11	6.31E+11	8.99E+13	3.14E+10	3.45E+12		1.08E+14	1.53
Ba-133	9.99E+07	5.30E+08	8.09E+06	1.24E+07	1.36E+09	5.90E+05	3.33E+07		2.05E+09	2.47
Pm-147	7.63E+08	8.59E+08	7.68E+06	9.14E+06	1.18E+12	9.08E+05	5.51E+06	2.49E+06	1.18E+12	3.28
Sm-151	1.66E+11	1.36E+11	1.33E+10	1.23E+10	1.03E+12	3.97E+08	1.58E+10	6.23E+08	1.38E+12	2.29
Eu-152	2.07E+08	4.78E+11	1.24E+08	1.31E+07	2.29E+09	2.22E+08	4.57E+10	9.86E+05	5.26E+11	3.47
Eu-154	4.71E+10	1.93E+10	4.04E+09	3.61E+09	1.48E+12	1.03E+08	8.01E+08	1.69E+08	1.55E+12	2.78
Eu-155	2.07E+09	9.72E+08	1.00E+08	1.17E+08	3.17E+11	4.45E+06	3.48E+07	4.37E+06	3.20E+11	3.17
Ho-166m	2.83E+09	2.11E+09	1.78E+08	3.21E+08	1.41E+10	1.04E+07	2.39E+08	1.46E+04	1.98E+10	2.17
U-232	1.99E+05	3.46E+05	3.28E+04	1.41E+04	1.57E+06	7.61E+03	3.66E+04	1.25E+04	2.22E+06	2.48
U-234	1.47E+07	9.73E+06	2.00E+06	9.57E+05	8.44E+07	4.29E+05	1.44E+06		1.14E+08	2.39
U-235	6.29E+06	2.32E+05	3.69E+07	2.33E+05	2.98E+07	7.21E+08	1.03E+09	2.71E+01	1.82E+09	2.77
U-236	5.75E+06	1.21E+07	8.22E+05	7.44E+05	4.13E+07	1.29E+05	9.61E+05	7.14E+05	6.25E+07	2.42
U-238	1.27E+07	3.92E+06	1.76E+06	1.83E+06	7.24E+07	1.55E+09	4.47E+08		2.09E+09	2.19
Np-237	5.73E+07	1.58E+07	2.19E+06	4.18E+06	1.61E+09	2.09E+05	1.06E+06	8.57E+05	1.69E+09	2.94
Pu-238	1.30E+10	9.11E+10	3.98E+09	6.41E+08	1.78E+11	1.12E+09	6.22E+09	4.95E+09	2.99E+11	2.27
Pu-239	4.10E+09	1.49E+10	8.52E+08	2.77E+08	3.53E+10	2.12E+08	1.10E+09	7.57E+08	5.75E+10	2.06
Pu-240	5.69E+09	1.97E+10	9.20E+08	3.87E+08	4.98E+10	2.15E+08	1.23E+09	1.08E+09	7.91E+10	2.04
Pu-241	5.95E+10	3.52E+11	1.48E+10	5.08E+09	7.88E+11	4.22E+09	2.36E+10	1.65E+10	1.26E+12	2.42
Pu-242	4.40E+07	1.03E+08	6.00E+06	2.87E+06	3.12E+08	1.29E+06	7.01E+06	5.66E+06	4.82E+08	2.38
Am-241	7.46E+10	1.98E+11	5.16E+10	6.10E+09	2.81E+14	6.08E+09	2.21E+10	3.62E+09	2.81E+14	12.1
Am-242m	9.91E+07	3.62E+08	1.49E+07	6.76E+06	8.38E+08	3.32E+06	2.07E+07	2.40E+07	1.37E+09	2.36
Am-243	2.97E+08	1.32E+09	5.67E+07	2.53E+07	3.21E+09	1.28E+07	8.02E+07	7.54E+07	5.07E+09	1.97
Cm-243	3.17E+07	2.12E+08	7.57E+06	7.98E+05	4.18E+08	2.46E+06	1.40E+07	1.16E+07	6.99E+08	2.15
Cm-244	1.48E+09	2.15E+10	5.21E+08	3.74E+07	2.64E+10	1.75E+08	1.26E+09	1.23E+09	5.26E+10	2.40
Cm-245	4.37E+06	2.00E+07	5.97E+05	2.86E+05	4.15E+07	1.28E+05	1.01E+06	1.24E+06	6.91E+07	2.44
Cm-246	1.16E+06	6.50E+06	1.59E+05	7.58E+04	1.23E+07	3.41E+04	3.27E+05	4.08E+05	2.10E+07	2.45
Total	4.61E+14	2.61E+14	7.90E+12	8.36E+12	2.17E+15	1.06E+12	1.20E+13	2.89E+13	2.95E+15	3.04

* C-14 has been divided into organic, inorganic and induced activity. ** Ratio to best estimate radionuclide inventory given in Table 3-16.

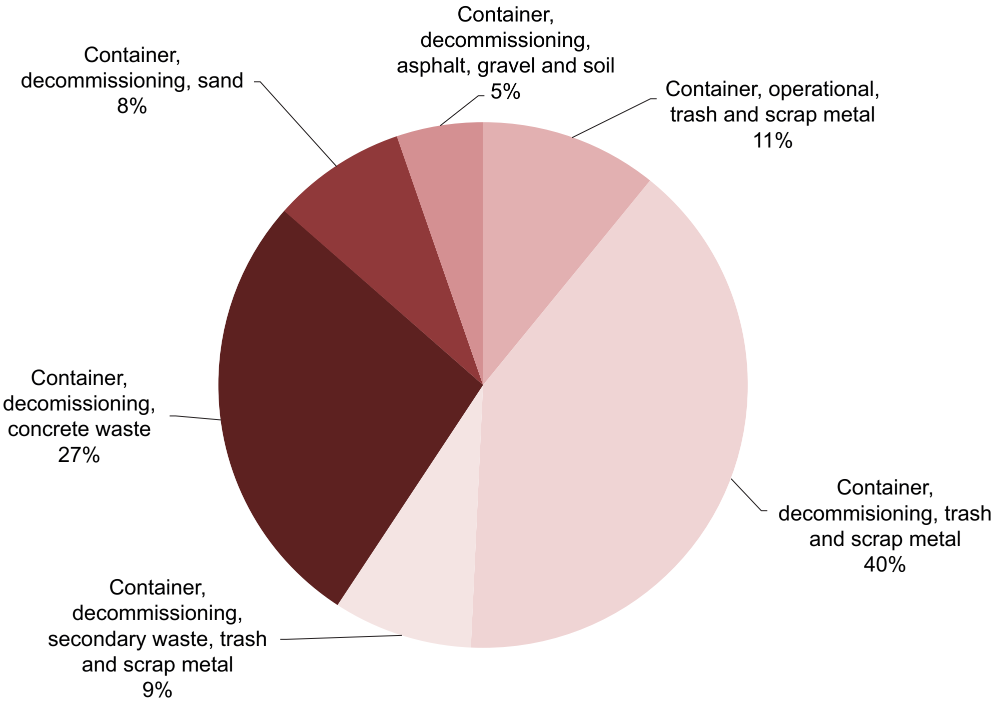

Figure 3-12. *Distribution between different wastes in 2–5BLA (vol%). None of the waste in 2–5BLA is conditioned.*

3.7.9 BRT

The waste in BRT comprises of the nine reactor pressure vessels from Barsebäck (B1, B2), Forsmark (F1, F2, F3), Oskarshamn (O1, O2, O3) and Ringhals (R1).

Waste emplacement

The pressure vessels will be stored in one row with a space of about 2 m between each reactor pressure vessel.

3.8 Material quantities and radioactivity

A summary of the material quantities in the waste packages in the different waste vaults is given in Table 3-15. The material quantities are calculated from the number of waste packages (Appendix A, Table A-1) and the current prognosis of the average quantities for different waste types given in the Inventory report (SKB 2013b). The amounts of cellulose and aluminium/zinc are expected to be overestimated in the prognosis, in particular.

Since the waste comprises a large variety of materials, foreign materials and stray materials that are present in the repository are foreseen to be of negligible importance for the safety. According to the regulations, SSMFS 2008:37, chemotoxic materials are not part of the long-term safety analysis for a final repository for nuclear waste.

A radionuclide inventory that is a best estimate, given Table 3-16, is calculated from the average inventory in each waste type package (SKB 2013b, SKBdoc 1481419 (Mo-93)) and the number of waste packages of each waste type in the waste vaults (Appendix A, Table A-1). A radionuclide inventory calculated from the best estimate inventory including uncertainties (95th percentile) (SKBdoc 1427105) is given in Table 3-17.

4 1BMA

4.1 Design

The waste vault for intermediate level waste, 1BMA, comprises an approximately 140 m long reinforced concrete structure divided into 13 large compartments and two smaller compartments, see Figure 4-1. The vault is built like a large box with separating walls creating the compartments. The floor and walls are made of in-situ cast reinforced concrete. Conventional techniques were used to build the compartments, and reinforcement bars and other steel construction components (e.g. form rods, grid plates, grouting pipes) are present in the concrete. The form rods, see Figure 4-2, were used to keep the formwork in place while casting the concrete walls and to prevent the concrete from collapsing or shifting. The supporting concrete structures rest on solid rock and the floor of the compartments rests on a base of crushed rock on the excavated bottom. The walls and roof of the vault are lined with shotcrete to stabilise the rock during the operating phase. The dimensions of the waste vault are given in Table 4-1 and Figure 4-3.

The waste packages (concrete and steel moulds or steel drums on a drum tray) are deposited by a remote-controlled overhead crane that runs on the top edge of the walls of the concrete structure, see Figure 4-1. The moulds are stacked six high and drums eight high and are emplaced in the compartments in such a way that each compartment will have at least two rows of concrete moulds that act as a support for prefabricated reinforced concrete lids.

The lids are put in position as soon as a compartment is filled and after that a thin concrete layer is cast on top of the lid in order to prevent water intrusion during the operating phase. When the operating phase is complete, an additional reinforced concrete lid will be cast on top of the compartments. In addition, the waste packages inside the compartments are planned to be embedded with a concrete grout that is similar to the type used to grout waste packages in the shafts inside the silo.

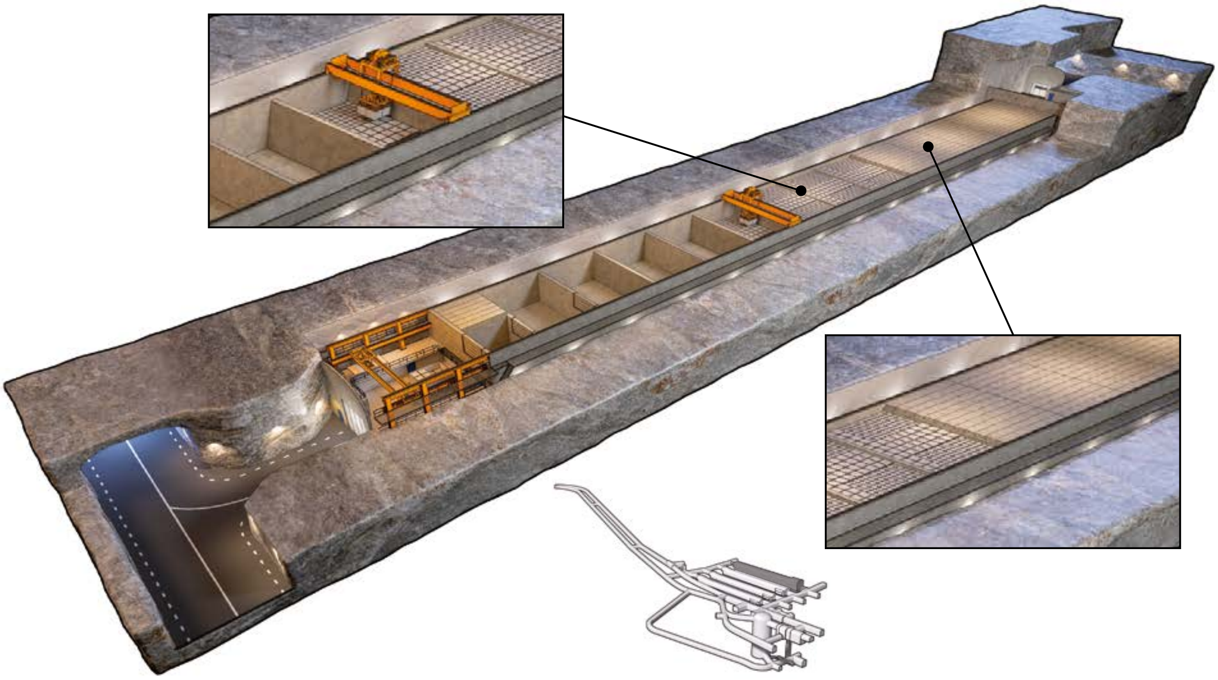

__Figure 4-1.__ Illustration of 1BMA during the operating phase. The upper detail shows the emplacement of waste packages, the lower detail shows the concrete lid in addition there is a view of SFR 1 with the position of 1BMA highlighted.

Figure 4-2. Example of form rods.

The demolition and dismantling of existing systems, for example the ventilation and electricity, will be adapted to the closure sequence. The Closure plan for SFR describes measures for the sealing and closure of 1BMA (SKBdoc 1358612). The space between the concrete structure and the rock walls and the space above the concrete lid are planned to be backfilled with macadam, see Figure 4-3. Macadam is crushed crystalline rock without fine particles, see definition in Section 1.4. At the end of the vault that connects to the transverse tunnel (1TT), a concrete plug is installed as a mechanical constraint for the bentonite in the tunnel. It is not possible to install a concrete plug in the connection to the waste vault tunnel (1BST); instead, here the mechanical constraint for the bentonite consists of a section with transition material and backfill material in the waste vault. The tunnels outside the waste vault will be backfilled with bentonite, see Figure 4-4 and Figure 11-2.

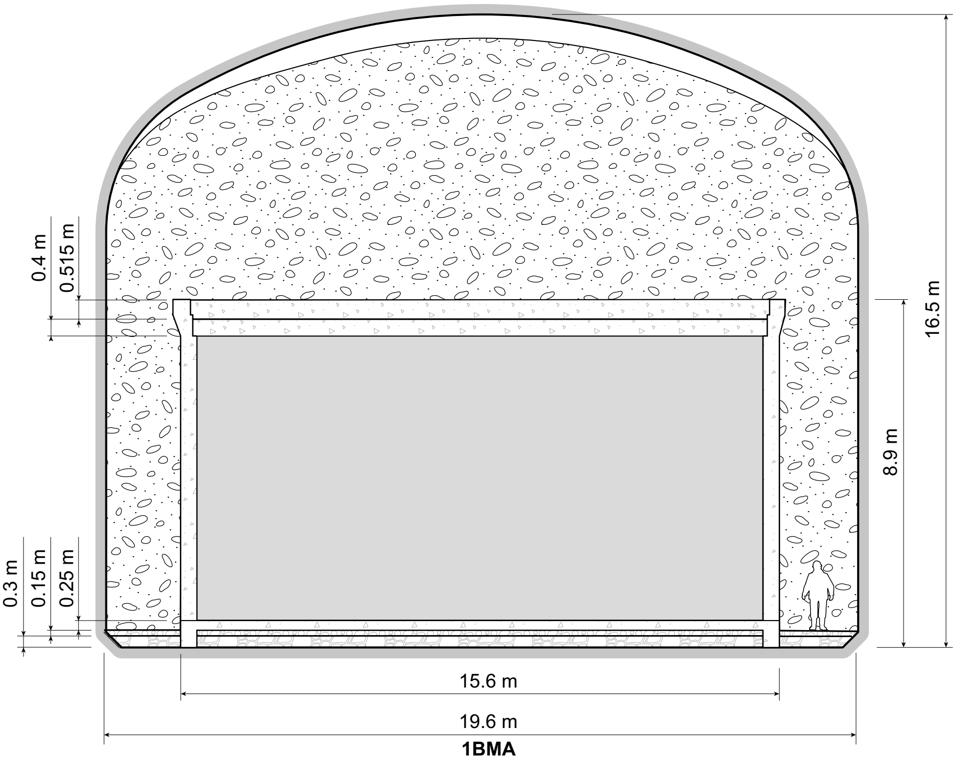

Figure 4-3. Schematic cross-section of 1BMA after closure. The dimensions of 1BMA are given in detail in Table 4-1.

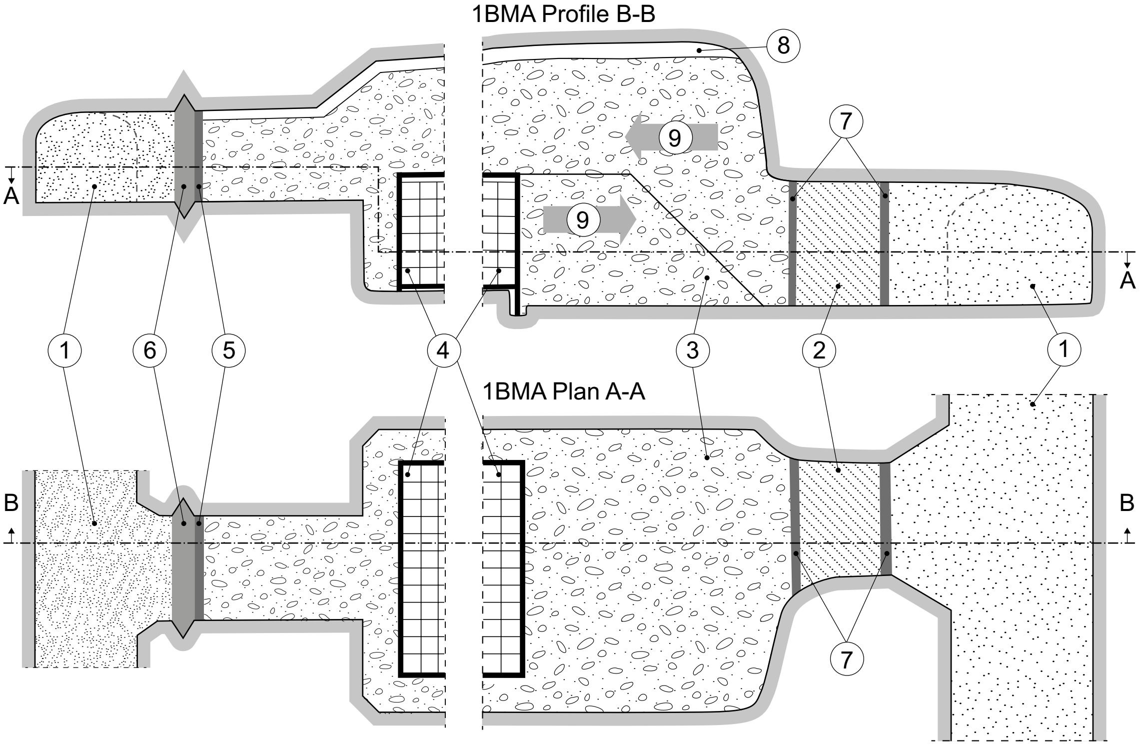

Figure 4-4. Schematic profile and plan of 1BMA after closure. Key to numbering: 1) Bentonite 2) Transition material, e.g. 30/70 mixture of bentonite and crushed rock 3) Macadam 4) Grouted waste packages 5) Constraining wall and concrete form 6) Mechanical plug of concrete 7) Constraining wall of concrete for transition material 8) Open gap between top surface of macadam and tunnel roof 9) Working direction for backfilling of waste vault.

4.2 Design considerations

The presented design of 1BMA in this report constitutes a solution that is technically feasible. However, it is foreseen that the design of sealing and closure of 1BMA can be further developed and optimised before closure of SFR.

Functions considered for the surrounding rock

The depth of 1BMA (~70 m) results in favourable conditions with respect to mechanical stability, low groundwater flow and redox conditions.

Functions considered for the system components in 1BMA

Level of radioactivity – The level of radioactivity in the waste deposited in 1BMA are mainly lower than those in the silo waste. The most important radiological safety principle is dependent on the radioactivity in the waste packages being limited. The waste consists mainly of ion-exchange resins solidified with cement/bitumen and some concrete embedded solid waste. The acceptance criteria for the waste packages are given in Section 3.2.

The requirements on waste packages with respect to level of radioactivity and design will together with the design of the system components in 1BMA give radiation protection during the operating phase and enhance the long-term safety.

Limited advective transport – Water flow in the interior of the compartments and through the waste packages will be limited. In 1BMA, the hydraulic contrast between the permeable macadam backfill surrounding the concrete structures and the less permeable concrete structure enclosing the waste diverts water flow away from the compartments to the more permeable surrounding materials. In addition, the grout in the interior of the compartments will initially be more permeable than the waste packages (waste form and packaging) and thereby limit the potential flow through the waste packages.

The inflow of water to 1BMA from connecting tunnels will be limited by the plugs in the ends of the waste vault and the bentonite backfilled sections in the connecting tunnels, see Section 11.1.

Mechanical stability – The long-term stability of the waste vault and the concrete structure (for example the stability against rock fallout) is enhanced by backfilling the waste vault with macadam. Each compartment will have at least two rows of concrete moulds that support the concrete lid and the macadam backfill on top of the lid.

The gap between walls and lid will act as a pathway for gas formed due to corrosion of metals in the waste packages. A permeable grout is used to allow gas produced inside the compartments to escape.

Limited dissolution – The dissolution of radionuclides from the bitumen-solidified waste is determined by the limited rate of water uptake in bitumen. The dissolution of some radionuclides, such as Ni-63 and Ni-59, will be solubility limited and the release of radionuclides present as induced activity in metal will be determined by the corrosion rate of the metal.

Sorption – The vast majority of radionuclides released from cement-solidified waste or concrete-embedded waste will be retarded by sorption on these cementitious materials. In addition, the radionuclide release from all waste matrices, including bitumen, will be limited by sorption in the concrete moulds, the concrete grout surrounding waste packages, the concrete structures and the macadam outside the concrete structures.

Favourable water chemistry – The water chemistry in the waste vault will be influenced by the chemical composition of intruding groundwater and the large amounts of cementitious materials in the waste packages, grout and structures. The resulting alkaline environment will limit the rates of corrosion and microbial degradation.

Reducing conditions will be established soon after closure of the vault due to metal corrosion and microbial degradation, that is favourable for the sorption of many radionuclides e.g. technetium and some actinides.

4.3 Inspection and control of 1BMA

An extensive investigation of the concrete structure in 1BMA revealed that repair and reinforcement measures need to be adopted to achieve the desired hydraulic and mechanical properties at closure. The Closure plan for SFR (SKBdoc 1358612) describes the planned measures for closure of 1BMA.

The inspection and control of 1BMA can be divided into the following three steps.

- Control and inspection of concrete structures in the waste vault during construction.
- Control and inspection of conditions in the waste vault during the emplacement of waste – the operating phase.
- Final inspection of the waste vault and concrete structures before backfilling with macadam and closure with plugs.

4.4 1BMA dimensions and material quantities

The main dimensions of the waste vault 1BMA are given in Table 4-1. The excavated volume is 48,000 m^3 and the estimated volumes of different materials in the waste vault after closure are given in Table A-2 in Appendix A. The total void in the vault including void and porosities in the materials are also given in Table A-2 in Appendix A.

The quantities of different materials in the waste packages in the different compartments in 1BMA are given in Table A-3 in Appendix A.

The dimensions and quantities given here and in Appendix A are valid for the present design. However, planned measures to be taken to improve the concrete structure are not defined in detail and therefore not included.

Table 4-1. 1BMA dimensions.

1BMA property	Value	Comment*
Excavated rock cavity		
Total length [m]	160	Calculated from values (120+40) given in drawing 1411−10020800
Width [m]	19.6	Value given in drawing 1411-10020810
Height (max) [m]	16.5	Value given in drawing 1411-10020810
Height average [m]	15.3	Calculated 300/19.6
Vertical cross-sectional area [m^2]	300	Value given in Closure plan for SFR (SKBdoc 1358612)
Excavated volume [m^3]	48,000	Calculated 160·300
Shotcrete thickness [m]	0.05	From Carlsson and Christiansson 2007, Table 6-2 Un-reinforced 1 or 2 layers: 0.03 or 0.05 m Fibre reinforced: 0.05 or 0.08 m
Inner zone (at tunnel TT)		
Length [m] (outside concrete wall)	2.4/4.95	Given in drawings 1470−10097060 and 1411-10020800. 2.4 m with full cross-sectional area and 2.55 m with smaller cross-sectional area, but within the total length of 160 m
Waste disposal area		
Concrete structure		
Length outer [m]	139.85	Calculated from values (174.650+0.400–35.200) given in drawings 1-1009702, 1-1009703
Width outer [m]	15.62	Calculated from values given in drawing 1-1009703 (0.4+0.4+14.82 ± 0.03 m)
Height outer wall [m] (above floor)	8.215	Standing on floor. Calculated from values given in drawing 1-1009708 (0.915+7.3)
Outer concrete lid [m]	0.515	Value given in Closure plan for SFR (SKBdoc 1358612)
Prefabricated concrete lid (reinforced) [m]	0.4	Value given in Closure plan for SFR (SKBdoc 1358612)
Thickness outer walls (reinforced) [m]	0.4	Value given in drawings 1-1009702 and 1-1009703
Thickness outer wall facing inner zone at tunnel TT (reinforced) [m]	0.4	Value given in drawing 1-1009702
Thickness outer wall facing reloading zone at tunnel BST (reinforced) [m]	0.6	Value given in drawing 1-1009703
Concrete floor (reinforced) [m]	0.25	Value given in drawing 1-1009727, 1-1009728. The floor also has beams below the walls and in the middle, the height of the beams bellow the outer side walls increases with the depth of the ditches of the vault. The other beams are 0.15 m.
13 large storage compartments		
Length inner [m]	9.9	Value given in drawings 1-1009702 and 1-1009703 (9.90 ± 0.03 m)
Width inner [m]	14.82	Value given in drawings 1-1009702 and 1-1009703 (14.82 ± 0.03 m)
Height inner walls [m]	7.3	Calculated from values given in drawing 1-1009706 (422.32-415.02)
Thickness inner walls (reinforced) [m]	0.4	Value given in drawings 1-1009702 and 1-1009703
2 small storage compartments		
Length inner [m]	4.95	Value given in drawing 1-1009703 (4.95 ± 0.03 m)
Width inner [m]	7.21	Value 7.210 given in drawing 1-1009703 (thickness inner wall 0.4 m)
Height inner [m]	7.3	Calculated from values given in drawing 1-1009706 (422.32-415.02)
Bottom		
Macadam thickness [m]	0.15	Value given in drawing 1-1009727, 1-1009728
Rock fill thickness [m]	0.3	Min value given in drawing 1-1009727
Coarse concrete below beams height [m]	0.3	Typical value, given in drawings 1-1009727, 1-1009728
Reloading zone (at tunnel BST)		
Length [m] (outside concrete wall)	15.2	Calculated from values (160-2.4-2.55-139.85) given in drawings 1411−10020800 and 1470−10097060

* Drawing numbers in column "Comment" refer to SKB's internal documents.

5 2BMA

5.1 Design

As part of the planned extension of SFR, a vault for intermediate level waste from decommissioning will be built, see Figure 5-1. Based on experience from the existing vault for intermediate level waste, 1BMA, a number of improvements are suggested for the new vault. The most important improvements are:

- In the waste vault, 14 free-standing unreinforced concrete caissons with a base of 16×16 m and a height of more than 8 m are to be built.
- The concrete caissons will not have any supporting structures that rest on the solid rock, instead they will be founded on a base of crushed rock.
- The floor and walls of the concrete caisson will be cast in one step to limit the number of joints that are susceptible to fracture formation. Hence, this reduces the risk of fracture formation and minimises the risk of building in stresses in the structure.
- The overhead crane will be mounted on a system of columns along the rock wall and will not rest on the caissons.
- The volume around the waste packages has been increased to facilitate grouting of the caisson interior. The grout will make a contribution to the total load-bearing capacity of the caissons.

The walls and roof of the vault will be lined with shotcrete. The waste packages (mainly steel moulds and tetramoulds of steel) will be emplaced using the overhead crane. The caissons are planned to be successively grouted with a similar type of grout to that used for the silo shafts during the operating phase. Prefabricated concrete elements can, if needed, be placed on top of the caissons to act as radiation protection during the operating phase. The dimensions of the waste vault are given in Table 5-1 and Figure 5-2.

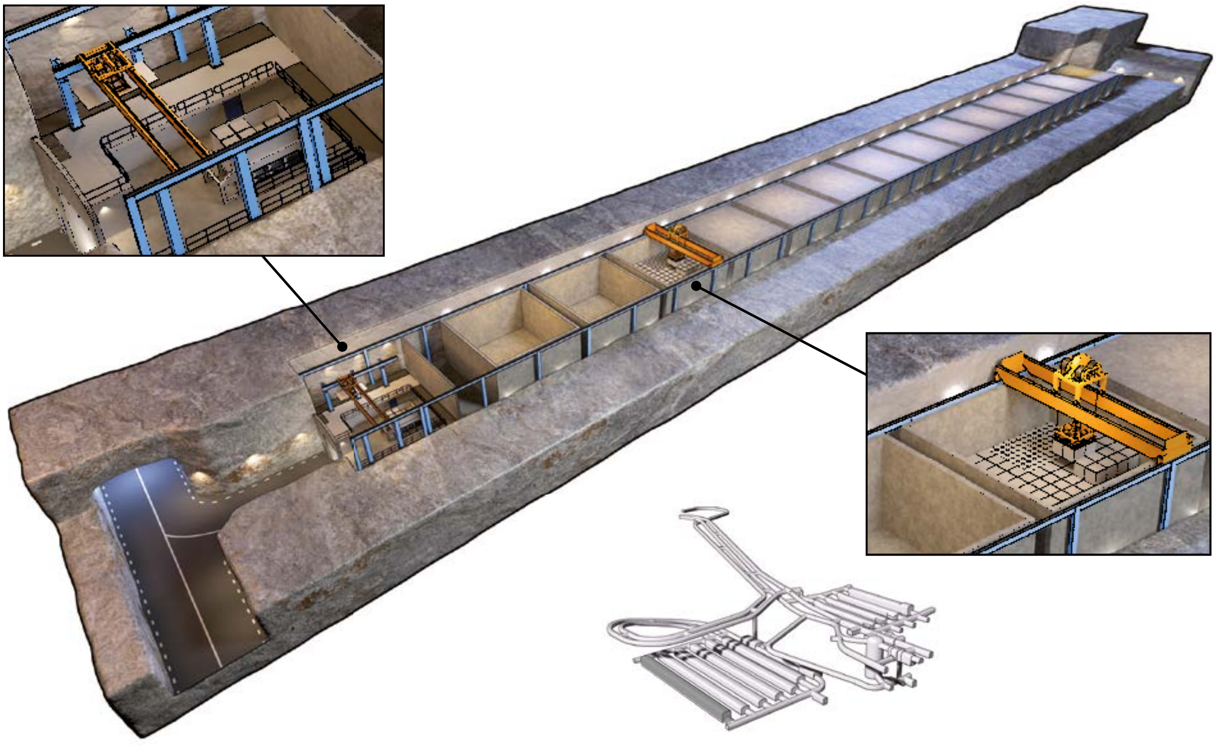

Figure 5-1. *Illustration of 2BMA during the operating phase. The upper detail shows the reloading zone, the lower details show the emplacement and a view of SFR with the position of 2BMA in SFR 3 highlighted.*

The demolition and dismantling of existing systems, for example the ventilation and electricity, will be adapted to the closure sequence. The Closure plan for SFR describes measures for the sealing and closure of 2BMA (SKBdoc 1358612). At repository closure, the prefabricated concrete elements (if installed) will be removed and an unreinforced concrete lid will be cast on top of the grout-embedded waste in the caisson. The space between caissons as well as between caissons and the rock wall and above the concrete lid is planned to be backfilled with macadam, see Figure 5-2. The geometry of the waste vault is such that concrete plugs can be installed at both ends of the waste vault as mechanical constraints for the bentonite in the connecting tunnels, see Figure 5-3 and Figure 11-2.

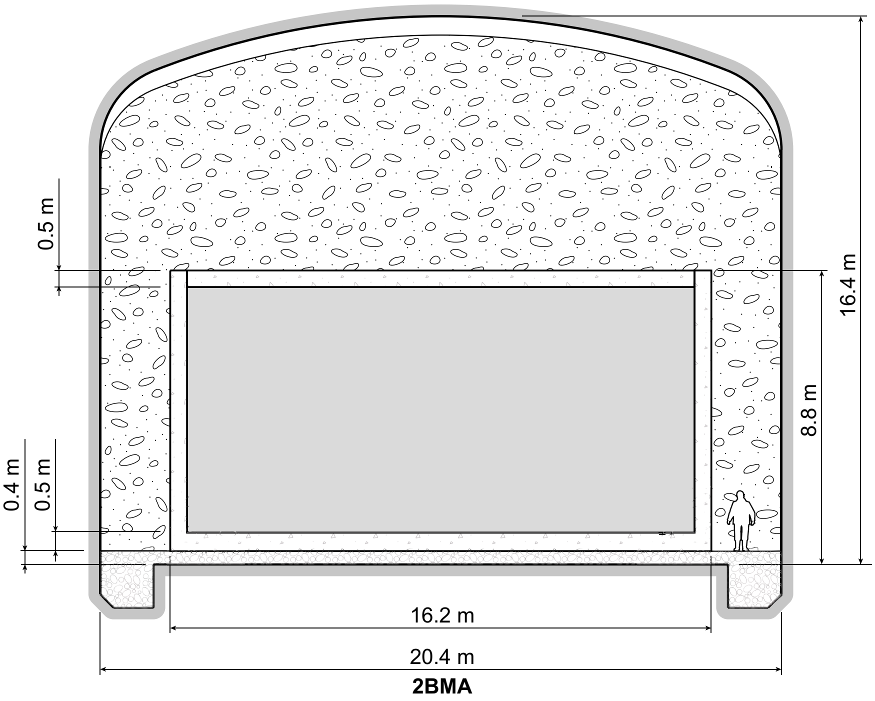

***Figure 5-2.** Schematic cross-section of 2BMA after closure. Note that the figure shows Layout 2.0; Layout 1.5 is used in SR-PSU modelling. The concrete structure has the same dimensions in Layout 1.5, but the width of the vault is 19.8 m and the height is 16.8 m. The dimensions of 2BMA are given in detail in Table 5-1.*

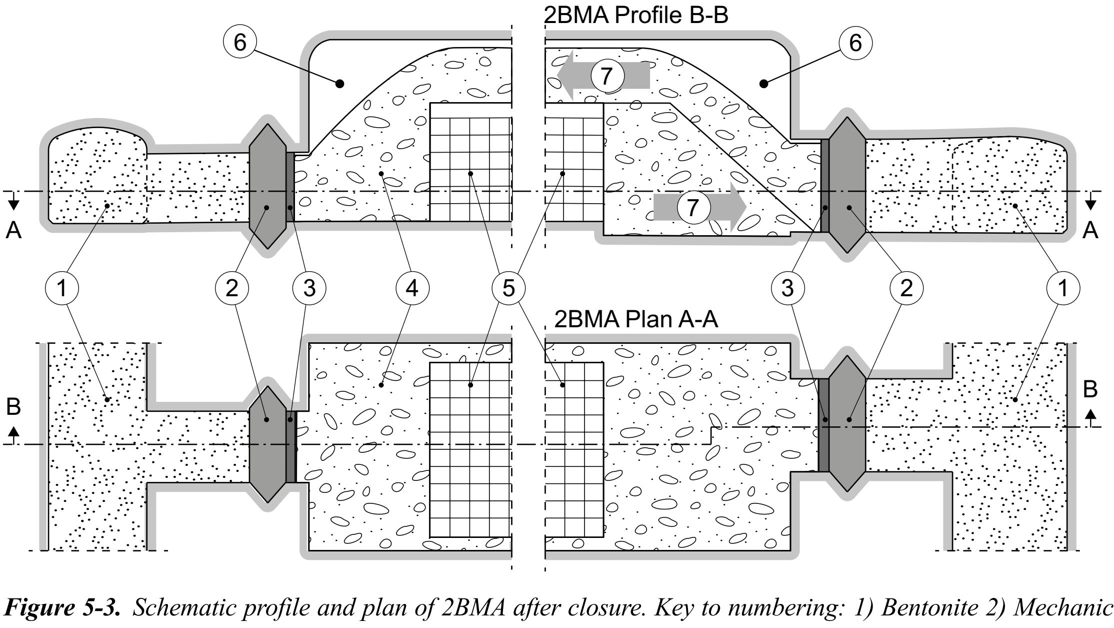

***Figure 5-3.** Schematic profile and plan of 2BMA after closure. Key to numbering: 1) Bentonite 2) Mechanical plug of concrete 3) Constraining wall and concrete form 4) Macadam 5) Grouted waste packages 6) Open gap between top surface of macadam and tunnel roof 7) Working direction for backfilling of waste vault.*

5.2 Design considerations

The suggested design for 2BMA is based on experience from the existing vault for intermediate level waste 1BMA.

Functions considered for the surrounding rock

The depth of 2BMA (~120 m) results in favourable conditions, with respect to mechanical stability, low groundwater flow and redox conditions.

Functions considered for the system components in 2BMA

Level of radioactivity – The level of radioactivity in the waste deposited in 2BMA is in the same order of magnitude as that in the waste allocated to 1BMA, which is lower than in the silo waste. The most important radiological safety principle is dependent on the radioactivity in the waste packages being limited. The waste consists mainly of concrete-embedded trash and scrap metal from decommissioning. The acceptance criteria for the waste packages are assumed to be similar to those for 1BMA.

The requirements on waste packages with respect to level of radioactivity and design will together with the design of the system components in 2BMA give radiation protection during the operating phase and enhance the long-term safety.

Limited advective transport – Water flow in the interior of the caissons and through the waste packages will be limited. In 2BMA, the hydraulic contrast between the permeable macadam backfill surrounding the concrete caissons and the less permeable concrete caissons diverts water flow away from the caissons to the more permeable surrounding materials. In addition, the grout surrounding the waste packages in the interior of the caissons will limit the potential flow through the waste packages.

The inflow of water to 2BMA from connecting tunnels will be limited by the plugs in the ends of the waste vault and the bentonite backfilled sections in the connecting tunnels, see Section 11.1.

Mechanical stability – The long-term stability of the waste vault and the integrity of concrete caissons (for example the stability against rock fallout) is enhanced by the concrete grout around waste packages in the caissons and the macadam backfill around and on the top of the caissons. The waste allocated to 2BMA will be solidified with cement or embedded in concrete, which contributes to the mechanical stability. The interaction between the different components, i.e. the caisson, grout and waste, ensures that the water pressure that develops will not lead to significant damage.

The casting joint formed between walls and lid in the caisson due to shrinkage of the concrete will act as a pathway for gas formed due to corrosion of metals in the waste packages. A permeable grout is used to allow gas produced inside the caissons to escape.

Limited dissolution – The dissolution of some radionuclides, such as Ni-63 and Ni-59, will be solubility limited and the release of radionuclides present as induced activity in metal will be determined by the corrosion rate of the metal.

Sorption – The vast majority of radionuclides released from the waste packages will be retained by sorption in the concrete grout surrounding the waste packages, concrete caissons and the macadam backfill outside the caissons. The allowed amounts of cellulose in the waste will be limited to such an extent that the sorption is not affected by degradation products e.g. ISA.

Favourable water chemistry – The water chemistry in the waste vault will be influenced by the chemical composition of intruding groundwater and the large amounts of cementitious materials in waste packages, caisson structures and grout in caissons. The resulting alkaline environment will limit the rates of corrosion and microbial degradation.

Reducing conditions will be established soon after closure of the vault due to metal corrosion and microbial degradation, that is favourable for the sorption of many radionuclides e.g. technetium and some actinides.

5.3 Inspection and control of 2BMA

The inspection and control of 2BMA can be divided into the following three steps.

- Control and inspection of the concrete caissons in the waste vault during construction.
- Control and inspection of the caissons and conditions in the waste vault during the emplacement of waste – the operating phase.
- Final inspection of the waste vault and concrete caissons before grouting, backfilling with macadam and closure with plugs.

The requirements on suppliers and materials to be used and methods for tests and inspections during construction will be defined in the detailed planning of the waste vault design. It is foreseen that requirements will be set on the construction of the caissons e.g. working personnel, receiving control for material, casting methods and controls, methods for inspection and control of cast caissons and documentation. In addition, programmes will be defined for control and maintenance to ensure that the required initial conditions of the concrete caissons at repository closure can be achieved.

5.4 2BMA dimensions and material quantities

The main dimensions of the waste vault 2BMA are given in Table 5-1. The values given in the column for Layout 1.5 are used in the long-term safety assessment for the SFR repository (SR-PSU). However, all other parts of the application for the extension are based on the values given in the column for Layout 2.0. The main differences between these are the height and width of the vault. The estimated volumes of different materials in the waste vault after closure are given in Table A-4 in Appendix A. The total void in the vault including void and porosities in the materials are also given in Table A-4 in Appendix A.

Table 5-1. 2BMA dimensions.

2BMA property	Value (Layout 1.5)	Value (Layout 2.0)	Comment*
Excavated rock cavity			
Total length [m]	275	275	Given in drawing SKBdoc 1391453
Width [m]	19.2	20.4	Layout 1.5, calculated from values (0.3+18.6+0.3) given in drawing SKBdoc 1316398 ver. 2.0 Layout 2.0, calculated from values (0.3+19.8+0.3) given in drawing SKBdoc 1391456 ver. 1.0
Vertical cross sectional area [m^2]	310	322	Layout 1.5 given in drawing SKBdoc 1316398 ver. 2.0 Layout 2.0, given in drawing SKBdoc 1391456 ver. 1.0
Height max [m]	16.8	16.4	Layout 1.5, calculated from values(16.41+0.4) given in drawing SKBdoc 1316398 ver. 2.0 Layout 2.0, calculated from values (0.4+15.71+0.3) given in drawing SKBdoc 1391456 ver.1.0
Height average [m]	16.1	15.8	Layout 1.5 calculated 310/19.2 Layout 2.0 calculated 322/20.4
Excavated volume [m^3]	85,250	88,550	Layout 1.5 calculated 275·310 Layout 2.0 calculated 275·322
Shotcrete thickness [m]	0.05	0.05	From Carlsson and Christiansson 2007, Table 6-2 Un-reinforced 1 or 2 layers: 0.03 or 0.05 m Fibre reinforced: 0.05 or 0.08 m
Inner zone (at tunnel 2TT)			
Length [m]	4.7	4.7	Calculated from values (24,255–19,555) given in drawing SKBdoc 1391802
Waste disposal area			
Concrete structure (14 disposal caissons)			
Length outer [m]	246.3	246.3	Calculated from values (14·16.2+13·1.5) given in drawings SKBdoc 1391802, 139803, 139804
Distance between caissons	1.5	1.5	Given in drawing SKBdoc 1391802
Width outer [m]	16.2	16.2	Given in drawing SKBdoc 1391456 ver. 1.0
Height outer [m]	8.4	8.4	Given in drawing SKBdoc 1391456 ver. 1.0
Concrete lid [m]	0.5	0.5	Given in drawing SKBdoc 1391456 ver. 1.0
Thickness outer walls [m]	0.5	0.5	Given in drawing SKBdoc 1391456 ver. 1.0
Concrete floor [m]	0.5	0.5	Given in drawing SKBdoc 1391456 ver. 1.0
Disposal caissons			
Width inner [m]	15.2	15.2	Calculated from values (16.2–0.5–0.5) given in drawing SKBdoc 1391456 ver. 1.0
Length inner [m]	15.2	15.2	Calculated from values (14·16.2+13·1.5) given in drawing SKBdoc 1391802
Height inner [m]	7.4	7.4	Calculated from values (8.4–0.5–0.5) given in drawing SKBdoc 1391456 ver. 1.0
Bottom			
Macadam/Rock fill thickness [m]	0.4	0.4	Given in drawing SKBdoc 1391456 ver. 1.0
Reloading zone (at tunnel 2BST)			
Length [m]	24	24	Calculated from 275–4.7–246.3

* Drawing numbers in column “Comment” refer to SKB’s internal documents.

6 1BTF and 2BTF

6.1 Design

The concrete tank vaults, 1BTF and 2BTF, have been designed primarily for storing concrete tanks and drums with low radioactivity. The walls and roofs of the two vaults are lined with shotcrete. The concrete floor is cast on a drained foundation and the floor is finished with a 1 m high moulded skirting to divert possible leaking water. The skirting is shown in a detail in Figure 6-1. In addition, a number of concrete pillars are cast to divide the vault into sections to facilitate future grouting of the waste vault.

In 1BTF, disposal sections for the emplacement of drums with ash are built by using concrete tanks as the outer walls and concrete moulds with low activity content and low surface dose rate as the inner walls. When six rows of drums have been piled, the supporting inner wall is mounted and the newly filled section is grouted with concrete, see Figure 6-1. In the vault, there will be about eight sections with drums and the remaining disposal volume, more than 50%, will be used for concrete tanks, see Figure 3-8.

In 2BTF, mainly concrete tanks will be stored; four abreast and two in height. The concrete tanks are emplaced by a truck on the floor, after which prefabricated concrete elements are placed on top as radiation shielding and a thin concrete layer is cast to protect the waste packages, see Figure 6-2.

The dimensions of the waste vaults 1BTF and 2BTF are given in Table 6-1 and Table 6-2 respectively and in Figure 6-3.

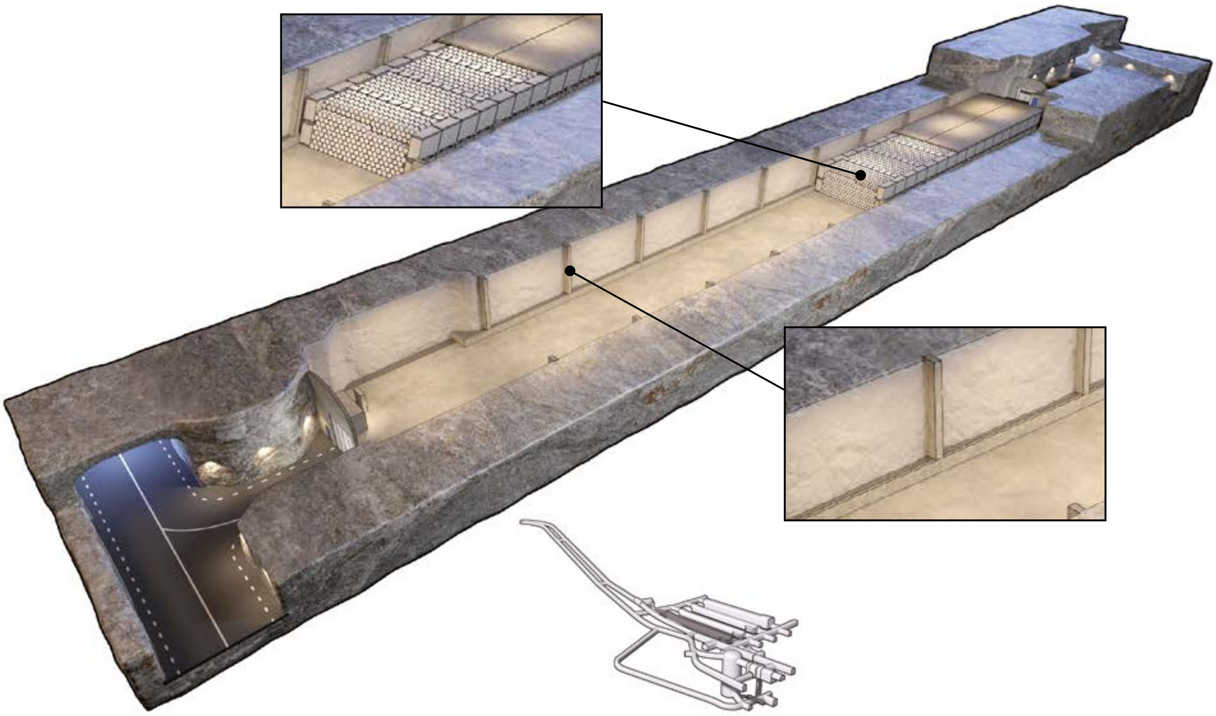

__Figure 6-1.__ Illustration of 1BTF during the operating phase. The upper detail shows the emplacement of the ash drums between concrete tanks, the lower detail shows the skirting and concrete pillars in addition there is a view of SFR 1 with the position of 1BTF highlighted.

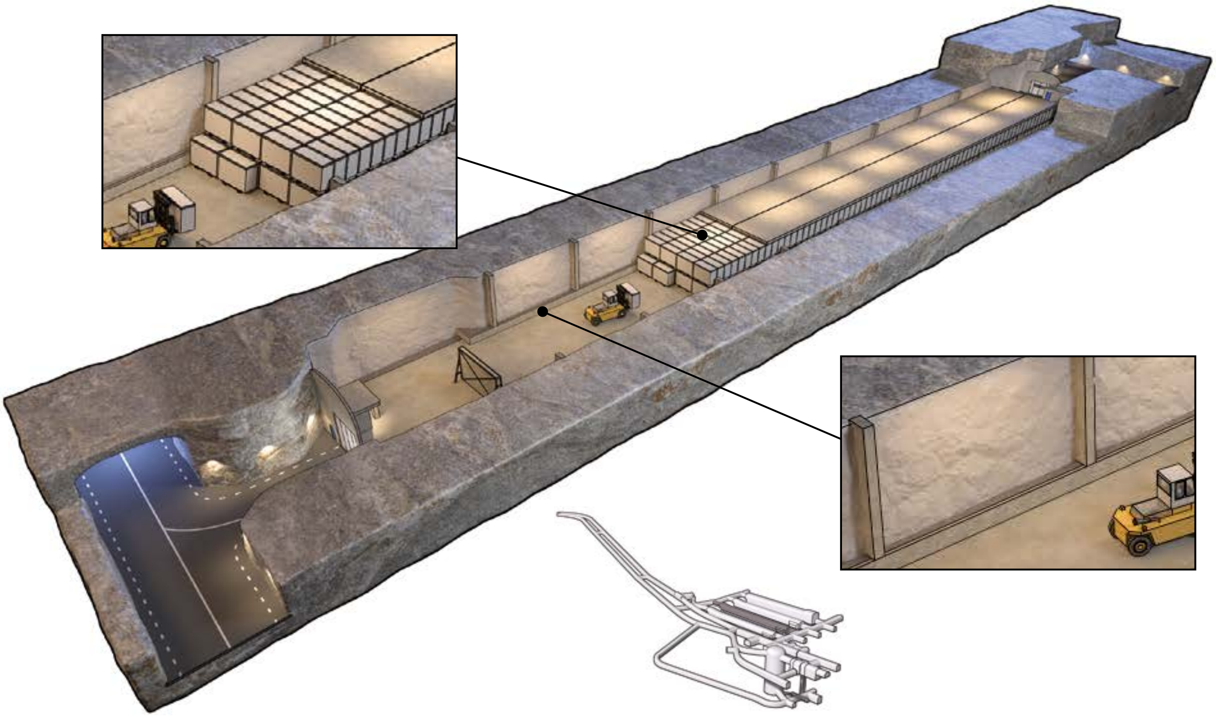

Figure 6-2. Illustration of 2BTF during the operating phase. The upper detail shows the emplacement of concrete tanks, the lower detail shows the skirting and concrete pillars in addition there is a view of SFR 1 with the position of 2BTF highlighted.

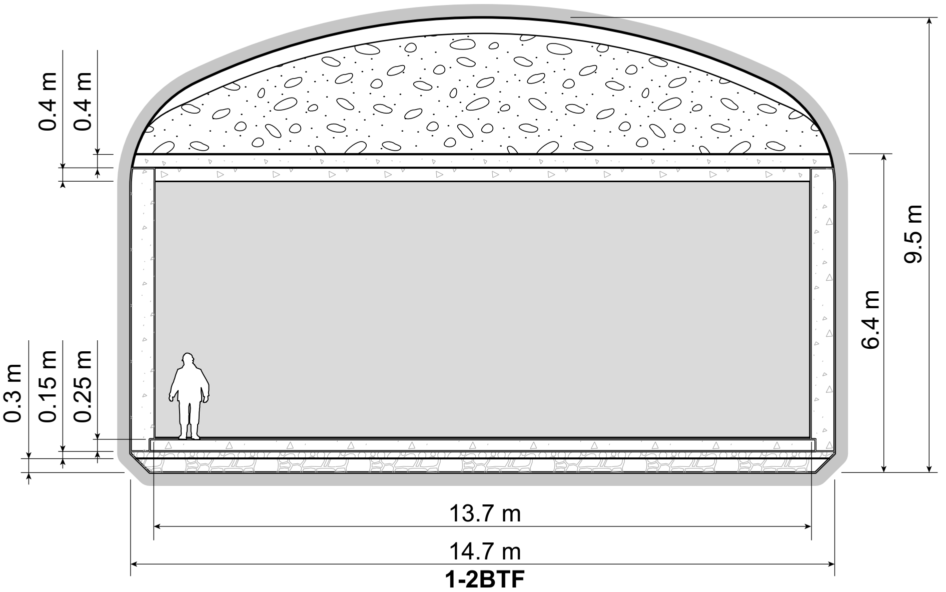

Figure 6-3. Schematic cross-section of 1BTF and 2BTF after closure. The dimensions of 1BTF and 2BTF are given in detail in Table 6-1 and Table 6-2, respectively.

The demolition and dismantling of existing systems, for example the ventilation and electricity, will be adapted to the closure sequence. The Closure plan for SFR describes measures for the sealing and closure of 1BTF and 2BTF (SKBdoc 1358612). In both waste vaults the space between the outer concrete tanks and the rock walls will be grouted with concrete.

In 2BTF, which will only contain concrete tanks, the spaces between the concrete tanks will be filled with grout and a concrete slab will be cast on top of the prefabricated concrete elements to bear the weight of the macadam. In 1BTF, the ash drums in the inner half of the waste vault are grouted during the operating phase, and the outer half, which only contains concrete tanks, will be grouted in the same way as in 2BTF near closure. Finally, the space above the grout and the concrete slab will be filled with macadam up to the roof, see Figure 6-3.

At the end of the vault that connects to the transverse tunnel (1TT), a concrete plug will be installed as a mechanical constraint for the bentonite in the tunnel. It is not possible to install a concrete plug in the connection to the waste vault tunnel (1BST); instead, here the mechanical constraint for the bentonite consists of a section with transition material and backfill material in the waste vault. The aim with the new rock profile (10 in Figure 6-4) is to increase the contact area between the macadam and the rock and thereby increase the mechanical support for the transition material in the plug. The tunnels outside the vaults will be backfilled with bentonite, see Figure 6-4 and Figure 11-2.

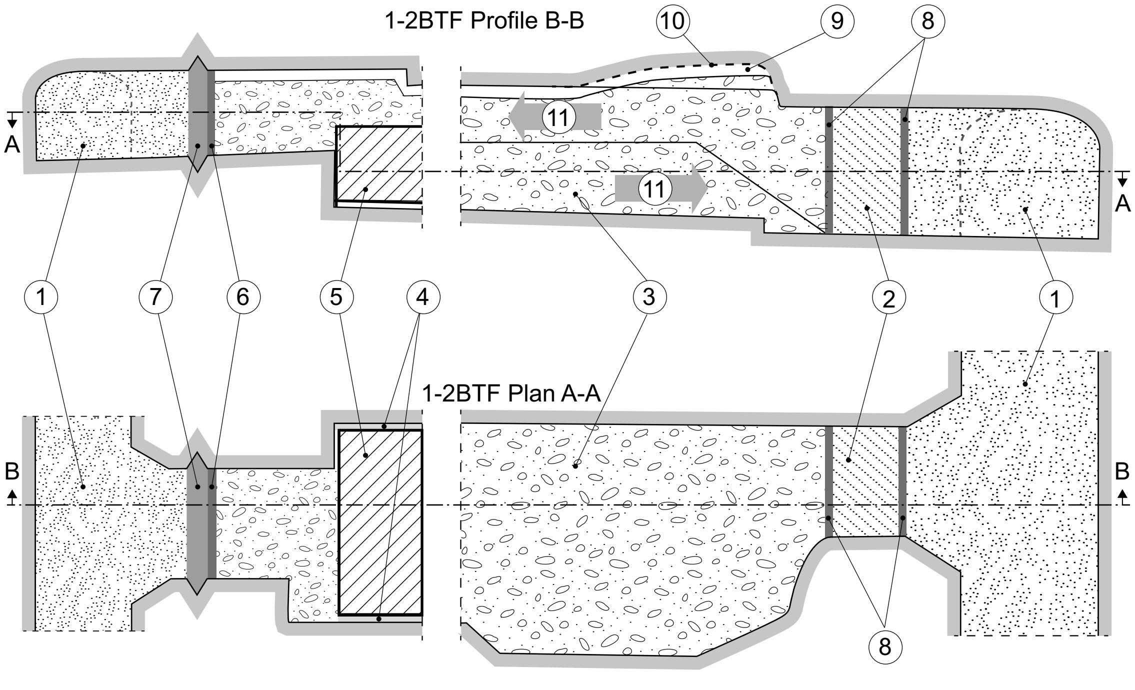

***Figure 6-4.** Schematic profile and plan of 1BTF and 2BTF after closure. Key to numbering: 1) Bentonite 2) Transition material e.g. 30/70 mixture bentonite crushed rock 3) Macadam 4) Concrete between waste and rock wall 5) Grouted waste packages 6) Constraining wall and concrete form 7) Mechanical plug of concrete 8) Constraining wall of concrete for transition material 9) Open gap between macadam and tunnel roof 10) New rock profile 11) Working direction when backfilling the waste vault.*

6.2 Design considerations

Functions considered for the surrounding rock

The location of 1BTF and 2BTF at a depth of about 70 m results in favourable conditions with respect to mechanical stability, low groundwater flow and redox conditions.

Functions considered for the system components in 1BTF and 2BTF

Level of radioactivity – The most important radiological safety principle is that the level of radioactivity in the waste packages is limited. The level of radioactivity in the waste deposited in 1BTF and 2BTF is lower than in the BMA waste and about 1% of the concentration in the silo waste. The waste deposited in the waste vaults is mainly dewatered ion-exchange resins in concrete tanks. However, drums with ashes from incineration are also disposed of in 1BTF, and concrete tanks and concrete moulds with low activity content are used as building components surrounding the piles of drums with ashes. The acceptance criteria for the waste packages are given in Section 3.2.

Limited advective transport – The flow through the waste packages will be limited. The plugs in the end of the tunnel in combination with the bentonite backfilled connecting tunnels should limit the inflow of water from the tunnel system, see Section 11.1. The water flow in the vault will be determined by the inflow to the waste vault from surrounding rock. In 1BTF and 2BTF the hydraulic contrast between the permeable macadam backfill and the less permeable pile with grouted waste packages will limit the flow through the waste.

In addition, the concrete tanks surrounding drums with ashes will limit the flow through the drums. As for all concrete packaging, the concrete will limit the flow through the waste form, i.e. the dewatered ion-exchange resins here.

Mechanical stability – The long-term stability of the waste vault is enhanced by the concrete grout between waste packages, the concrete between the pile of waste packages and the rock wall, and the backfilling of the waste vault with macadam. In addition, the reinforced concrete-tank walls are positive for the stability.

Limited dissolution – The release of radionuclides from the dewatered ion-exchange resins and ashes is not considered to be limited by dissolution.

Sorption – The radionuclides released from the waste packages can be retarded by sorption mainly in concrete walls in tanks and moulds, concrete grout surrounding the waste packages and the macadam above the waste pile. In addition for the drums containing ashes, radionuclides can be retarded by sorption in the concrete between the inner and outer drum.

Favourable water chemistry – The water chemistry in the waste vault will be influenced by the chemical composition of intruding groundwater and the large amounts of cementitious materials in waste packaging, concrete structures and concrete grout. The resulting alkaline environment will limit the rates of corrosion and microbial degradation.

Reducing conditions will be established soon after closure of the vault due to metal corrosion and microbial degradation, that is favourable for the sorption of many radionuclides e.g. technetium and some actinides.

6.3 Inspection and control of 1BTF and 2BTF

The inspection and control of the waste vaults can be divided into the following three steps.

- Control and inspection of the concrete structures in the waste vault during construction.
- Control and inspection of conditions in the waste vault during emplacement of waste – the operating phase.
- Final inspection of the waste vault and pile of waste packages before grouting with concrete, backfilling with macadam, and closure with plugs.

6.4 1BTF dimensions and material quantities

The main dimensions of the waste vault 1BTF are given in Table 6-1. The excavated volume is 20,640 m^3 and the estimated volumes of different materials in the waste vault after closure are given in Table A-5 in Appendix A. The total void in the vault including void and porosities in the materials are also given in Table A-5 in Appendix A.

Table 6-1. 1BTFdimensions.

1BTF property	Value	Comment*
Excavated rock cavity		
Total length [m]	160	Calculated from values (120+40) given in drawing 1411-10020820
Width [m]	14.7	Value given in drawing 1411-10020820
Height (max) [m]	9.5	Value given in drawing 1411-10020820
Height (average) [m]	8.8	Calculated 129/14.7
Vertical cross-sectional area [m^2]	129	Value given in Closure plan for SFR (SKBdoc 1358612)
Excavated volume [m^3]	20,640	Calculated 160·129
Shotcrete thickness [m]	0.05	From Carlsson and Christiansson 2007, Table 6-2, Un-reinforced 1 or 2 layers: 0.03 or 0.05 m Fibre reinforced: 0.05 or 0.08 m
Inner zone (at tunnel TT)		
Length [m] (between plug and concrete wall)	3.6	Value given in drawing 1411-10020820
Waste disposal area		
Concrete wall (reinforced)	0.3	Calculated from values (180–3.6–176.1) given in drawings 1411-10020820 and 1440-10021840
Length where waste can be stored [m] (behind concrete wall)	130	Assumed value
Width outer (4 concrete tanks incl. tolerances) [m]	13.7	Calculated from values (2·6,840) given in drawing 1442-10111590
Height outer (2 concrete tanks incl. tolerances) [m]	4.9	Calculated from values (0.15+2.3+0.15+2.3) given in drawing 1440-10570770
Cast outer concrete lid (reinforced) [m]	0.4	Value given in Closure plan for SFR (SKBdoc 1358612)
Prefabricated reinforced concrete lid on concrete tanks (cast on sections with drums [m]	0.4	Assumed value. Based on values given in drawing 1442-10111600 (max 0.6, min 0.35 most of it 0.42 m)
Thickness of concrete grout between concrete tanks and rock wall (incl. concrete structures for drainage and stabilisation [m]	0.5	Calculated from values (14.7–13.7)/2 given in drawings1411-10020820, 1442-10111590 and disposal of concrete tanks, see Section 3.7.4
Thickness supporting wall facing reloading zone (reinforced) [m]	0.3	Assumed same wall thickness as wall facing tunnel TT
Concrete floor (reinforced) [m]	0.25	Value given in drawing 1442-10153280
Bottom		
Macadam thickness [m]	0.15	Value given in drawing 1442-10153280
Rock fill thickness [m]	0.3	Value assumed from drawing 1442-10153280
Reloading zone (at tunnel BST)		
Length [m] (between outer supporting wall and plug)	25.8	Calculated from values given above:160–(3.6(inner zone)+2·0.3(concrete wall))–130. Assumed same as 2BTF
1BTF disposal structure for drums		
Number of concrete tanks in outer “wall” in 1 “compartment”		
height	2	See Section 3.7.4
length	2	See Section 3.7.4
Number of concrete moulds in inner “wall”		
height	4	See Section 3.7.4
length	9	See Section 3.7.4
Number of drums in 1 “compartment”	1,110	6 rows with about 185 drums in each row, See Section 3.7.4
Total length (8 “compartments”)	55.7	Assumed (1.3+16·3.3+16·0.1)
Height outer (2 concrete tanks incl. tolerances) [m]	4.9	Calculated from values (0.15+2.3+0.15+2.3) given in drawing 1440-10570770
Thickness outer “wall” (concrete tank) [m]	1.3	Inventory report (SKB 2013b)
Thickness inner “wall” (concrete mould) [m]	1.2	Inventory report (SKB 2013b)
Width inner [m]	11.1	Assumed (13.7–2·1.3)
Length inner [m]	5.6	Assumed (2·3.3+2·0.1–1.2)

* Drawing numbers in column “Comment” refer to SKB’s internal documents.

6.5 2BTF dimensions and material quantities

The main dimensions of the waste vault 2BTF are given in Table 6-2. The excavated volume is 20,640 m^3 and the estimated volumes of different materials in the waste vault after closure are given in Table A-6 in Appendix A. The total void in the vault including void and porosities in the materials are also given in Table A-6 in Appendix A.

Table 6-2. 2BTFdimensions.

2BTF property	Value	Comment*
Excavated rock cavity		
Total length [m]	160	Calculated from values (120+40) given in drawing 1411-10020840
Width [m]	14.7	Value given in drawing 1411-10020840
Height (max) [m]	9.5	Value given in drawing 1411-10020840
Height (average) [m]	8.8	Calculated 129/14.7
Vertical cross-sectional area [m^2]	129	Value given in Closure plan for SFR (SKBdoc 1358612)
Excavated volume [m3]	20,640	Calculated 160·129
Shotcrete thickness [m]	0.05	From Carlsson and Christiansson 2007, Table 6-2, Un-reinforced 1 or 2 layers: 0.03 or 0.05 m Fibre reinforced: 0.05 or 0.08 m
Inner zone (at tunnel TT)		
Length [m] (between plug and concrete wall)	3.6	Value given in drawing 1411-10020840
Waste disposal area		
Concrete wall (reinforced)	0.3	Assumed same as 1BTF
Length where waste can be stored [m] (behind concrete wall)	130	Assumed value
Width outer (4 concrete tanks incl. tolerances) [m]	13.7	Calculated from values (2·6,840) given in drawing 1442-10111590
Height outer (2 concrete tanks incl. tolerances) [m]	4.9	Calculated from values (0.15+2.3+0.15+2.3) given in drawing 1440−10570770
Cast outer concrete lid (reinforced) [m]	0.4	Value given in Closure plan for SFR (SKBdoc 1358612)
Prefabricated reinforced concrete lid on concrete tanks (cast on sections with drums [m]	0.4	Assumed value. Based on values given in drawing 1442-10111600 (max 0.6, min 0.35 most of it 0.42 m)
Thickness of concrete grout between concrete tanks and rock wall (incl. concrete structures for drainage and stabilisation [m]	0.5	Calculated from values (14.7–13.7)/2 given in 1411-10020840, 1442-10111590
Thickness supporting wall facing reloading zone (reinforced) [m]	0.3	Assumed same wall thickness as wall facing tunnel TT
Concrete floor (reinforced) [m]	0.25	Value given in drawing 1452-10153630
Bottom		
Macadam thickness [m]	0.15	Value given in drawing 1452-10153630
Rock fill thickness [m]	0.3	Value assumed from drawing 1452-10153630
Reloading zone (at tunnel BST)		
Length [m] (between outer supporting wall and plug)	25.8	Calculated from values given above:160–(3.6(inner zone) +2·0.3(concrete wall))–130

* Drawing numbers in column “Comment” refer to SKB’s internal documents.

7 Silo

7.1 Design

The silo consists of a cylindrical vault in which a free-standing reinforced concrete cylinder has been erected. The concrete cylinder is constructed of in-situ cast concrete and is founded on a layer of 90% sand and 10% bentonite by weight. The slot between the reinforced concrete walls and the surrounding rock is filled with bentonite. The bentonite is a sodium montmorillonite with the product name GEKO/QI. The rock itself is covered with shotcrete and there is a rock drainage system for groundwater between the rock and the bentonite. The drainage system goes from the top to the bottom of the silo and is installed to limit the water uptake in the bentonite and the risk for development of non-uniform swelling pressures.

The interior of the concrete cylinder is divided into vertical shafts with intervening concrete walls. Conditioned intermediate-level waste is deposited in the silo in concrete and steel moulds as well as in steel drums (on a drum tray or in a steel box). The waste packages are placed in the shafts and the voids between the packages are gradually grouted with concrete, see Figure 7-1 and Figure 7-2. A permeable grout is used to allow gas produced inside the shafts to escape. During operation, each shaft is provided with a radiation-shielding lid that is removed at closure. The dimensions of the silo are given in Table 7-3 and in Figure 7-3.

Figure 7-1. *Illustration of the silo during the operating phase.*

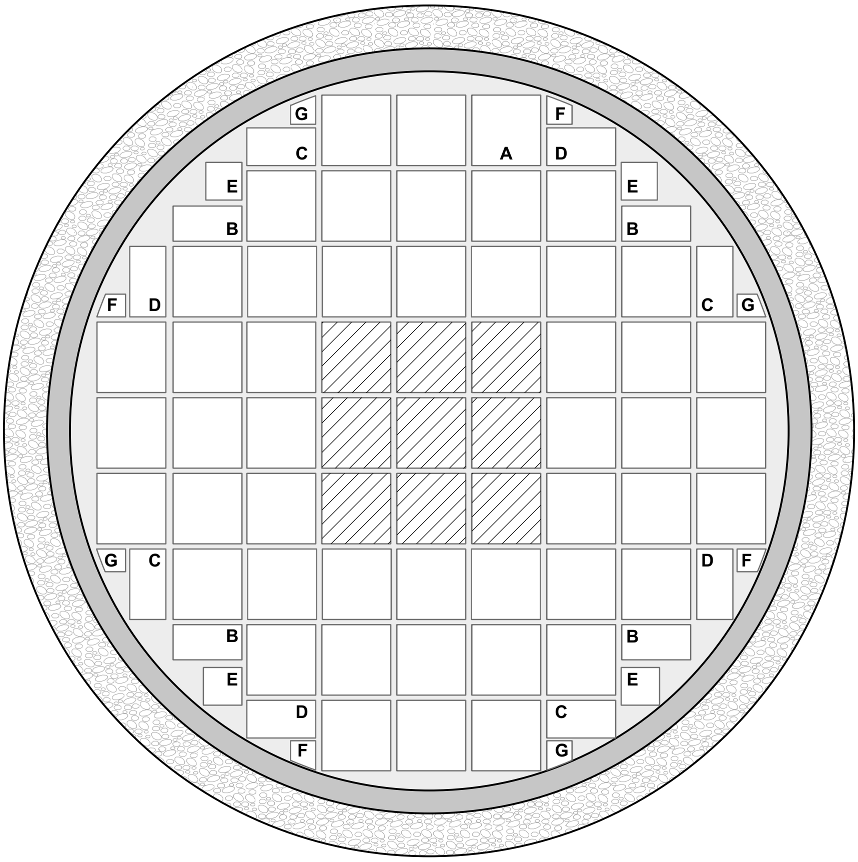

***Figure 7-2.** Schematic illustration from above of the division of the silo in shafts, indicating the location of the bituminised wastes in the central shafts. A denotes full-size shafts; B, C and D half-size shafts; E quarter-size shafts; F and G small shafts. There are also small shafts in the periphery that are assumed to be backfilled with grout and hence they are not shown in the figure.*

The demolition and dismantling of existing systems, for example the ventilation and electricity, will be adapted to the closure sequence. The Closure plan for SFR described measures for the sealing and closure of the silo (SKBdoc 1358612). In an initial step, the shafts are overcast with concrete grout up to the top rim of the concrete silo. This provides a radiation shield on top of the concrete silo, which simplifies the work of reinforcing and casting a concrete lid. The concrete lid is cast on a thin layer of sand and provided with evacuation pipes in order to allow escape of the gas that is generated inside the concrete cylinder, see Figure 7-4. The top bentonite layer in the gap between rock and concrete silo may have been affected during the operating phase and is to be replaced with new bentonite.

The silo top above the concrete lid is to be backfilled with different layers of backfill material. A mixture of sand and bentonite is placed on top of a thin layer of sand and protected by a thin unreinforced concrete slab. The remaining void above the sand bentonite mixture is backfilled with packed friction material e.g. crushed rock or macadam and, at the very top, with cement-stabilised sand, see Figure 7-4. Finally, the tunnels at the top and bottom of the silo are planned to be sealed off by three plug sections, see Section 11.1 and Figure 11-3.

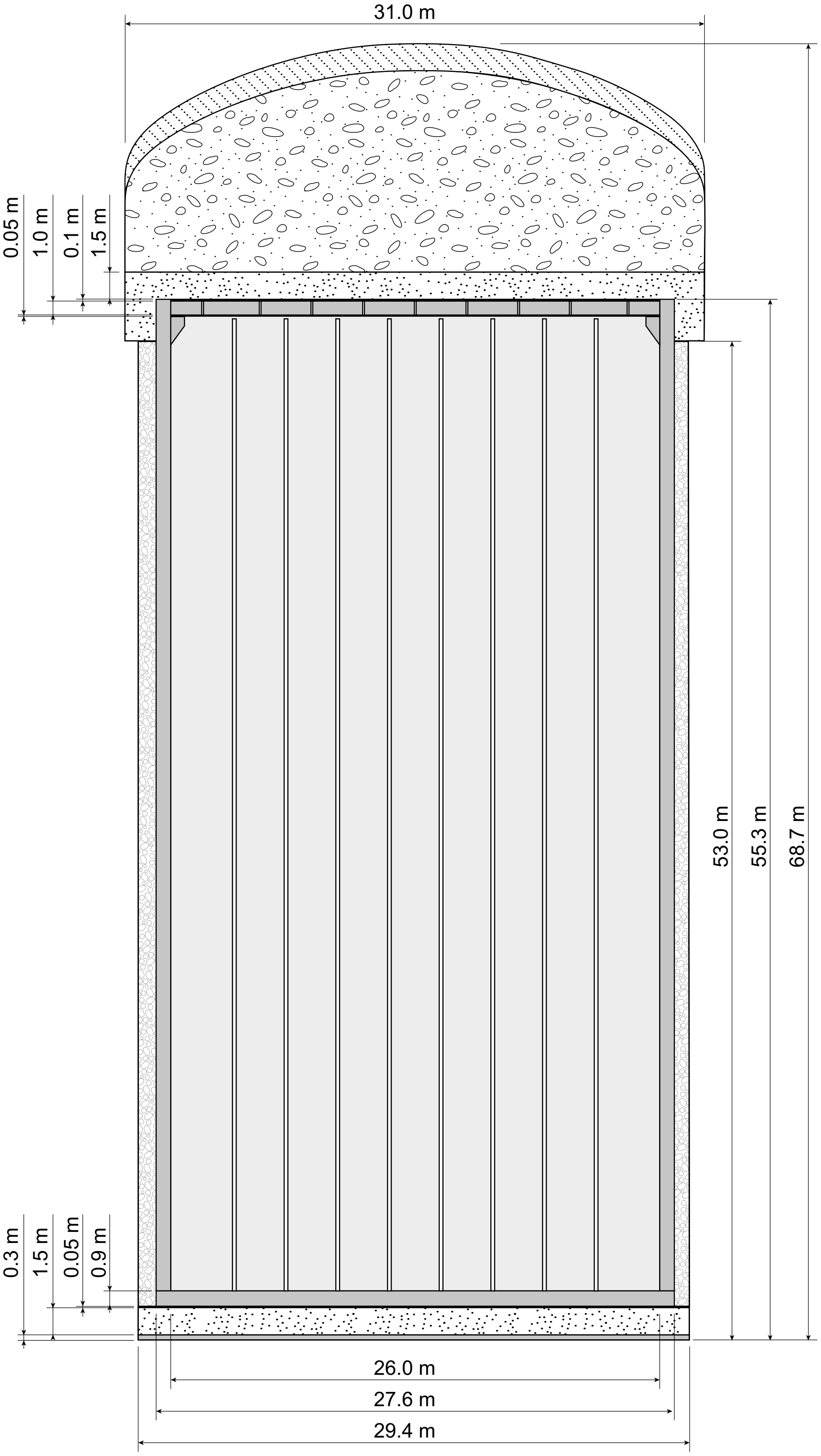

Figure 7-3. *Schematic cross-section of the silo after closure. The dimensions of the silo are given in detail in Table 7-3.*

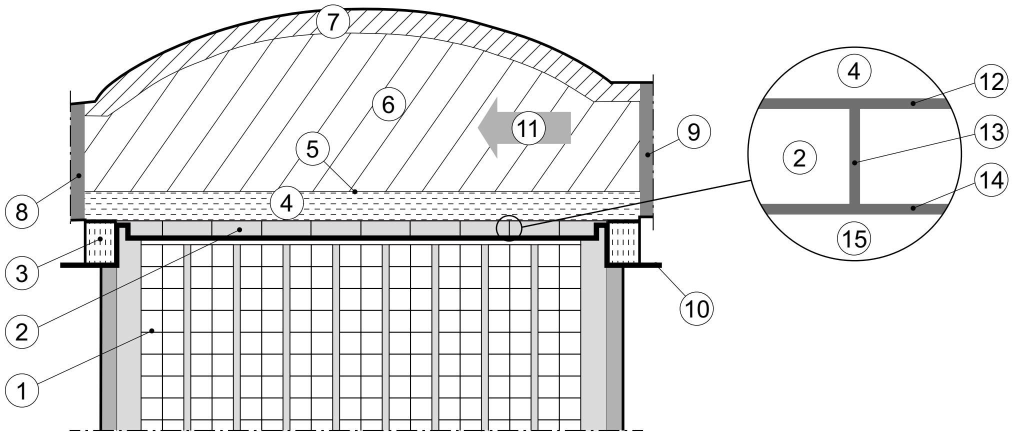

Figure 7-4. Schematic cross-section of silo top after closure. Key to numbering: 1) Waste 2) Reinforced concrete slab with sand layer and gas evacuation pipes 3) Compacted fill of 30/70 bentonite/sand mixture 4) Compacted fill of 10/90 bentonite/sand mixture 5) Unreinforced concrete slab 6) Compacted fill of friction material 7) Cement-stabilised sand 8) Constraining wall of concrete against silo roof tunnel (1STT) 9) Constraining wall of concrete against loading-in building (IB) 10) Boundary between works associated with grouting and backfilling 11) Working direction for backfilling with material described in (6) and (7) 12) Sand layer 100 mm 13) Gas evacuation pipe Ø 0.1 m 14) Sand layer 50 mm 15) Grout (permeable).

7.2 Design considerations

Functions considered for the surrounding rock

The depth of the silo (~60 to 130 m) results in favourable conditions with respect to mechanical stability, low groundwater flow and redox conditions.

Functions considered for the system components in the silo

The silo has the most extensive barriers of the SFR vaults.

Level of radioactivity – The silo contains most of the radioactivity in SFR. Even though the level of radioactivity is greater than in the other waste vaults, limitation of the amount of radioactivity in the waste packages is an important factor for radiological safety. The waste is solidified with cement/bitumen or embedded with concrete to limit the release of radionuclides from the waste packages. The acceptance criteria for the waste packages are given in Section 3.2.

Limited advective transport – Water flow in the interior of the silo shafts and through the waste packages will be limited. The bentonite buffer surrounding the silo has a low hydraulic conductivity and will limit the advective flow through the silo. In addition, the shaft walls and concrete grout surrounding the waste packages will limit the potential flow through the waste packages.

The inflow of water to the silo top and the bottom from connecting tunnels will be limited by a number of plugs and bentonite backfilled sections in connecting tunnels, see Section 11.1.

Mechanical stability – The long-term stability of the silo concrete structure is enhanced by the concrete grout around waste packages and the bentonite buffer surrounding the silo concrete structure. The concrete structure is designed to withstand a swelling pressure from the surrounding bentonite of 500 kPa (Pusch 2003). The backfilling of the silo cupola will limit the effect of potential rock fallout from the silo roof. The gas transport properties of the selected concrete grout and the gas evacuation pipes in the silo lid are there to ensure that gas can be released.

Limited dissolution – The dissolution of radionuclides from the bitumen-solidified waste is determined by the limited rate of water uptake in the bitumen. The dissolution of some radionuclides, such as Ni-63 and Ni-59, will be solubility limited and the release of radionuclides present as induced activity in metal will be determined by the corrosion rate of the metal.

Sorption – The vast majority of radionuclides released from cement-solidified waste or concrete-embedded waste will be retarded by sorption on these cementitious materials. In addition, the radionuclide release from all waste matrices, including bitumen, will be limited by sorption in the concrete moulds, the concrete grout surrounding waste packages, the silo's concrete walls and the bentonite outside the concrete structures.

Favourable water chemistry – The water chemistry in the silo is influenced by the large amounts of cementitious materials in the waste packages, silo structures and concrete grout. The resulting alkaline environment will limit the rates of corrosion and microbial degradation. In addition, the creation of reducing conditions in the silo shafts that is caused by the consumption of oxygen by aerobic corrosion will favour the sorption of many radionuclides e.g. technetium and some actinides.

7.3 Inspection and control of the silo

The inspection and control of the silo can be divided into the following steps.

- Inspection and control of the concrete structures in the silo during construction.
- Inspection and control of the bentonite material surrounding the silo's concrete walls and bottom during construction.
- Inspection and control of the silo during the emplacement of waste. Measurements are made regularly (e.g. measurements of the settlement of the silo, silo top subsidence and swelling pressures in the surrounding buffer).
- Final inspection of the silo top before backfilling with friction material e.g. crushed rock.

Construction

The concrete silo was constructed using a slip form. The concrete structure rests on a bed of a mixture of 10% finely ground GEKO/QI bentonite and 90% sand. The bed material was applied in several layers and compacted to get the required density. Pure GEKO/QI bentonite granulate with a grain size ranging between 0.1 and 20 mm was used to fill the gap between the silo concrete walls and the rock. The filling material was not compacted. Frequent measurements and tests were made of the bentonite material properties of the installed materials (Pusch 2003).

Settlement of the silo

Settlement has been measured regularly in the silo since its construction in 1987. Annual data gathered up to 1999 and model predictions suggested that the settlement process was so slow and predictable that its progress could be checked and reported on every three years. However, since 2002 the measurements have been made on yearly basis. Figure 7-5 shows the measured settlement of the silo top from year 1987 (year 1) to 2010 (year 23) as well as the predicted settlement over the next ten years, based on a viscoelastic model.

The settlement of the silo is small and is not judged to deviate from the original expectation of about five centimetres by year 2040. The settlement is steady and decreasing. The accuracy in the measurements is judged to be in the order of ± 0.3 mm (Pusch 2003).

Vertical movements of the bentonite top filling

Reference bolts were anchored in the shotcreted rock early after the construction of the silo and corresponding bolts were cast in the silo so that its vertical movements can be measured by precision levelling. The measured movements of the bentonite top filling are shown in Table 7-1. It can be concluded from the recent years' measurements that the movements have been small. These small movements show that no significant wetting has yet occurred of the bentonite wall fill, which in turn suggests that the wall drainage is functioning as intended (Pusch 2003).

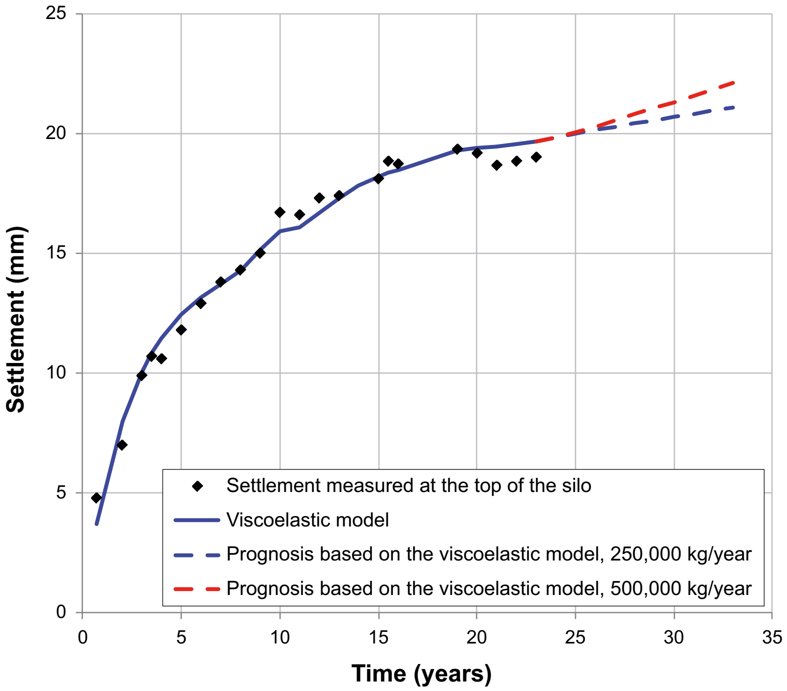

Figure 7-5. *Measured movements (dots), viscoelastic model (full line) and predicted settlements with the viscoelastic model for two different prognoses on future waste load (dotted lines).*

Table 7-1. Movements in the bentonite top filling (mm). (+settlements and –upheaval)

Date	Measuring point					
	A		B		D	
	Silo	Rock	Silo	Rock	Silo	Rock
Sep 1999	+7.5	+1.0	0.0	–1.0	–37.0	–4.0
Sep 2000	+7.5	+1.0	+1.6	–1.4	–39.8	–3.8
Sep 2001	+8.0	+1.0	+2.0	–2.0	–41.0	–5.0
Oct 2002	+8.0	+1.0	+1.0	–2.0	–42.0	+1.0
Jun 2003	+8.3	+1.0	+1.9	–1.6	–42.9	–5.6
Sep 2003	+8.3	+0.8	+1.9	–1.6	–42.9	–5.6
Sep 2006	+8.7	+1.3	+0.9	–2.2	–44.2	–5.6
Sep 2007	+8.4	+1.1	+0.8	–1.9	–44.4	–5.8
Sep 2008	+8.0	+0.7	+0.4	–1.9	–44.2	–5.1
Sep 2009	+8.7	+1.6	+0.4	–2.0	–44.1	–5.4
Sep 2010	+8.6	+0.8	+0.7	–2.0	–44.5	–6.1
Change since Sep 1999	+1.1	–0.2	+0.7	–1.0	–7.5	–2.1

Pressure build up in the silo bentonite

A number of pressure cells are installed for measurement of the swelling pressure in the bentonite surrounding the concrete structure to ensure that the swelling pressure is below the tolerable level for the design. Pressure gauges are installed at floor level, mid-height level (25 m above the floor) and at silo top level (50 m above the floor). The most recent values are from 2010 and are roughly the same as the preceding measurements, see Table 7-2.

At the uppermost measurement level, the values have decreased slightly and are well below the acceptable pressure. At mid-height and the bottom of the silo, the pressures are considerably lower than the acceptable pressure. This indicates more effective dewatering of the surface rock and drainage than had been assumed at the design stage.

Table 7-2. Readings from the pressure build-up in the wall fill. For information on the location of the pressure cells, see Appendix in Pusch (2003).

	Measured pressures [MPa]								
	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**
Date	**0.130**[a)]	**0.130**[a)]	**0.140**[a)]	**0.130**[a)]	**0.140**[a)]	**0.330**[a)]	**0.340**[a)]	**0.080**[a)]	**0.050**[a)]
Oct 1992	0.070	0.070	0.065	0.055	0.030	0	0	0.045	0.015
Sep 2000	0.100	0	0.085	0.070	0.050	0	0	0.050	0.035
Sep 2001	0.095	0	0.085	0.065	0.050	0	0	0.050	0.030
Oct 2002	0.095	0	0.100	0.070	0.050	0	0	0.030	0.015
Sep 2004	0.095	0	0.090	0.065	0.055	0	0	0.050	0.040
Sep 2006	0.100	0	0.090	0.070	0.055	0	0	0.050	0.045
Sep 2007	0.095	0	0.090	0.070	0.055	0	0	0.050	0.050
Sep 2008	0.100	0	0.090	– [b)]	0.055	0	0	0.050	0.055
Sep 2009	0.105	0	0.095	– [b)]	0.055	0	0	0.045	0.050
Sep 2010	0.105	0	0.095	– [b)]	0	0	0	0.050	0.055
Change since Oct1992	0.035	–0.070	0.030	–	–0.030	0	0	0.005	0.040

a) Pressure required for Gloetzl piezometer to open. If the actual pressure is lower it is set as 0. Where pressure values are given they represent the excess pressure above the opening pressure and thereby the actual pressure (difference between measured pressure and opening pressure).

b) Leaking sensor.

7.4 Silo dimensions and material quantities

The main dimensions of the silo are given in Table 7-3. The silo is divided in 57 full-size shafts, 12 half-size shafts and a number of smaller shafts denoted C to G in Figure 7-2. In addition, there are several even smaller shafts that are assumed to be backfilled with grout. The excavated volume of the cylindrical vault for the silo is 45,900 m^3 and the estimated volumes of different materials in the silo after closure are given in Table A-7 in Appendix A. The total void in the vault including void and porosities in the materials are also given in Table A-7 in Appendix A.

Table 7-3. Silo dimensions.

Silo property	Value	Comment*
Excavated rock cavity		
Maximum height [m]	68.7	Calculated from values (435.7–367) given in drawing 1411-10020610
Diameter Silo cupola [m] (above cylindrical part)	31	Value given in drawing 1411-10020610
Diameter cylindrical part [m] (outside concrete silo)	29.4	Value given in drawing 1411-10020610
Height Silo cupola [m]	15.7	Calculated from values (435.7–420) given in drawing 1411-10020610
Height of cylindrical part [m] (Silo bottom to cupola)	53	Calculated from values (420–367) given in drawing 1411-10020610
Excavated volume [m^3]	45,900	Estimated
Bottom		
Cast coarse concrete for drainage system [m]	0.1	Calculated from values given in drawings1411-10020610 and 1-1010008, Periphery (367.1–367.1) and Centre (367.1 – 367.0), i.e 0–0.1 m
Concrete plate with drainage system [m]	0.2	Value given in drawing 1-1010008
Sand-bentonite (90/10) thickness [m]	1.5	Value given in drawing 1-1010008
Sand-bentonite (90/10) diameter [m]	28.6	Value radius 14.300 m given in drawing 1-1010012
Thin concrete layer	0.05	Value given in drawing 1-1010008
Thickness reinforced floor [m]	0.9	Value given in drawing 1-1010008
Concrete structure		
Diameter outer [m]	27.6	Value radius 13.800 m given in drawings 1-1010006, 1-1010021
Height outer walls [m] (standing on floor)	52.55	Calculated from values (422.3–369.75) given in drawing 1-1010008
Thickness cylindrical wall [m]	0.8	Value given in drawing 1-1010006
Height shaft walls [m]	51.3	Calculated from values (421.05–369.75) given in drawing 1-1010008
Thickness shaft walls [m]	0.2	Value given in drawings 1-1010021
57 Shafts full-size [m]x[m] – A	2.55x2.55	Values given in drawings 1-1010021. Type of shafts in drawing 3-1057070 and 42-1057063
12 Shafts half-size [m]x[m] – B,C,D	2.55x1.35	Values given in drawings 1-1010021. Type of shafts in drawing 3-1057070 and 42-1057063
4 Shafts quarter-size [m]x[m] – E	1.3x1.3	Values given in drawings 1-1010021. Type of shafts in drawing 3-1057070 and 42-1057063
8 Small shafts [m]x[m] – F, G	0.75x (0.64–0.91)	Values given in drawings 1-1010021. Type of shafts in drawing 3-1057070 and 42-1057063
Bentonite buffer surrounding concrete silo		
Bentonite thickness [m]	0.9	Calculated from values ((29.400–(2·13.800))/2) given in drawings 1411-10020610 and 1-1010006
Bentonite height [m]	51.2	Calculated from values (420–368.85+0.05) from 1-1010008, 1411-10020610
Silo top		
Top lid – Sand layer above concrete grout thickness [m]	0.05	Value given in Closure plan for SFR (SKBdoc 1358612)
Top lid – Reinforced lid with gas evacuation pipes thickness [m]	1	Value given in Closure plan for SFR (SKBdoc 1358612)
Top lid – Gas evacuation pipes, diameter [m]	0.1	Assumed 57 pipes (one per full-size shaft) with a diameter of 0.1 m
Top lid – Sand above concrete lid thickness [m]	0.1	Value given in Closure plan for SFR (SKBdoc 1358612)
Sand – bentonite (90/10) thickness [m]	1.5	Value given in Closure plan for SFR (SKBdoc 1358612)
Concrete not reinforced [m]	thin	Value given in Closure plan for SFR (SKBdoc 1358612)
Friction material thickness [m]	up to about 1 m from top	Assumed from Closure plan for SFR (SKBdoc 1358612)
Cement-stabilised sand thickness [m]	1	Assumed from Closure plan for SFR (SKBdoc 1358612)

* Drawing numbers in column “Comment” refer to SKB’s internal documents.

8 1BLA

8.1 Design

The waste vault for low-level waste, 1BLA, has a concrete floor cast on a drained foundation. The rock walls and the roof of the waste vault are lined with shotcrete. The waste packages are standard ISO-containers and are handled by forklift and stacked two abreast and three to six in height, depending on their size, see Figure 8-1. The dimensions of the waste vault are given in Table 8-1 and Figure 8-2.

The demolition and dismantling of existing systems, for example the ventilation and electricity, will be adapted to the closure sequence. The Closure plan for SFR describes measures for the sealing and closure of 1BLA (SKBdoc 1358612). The space around and above the containers is not planned to be backfilled, see Figure 8-2. The ends of the vault will be plugged. A concrete wall will be installed at the end towards the transverse tunnel (1TT) and approximately 4 m will be backfilled with macadam, after which a concrete plug will be cast. A mechanical constraint consisting of backfill material is needed at the end towards the waste vault tunnel (1BST) to hold the transition material in the earth dam plug in place. The constraint will be made by backfilling 10 m of the waste vault with macadam against a retaining wall and filling the space above the backfill and above the level of the connecting tunnel with concrete. The space around and above the containers will not be backfilled, as backfilling is used to protect concrete structures from rock fallout. Also backfilling may damage the ISO-containers. The tunnels outside the vaults will be backfilled with bentonite, see Figure 8-3 and Figure 11-2.

Figure 8-1. *Illustration of 1BLA during the operating phase and below there is a view of SFR 1 with the position of 1BLA highlighted.*

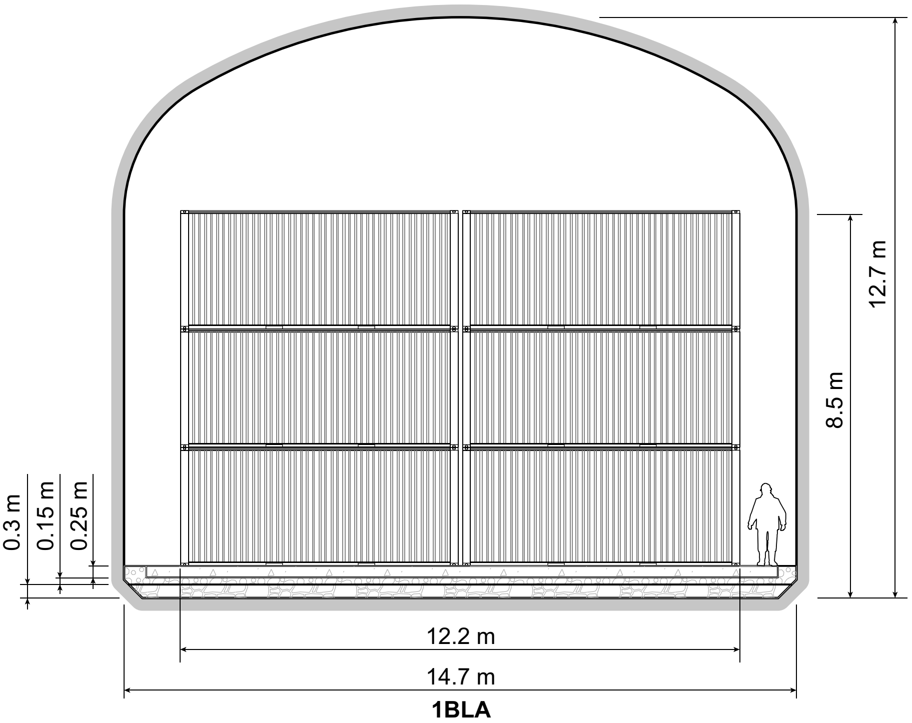

Figure 8-2. Schematic cross-section of 1BLA after closure. The dimensions of 1BLA are given in detail in Table 8-1.

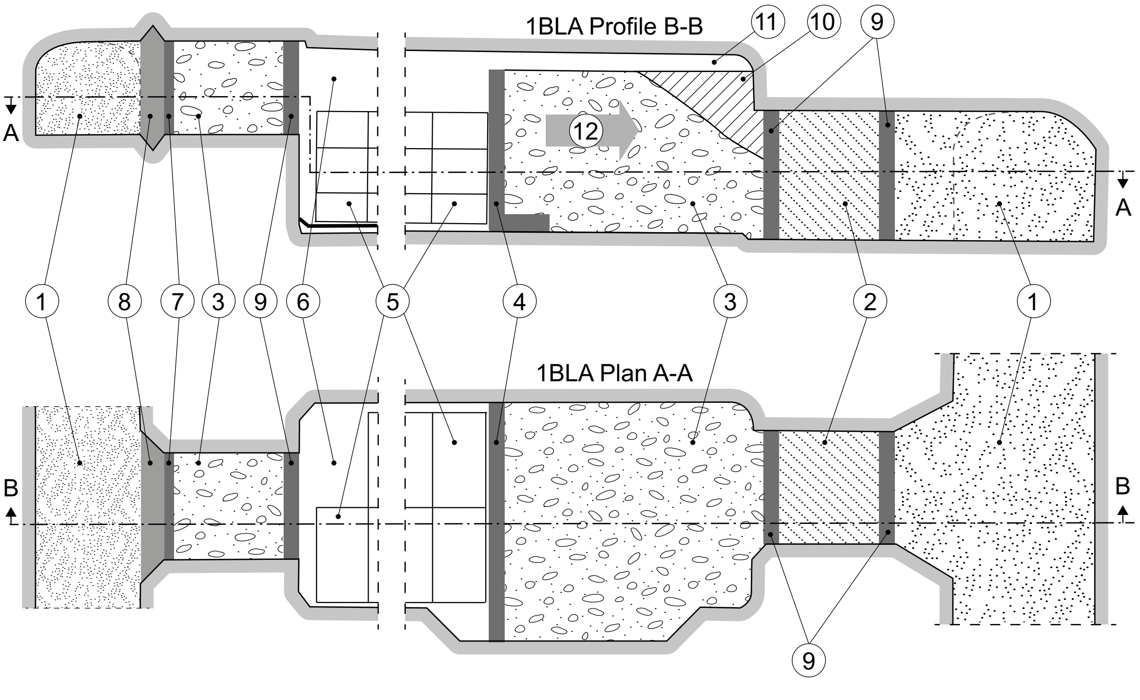

Figure 8-3. Schematic profile and plan of 1BLA after closure. Key to numbering: 1) Bentonite 2) Transition material e.g. 30/70 mixture bentonite crushed rock 3) Macadam 4) Retaining wall 5) Waste 6) Open waste vault 7) Constraining wall and concrete form 8) Mechanical plug of concrete 9) Constraining wall of concrete for transition material 10) Concrete 11) Gap at roof 12) Working direction for backfilling of waste vault.

8.2 Design considerations

Functions considered for the surrounding rock

The depth of 1BLA (~70 m) results in favourable conditions with respect to mechanical stability, low groundwater flow and redox conditions.

Functions considered for the system components in 1BLA

Level of radioactivity – The waste deposited in 1BLA is mainly low-level trash and scrap metal, placed in standard ISO-containers, see Section 3.7.7. The most important safety principle is dependent on the level of radioactivity in the waste packages being limited. The acceptance criteria for the waste packages are given in Section 3.2.

Limited advective transport – The plugs in the end of the tunnel in combination with the bentonite backfilled connecting tunnels will limit the inflow of water from the tunnel system, see Section 11.1. The water flow through waste will then be determined by the inflow to the vault from surrounding rock.

In all vaults, the rock grout in the surrounding rock will limit the inflow of water during the operating phase. However, in 1BLA, the effect of the grout on the inflow of water after closure will also be beneficial to some degree, due to the lack of other barriers inside the waste vault.

Mechanical stability – The stability of the waste vault during the operating phase is increased by the shotcrete on the rock walls. The waste packages and the shotcrete will only marginally influence the stability of the waste vault for longer times after closure.

Limited dissolution – The release of radionuclides from the waste packages is not considered to be limited by dissolution.

Sorption – Sorption in 1BLA is very limited. However, as in all other waste vaults, sorption occurs on corrosion products, shotcrete and other cementitious materials.

Favourable water chemistry – The water chemistry in the waste vault will be determined by the chemical composition of intruding water but influenced by the leaching of shotcrete and other cementitious materials. Reducing conditions will be established soon after closure of the vault due to consumption of oxygen by metal corrosion and microbial degradation.

8.3 Inspection and control of 1BLA

The inspection and control of the waste vaults can be divided into the following three steps.

- Control and inspection of the shotcrete and rock reinforcements and the concrete floor in the waste vault during construction.
- Control and inspection of conditions in the waste vault during the emplacement of waste – the operating phase.
- Final inspection and control of the waste vault before closure with plugs.

8.4 1BLA dimensions and material quantities

The main dimensions of the waste vault 1BLA are given in Table 8-1. The excavated volume is 27,680 m^3 and the estimated volumes of different materials in the waste vault after closure are given in Table A-8 in Appendix A. The total void in the vault including void and porosities in the materials are also given in Table A-8 in Appendix A.

Table 8-1. 1BLA dimensions.

1BLA property	Value	Comment*
Excavated rock cavity		
Total length [m]	160	Calculated from values (120 + 40) given in drawing 1411-10020780
Width [m]	14.7	Value given in drawing 1411-10020780
Height (max) [m]	12.7	Value given in drawing 1411-10020780
Height (average) [m]	11.8	Calculated (173/14.7)
Vertical cross-sectional area [m^2]	173	Value given in Closure plan for SFR (SKBdoc 1358612)
Excavated volume [m^3]	27,680	Calculated 173·160
Shotcrete thickness [m]	0.05	From Carlsson and Christiansson 2007, Table 6-2 Un-reinforced 1 or 2 layers: 0.03 or 0.05 m Fibre reinforced: 0.05 or 0.08 m
Inner zone (at tunnel TT)		
Length [m]	3.7	Value given in drawing 1411-10020780
Waste disposal area		
Length where waste can be stored [m]	146.3	146.3 m Max length (160–3.7(TT)–10 (plug support at BST))
Width outer (2 ISO-containers) [m]	12.2	Calculated from ISO standard 6.06 m and emplacement of containers with 0.1 m spacing (2·6.06+0.1), see Sections 3.6.5 and 3.7.7
Height outer (3 ISO-containers full height) [m]	7.8	Calculated from ISO standard 2.59 m and emplacement of 3 containers without spacing (3·2.59), see Sections 3.6.5 and 3.7.7
Bottom		
Concrete floor (reinforced) [m]	0.25	Value given in drawing 1462-10153140
Concrete floor width [m]	13.7	Value given in drawing 1460-10021930
Macadam thickness [m]	0.15	Value given in drawing 1462-10153140
Rock fill thickness [m]	0.3	Value assumed from drawing 1462-10153140
Reloading zone (at tunnel BST)		
Length [m]	10	Required length for plug support given in Closure plan for SFR (SKBdoc 1358612)

* Drawing numbers in column "Comment" refer to SKB's internal documents.

9 2–5BLA

9.1 Design

The four waste vaults 2–5BLA are similar in design to 1BLA, however, the main difference is that they are wider to accommodate the longitudinal walls. The vault will have a concrete floor cast on top of a drained foundation. The rock walls and the roof of the waste vault are lined with shotcrete. The waste packages are standard ISO-containers. The containers e.g. 20-foot half-height will be placed on the concrete floor two abreast and six in height inside the longitudinal walls. The primary function of the walls is to ensure stability of the pile of containers, but the space will also facilitate inspection and maintenance during the operating phase, see Figure 9-1. The dimensions of the waste vault are given in Table 9-1 and Figure 9-2.

The demolition and dismantling of existing systems, for example the ventilation and electricity, will be adapted to the closure sequence. The Closure plan for SFR describes measures for the sealing and closure of 2–5BLA (SKBdoc 1358612). The waste vaults are planned to be left unfilled. However, the ends of the vaults adjacent to the connecting tunnels are planned to be backfilled to provide mechanical support to the concrete plugs. The support is achieved by backfilling about 10 m of the vault with macadam against a retaining wall. It is difficult to fill the ends of the vault with macadam and therefore the uppermost part is planned to be filled with concrete. The tunnels outside the plugs are planned to be backfilled with bentonite, see Figure 9-3 and Figure 11-2.

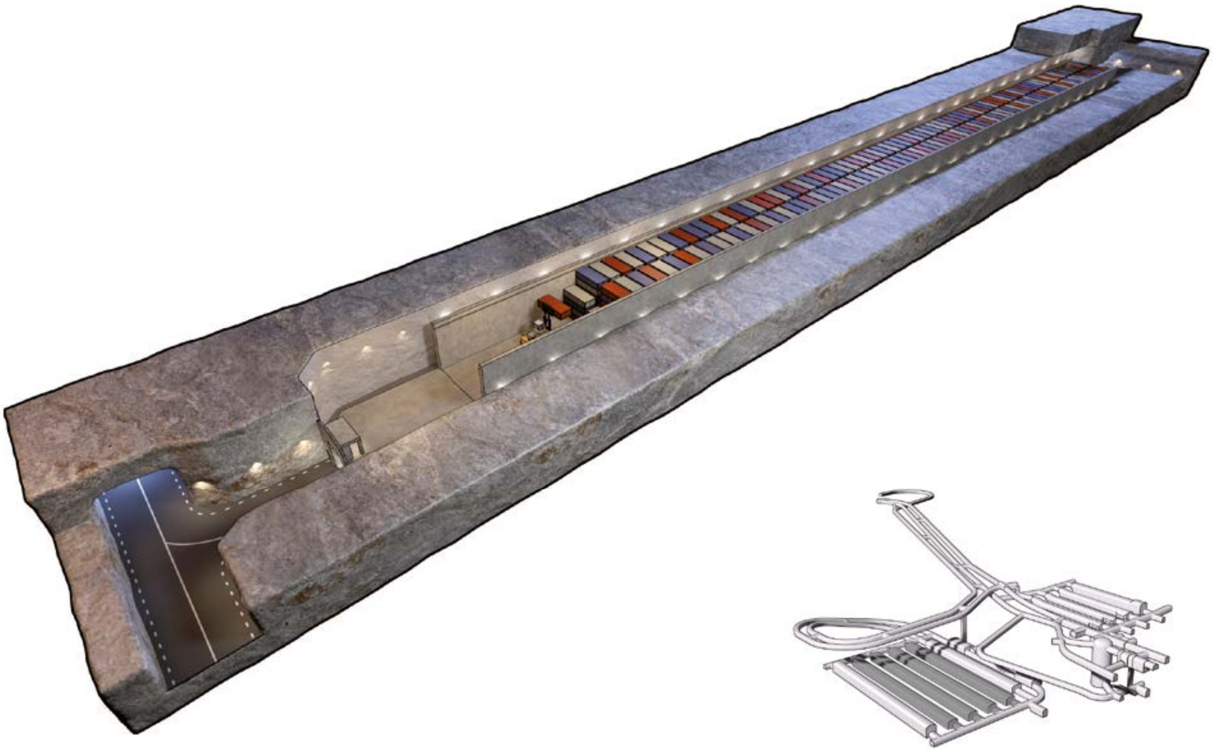

Figure 9-1. *Illustration of 2–5BLA during the operating phase and below there is a view of SFR with the position of the four waste vaults highlighted.*

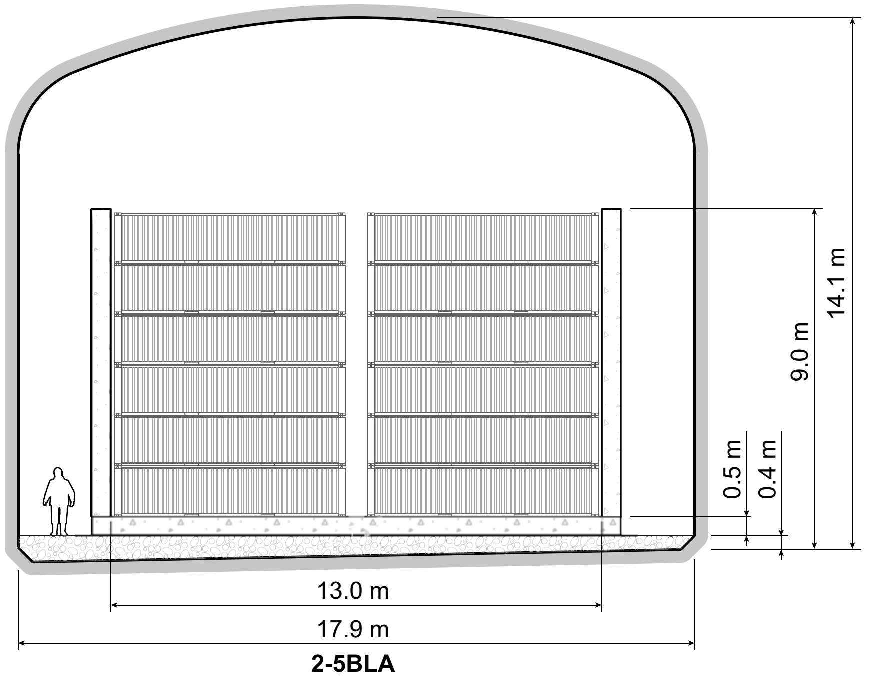

Figure 9-2. Schematic cross-section of 2–5BLA after closure. Note that the figure shows Layout 2.0; Layout 1.5 is used in SR-PSU modelling. The difference that can be seen in the figure is that the height of the longitudinal walls are 0.5 m higher in Layout 1.5. The dimensions of 2–5BLA are given in detail in Table 9-1.

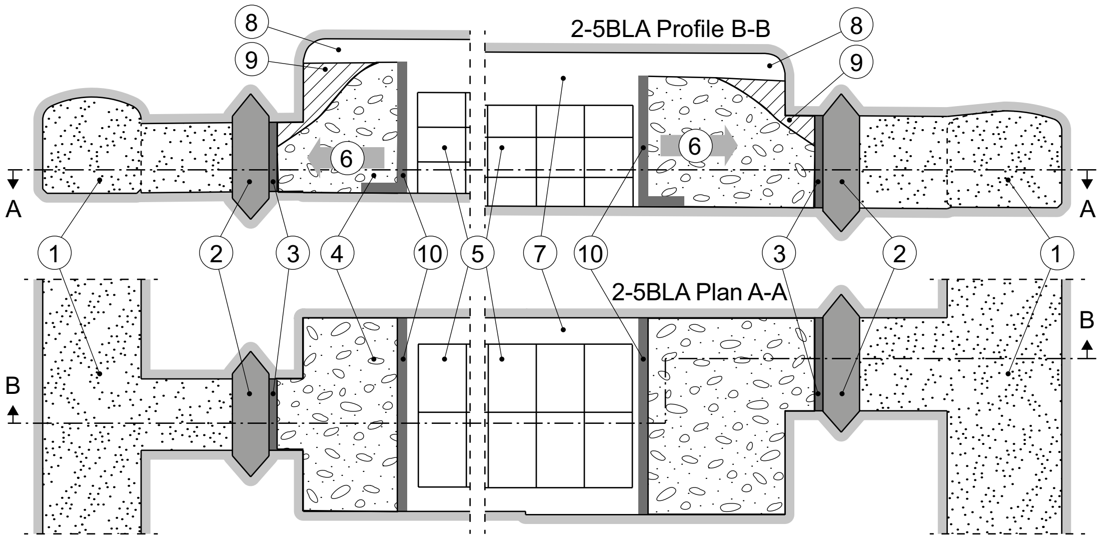

Figure 9-3. *Schematic profile and plan of 2–5BLA after closure. Key to numbering: 1) Bentonite 2) Mechanical plug of concrete 3) Constraining wall and concrete form 4) Macadam 5) Waste 6) Working direction for backfilling of waste vault 7) Open vault 8) Gap at roof 9) Concrete 10) Retaining wall.*

9.2 Design considerations

The suggested design for the waste vaults 2–5BLA is similar to the existing waste vault for low level waste 1BLA. The exception is the longitudinal walls for the ISO-containers that will mainly influence safety during the operating phase.

Functions considered for the surrounding rock

The depth of 2–5BLA (~120 m) results in favourable conditions with respect to mechanical stability and low groundwater flow.

Functions considered for the system components in 2–5BLA

Level of radioactivity – The waste deposited in 2–5BLA is mainly low-level trash and scrap metal from decommissioning, placed in standard ISO-containers, see Section 3.7.8. The most important safety principle depends on the level of radioactivity in the waste packages being limited. The waste acceptance criteria for the waste packages are given in Section 3.2.

Limited advective transport – The plugs in the end of the tunnel in combination with the bentonite backfilled connecting tunnels will limit the inflow of water from the tunnel system, see Section 11.1. The water flow through waste will then be determined by the inflow to the waste vault from surrounding rock.

In all vaults, the rock grout in the surrounding rock will limit the inflow of water during the operating phase. For 2-5BLA, the effect of the grout on the inflow of water after closure will also be beneficial to some degree, due to the lack of other barriers inside the waste vaults.

Mechanical stability – The stability of the waste vault during the operating phase is increased by the shotcrete on the rock walls. The waste packages, supporting walls and shotcrete will have only a marginal influence on the stability of the waste vault after closure.

Limited dissolution – The release of radionuclides from the ISO-containers is not considered to be solubility limited.

Sorption – Sorption in 2–5BLA is very limited. However, as in all other waste vaults, sorption occurs on corrosion products, shotcrete and other cementitious materials.

Favourable water chemistry – The water chemistry in the waste vault will be determined by the chemical composition of intruding water but influenced by the leaching of shotcrete and other cementitious materials. Reducing conditions will be established soon after closure of the vault due to consumption of oxygen by metal corrosion and microbial degradation.

9.3 Inspection and control of 2–5BLA

The inspection and control of the waste vaults can be divided into the following three steps.

- Control and inspection of the shotcrete and rock reinforcements in the waste vaults during and after construction.
- Control and inspection of the physical condition of the waste vaults during the emplacement of waste – the operating phase.
- Final inspection and control of the waste vaults before backfilling the ends with macadam and closure with plugs.

9.4 2–5BLA dimensions and material quantities

The main dimensions of the waste vaults 2–5BLA are given in Table 9-1 The values given in the column for Layout 1.5 are used in the long-term safety assessment for the SFR repository (SR-PSU). However, all other parts of the application for the extension are based on the values given in the column for Layout 2.0. For 2–5BLA the only difference is the height of the supporting walls.

The estimated volumes of different materials in one waste vault after closure are given in Table A-9 in Appendix A. The total void in the vault including void and porosities in the materials are also given in Table A-9 in Appendix A.

Table 9-1. 2–5BLA dimensions.

2–5BLA property	Value (Layout 1.5)	Value (Layout 2.0)	Comment*
Excavated rock cavity			
Total length [m]	275	275	Value given in drawing SKBdoc 1391454
Width [m]	17.9	17.9	Calculated from values (0.3+17.3+0.3) given in drawing SKBdoc 1391456 ver. 1.0
Height max [m]	14.1	14.1	Calculated from values (0.4+13.4+0.3) given in drawing SKBdoc 1391456 ver. 1.0
Height average [m]	13.5	13.5	Calculated (242/17.9)
Vertical cross-sectional area [m^2]	242	242	Value given in drawing SKBdoc 1391456 ver. 1.0
Excavated volume [m^3] (per vault)	66,550	66,550	Calculated 275·242
Shotcrete thickness [m]	0.05	0.05	From Carlsson and Christiansson 2007, Table 6-2 Un-reinforced 1 or 2 layers: 0.03 or 0.05 m Fibre reinforced: 0.05 or 0.08 m
Inner zone (at tunnel 2TT)			
Length [m]	8	8	Calculated from values (270,550–27,670) m given in drawing SKBdoc1391792,1391794 and 24 m given in drawing SKBdoc1391454 and tunnel length 275 m
Waste disposal area			
Length where waste can be stored [m]	243	243	Calculated from values (270,550–27,670) m given in drawing SKBdoc1391792 and 1391794
			1,080 containers (20-fots half-height) given in SKBdoc 1389672 gives 90 containers in length (90·2.5+60·0.1+29·0.4) = 243
Width outer (2 ISO-containers) [m]	12.2	12.2	Calculated from ISO standard 6.06 m and emplacement of containers with 0.1 spacing (2·6.06+0.1), see Sections 3.6.5 and 3.7.8
Height outer (3 ISO-containers full height) [m]	7.8	7.8	Calculated from ISO standard 2.59 m and emplacement of 3 containers without spacing (3·2.59), see Sections 3.6.5 and 3.7.8
Thickness longitudinal walls [m]	0.5	0.5	Value given in drawing SKBdoc 1391456 ver. 1.0
Height longitudinal walls [m]	8.64	8.1	Layout 1.5, calculated from values (9.14–0.5). Layout 2.0, calculated from values (8.6–0.5) given in drawing SKBdoc 1391456 ver.1.0
Bottom			
Concrete floor (reinforced) [m]	0.5	0.5	Value given in drawing SKBdoc 1391456 ver. 1.0
Concrete floor width [m]	14	14	Value given in drawing SKBdoc 1391456 ver. 1.0
Macadam/Rock fill thickness [m]	0.4	0.4	Value given in drawing SKBdoc 1391456 ver. 1.0
Reloading zone (at tunnel 2BST)			
Length [m]	24	24	Value given in drawing SKBdoc 1391454

* Drawing numbers in column "Comment" refer to SKB's internal documents.

10 BRT

10.1 Design

As part of the planned extension of SFR, a vault will be built for nine reactor pressure vessels (RPV) arising from the decommissioning of boiling water reactors. The concrete floor will be cast on a layer of crushed rock and designed to bear the load from a reactor pressure vessel including the transport vehicle. The rock walls and the roof of the waste vault will be lined with shotcrete. The vessels will be placed in a row on special concrete fundaments, see Figure 10-1. In the design of the fundaments the point loads from the vessel are taken into account. The dimensions of the waste vault are given in Table 10-1 and Figure 10-2.

The demolition and dismantling of existing systems, for example the ventilation and electricity, will be adapted to the closure sequence. The Closure plan for SFR describes measures for the sealing and closure of 1BRT (SKBdoc 1358612). At repository closure, the reactor vessels are planned to be embedded in concrete to ensure a low corrosion rate. In addition, each individual RPV will be filled with concrete or cementitious grout to both reduce the corrosion rate and minimise the risk of collapse. The filling will hinder floating-up during embedment grouting and will also limit the release of any loose contamination remaining after decontamination. The space between the vessels and the rock walls and roof is planned to be backfilled with macadam, see Figure 10-2. The waste vault is planned to be sealed by concrete plugs at both ends and the connecting tunnels outside the vault to be backfilled with bentonite, see Figure 10-3 and Figure 11-2.

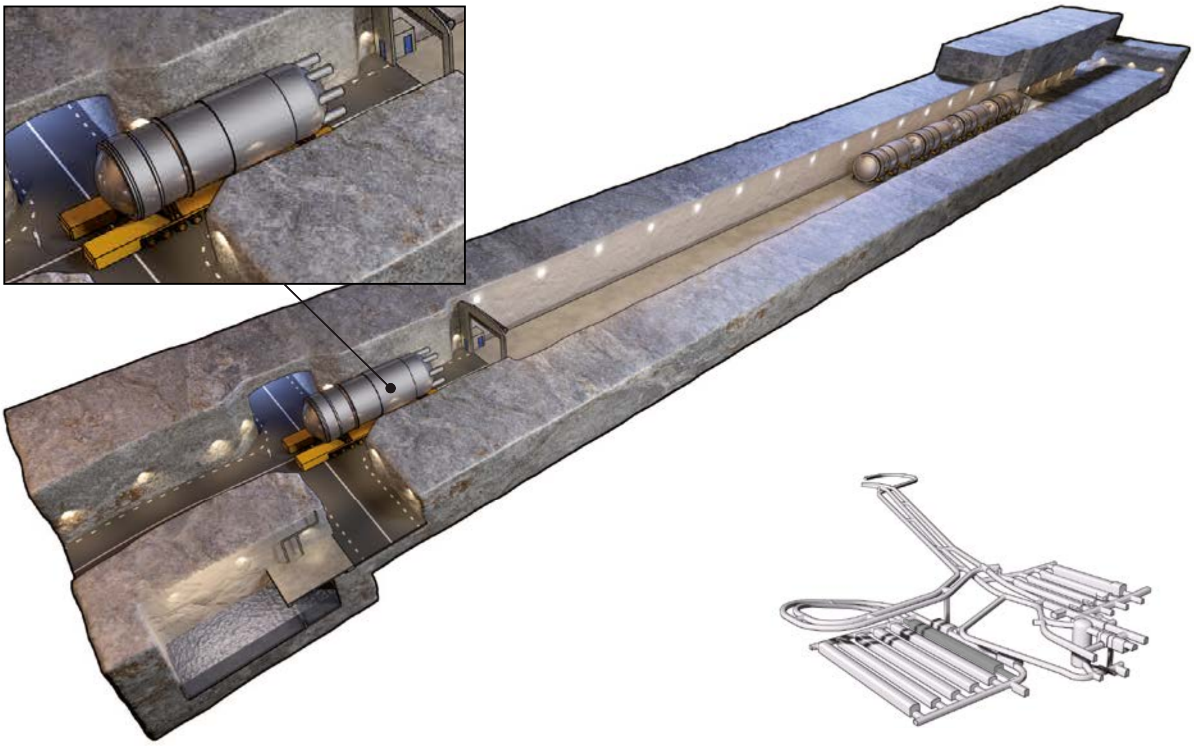

__Figure 10-1.__ Illustration of BRT during the operating phase. Below there is a view of SFR with the position of BRT highlighted.

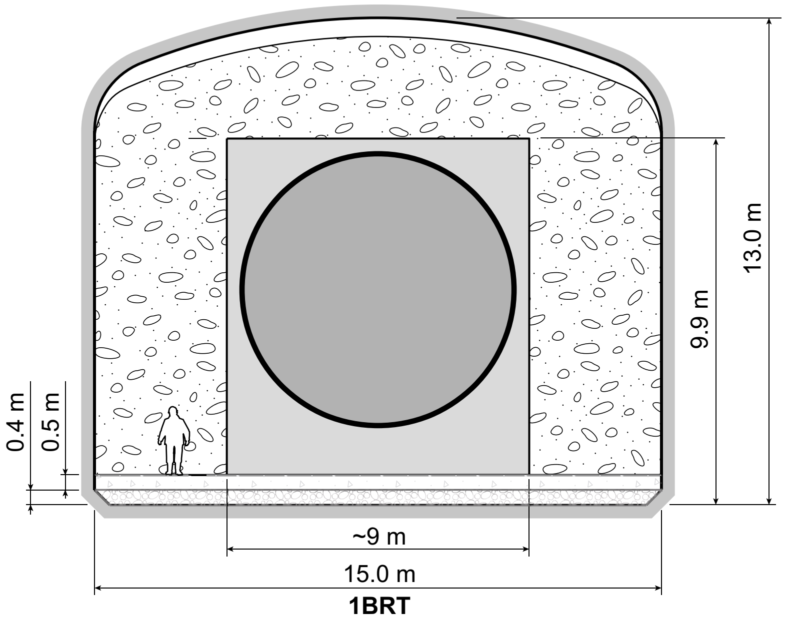

Figure 10-2. Schematic cross-section of BRT after closure. Note that the figure shows Layout 2.0; Layout 1.5 is used in SR-PSU modelling. The difference that can be seen in the figure is that the height is 12.9 m in Layout 1.5. The dimensions of BRT are given in detail in Table 10-1.

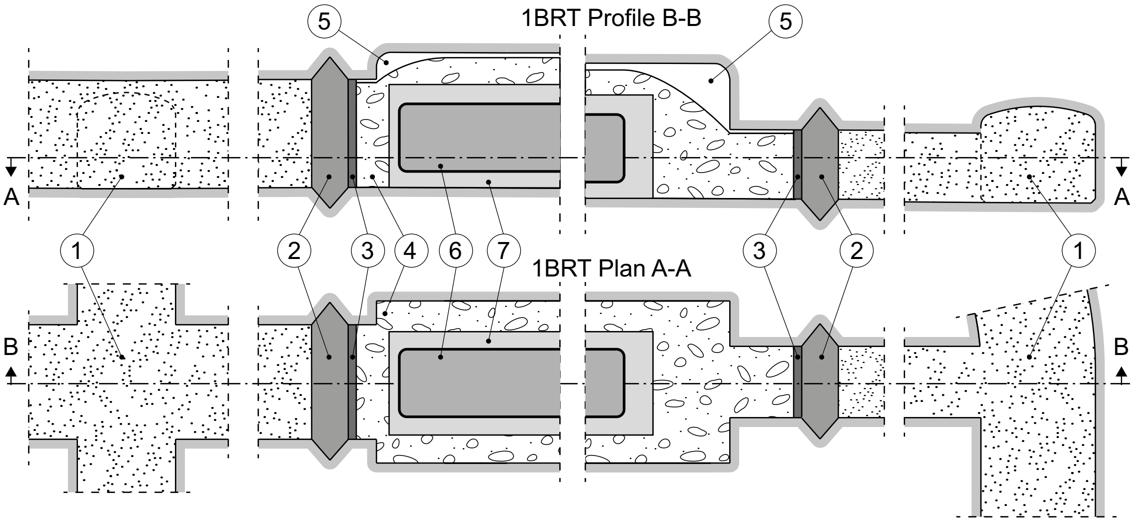

Figure 10-3. Schematic profile and plan of BRT after closure. Key to numbering: 1) Bentonite 2) Concrete plug 3) Supporting wall and mould for casting 4) Macadam 5) Open gap between macadam and tunnel roof 6) Reactor pressure vessel filled with concrete 7) Concrete casting.

10.2 Design considerations

The suggested design for the waste vault BRT is simple; the vessels are placed on concrete floor and embedded in concrete to ensure a low corrosion rate.

Functions considered for the surrounding rock

The depth of BRT (~120 m) results in favourable conditions with respect to mechanical stability, low groundwater flow and redox conditions.

Functions considered for the system components in BRT

Level of radioactivity – The most important radiological safety principle for BRT depends on the radioactivity in the waste being limited. The reactor pressure vessels are planned to be decontaminated and the interior to be filled with concrete or cement-based grout. The acceptance criteria for the waste are given in Section 3.2.

Limited advective transport – The plugs in the end of the tunnel in combination with the bentonite backfilled connecting tunnels should limit the inflow of water from the tunnel system, see Section 11.1. The water flow in the vault will be determined by the inflow to the waste vault from surrounding rock. In addition, the hydraulic contrast between the permeable macadam backfill and the less permeable concrete surrounding the vessels diverts water flow away from the vessels to the more permeable surrounding materials. However, the design with concrete surrounding the vessels is mainly chosen to establish favourable water chemistry.

Mechanical stability – The long-term stability of the waste vault (for example stability against rock fallout) is enhanced by the concrete in and around the reactor pressure vessels and the backfilling of the waste vault with macadam.

Limited dissolution – For radionuclides present as induced activity in the vessels, release will be determined by the rate of metal corrosion. The dissolution of radionuclides from the reactor pressure vessels will be solubility limited in some cases.

Sorption – Radionuclides released from the vessels are retained by sorption in the concrete or cementitious grout inside and around the vessels and in the macadam backfill.

Favourable water chemistry – The water chemistry in the waste vault will be influenced by the large amounts of cementitious materials in the waste vault. The resulting alkaline environment will limit the rates of corrosion and thereby also the release of induced radioactivity.

In addition, the creation of reducing conditions in the vault caused by the consumption of oxygen by mainly metal corrosion favour the sorption of many radionuclides e.g. technetium and some actinides.

10.3 Inspection and control of BRT

The inspection and control of BRT can be divided into the following three steps.

- Control and inspection of the concrete floor and fundaments for the reactor pressure vessels.
- Control and inspection of conditions in the waste vault during the emplacement, grouting and concrete embedding of the reactor pressure vessels.
- Final inspection of the waste vault and the concrete surrounding the reactor pressure vessels before backfilling with macadam and closure with plugs.

10.4 BRT dimensions and material quantities

The main dimensions of the waste vault BRT are given in Table 10-1. The values given in the column for Layout 1.5 are used in the long-term safety assessment for the SFR repository (SR-PSU). However, all other parts of the application for the extension are based on the values given in the column for Layout 2.0. The main differences are the length and the height of the vault and the dimensions of the disposal area.

The estimated volumes of different materials in the waste vault after closure are given in Table A-10 in Appendix A. The total void in the vault including void and porosities in the materials are also given in Table A-10 in Appendix A.

Table 10-1. BRT dimensions.

BRT property	Value (Layout 1.5)	Value (Layout 2.0)	Comment*
Excavated rock cavity			
Total length [m]	210	240	Layout 1.5 given in SKBdoc 1360626 ver. 1.0 Layout 2.0, given in drawing SKBdoc 1391452
Width [m]	15	15	Calculated from values (0.3+14.4+0.3) given in drawing SKBdoc 1391456 ver. 1.0
Height (max) [m]	12.9	13	Layout 1.5, calculated from values (0.4+12.2+0.3) given in SKBdoc 1316398 ver. 2.0 Layout 2.0, calculated from values (0.4+0.5+11.8+0.3) given in drawing SKBdoc 1391456 ver. 1.0
Height average [m]	11.9	12.5	Layout1.5 calculated 178/15 Layout 2.0 calculated 188/15
Vertical cross-sectional area [m^2]	178	188	Layout 1.5 value given in drawing 1316398 ver. 2.0 Layout 2.0 value given in drawing SKBdoc 1391456 ver. 1.0
Excavated volume [m^3]	37,380	45,120	Layout 1.5 calculated 210·178 Layout 2.0 calculated 240·188
Shotcrete thickness [m]	0.05	0.05	From Carlsson and Christiansson 2007, Table 6-2 Un-reinforced 1 or 2 layers: 0.03 or 0.05 m Fibre reinforced: 0.05 or 0.08 m
Zone facing tunnel 2TT – Note that loading is done from 2TT for BRT, but from 2BST for all other vaults			
Length [m]	1.5	31.5	Layout 1.5 calculated 210–207–1.5 Layout 2.0 calculated 240–207–1.5
Disposal area			
Length required for 9 reactor pressure vessels incl. space [m]	207	207	Calculated from length of vessels from Inventory report (SKB 2013b) (2·23 (B1,B2) + 2·21.5 (F1,F2) + 21.4(F3) + 18 (O1) + 20.2 (O2) + 21.4 (O3) + 20.2 (R1) + 8·2 (space between vessels) + 2·0.5 (at ends))
Width [m]	8	8.6	Layout 1.5 value given in drawing SKBdoc 1316398 ver. 2.0 Layout 2.0 value given in drawing SKBdoc 1391456 ver. 1.0
Height [m]	8.9	9	Layout 1.5 value given in drawing SKBdoc 1316398 ver. 2.0 Layout 2.0 value given in drawing SKBdoc 1391456 ver. 1.0
Concrete floor (reinforced) [m]	0.5	0.5	Value given in drawing SKBdoc 1391456 v.0.4
Concrete floor width [m]	12.8	12.8	Calculated from values (14.4–2·0.8) given in drawing SKBdoc 1391456 ver. 1.0
Bottom			
Macadam/Rock fill thickness [m]	0.4	0.4	Value given in drawing SKBdoc 1391456 ver. 1.0
Zone facing tunnel 2BST – Note that loading is done from 2TT for BRT, but from 2BST for all other vaults			
Length [m]	1.5	1.5	Assumed

* Drawing numbers in column "Comment" refer to SKB's internal documents.

11 Plugs and other closure components

11.1 Design

The Closure plan for SFR (SKBdoc 1358612) describes measures for the plugging and closure of SFR. An overview of plugs and other closure components in SFR is shown in Figure 11-1.

Plugs to waste vaults (except silo)

For the waste vaults, the plug sections consist of tunnel sections filled with bentonite that are confined by mechanical plugs. A total of five plug sections (P1TT, P1BTF, P1BST, P2TT and P2BST) are to be installed to seal the waste vaults in SFR 1 and SFR 3, see Figure 11-2. In most positions, concrete plugs are planned for mechanical support. In the sections adjacent to the connecting tunnel 1BST where the geometry and the local geology make it difficult to construct concrete plugs "earth dam plugs" are planned. "Earth dam plugs" do not require local mechanical support from the rock walls. The function of the bentonite-filled sections is to act as hydraulic seals and the function of the plugs is as mechanical constraints for the bentonite sections.

Plugs to silo

The closure of the silo is planned to be done with three plug sections: lower silo plug (NSP), upper silo plug (ÖSP) and silo roof plug (STP), see Figure 11-3. An important factor in designing the plugs has been to find suitable tunnel geometries to install the mechanical constraints that hold the hydraulically tight sections with bentonite in place. The installation starts with plugging the silo bottom tunnel (1SBT) and the drainage tunnel (1SDT) with four concrete plugs and bentonite. Thereafter the silo roof tunnel (1STT) is plugged and finally three concrete plugs and bentonite are installed to plug the silo tunnel (ST) and the loading-in building (IB).

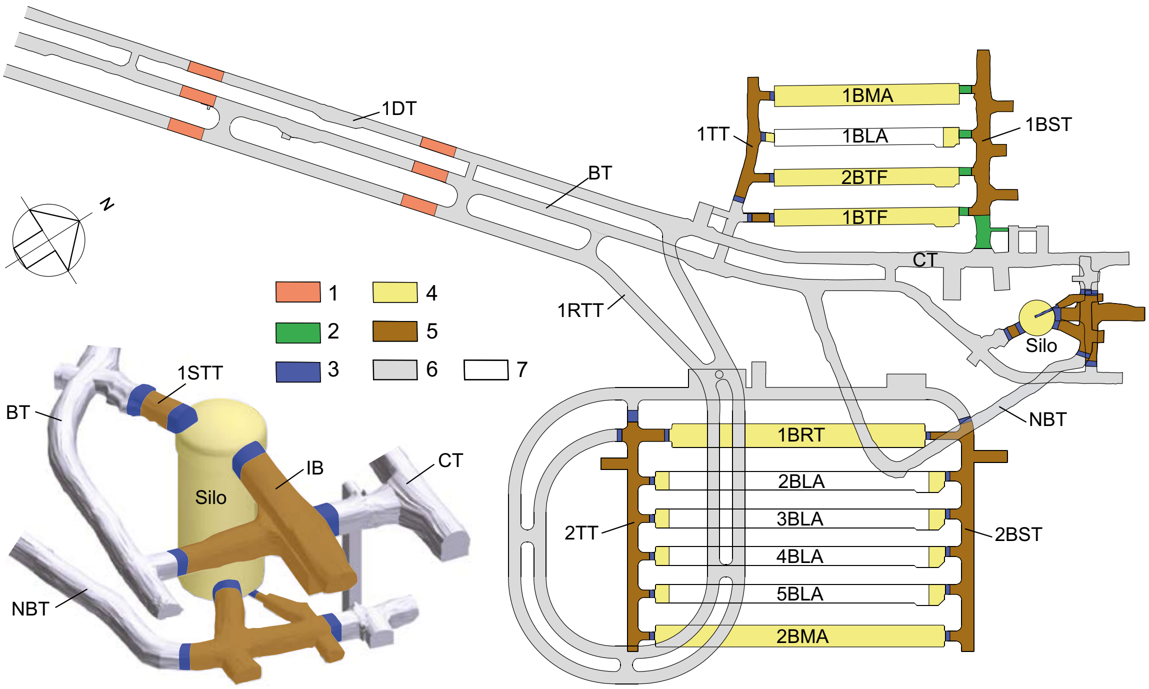

Figure 11-1. *Schematic plan of SFR 1 and SFR 3, with a detailed view of the silo. Key to numbering: 1) Plugs in access tunnels 2) Transition material e.g. 30/70 bentonite crushed rock in earth dam plug 3) Mechanical plug of concrete 4) Macadam backfill 5) Hydraulically tight section with bentonite 6) Backfill in access tunnels and tunnel systems 7) Non-backfilled openings. Note that the figure shows Layout 2.0; Layout 1.5 is used in SR-PSU modelling. The only difference relevant to this figure is that BRT is longer here than in Layout 1.5. The labels in the figure are referred to in the text.*

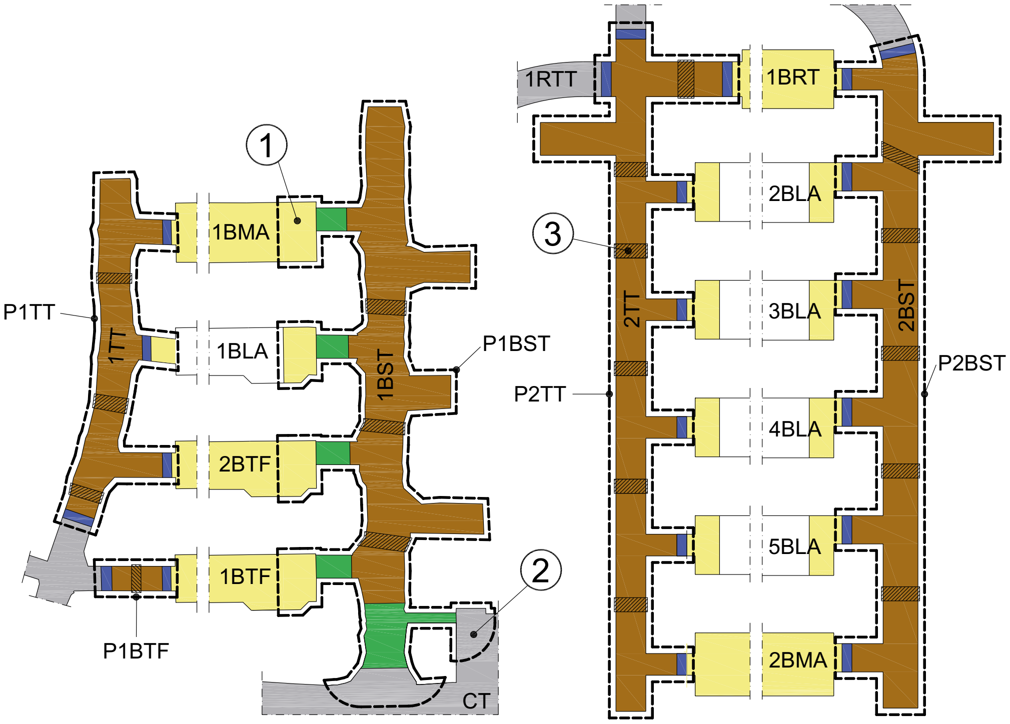

Figure 11-2. *Plugs adjacent to waste vaults are marked with a dashed line. Key to numbering: 1) Yellow colour within borderline for plug sections shows parts of backfill in rock that are active parts of the earth dam plug, green colour shows transition material and brown colour shows hydraulically tight material 2) Grey colour within borderline for plug shows parts of backfill in tunnel system that are active parts of the earth dam plug 3) Hatched areas indicate where damaged zone should be removed by controlled methods.*

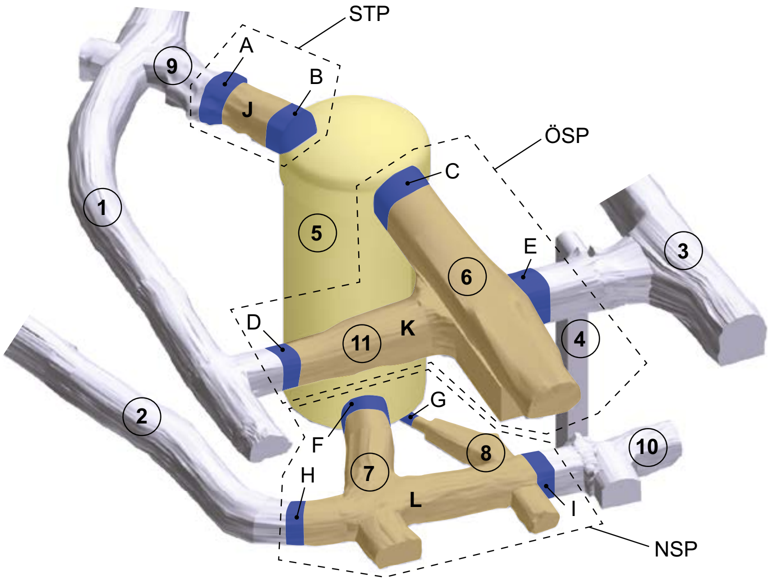

Figure 11-3. *Illustration of closed silo with three plug sections (NSP, ÖSP and STP). Blue colour shows concrete plugs (A,B,…I) and brown colour shows hydraulically tight sections (J, K, L). Key to numbering: 1) Construction tunnel, BT 2) Lower construction tunnel, NBT 3) Central tunnel, CT 4) Connecting shaft 5) Silo 6) Loading-in building, IB 7) Silo bottom tunnel, 1SBT 8) Drainage tunnel 1SDT 9) Silo roof tunnel, 1STT 10) Terminal part of lower construction tunnel 11) Silo tunnel, ST. Tunnel parts 1, 2, 3, 4 and 10 belong to the tunnel system.*

Closure of the tunnel system at repository level (CT, NBT, 1TIT etc.)

The tunnels at repository level in connection with the plugged sections of the waste vaults and silo are planned to be backfilled with macadam. The selected material has the required high hydraulic conductivity and favourable mechanical properties for limiting subsidence in the tunnels.

Closure of access tunnels (1DT, BT 1RTT)

The access tunnels are also planned to be backfilled with macadam. In addition, the connections between the three tunnels will be isolated by the installation of plug sections. The plug section is made up of a 10 metre long hydraulically tight section of bentonite surrounded by concrete plugs as mechanical support, see Figure 11-4.

Closure of the upper part of access tunnel

The first fifty metres of the access tunnels is planned to be backfilled with boulders and a concrete plug will be cast to obstruct unintentional intrusion into the repository. Finally, the ground surface will be restored to match the surroundings.

Closure of shafts

Vertical shafts connecting different parts of the repository are planned to be closed and plugged. The aim is to limit the direct water flow from one place to another. The suggested solution comprises a hydraulically tight section with bentonite surrounded by upper and lower concrete plugs for mechanical support.

Sealing of boreholes

The boreholes that were included in the preliminary investigations and those that intersect or are located very close to the underground facility have been or will be sealed prior to the start of construction of SFR 3, and the remaining boreholes will be sealed after operation is concluded.

Where the rock has low hydraulic conductivity, the borehole seal must also have low hydraulic conductivity. In the case of positions along boreholes where the rock has high hydraulic conductivity (fractures and deformation zones), requirements are only defined for mechanical stability. Highly compacted bentonite is used where low hydraulic conductivity sections are needed and cement-stabilised plugs are cast where the boreholes pass through fracture zones. The functions of the different sections of the borehole sealing are given in Table 11-1. Two plugging techniques including bentonite for low hydraulic conductivity sections in the borehole (Basic type and Couronne concept) are shown in Figure 11-5.

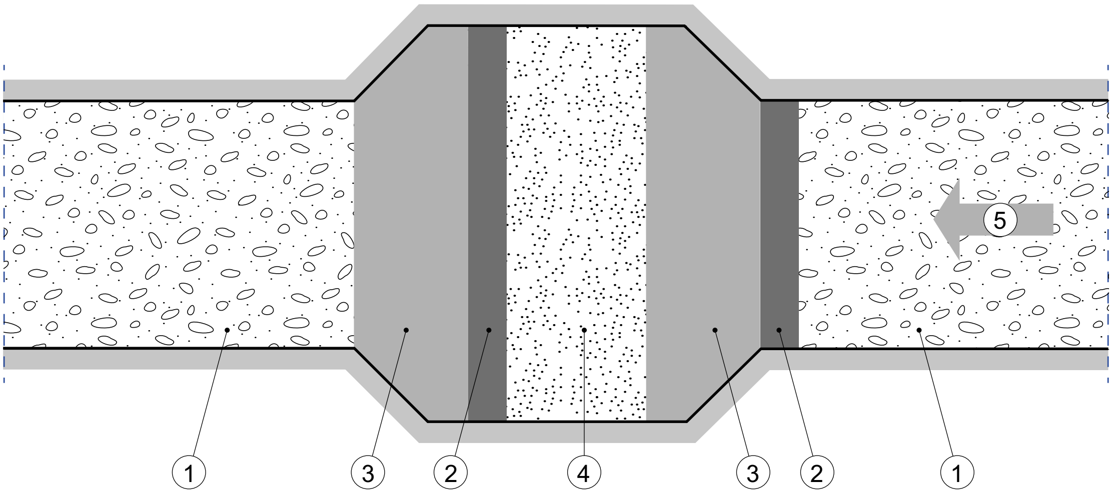

Figure 11-4. Conceptual reference design of plugs in access tunnels. Key to numbering: 1) Macadam backfill 2) Supporting wall 3) Concrete 4) Bentonite 5) Working direction.

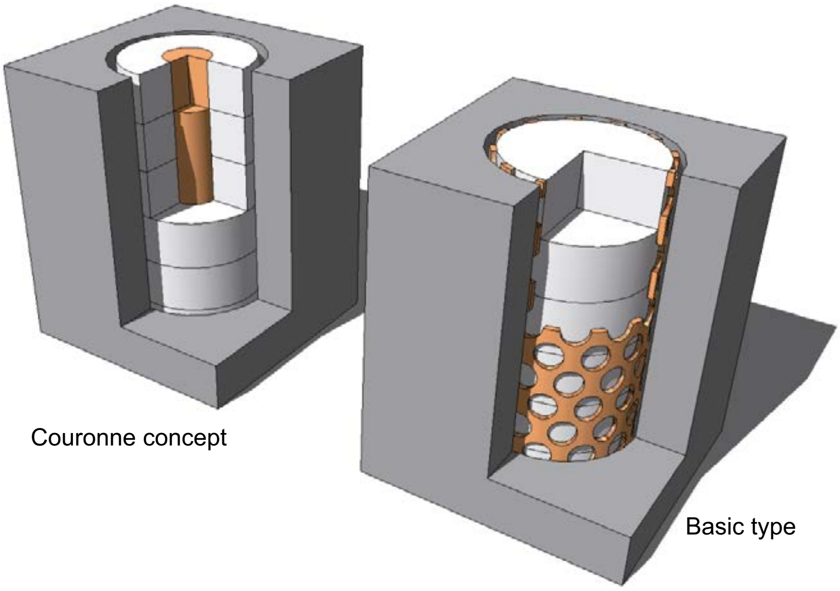

Figure 11-5. *Two alternative plugging techniques with copper and bentonite proposed for low hydraulic conductivity sections in the borehole.*

Table 11-1. Description of borehole sealing.

Function	Description
Low hydraulic conductivity in borehole.	Alternative 1) Basic Type – Compacted clay (bentonite) columns confined in perforated copper tube – borehole length > 20 m. Alternative 2) Couronne Concept – Compacted clay (bentonite) stacked around jointed copper rods that are pushed into the hole – borehole length < 20 m.
Mechanical support in borehole Limit erosion of clay material.	Quartz/Cement plug.
Protection of borehole against erosion and intrusion.	Physical securing of the upper end of boreholes extending from the ground surface downward with e.g. concrete plugs, rock cylinders or copper plugs.

11.2 Design considerations

The presented design of plugs and closure components in this report constitutes solutions that are technically feasible. However, it is foreseen that the design of plugs and closure components can be further developed and optimised before closure of SFR.

Functions considered for the upper parts of the access tunnel

The closure of the upper parts of the access tunnels will be designed to hinder unintentional intrusion from the surface to the repository.

Functions considered for plugs and other closure components

Level of radioactivity – Not applicable.

Limited advective transport – The main functions of plugs and hydraulically tight sections will be to limit the flow through the waste vaults. If there is a hydraulically damaged zone surrounding the tunnels, the zone will be removed before plug installation and the plugs will be designed to cut it off. The plugs will be placed so that they are not short-circuited by water-bearing fractures.

The boreholes will be sealed to prevent the formation of water conducting channels that can act as potential transport pathways for radionuclides from the repository. In rock with low hydraulic conductivity, the boreholes will be designed to have low hydraulic conductivity, however, in rock with high conductivity only mechanical stability is required.

Mechanical stability – The long-term stability of the tunnels (for example the stability against rock fallout) is enhanced by backfilling the tunnels with e.g. macadam, crushed rock, bentonite and bentonite mixtures.

Limited dissolution – Not considered.

Sorption – The vast majority of radionuclides released from the waste vaults via the plugs will be limited by sorption in the bentonite filled sections outside the mechanical plugs and the macadam or other backfill material in the connecting tunnels.

Favourable water chemistry – Not considered.

11.3 Inspection and control

The production of plugs and other closure components will follow generally applied procedures for manufacturing, installation, inspection and control. Several tests and experiments have been performed by SKB at the Äspö hard rock laboratory and the Bentonite laboratory (SKB 2013a). These laboratories also provide the opportunity to demonstrate that plugs and other closure components can be fabricated and installed with the quality required to meet the requirements for long-term safety.

SKB has studied and developed several concepts for borehole sealing. The main principles for sealing of boreholes as well as results from experiments and tests are summarised in Pusch and Ramqvist (2007). However, investigation boreholes drilled for SFR 1 exist that were sealed in accordance with former requirements that may not fulfil present requirements.

11.4 Dimensions and material volumes

The excavated volume in SFR 1 is approximately 400,000 m^3 (SKB 2008) and the excavated volume in SFR 3 is estimated to be approximately 770,000 m^3 (SKBdoc 134767). In Table 11-2 estimated volumes of different parts of the plug sections are given. The materials to be used in different parts of the plug sections are described in the Closure planning report for PSU (SKBdoc 1358612). Low conductivity sections are planned to be filled with bentonite blocks and pellets with a block-filling degree of between 60 and 80%. The transition material in the earth dam plugs is assumed to consist of 30% bentonite and 70% crushed rock (dry weight) and the concrete plugs will consist of standard concrete.

Table 11-2. Estimated volumes [m^3] of different materials in the plug sections.

Tunnels	Bentonite	Transition material	Concrete
Transverse tunnel in SFR 1 (P1TT+P1BTF)	8,622	0	1,941
Waste vault tunnel in SFR 1 (P1BST)	20,143	5,365	neglected
Transverse tunnel in SFR 3 (P2TT)	27,586	0	3,456
Waste vault tunnel in SFR 3 (P2BST)	30,299	0	3,413
Silo tunnels in SFR 1	24,253	0	3,185
Access tunnels and shaft	6,144	0	6,979
Total volumes*	117,047	5,365	18,974

* The remaining volume of the tunnel system will mainly be filled with macadam.

12 Variables for the system components

12.1 Variables for the waste form

The waste packages (moulds and drums) in the silo shafts are embedded in concrete grout during the operating phase. Following this, the condition of the waste packages cannot be inspected.

For the BMA, 2BTF and BLA repository components, the waste packages are not grouted during the operating phase, hence it is possible to relocate waste packages and inspect them before closure if deemed necessary. The drums containing ash placed in 1 BTF need stabilising walls. These walls are constructed using concrete tanks and moulds. When six rows of drums have been piled, moulds are placed across the waste vault and concrete is poured over the drums in order to stabilise them. This means that the condition of the waste packages cannot be inspected afterwards.

If the waste packages corrode in the silo under anaerobic conditions, hydrogen may form. Simulations of corrosion of the waste packages show that the hydrogen concentration in the air will increase (Moreno et al. 2001). Aerobic corrosion will form Fe_2O_3 (rust) and may lead to altered initial conditions of the waste packages.

The initial state of the radioactivity in the waste packages is well known, since it is measured at the time when the waste is conditioned. No or negligible release is deemed possible during the operating phase thus only radioactive decay is considered during this period.

Table 12-1 shows the variables for the waste form that are deposited in SFR.

Table 12-1. Variables for the waste form and their definition from the Waste process report (SKB 2014f).

Variable	Definition
Geometry	Volume and dimensions of the waste form and voids inside the waste packaging. Porosity and pore characteristics of the waste form. Amount and characteristics of fractures in the waste form.
Radiation intensity	Intensity of alpha, beta and gamma radiation.
Temperature	Temperature.
Hydrological variables	Magnitude, direction and distribution of water flow. Degree of water saturation. Water pressure. Aggregation state (water and/or ice).
Mechanical stresses	Stress and strain in waste form.
Radionuclide inventory	Inventory of radionuclides as a function of time within the waste package. Type, amount, chemical and physical form.
Material composition	Amount and surface characteristics of materials inside the waste package (excluding radionuclides). Type and amount of chemicals. Type, amount of organic materials and other substances that can be used by microbes as nutrients and energy sources. Types and amount of microbes and bacteria and other types of biomass.
Water composition	Composition of water including radionuclides. Redox, pH, ionic strength, concentration of dissolved species, type and amount of colloids and/or particles, amount and composition of dissolved gas. Types and amount of microbes and bacteria and other types of biomass. Density and viscosity.
Gas variables	Amount and composition including radionuclides. Volume, pressure and degree of saturation. Magnitude, direction and distribution of gas flow.

12.1.1 Geometry

The geometry of the waste is described in Chapter 3. The internal initial void volume of the different waste types is described in the Inventory report (SKB 2013b). The porosity of the waste form is dependent on the type of waste and whether the waste is conditioned and the type of conditioning, i.e. bitumen, cement or concrete. Here it is assumed that waste conditioned with cement and concrete as well as bituminised waste from Barsebäck have an average porosity of 15%. Since the ion-exchange resins from Forsmark are totally dried before they are bituminised no porosity is assumed to be present in that waste form. Dewatered ion-exchange resins in concrete tanks are assumed to have a porosity of 40%. The total internal void and porosity inside the packaging in BLA is assumed to be 60% in average. The internal total void volume and porosities in the different waste vaults are given in Appendix A. The abundance and character of the fractures initially present in the waste deposited in SFR are not known.

12.1.2 Radiation intensity

The energy liberated during decay is converted for the most part into heat. However, the effect of radioactive decay on the temperature in the waste is negligible. Radiolysis is not considered, for the low and intermediate level waste in SFR, to have a significant effect on the waste since the intensity is less than 10^6 Gy and is therefore not considered (SKB 2014f).

12.1.3 Temperature

The temperature of the waste is set by the temperature of the surroundings. The temperature in the rock in the Forsmark area at about 50 metres depth is 5–7°C (Sundberg et al. 2009, Väisäsvaara 2009). The increase in temperature due to heat from decay, corrosion and concrete hydration is judged to be small (SKB 2014f).

12.1.4 Hydrological variables

Directly after plugging and the cessation of drainage pumping, water will start to saturate the repository. Bounding calculations have estimated that it will take about 25 years for water to fully saturate the silo, surrounded with bentonite (Holmén and Stigsson 2001). Full resaturation of the other waste vaults has been calculated to take a few years (Holmén and Stigsson 2001). The cement conditioned waste will be saturated shortly after the repository closure as predicted by Holmén and Stigsson (2001) saturation of the bitumen conditioned waste will take a considerably longer time due to the hydrophobic character of bitumen. The driving force for water saturation of the bituminised waste form is the hydroscopic character of the ion-exchange resins as well as different salts (SKB 2014f).

The hydraulic conductivity varies largely between waste forms of different types from very permeable to almost completely tight depending both on the type of waste and conditioning.

The water pressure in the waste form is assumed to be the same as the hydrostatic pressure. For waste forms in the silo this varies depending on each waste package allocation within the silo construction. For waste packages in the other waste vaults this effect is deemed negligible.

Initially, all water within the waste form is in liquid form due to temperature, see Section 12.1.3.

12.1.5 Mechanical stresses

Mechanical stresses, caused by external pressure on the waste form, may lead to fracturing of the waste form.

12.1.6 Radionuclide inventory

The radionuclide inventory in each waste vault is given in Table 3-16. This is based on the activity of the radionuclides present in each waste type given in the Inventory report (SKB 2013b, SKBdoc 1481419 (Mo-93)). All radionuclides are present in such low concentrations that their solubility limits are not expected to be exceeded to a significant extent. The chemical form of each radionuclide is set by the surrounding environment i.e. pH and presence of complexing agents. Initially, negligible amounts of radioactive gases are present within the repository some Rn-222 may be present due to the decay of U-238.

12.1.7 Material composition

The different materials found in the waste packages are presented in the Inventory report (SKB 2013b) and a summary is given in Section 3.8. Corrosion is the only considered process that has influenced the material composition during the operating phase, however, other processes such as carbonatisation might occur. Initially, organic complexing agents might be present within different waste forms. These chemicals originate from decontamination processes at the nuclear power plants. The amounts of complexing agents deposited in SFR are presented in Keith-Roach et al. (2014). The loads of complexing agents are regulated by the means of waste acceptance criteria's. Microbes might utilise some of the material deposited of in SFR as energy sources especially cellulose are a favourable energy source for microbes but other sources might occur within the waste form. The microbial population initially present in the waste form depends on the origin of the waste form and whether microbes have been transported to the waste by the infiltrating groundwater.

For the concrete-embedded solids, trash and scrap metal, the waste packages are filled with the same type of concrete as used in the concrete waste packaging, see Section 12.3.5. About 75 kg cement is used which corresponds to 10% by weight for waste in concrete moulds and 13% by weight for waste form in steel moulds. For cement-solidified ion-exchange resins in concrete moulds about 460 kg cement is used, which corresponds to about 64% by weight in the waste form. For steel moulds 1,500 kg cement is used, which corresponds to about 60% by weight in the waste form. For cement-solidified ion-exchange resins in drums about 60 kg cement is used per 100 kg final waste form, i.e. 60% by weight. About 800 kg is used to solidify sludges in concrete moulds. This corresponds to about 55% by weight.

12.1.8 Water composition

The composition of the groundwater will affect the concrete pore water composition. However, the concentration of dissolved species in the groundwater is lower than in the concrete pore water, hence the pore water is initially assumed to have the composition of fresh and/or leached cement, see Table 12-2. Shortly after closure, reducing conditions will prevail in SFR due to for example corrosion of the extensive amount of iron present in the repository (Duro et al. 2012).

The amount of radionuclides dissolved in the pore water depends on the amount in each individual waste package. It is assumed that all radionuclides dissolve in the waste form pore water immediately after saturation. Colloids are not deemed to be stable within the waste forms that have high ionic strength and are rich in dissolved Ca^{2+} concentration, i.e. waste forms within 1BMA, silo, 1BTF, 2BTF, 2BMA and 2–5BLA. In 1BLA, colloids originating both from the groundwater and the waste may be present (SKB 2014f). Initially, dissolved gases in the water originate from dissolved air that might have been trapped in the waste form during saturation. The abundance of microbes within the different waste forms is discussed in 12.1.7.

The density and viscosity of the water are assumed to be the same as tabulated values found in the literature at the temperature present.

Table 12-2. Analysis of pore water from fresh and leached cement (ion concentrations in [mmol/l]) and values calculated from groundwater equilibrated with cement pore water.

Parameter	Fresh cement (Lagerblad and Trägårdh 1994)	Leached cement (Engkvist et al. 1996)
pH	> 13	12.6
SO_4^{2-}	0.04	0.02
Cl^-	< 0.06	2
Na^+	28	3
K^+	83	0.1
Ca^{2+}	0.9	20
Si_{tot}	0.8	0.003
Al_{tot}	0.04	0.002
OH^-	114	36

12.1.9 Gas variables

As the repository fills with water, the most abundant gas in the interior of the waste packages is the undissolved air that may be found in air pockets and pores. Small amounts of Rn-222 might be present in the interior of the waste packaging, Rn-222 forms within the U-238 decay chain.

Aluminium is covered by a passivating oxide layer, and alkaline conditions cause the oxide to dissolve. Alkaline conditions are obtained when the groundwater has reacted with concrete. While the repository is drained by pumping during the operating phase, the aluminium waste will be covered by this passivating oxide layer. Corrosion of aluminium is therefore negligible during the operating phase, but will be rapid and extensive after saturation leading to production of hydrogen.

12.2 Variables for the waste packaging

Waste to be deposited in SFR is mainly packaged in the following types of packaging.

- Concrete moulds (with cement-solidified ion-exchange resins, filter aids and evaporator concentrate as well as concrete-embedded trash and scrap metal).
- Steel moulds (with cement- or bitumen-solidified ion-exchange resins or concrete-embedded trash and scrap metal).
- Steel drums (with concrete embedded ash or bitumen-solidified ion-exchange resins).
- Standard ISO-containers (mainly with trash and scrap metal).
- Concrete tanks (with dewatered ion-exchange resins).

There may be certain other odd packaging, and, in some cases, large items of waste (components) may be deposited without packaging. For more detailed information about the different packaging types, see Section 3.6 and Figure 3-2.

Oxygen is available during the operating phase, which means that aerobic corrosion can occur (SKB 2014f). Corrosion of iron is extensive in the environment when moisture and oxygen are available, and these will be present in most of the repository during the operating phase. Aerobic corrosion is so rapid that the ISO-containers, steel moulds and certain older drums are expected to corrode extensively during the operating phase.

Anaerobic corrosion can occur during the operating phase in parts of the repository where oxygen is not present. There are no requirements with regard to the long-term function of steel packaging.

Table 12-3 shows the variables for the concrete and steel packaging that are used for the waste in SFR.

12.2.1 Geometry

The volume and dimensions of the waste packaging are described in detail in Section 3.6.

The steel in the packaging has no porosity whereas the concrete packaging has a porosity of about 15%.

Steel waste packaging will probably start to corrode during the operating phase. The amount and character of the fractures initially present in the concrete packaging deposited in SFR are not known. The possibility cannot be ruled out that small fractures, more than 0.1 mm wide, will form in concrete packaging during the operating phase or even initially.

Table 12-3. Variables for steel and concrete packaging and their definition from the Waste process report (SKB 2014f).

Variable	Definition
Geometry	Volume and dimensions of the packaging Porosity and pore characteristics of the packaging Amount and characteristics of fractures in the packaging
Temperature	Temperature
Hydrological variables	Magnitude, direction and distribution of water flow Degree of saturation Water pressure Aggregation state (water and/or ice)
Mechanical stresses	Stress and strain in waste packaging
Material composition	Amount, composition and surface characteristics of materials in the waste packaging Type and amount of chemicals Extent of cement hydration in concrete Type, amount of organic materials and other substances that can be used by microbes as nutrients and energy sources Types and amount of microbes and bacteria and other types of biomass
Water composition	Composition of water including radionuclides Redox, pH, ionic strength, concentration of dissolved species, type and amount of colloids and/or particles, amount and composition of dissolved gas Types and amount of microbes and bacteria and other types of biomass. Density and viscosity
Gas variables	Amount and composition including radionuclides Volume, pressure and degree of saturation Magnitude, direction and distribution of gas flow

12.2.2 Temperature

The temperature in the different waste packages is controlled by the temperature of the surroundings as described in Section 12.1.3.

12.2.3 Hydrological variables

Directly after plugging and cessation of drainage pumping, water will start to saturate the repository. Bounding calculations have estimated that it will take about 25 years for water to fully saturate the silo (Holmén and Stigsson 2001). Full resaturation of the other waste vaults has been calculated to take a few years (Holmén and Stigsson 2001). This means that within 25 years all the concrete packaging will be fully water saturated. The water pressure in the concrete packaging are assumed to be the same as the hydrostatic pressure. For packaging in the silo this varies depending on each waste package allocation within the silo construction. For packaging in the other waste vaults this effect is deemed negligible.

The hydraulic conductivities of the different concrete types are given in the Data report (SKB 2014b).

Initially, all water within the waste packaging is in liquid form due to temperature, see Section12.1.3. However, this variable is not relevant for the steel packaging.

12.2.4 Mechanical stresses

Mechanical stresses, caused by corrosion of reinforcement bars in the concrete moulds and tanks during operation, may lead to fracturing of the packaging.

The physical status of the concrete tanks in 2BTF has been inspected during 2010. The results indicate that up until 2010 no or little deterioration of the concrete integrity can be found.

12.2.5 Material composition

The packaging is composed of carbon steel, stainless steel or reinforced concrete. In the Inventory report (SKB 2013b), the composition of different packaging is described in further detail, however the exact composition varies between different waste suppliers and over time due to changed concrete recipes. The microbial population initially present in the packaging mainly depends on if microbes have been transported to the packaging by the infiltrating groundwater. After saturation it is assumed that the concrete in the packaging is fully hydrated.

12.2.6 Water composition

The water compositions for the concrete packaging are mainly the same as for the waste form, see Section 12.1.8 for details. This variable is not relevant for the steel packaging.

12.2.7 Gas variables

As the repository fills with water, the most abundant gas in the concrete packaging is the undissolved air that may be found in pores. This variable is not relevant for the steel packaging. Initially, the packaging is not deemed to have any significant levels of radionuclides present.

12.3 Variables for the 1BMA and 2BMA system components

The system components are valid for both 1BMA and 2BMA. The compositions of the concretes to be used in structural parts of 2BMA and the grouting have not been determined in detail. Only minor deviations are expected from the concrete recipes used today, except that there will be no cellulose allowed in the additives used in the grouting concrete and that the recipe is adjusted for unreinforced concrete.

The concrete barriers include the concrete structures in the different waste vaults: the bottom, lid, outer as well as inner walls in 1BMA; caissons in 2BMA; and shotcrete. The shotcrete is used to stabilise the rock during the operating phase.

A prefabricated concrete lid is placed over each full compartment in 1BMA. The lids provide radiation shielding and fire protection. Another concrete layer is cast on top of the prefabricated lids to give the structure added stability and water tightness. At closure, the waste in 1BMA compartments is planned to be grouted with concrete. In addition, to achieve good condition for the concrete structures as well, measures are planned to repair it prior to closure as described in SKBdoc 1358612.

When each of the individual caissons in 2BMA is filled with waste moulds, a prefabricated concrete lid will be placed on top. Before closure, this lid will be removed and a new unreinforced lid cast. At closure, the waste in the 2BMA caissons are planned to be grouted with concrete as described in SKBdoc 1358612.

Table 12-4 shows the variables for the technical barriers in SFR.

Table 12-4 Variables for the engineered barriers in SFR and their definition from the Barrier process report (SKB 2014c).

Variable	Definition
Geometry	Volume and dimensions of the barriers Porosity and pore characteristics of the barriers
Temperature	Temperature
Hydrological variables	Magnitude, direction and distribution of water flow Degree of saturation Water pressure Aggregation state (water and/or ice)
Mechanical stresses	Stress and strain in the barriers
Material composition	Amount, composition and surface characteristics of materials in the barriers Type and amount of chemicals Type, amount of organic materials and other substances that can be used by microbes as nutrients and energy sources Type and amount of microbes and bacteria
Water composition	Composition of water including radionuclides Redox, pH, ionic strength, concentration of dissolved species, type and amount of colloids and/or particles, amount and composition of dissolved gas Density and viscosity Type and amount of microbes, bacteria and other types of biomass
Gas variables	Amount, composition including radionuclides Volume, pressure and degree of saturation Magnitude, direction and distribution of gas flow

12.3.1 Geometry

The design of the 1BMA and 2BMA vaults is described in Sections 4.1 and 5.1. The dimensions and material volumes are described in Sections 4.4 and 5.4.

The porosity can vary between 9–15% in the construction concrete, see for example Höglund (1992, 2014). For the evaluation of the long-term safety, 15% is used as the porosity in the construction concrete, 30% in the shotcrete and grout and 30% in the macadam. Initially, fractures up to a width of 0.1 mm may be present in the construction concrete.

12.3.2 Temperature

The temperature in the waste vault is set by the surrounding rock temperature, see Section 12.1.3.

12.3.3 Hydrological variables

Directly after plugging and cessation of drainage pumping, water will start to saturate the repository. Full resaturation of the waste vaults, except the silo, has been calculated to take a few years (Holmén and Stigsson 2001). This means that within a few years all the concrete structures will be fully water saturated. For SFR 3, the same resaturation rate is assumed even though the hydrostatic pressure differs at the deeper depth.

The water pressure is assumed to be the same as the hydrostatic pressure. The hydrostatic pressure differs between 1 and 2BMA due to the different depths.

The hydraulic conductivities of the different concrete types are given in the Data report (SKB 2014b). The hydraulic conductivity in the macadam is high, initially higher than 10^{-2} m/s (SKBdoc 1358612).

Initially, all of the water within the waste packaging is liquid due to the temperature, see Section 12.1.3, this variable is not relevant for the steel packaging.

12.3.4 Mechanical stresses

Mechanical stresses on the concrete structures may occur due to waste loads. The 1BMA and 2BMA floors are subjected to loads from the waste placed on them. The surrounding walls are subjected to pressure from the groundwater and backfill.

During casting of the concrete, the hydration process generates heat. As the hydrated concrete then cools, stresses may be induced within the concrete structure, which may eventually lead to fracturing (micro fractures).

12.3.5 Material composition

The cement used for the major concrete structures in SFR 1 is Degerhamn Anläggningscement. The chemical composition of this cement is presented in Table 12-5. The caissons in 2BMA do not contain any reinforcement therefore the caissons must be grouted in order to withstand the water pressure during saturation. The composition of the grout in the silo is given in Table 12-6, whereas the grout composition for 2BMA has not yet been determined.

Degerhamn Anläggningscement satisfies the requirements of EN 197-1 Cement-Part 1: Composition, specifications and conformity criteria for common cements and is in accordance with SS 13 42 02–03 for MH/LA. Anläggningscement has a low C_3A content and satisfies the requirements (i) for sulphate resistance of SR 3 type cement in EN 197-1, for low alkali cement in accordance with SS 13 42 03 and (ii) for cement with moderate heat development in accordance with SS 13 42 02 (Heidelberg Cement 2013).

The cement to be used in the structural parts of 2 BMA has not yet been determined in detail but the cement will be sulphate-resistant (common practice) and alkali-silica reactions will be avoided.

The mixing proportions used for cementitious materials in SFR 1 are given in Table 12-6.

The ballast material is selected to comply with Swedish standards on resistance to alkali-silica reactions. The ballast material in the construction concrete of the silo consists of Baskarpsand, the chemical composition of this material is given in Table 12-7.

Table 12-5. Chemical composition of Degerhamn Anläggningscement, including both the oxide composition and the corresponding clinker mineral composition as given in SKBdoc 1430502.

Component	Content % by weight
Ca	64
SiO_2	21
Al_2O_3	3.5
Fe_2O_3	4.6
MgO	0.7
K_2O	0.62
Na_2O	0.07
SO_3	2.2
Cl	< 0.1
Free $CaCO_3$	0.9
Corresponding clinker components	
Tricalcium silicate, C_3S	64.4
Dicalcium silicate, C_2S	10.9
Tricalcium aluminate, C_3A	2.0
Tetracalcium aluminate ferrite, C_4AF	13.9
Calcium sulphate (gypsum), $C\$H_2$	3.7
Alkali hydroxides, N + K	0.7

Abbreviations used for the clinker components: $C=CaO$, $S=SiO_2$, $A=Al_2O_3$, $F=Fe_2O_3$, $H=H_2O$, $C\$H_2=CaSO_4{\cdot}2H_2O$, $N=Na_2O$, $K=K_2O$

Table 12-6. Mixing proportions for cementitious materials in SFR 1, amounts given in kg/m^3.

Component	Construction concrete (Jacobsen and Gjörv 1987)	Grout (Björkenstam 1997)	Conditioning cement
Degerhamn anläggningscement	350	325	1,180
Water	164.5	366	437
Ballast	1,829 (total) 0–8 mm 920 kg/m^3 8–16 mm 374 kg/m^3 16–32 mm 535 kg/m^3	1,302	–
Additives (anti-foaming, cellulose)*	0.5% Sika Plastiment BV-40 0.05–0.2% Sika Retarder	6.5	–
Air	–	2.5% by volume	–
w/c ratio	0.47 (0.46 – 0.49)	1.125	0.37

* Not allowed in future grout.

Table 12-7. Chemical composition of Baskarpsand* (SKBdoc 1392924).

Component	Content % by weight
CaO	1.12
SiO_2	78.8
Al_2O_3	11.6
Fe_2O_3	1.21
MgO	0.28
K_2O	3.86
Na_2O	3.09
Loss on ignition, 1,000°C	0.48
Fraction free quartz	43

* Sintering temperature 1,250°C

The BMA tunnels are planned to be backfilled with macadam in the size range 16–32 mm. This type of material has high hydraulic conductivity and is a suitable backfill according to the Closure Plan for SFR (SKBdoc 1358612). The concrete structures found within the SFR repository are not deemed to contribute to any significant amounts of nutrients for microbes compared to the nutrient amounts found in the infiltrating groundwater. The microbial population initially present in the concrete structures mainly depends on the transport of microbes into the repository by the infiltrating groundwater as well as the microbial population established during the operating phase.

12.3.6 Water composition

Initially, the BMA vaults will be filled by the groundwater that surrounds the SFR repository (Auqué et al. 2013) no radionuclides, except for those naturally occurring in the groundwater, are deemed to be initially present. The composition of the groundwater will affect the concrete pore water composition. Reducing conditions will prevail in SFR from shortly after closure due to for example corrosion of the extensive amount of iron present in the repository (Duro et al. 2012). Colloids are not deemed to be stable within the concrete structures for the same reasons as given in Section 12.1.8. Initially, dissolved gases may be present in the concrete structures originating from air that might have been trapped and subsequently dissolved during saturation. The abundance of microbes within the different structures is discussed in Section 12.3.5.

The density and viscosity of the free water are assumed to be the same as tabulated values found in the literature for the prevailing salinity and temperature present.

12.3.7 Gas variables

As the repository fills with water, the most abundant gas is the undissolved air that may be found in air pockets and pores in the materials surrounding the waste packaging, backfill materials and concrete structures.

12.4 Variables for the 1BTF and 2BTF system components

The 1BTF and 2BTF waste vaults have been designed primarily for storing concrete tanks and drums with low activity waste. The waste vaults have a concrete floor, and the rock walls and ceilings are lined with shotcrete. The space between the concrete tanks will be grouted with concrete. The concrete lid, grout, the floor, the backfill and shotcrete constitute barriers. Shotcrete is used to stabilise the rock during the operating phase. The only long-term function of the shotcrete is that it contributes to the high pH, through the dissolution of cement minerals.

12.4.1 Geometry

The design of 1BTF and 2BTF are described in Section 6.1. The dimensions and material volumes are given in Sections 6.4 and 6.5.

The porosities are the same as for the BMA vaults, see Section 12.3.1. Fractures (> 0.1 mm) may be present in the grouting.

12.4.2 Temperature

The temperature in the waste vaults is set by the surrounding rock temperature, see Section 12.1.3.

12.4.3 Hydrological variables

For the BTF waste vaults, this system variable is the same as for the BMA vaults, see Section 12.3.3.

12.4.4 Mechanical stresses

For the BTF waste vaults, this system variable is the same as for the BMA vaults, see Section 12.3.4.

12.4.5 Material composition

For the BTF waste vaults, this system variable is the same as for the BMA vaults, see Section 12.3.5.

12.4.6 Water composition

For the BTF waste vaults, this system variable is the same as for the BMA vaults, see Section 12.3.6.

12.4.7 Gas variables

For the BTF waste vaults, this system variable is the same as for the BMA vaults, see Section 12.3.7.

12.5 Variables for the silo system components

The waste packages are embedded in concrete grout which, together with the compartment walls and the silo walls of reinforced concrete, constitute the concrete barriers. The silo walls are completely surrounded by bentonite, which constitutes a barrier between the silo and the rock. The rock is covered with shotcrete. The bottom part of the silo consists of a reinforced concrete pad resting on a layer of sand mixed with bentonite.

The condition of the concrete and grout system components of the silo at closure is assumed to be the same as for the BMA waste vaults, see Section 12.3.

12.5.1 Geometry

The design of the silo barriers is described in Section 7.1. The dimensions and material volumes are given in Section 7.4.

The porosities are about 60% for the pure bentonite at the walls of the silo (calculated from an average dry bulk density of about 1,000 kg/m^3 (Pusch 2003)) and about 15–25% for the sand/bentonite (90/10) at the bottom and top of the silo (calculated from a dry bulk density of about 2,170 kg/m^3 for the bottom (Pusch 2003)) and an estimate for the less compacted top layer). The porosity of the crushed rock is 30%.

The porosities and status of fracturing in the concrete are assumed to be the same as for the BMA vaults, see Section 12.3.1.

12.5.2 Temperature

The temperature in the waste vault is set by the surrounding rock temperature, see Section 12.1.3.

12.5.3 Hydrological variables

Directly after plugging and cessation of drainage pumping, water will start to saturate the repository. Bounding calculations have estimated that it will take about 25 years for water to fully saturate the silo (Holmén and Stigsson 2001). This means that within 25 years the bentonite and all the concrete structures will be fully water saturated.

The water pressure is assumed to be the same as the hydrostatic pressure. For structural parts in the silo, this varies depending on the allocation within the silo structure.

The hydraulic conductivity in the pure bentonite at the walls of the silo varies from the bottom to the top depending on the degree of self-compacting. It was concluded that the hydraulic conductivity will be less than about $1 \cdot 10^{-10}$ m/s for all parts of the wall fill (Pusch 2003). The lower part has a hydraulic conductivity of about $9 \cdot 10^{-12}$ m/s and the upper part about $9 \cdot 10^{-11}$ m/s (Pusch 1985). The hydraulic conductivity of the sand/bentonite in the bottom and top will be less than $1 \cdot 10^{-9}$ m/s (Pusch 2003).

12.5.4 Mechanical stresses

For the silo, this system variable is the same as for the BMA vaults, see Section 12.3.4. In addition, mechanical stresses can arise in the silo during operation due to settling of the concrete structure. Details of how this is quantified and controlled are given in Section 4.3.

One of the design considerations for the silo is that the concrete structure must be able to withstand the swelling pressure from the surrounding bentonite.

12.5.5 Material composition

The silo is surrounded by a layer of bentonite, between the reinforced concrete and the rock. The bentonite is a bentonite from Greece (Milos) converted from its original Ca-form to the Na-state by soda treatment (Pusch 2003). The product name of the bentonite is GEKO/QI. The bentonite material contains various accessory minerals in addition to the montmorillonite. The mineralogical and chemical composition of the bentonite used is given in Table 12-8.

In addition, small amounts of iron oxides, cristobalite, feldspar and mica were identified in the original quality control of the bentonite (Pusch and Cederström 1987).

Table 12-8. Mineralogical and chemical composition of the bentonite surrounding the silo.

Mineral phase	Chemical formula	Content in bentonite	Comment
Montmorillonite		~80 wt%	72% Na-form 27% Mg-form small amounts of K- and Ca-forms
Soluble sulphate	SO_4^{2-}	0.12–0.18 wt%	
Carbonate	CO_3^{2-}	< 2%	
Pyrite	FeS_2	–	–
pH (of the porewater)		10.1–10.35	

12.5.6 Water composition

For the silo, this system variable is the same as for the BMA vaults, see Section 12.3.6.

The water composition of the bentonite surrounding the concrete structure will be affected both by the surrounding groundwater composition and the dissolved species from the surrounding concrete. The assumed composition of the bentonite pore water depends on the bentonite chemical composition, degree of saturation and the chemical composition of the infiltrating groundwater.

12.5.7 Gas variables

For the silo, these system variables are the same as for the BMA vaults, see Section 12.3.7.

Initially, some undissolved air may also be present in the pores of the bentonite surrounding the concrete structure.

12.6 Variables for the 1BLA and 2–5BLA system components

1BLA is considered to have limited barrier functions in the long-term safety assessment. Although intact waste containers can limit the water flow through the waste to some extent, they are not considered to be a barrier. Shotcrete is used to stabilise the rock during the operating phase. The only long-term function of the shotcrete considered is that it contributes to the high pH through the dissolution of its cement mineral content. The concrete bottom plate is also included in the assessment of the pH conditions.

In 2–5BLA, there will be longitudinal walls surrounding the waste, these structures are mainly present for radiation protection and maintenance during operation. For the long-term safety assessment, these structures are not considered to act as barriers to water flow. However, both the concrete used and the concrete in the waste are included in the assessment of the pH of the water flowing through these vaults.

12.6.1 Geometry

The design of the 1BLA and 2–5BLA vaults is described in Sections 8.1 and 9.1, respectively. The dimensions and material volumes used in the 1BLA and 2–5BLA vaults are presented in Sections 8.4 and 9.4, respectively.

The porosities and status of fracturing in the concrete are assumed to be the same as for the BMA vaults, see Section 12.3.1.

12.6.2 Temperature

The temperature in the waste vaults is set by the surrounding rock temperature, see Section 12.1.3.

12.6.3 Hydrological variables

For the 1BLA and 2–5BLA vaults, the system variable is the same as for the BMA vaults, see Section 12.3.3. The water pressure is assumed to be the same as the hydrostatic pressure.

Initially, all water is in liquid form due to temperature see Section 12.1.3; this variable is not relevant for the steel packaging.

12.6.4 Mechanical stresses

Mechanical stresses on the concrete floors may occur due to waste loads. The longitudinal walls in 2–5BLA are subjected to pressure from the groundwater and backfill.

12.6.5 Material composition

Macadam will not be used as backfill material in the BLA vaults. The concrete floor in 1BLA have the same material composition as the concrete structures in 1BMA and this is also assumed for the concrete structures in 2–5BLA.

12.6.6 Water composition

Initially, the BLA vaults will be filled by the groundwater that surrounds the SFR repository (Auqué et al. 2013) no radionuclides, except for those naturally occurring in the groundwater, are deemed to be initially present. The composition of the groundwater will affect the concrete pore water composition as discussed in Section 12.3.6. To what extent the groundwater will be affected by the pore water from the concrete structures in the different vaults depends on the material composition and amounts of concrete and shotcrete.

Colloids are not deemed to be stable within the concrete structures for the same reasons as given in Section 12.1.8. For 1BLA, the initial presence of colloids cannot be excluded, see Section 12.1.8.

Initially, dissolved gases may be present in the concrete structures originating from dissolved air that might have been trapped during saturation as well as in the water surrounding the BLA vaults. The abundance of microbes within the different structures is discussed in Section 12.3.5.

The density and viscosity of the water are assumed to be the same as tabulated values found in the literature at the temperature present.

12.6.7 Gas variables

As the vaults fills with water, the most abundant gas is the undissolved air that may be found in air pockets and pores in the materials.

12.7 Variables for the BRT system components

The reactor pressure vessels (RPVs) are planned to be embedded and filled with concrete grout. BRT will be backfilled with macadam.

12.7.1 Geometry

The design of the BRT waste vault is described in Section 10.1. The dimensions and material volumes are given in Section 10.4.

The porosities are assumed to be the same as for the BMA vaults, see Section 12.3.1. Fractures (> 0.1 mm) may be present in the grouting.

12.7.2 Temperature

The temperature in the waste vault is set by the surrounding rock temperature, see Section 12.1.3.

12.7.3 Hydrological variables

For the BRT waste vault, these system variables are the same as for the BMA vaults, see Section 12.3.3.

12.7.4 Mechanical stresses

For the BRT waste vault, this system variable is the same as for the BMA vaults, see Section 12.3.4.

12.7.5 Material composition

For the BRT waste vault, this system variable is the same as for the BMA vaults, see Section 12.3.5.

12.7.6 Water composition

For the BRT waste vault, this system variable is the same as for the BMA vaults, see Section 12.3.6.

12.7.7 Gas variables

For the BRT waste vault, these system variables are the same as for the BMA vaults, see Section 12.3.7.

12.8 Variables for plugs and other closure components

The closure of SFR will be performed according to the Closure plan for SFR (SKBdoc 1358612), see also Section 11.1. The plugs consist of tunnel sections filled with bentonite that are confined by mechanical plugs. In most positions, concrete plugs are used for mechanical support. In some sections, where the geometry and the local geology make it difficult or impossible to construct concrete plugs, “earth dam plugs” are used. Earth dam plugs do not require local mechanical support from the rock walls. The function of the bentonite-filled sections is to act as hydraulic seals. The function of the mechanical seals is to confine the bentonite sections. The remaining parts of the tunnel system will be filled with macadam.

12.8.1 Geometry

The porosity can vary between 9–15% in the construction concrete, see for example Höglund (1992, 2014). For the evaluation of the long-term safety 15% is used as the porosity in the concrete, and 30% in the macadam. Initially, there might be fractures up to a width of 0.1 mm in the construction concrete. The properties for the bentonite are described in the Closure plan for SFR (SKBdoc 1358612).

12.8.2 Temperature

For the plugs and other closure components, this system variable is set by the surrounding rock temperature, see Section 12.1.3.

12.8.3 Hydrological variables

The hydraulic conductivity of the concrete used in plugs and other concrete closure components is assumed to be the same as assumed for the concrete in the BMA vaults. The water pressure is assumed to be the same as the hydrostatic pressure at the depth where the plugs and other closure components are placed. The hydraulic conductivities of the different concrete types are given in the Data report (SKB 2014b). The hydraulic conductivity in the macadam is high, initially higher than 10^{-2} m/s (SKBdoc 1358612).

The hydraulic conductivity of the bentonite in the connecting tunnels (brown in Figure 1-4) is assumed to be less than 10^{-10} m/s, i.e. the same as the hydraulic conductivity for the deposition tunnels in the repository for spent fuel (SKB 2010, p 151). Possible initial hydraulic conductivity is as low as 10^{-13}–10^{-12} m/s (SKBdoc 1358612). The hydraulic conductivity of the low hydraulic conductivity sections in the access tunnels (orange in Figure 1-4) is calculated from the requirement of a resistance of at least $2 \cdot 10^{9}$ s that correspond to $5 \cdot 10^{-10}$ m/s for a 1 m section.

12.8.4 Mechanical stresses

For the plugs, the swelling pressure of the bentonite will dominate the mechanical stresses on the concrete structures. In SR-PSU, it is assumed that the concrete closure components will be designed to withstand the swelling pressure from the bentonite in SR-PSU.

12.8.5 Material composition

The transition materials in the earth dam plugs are assumed to consist of 30% bentonite and 70% crushed rock (dry weight) (SKBdoc 1358612). The concrete plugs will consist of standard concrete. The bentonite consists of a high quality bentonite, the properties are described in the Closure plan for SFR (SKBdoc 1358612).

12.8.6 Water composition

Initially, the plugs and other components will be filled by the groundwater that surrounds the SFR repository (Auqué et al. 2013). The composition of the groundwater will affect the concrete pore water composition. Reducing conditions will prevail in SFR from shortly after closure due to for example corrosion of the extensive amount of iron present in the repository (Duro et al. 2012). Colloids are not deemed to be stable within the concrete structures for the same reasons as given in Section 12.1.8. Initially, dissolved gases may be present in the concrete structures originating from air that might have been trapped and subsequently dissolved during saturation. The microbial population initially present in the structures mainly depends on the transport of microbes into the repository by the infiltrating groundwater as well as the microbial population established during the operating phase.

The density and viscosity of the free water are assumed to be the same as tabulated values found in the literature for the prevailing salinity and temperature present.

12.8.7 Gas variables

As the repository fills with water, the most abundant gas is the undissolved air that may be found in air pockets and pores in the material.

13 Summary and conclusions

This chapter gives a summary of the conditions of the repository at the initial state. The initial state is defined as the expected state of the repository and its environs immediately after closure. The initial state of the repository part in operation (SFR1) is based on verified and documented properties of the wastes and the repository components plus an assessment of changes in these properties up to the time of closure, whereas the initial state of the extension (SFR 3) is mainly based on the reference design and present waste prognosis.

13.1 1BMA

In 1BMA, the radioactive waste is deposited in a concrete structure that is divided into compartments. The compartments are covered with prefabricated concrete elements and overcast with concrete. The waste in 1BMA is conditioned in cement, bitumen or concrete. Inside the compartments, the waste packages are embedded in grout at closure. The space above the concrete structure and between the structure and the rock wall is filled with macadam.

Condition of the subcomponents

The conditioned waste is surrounded by the following subcomponents:

- Waste packaging.
- Grout in compartments.
- Concrete structure, i.e. reinforced concrete compartment walls and bottom, plus prefabricated concrete elements and overcast concrete lid.
- Backfill of macadam.
- Mechanical plugs (see Section 13.9).

The waste packaging in 1BMA is made of concrete or steel plate. Steel packaging will probably start to corrode during the operating phase. The possibility cannot be ruled out that small fractures, more than 0.1 mm wide, will form in concrete waste packaging during the operating phase or even initially. Steel reinforcement (rebar) in the concrete structure will corrode during the operating phase.

Other subcomponents that are emplaced prior to closure are expected to be in the condition the items had at the time of emplacement i.e. only minor changes during the operating phase.

In order to achieve good condition for the concrete structure, measures are planned to repair it prior to closure (SKBdoc 1358612).

13.2 2BMA

In 2BMA, the radioactive waste is stored in concrete caissons that are sealed with a concrete lid when they have been filled with waste. The waste in 2BMA is conditioned in concrete or cement. The waste packages in 2BMA will also be embedded in grout, and the space between and outside the caissons will be backfilled with macadam.

Condition of the subcomponents

The conditioned waste is surrounded by the following subcomponents:

- Waste packaging.
- Grout in caissons.
- Walls and bottom of caissons of unreinforced concrete.
- Lids on caissons of unreinforced concrete.

- Backfill of macadam.
- Mechanical plugs (see Section 13.9).

The waste packages in 2BMA are continuously grouted during the operating phase. This means that the condition of the waste packages cannot be inspected afterwards. Steel waste packaging will probably start to corrode during the operating phase. The possibility cannot be ruled out that small fractures, more than 0.1 mm wide, will form in concrete waste packaging during the operating phase or even initially.

Other subcomponents that are emplaced prior to closure are expected to be in the condition the items had at the time of emplacement i.e. only minor changes during the operating phase.

13.3 1BTF

The waste packaging placed in 1BTF is made of concrete or steel. Steel drums are placed in the inner half of 1BTF. The steel drums consist of drums placed in larger drums, and the space between the inner and outer drum is filled with concrete. Concrete moulds and concrete tanks are used as support walls for the steel drums. The steel drums in 1BTF are continuously grouted during the operating phase, and a concrete lid is placed on top of this grout, see Figure 6-1. At closure, the support walls and the space between them and the rock wall are also grouted. Another concrete lid is cast on top of this grout. On top of this lid, the repository is backfilled with macadam up to the rock. Concrete tanks will be placed in the outer half of 1BTF in the same way as in 2BTF, see Section 13.9.

Condition of the subcomponents

The waste is surrounded by the following subcomponents:

- Waste packaging.
- Grout.
- Moulds and concrete tanks positioned as support walls for drums.
- Concrete floor.
- Prefabricated concrete elements and overcast conrete lid.
- Backfill of macadam.
- Mechanical plugs (see Section 13.9).

The waste packages (drums with ashes) in 1BTF are embedded in grout as they are emplaced. This means that the condition of the waste packages cannot be inspected afterwards. Steel waste packaging will probably start to corrode during the operating phase. The possibility cannot be ruled out that small fractures will form in concrete tanks and moulds during the operating phase or even initially.

Other subcomponents that are emplaced prior to closure are expected to be in the condition the items had at the time of emplacement i.e. only minor changes during the operating phase.

13.4 2BTF

The waste packaging (concrete tanks) emplaced in 2BTF is made of reinforced concrete. The waste in 2BTF is not conditioned. At closure, the concrete tanks will be embedded in grout and a concrete lid will be cast on top of the grout. The space above this will be backfilled with macadam all the way up to the rock.

Condition of the subcomponents

The waste is surrounded by the following subcomponents:

- Waste packaging (concrete tank lined with butyl rubber).
- Grout.
- Concrete floor.

- Prefabricated concrete elements and overcast conrete lid.
- Backfill of macadam.
- Mechanical plugs (see Section 13.9).

The possibility cannot be ruled out that small fractures will form in the concrete tanks during the operating phase or even initially.

Other subcomponents that are emplaced prior to closure are expected to be in the condition the items had at the time of emplacement i.e. only minor changes during the operating phase.

13.5 Silo

The silo is made of in-situ cast concrete and sits on a bed of sand and bentonite. In the silo, the radioactive waste is deposited in a cylindrical concrete structure. Inside, the silo is divided into shafts with concrete walls. The waste in the silo is conditioned in cement, bitumen or concrete. The waste packages in the silo are continuously grouted during the operating phase.

Condition of the subcomponents

The conditioned waste is surrounded by the following subcomponents:

- Waste packaging.
- Grout.
- Shaft walls.
- Concrete structure of the silo.
- Bentonite or sand/bentonite buffer.
- Backfill material in the silo top.
- Mechanical plugs (see Section 13.9).

The waste packages in the silo are embedded in grout as they are emplaced. This means that the condition of the waste packages cannot be inspected afterwards. Steel waste packaging will probably start to corrode during the operating phase. The possibility cannot be ruled out that small fractures will form in concrete waste packaging during the operating phase or even initially.

The control and inspection of bentonite material surrounding the silo's concrete walls and bottom (e.g. measurements of the settlement of the silo, silo top subsidence and swelling pressures in the surrounding buffer) are described in Section 7.3. The following conclusions can be drawn:

- The silo movements are small and correspond well with the prognosis.
- The bentonite wall filling is stable and only small movements have been detected in the top filling, which indicates that the water absorption in the bentonite is insignificant.
- The measured pressures are less than expected, which indicates a more efficient dewatering of the surface rock than assumed during the design of the silo. The system consisting of silo/bentonite/rock behaves in a satisfying way.

Other subcomponents that are emplaced prior to closure are expected to be in the condition the items had at the time of emplacement i.e. only minor changes during the operating phase.

13.6 1BLA

The waste packages in 1BLA consist of ISO-containers. A small fraction of the waste is conditioned in cement or bitumen. The containers are placed directly on a concrete floor. No grouting of the waste packages is planned, nor will the vault be backfilled.

Condition of the subcomponents

The waste is surrounded by the following subcomponents:

- Waste packaging (ISO-containers).
- Concrete floor.
- Mechanical plugs (see Section 13.9).

Steel waste packaging will corrode during the repository's operating phase.

Other subcomponents that are emplaced prior to closure are expected to be in the condition the items had at the time of emplacement i.e. only minor changes during the operating phase.

13.7 2–5BLA

The waste packaging in 2–5BLA consist of ISO-containers. All waste will be loosely packed in the ISO-containers and will thereby not be conditioned. The containers are placed directly on a concrete floor. No grouting of the waste packages is planned, nor will the vaults be backfilled.

Condition of the subcomponents

The waste is surrounded by the following subcomponents:

- Waste packaging (ISO-containers).
- Concrete floor.
- Mechanical plugs (see Section 13.9).

Steel waste packaging will probably start to corrode during the operating phase.

Other subcomponents that are emplaced prior to closure are expected to be in the condition the items had at the time of emplacement i.e. only minor changes during the operating phase.

13.8 BRT

RPVs from BWRs are deposited in BRT. The RPVs will be filled with and embedded in concrete. BRT will be backfilled with macadam.

Condition of the subcomponents

The RPVs are surrounded by the following subcomponents:

- Concrete filling.
- Concrete grout.
- Concrete floor.
- Backfill of macadam.
- Mechanical plugs (see Section 13.9).

The possibility cannot be ruled out that the RPVs will corrode during the period up to repository closure.

Other subcomponents that are emplaced prior to closure are expected to be in the condition the items had at the time of emplacement i.e. only minor changes during the operating phase.

13.9 Plugs and other closure components

Plugs and other closure components are installed near the time of closure and are expected to be in good condition at closure.

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1358612 ver 1.0	SFR förslutningsplan. (In Swedish)	SKB, 2014
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1392924 ver 1.0	Analys av sand. (In Swedish)	Glasforskningsinstitutet, 2005
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1427105 ver 4.0	Radionuclide inventory for application of extension of the SFR repository – Treatment of uncertainties.	SKB, 2014
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1481419 ver 1.0	Ny beräkning av Mo-93 i normkolli till PSU 2015-05 (In Swedish.)	SKB, 2015

Appendix A

Detailed information for the waste packages and waste vaults

Table A-1. Number of waste packages in SFR at repository closure 2075. The prognosis is from the Inventory report (SKB 2013b) and the distribution between waste vaults is described in Section 3.7 in this report.

Waste type	Packaging	Waste	Number of waste packages
1BMA			
B.05/B.05:9	Drum	Ion-exchange resin	3,360
B.05:2	Box with drums	Ion-exchange resin	224
B.23	Steel mould	Trash and scrap metal	33
C.01:9	Concrete mould	Ion-exchange resin	7
C.01:9–30 [a)]	Concrete mould	Ion-exchange resin	61
C.23	Concrete mould	Trash and scrap metal	63
F.05:1	Drum	Ion-exchange resin	1,454
F.05:2	Drum	Ion-exchange resin	258
F.15	Steel mould	Ion-exchange resin	11
F.17/F.17:1	Steel mould	Ion-exchange resin	1,187
F.17Cellulose [b)]	Steel mould	Ion-exchange resin	195
F.23C [c)]	Concrete mould	Trash and scrap metal	57
F.23	Steel mould	Trash and scrap metal	220
F.99:1	Steel mould	Odd waste	2
O.01:9	Concrete mould	Ion-exchange resin	397
O.01:9–30 [a)]	Concrete mould	Ion-exchange resin	278
O.23/O.23:9	Concrete mould	Trash and scrap metal	509
R.01/R.01:9	Concrete mould	Ion-exchange resin	1,689
R.10	Concrete mould	Sludge	121
R.15	Steel mould	Ion-exchange resin	186
R.23C [c)]	Concrete mould	Trash and scrap metal	338
R.23	Steel mould	Trash and scrap metal	172
R.29	Concrete mould	Evaporator concentrates	188
S.21	Drum	Trash and scrap metal	488
S.23	Concrete mould	Trash and scrap metal	113
2BMA			
B.23:D	Steel mould	Trash and scrap metal	486
B.23:Dsec [d)]	Steel mould	Trash and scrap metal, secondary waste	122
C.23	Concrete mould	Trash and scrap metal	98
C.4K23:D	Tetramould	Trash and scrap metal	3
F.23	Steel mould	Trash and scrap metal	250
F.4K23:D	Tetramould	Trash and scrap metal	237
F.4K23C:D	Tetramould	Concrete	70
O.23/O.23:9	Concrete mould	Trash and scrap metal	100
O.4K23:D	Tetramould	Trash and scrap metal	198
O.4K23C:D	Tetramould	Concrete	82
O.4K23S:D	Tetramould	Sand	15
R.15	Steel mould	Ion-exchange resin	68
R.23	Steel mould	Trash and scrap metal	96
R.23:D	Steel mould	Trash and scrap metal	153
R.4K23:D	Tetramould	Trash and scrap metal	314
R.4K23C:D	Tetramould	Concrete	149
R.29	Concrete mould	Evaporator concentrates	192
S.23	Concrete mould	Trash and scrap metal	605
S.23:D	Concrete mould	Trash and scrap metal	164
S.25:D	Drum	Trash and scrap metal	2,384

Table A-1 cont.

Waste type	Packaging	Waste	Number of waste packages
Å.4K23:D	Tetramould	Trash and scrap metal	45
Å.4K23C:D	Tetramould	Concrete	5
Silo			
B.04	Drum	Ion-exchange resin	768
B.06	Drum	Ion-exchange resin	1,776
C.02	Concrete mould	Ion-exchange resin	1,361
C.16:D	Steel mould	Ion-exchange resin	7
C.24	Concrete mould	Trash and scrap metal	350
F.18	Steel mould	Ion-exchange resin	804
F.18:D	Steel mould	Ion-exchange resin	21
O.02/O.02:9	Concrete mould	Ion-exchange resin	1,944
O.16:D	Steel mould	Ion-exchange resin	28
O.24	Steel mould	Trash and scrap metal	204
R.02/R.02:9	Concrete mould	Ion-exchange resin	371
R.02:D	Steel mould	Ion-exchange resin	42
R.16	Steel mould	Ion-exchange resin	2,839
R.24	Steel mould	Trash and scrap metal	60
S.04	Drum	Ion-exchange resin	452
S.11	Steel mould	Sludge and ion-exchange resin	106
S.24C	Concrete mould	Trash and scrap metal	697
S.24/S.24:1	Steel mould	Trash and scrap metal	129
1BTF			
B.07/B.07:9	Concrete tank	Ion-exchange resin	24
O.01:9	Concrete mould	Ion-exchange resin	28
O.07/O.07:9	Concrete tank	Ion-exchange resin	369
O.99:1	Cortén box	Odd waste	40
R.01/R.01:9	Concrete mould	Ion-exchange resin	91
R.10	Concrete mould	Sludge	4
R.23C	Concrete mould	Trash and scrap metal	21
R.99:1		Odd waste	1
S.13	Drum	Ash	8,116
2BTF			
B.07/B.07:9	Concrete tank	Ion-exchange resin	208
F.99:2	Steel box	Odd waste	18
O.07/O.07:9	Concrete tank	Ion-exchange resin	521
1BLA			
B.12 half-height	Container 20 m^3	Trash and scrap metal	171
B.12:1	Container 20 m^3	Trash and scrap metal	22
B.12	Container 40 m^3	Trash and scrap metal	47
B.20	Container 20 m^3	Ion-exchange resin	12
F.12	Container 10 m^3	Trash and scrap metal	18
F.12	Container 20 m^3	Trash and scrap metal	28
F.20	Container 20 m^3	Ion-exchange resin	15
O.12 20-foot half-height	Container 20 m^3	Trash and scrap metal	22
O.12 10-foot full-height	Container 20 m^3	Trash and scrap metal	10
O.12 20-foot full-height	Container 40 m^3	Trash and scrap metal	10
O.12:1 20-foot half-height	Container 20 m^3	Trash and scrap metal	1
O.99:3	Container 40 m^3	Odd waste	5
R.12 half-height	Container 20 m^3	Trash and scrap metal	31
R.12:1	Container 20 m^3	Trash and scrap metal	2
R.12 full-height	Container 40 m^3	Trash and scrap metal	67
S.12	Container 20 m^3	Trash and scrap metal	58
S.14	Container 20 m^3	Trash and scrap metal	75

Table A-1 cont.

Waste type	Packaging	Waste	Number of waste packages
2–5BLA			
B.12	Container 40 m^3	Trash and scrap metal	14
B.12:D	Container 20 m^3	Trash and scrap metal	267
B.12:Dsec [d)]	Container 20 m^3	Trash and scrap metal, secondary waste	30
B.12C:D	Container 20 m^3	Trash and scrap metal	389
B.12S:D	Container 20 m^3	Trash and scrap metal	190
C.12:D	Container 20 m^3	Trash and scrap metal	9
C.12:Dsec [d)]	Container 20 m^3	Trash and scrap metal, secondary waste	2
C.12C:D	Container 20 m^3	Trash and scrap metal	7
F.12	Container 10 m^3	Trash and scrap metal	9
F.12	Container 20 m^3	Trash and scrap metal	15
F.12:D	Container 20 m^3	Trash and scrap metal	454
F.12:Dsec [d)]	Container 20 m^3	Trash and scrap metal, secondary waste	75
F.12C:D	Container 20 m^3	Trash and scrap metal	152
F.12S:D	Container 20 m^3	Trash and scrap metal	53
O.12 20-foot half-height	Container 20 m^3	Trash and scrap metal	24
O.12 10-foot full-height	Container 20 m^3	Trash and scrap metal	24
O.12:D	Container 20 m^3	Trash and scrap metal	382
O.12:Dsec [d)]	Container 20 m^3	Trash and scrap metal	75
O.12C:D	Container 20 m^3	Trash and scrap metal	160
O.12S:D	Container 20 m^3	Trash and scrap metal	37
R.12 full-height	Container 40 m^3	Trash and scrap metal	51
R.12:D	Container 20 m^3	Trash and scrap metal	294
R.12:Dsec [d)]	Container 20 m^3	Trash and scrap metal	95
R.12C:D	Container 20 m^3	Trash and scrap metal	60
R.12S:D	Container 20 m^3	Trash and scrap metal	32
S.12	Container 20 m^3	Trash and scrap metal	202
S.12:D	Container 20 m^3	Trash and scrap metal	49
S.12: Dsec [d)]	Container 20 m^3	Trash and scrap metal, secondary waste	14
S.12C:D	Container 20 m^3	Trash and scrap metal	26
S.14	Container 20 m^3	Trash and scrap metal	12
V.12:D	Container 20 m^3	Trash and scrap metal	57
V.12:Dsec [d)]	Container 20 m^3	Trash and scrap metal, secondary waste	25
V.12A:D	Container 20 m^3	Trash and scrap metal	200
V.12C:D	Container 20 m^3	Trash and scrap metal	227
Å.12:D	Container 20 m^3	Trash and scrap metal	3
Å.12:Dsec	Container 20 m^3	Trash and scrap metal, secondary waste	7
Å.12C:D	Container 20 m^3	Trash and scrap metal	15
BRT			
B.BWR:D		Reactor pressure vessel	2
F.BWR:D		Reactor pressure vessel	3
O.BWR:D		Reactor pressure vessel	3
R.BWR:D		Reactor pressure vessel	1

[a)] The packaging of waste types C.01:9–30/O.01:9–30 contains cellulose, while C.01:9/O.01:9 don't.
[b)] The waste in F.17cellulose contains cellulosic filteraids
[c)] F.23C, R.23C are used in this table to identify the concrete moulds.
[d)] The extensions :Dsec are used in this table to identify secondary waste from decommissioning.

Table A-2. Estimated volumes and void including porosity in materials in 1BMA.

Material 1BMA	Volume [m^3]	Void+pore volume* [m^3]	Comment
Shotcrete			
Shotcrete (waste section+walls, i.e.139.85 m)	350	105	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 139.5·(2·(300/19.6–0.05)+19.6)·0.05.
Shotcrete inner zone	6	2	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 2.4·(2·(300/19.6–0.05)+19.6)·0.05.
Shotcrete reloading zone	44	13	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 17.75·(2·(300/19.6–0.05)+19.6)·0.05.
Total shotcrete	400	120	
Concrete floor in inner and reloading zone			
Floor inner zone	9	1	Calculated 2.4·15.62·0.25
Floor reloading zone	69	10	Calculated 17.75·15.62·0.25
Total concrete floor in inner and reloading zone	79	12	
Concrete structures			
Floor	546	82	Calculated 139.85·15.62·0.25
Outer long walls	919	138	Calculated 2·139.85·8.215·0.4 (above floor, outside lid)
Outer short wall (TT)	49	7	Calculated 14.82·8.215·0.4 (above floor, outside lid)
Outer short wall (BST)	73	11	Calculated 14.82·8.215·0.6 (above floor, outside lid)
Inner walls	563	84	Calculated 13·7.3·14.82·0.4 (between floor and lid)
Inner wall (between small compartments)	14	2	Calculated 1·7.3·4.95·0.4 (between floor and lid)
Lid	1,883	282	Calculated (139.85–(0.4+0.6))·14.82·0.915 (inside outer walls)
Total concrete structure	4,047	607	
Concrete structures divided into compartments			
Compartment 1			
Floor	41	6	Calculated (9.9+0.4+0.4/2)·15.62·0.25
Outer long walls	69	10	Calculated 2·((9.9+0.4+0.4/2)·8.215·0.4)
Outer short wall (TT)	49	7	Calculated 14.82·8.215·0.4
Inner walls	22	3	Calculated (half inner wall) 7.3·14.82·0.4/2
Lid	137	21	Calculated (9.9+0.4/2)·14.82·0.915
Total concrete structure Compartment 1	317	48	
Compartment 2–13			
Floor	40.2	6	Calculated (9.9+0.4/2+0.4/2)·15.62·0.25
Outer long walls	68	10	Calculated 2·((9.9+0.4/2+0.4/2)·8.215·0.4)
Inner walls	43.3	6	Calculated 2·7.3·14.82·0.4/2
Lid	139.7	21	Calculated (9.9+0.4/2+0.4/2)·14.82·0.915
Total concrete structure per compartment	291	44	
Compartment 14 and 15			
Floor	11	2	Calculated 15.62/2·(4.95+0.6+0.4/2)·0.25
Outer long walls	19	3	Calculated((4.95+0.6+0.4/2)·8.215·0.4)
Outer short wall (BST)	37	5	Calculated 14.82/2·8.215·0.6
Inner walls	18	3	Calculated1·7.3·4.95·0.4/2+7.3·14.82·0.4/2/2
Lid	35	5	Calculated (4.95+0.4/2)·(7.21+0.4/2)·0.915
Total concrete structure per compartment	120	18	

Table A-2 cont.

Material 1BMA	Volume [m^3]	Void+pore volume* [m^3]	Comment
Waste			
Concrete moulds	6,603	1,971	Reference waste inventory: 3,821 concrete moulds, outer volume 1.728 m^3, inner volume 1 m^3, porosity waste assumed 15%, porosity mould walls 15%, void=1,154 m^3.
Steel moulds (including steel boxes with drums)	3,853	794	Reference waste inventory: 2,230 steel moulds, outer volume 1.728 m^3, inner volume 1.7 m^3, porosity waste assumed 15% except 0% for dried bituminised ion-exchange resins in bitumen (i.e. bitumenised waste from Forsmark), void=639 m^3 (including void in steel boxes with drums).
Drums	1,340	316	Reference waste inventory: 5,560 drums, outer volume 0.241 m^3, inner volume 0.238 m^3, inner porosity 15% except for dried bituminised ion-exchange resins in bitumen (i.e. bitumenised waste from Forsmark), void=200 m^3. (Drums in boxes are treated as steel moulds).
Total	11,796	3,081	
Waste in compartment 1–15			
Compartment 1	995	311	Reference waste inventory and inplacement according to Table 3-3, void from Inventory report (SKB 2013b), assumed porosity of waste from is 15% except for dried bituminised ion-exchange resins in bitumen (i.e. bitumenised waste from Forsmark).
Compartment 2	834	238	See compartment 1, (including void in steel boxes with drums)
Compartment 3	897	253	See compartment 1, (including void in steel boxes with drums)
Compartment 4	995	270	See compartment 1
Compartment 5	821	246	See compartment 1, (including void in steel boxes with drums)
Compartment 6	814	175	See compartment 1, (including void in steel boxes with drums)
Compartment 7	995	301	See compartment 1
Compartment 8	982	307	See compartment 1
Compartment 9	995	297	See compartment 1
Compartment 10	911	202	See compartment 1
Compartment 11	742	141	See compartment 1
Compartment 12	745	143	See compartment 1
Compartment 13	745	141	See compartment 1
Compartment 14	162	28	See compartment 1
Compartment 15	162	28	See compartment 1
Total	11,796	3,081	
Concrete grout in compartment 1–15			
Compartment 1	76	23	Inner voloume of comartment (9.9·14.82·7.3) – waste volume
Compartment 2	237	71	See compartment 1
Compartment 3	174	52	See compartment 1
Compartment 4	76	23	See compartment 1
Compartment 5	250	75	See compartment 1
Compartment 6	258	77	See compartment 1
Compartment 7	76	23	See compartment 1
Compartment 8	90	27	See compartment 1
Compartment 9	76	23	See compartment 1
Compartment 10	160	48	See compartment 1
Compartment 11	329	99	See compartment 1
Compartment 12	326	98	See compartment 1
Compartment 13	326	98	See compartment 1
Compartment 14	98	29	Inner voloume of comartment (4.95·7.21·7.3) – waste volume
Compartment 15	98	29	See compartment 14
Total	2,649	795	

Table A-2 cont.

Material 1BMA	Volume [m^3]	Void+pore volume* [m^3]	Comment
Macadam/Rock fill			
Bottom (below compartments out to vault walls)	1,227	368	Calculated 139.85·(19.6–2·0.05)·(0.15+0.3) (Coarsed grout included)
Sides (between compartments and rock)	4,593	1,378	Calculated 139.85·(19.6–15.62–2·0.05)·(8.215+0.25)
Top (above compartments)	15,563	4,669	Calculated 90%·139.85·(19.6–2·0.05)·(300/19.6–0.05–0.3–0.15–0.25–8.215) (the top is assumed to be filled to 90%)
Bottom at inner zone (TT)	43	13	Calculated 4.95·(19.6–2·0.05)·(0.15+0.3)
Macadam inner zone (TT)	1,278	383	Calculated 90%·(4.95·(19.6–2·0.05)·(300/19.6–0.05–0.3–0.15)–9) (assumed to be filled to 90%)). The calculation has been simplified by assigning the same cross-sectional area for the whole length (4.95 m), eventough 2.55 m has a smaller cross-sectional area.
Bottom at reloading zone (BST)	133	40	Calculated 15.2·(19.6–2·0.05)·(0.15+0.3)
Macadam reloading zone (BST)	3,888	1,166	Calculated 90%·(15.2·(19.6–2·0.05)·(300/19.6–0.05–0.3–0.15)–69) (assumed to be filled to 90%))
Total macadam/rock fill	26,726	8,018	
Non filled volume			
Top (empty space above top macadam)	1,729	1,729	Calculated 10%·139.85·(19.6–2·0.05)·(300/19.6–0.05–0.3–0.15–0.25–8.215) (the top is assumed to be filled to 90%))
Top of inner zone	142	142	Calculated 10%·(4.95·(19.6–2·0.05)·(300/19.6–0.05–0.3–0.15)–9) (assumed to be filled to 90%))
Top of reloading zone	432	432	Calculated 10%·(15.2·(19.6–2·0.05)·(300/19.6–0.05–0.3–0.15)–69) (assumed to be filled to 90%))
Total non filled volume	2,303	2,303	
Totals			
Concrete construction with waste and grout	18,491	4,483	
Total waste section, i.e 139.85 m	41,954	12,732	
Total rock vault	48,000	14,936	

* Assumed porosities: Shotcrete and grout 0.3, construction concrete 0.15 and macadam/rock fill 0.3.

Table A-3. Quantities of different materials in the waste packages (waste+matrix+packaging) in the different compartments in 1BMA.

Compartment number	Weight [kg]					
	Aluminium/zinc	Concrete	Bitumen	Cellulose	Cement	Iron/steel
1	0	$1.06\cdot10^{6}$	0	0	$8.06\cdot10^{5}$	$1.67\cdot10^{5}$
2	0	$2.72\cdot10^{5}$	$2.15\cdot10^{5}$	0	$2.07\cdot10^{5}$	$1.47\cdot10^{5}$
3	0	$2.65\cdot10^{5}$	$3.34\cdot10^{5}$	$6.19\cdot10^{2}$	$2.02\cdot10^{5}$	$1.89\cdot10^{5}$
4	$3.25\cdot10^{2}$	$9.97\cdot10^{5}$	0	$7.45\cdot10^{3}$	$5.85\cdot10^{5}$	$1.95\cdot10^{5}$
5	0	$2.65\cdot10^{5}$	$3.37\cdot10^{5}$	$3.44\cdot10^{1}$	$2.02\cdot10^{5}$	$1.43\cdot10^{5}$
6	0	$2.65\cdot10^{5}$	$2.63\cdot10^{5}$	$1.85\cdot10^{2}$	$2.05\cdot10^{5}$	$2.06\cdot10^{5}$
7	$2.96\cdot10^{2}$	$1.15\cdot10^{6}$	0	$5.04\cdot10^{3}$	$6.08\cdot10^{5}$	$1.75\cdot10^{5}$
8	$1.31\cdot10^{3}$	$1.15\cdot10^{6}$	0	$2.20\cdot10^{4}$	$2.91\cdot10^{5}$	$2.44\cdot10^{5}$
9	$7.01\cdot10^{2}$	$1.18\cdot10^{6}$	0	$9.91\cdot10^{3}$	$4.93\cdot10^{5}$	$1.90\cdot10^{5}$
10	$5.86\cdot10^{2}$	$6.47\cdot10^{5}$	$1.73\cdot10^{5}$	$9.64\cdot10^{3}$	$2.51\cdot10^{5}$	$2.30\cdot10^{5}$
11	$9.87\cdot10^{2}$	$3.92\cdot10^{5}$	$1.73\cdot10^{5}$	$6.96\cdot10^{3}$	$1.62\cdot10^{5}$	$2.14\cdot10^{5}$
12	$9.80\cdot10^{2}$	$3.95\cdot10^{5}$	$1.73\cdot10^{5}$	$6.94\cdot10^{3}$	$1.62\cdot10^{5}$	$2.15\cdot10^{5}$
13	$9.91\cdot10^{2}$	$3.93\cdot10^{5}$	$1.74\cdot10^{5}$	$7.00\cdot10^{3}$	$1.61\cdot10^{5}$	$2.16\cdot10^{5}$
14	$4.78\cdot10^{2}$	$4.21\cdot10^{4}$	$4.35\cdot10^{4}$	$1.82\cdot10^{3}$	$2.86\cdot10^{4}$	$5.77\cdot10^{4}$
15	$4.78\cdot10^{2}$	$4.21\cdot10^{4}$	$4.35\cdot10^{4}$	$1.82\cdot10^{3}$	$2.86\cdot10^{4}$	$5.77\cdot10^{4}$

Table A-4. Estimated volumes and void including porosity in materials in 2BMA.

Material 2BMA	Volume [m^3]	Void+pore volume* [m^3]	Comment
Shotcrete			
Shotcrete (waste section, i.e.246.3 m)	633	190	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 246.3·(2·(310/19.2–0.05)+19.2)·0.05.
Shotcrete inner zone	12	4	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 4.7·(2·(310/19.2–0.05)+19.2)·0.05.
Shotcrete reloading zone	62	19	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 24·(2·(310/19.2–0.05)+19.2)·0.05.
Total shotcrete	707	212	
Concrete in caisson structures			
Floor 1 caisson	131	20	Calculated 16.2·16.2·0.5
Walls 1 caisson	248	37	Calculated 2·16.2·0.5·(7.4+0.5)+2·(16.2–2·0.5)·0.5·(7.4+0.5)
Lid 1 caisson	116	17	Calculated 15.2·15.2·0.5
Total 1 caisson	495	74	
Total 14 caissons	6,927	1,039	
Waste			
One caisson	1,493	477	If filled with moulds, i.e 864 moulds. 16% of the reference waste in 2BMA is in concrete moulds and hence this used here. 138 concrete moulds, outer volume 1.728 m^3, inner volume 1 m^3, porosity waste assumed 15%, porosity mould walls 15%, void=22.7 m^3 (average per caisson for concrete moulds in 2BMA in Reference waste). 726 steel moulds, outer volume 1.728 m^3, inner volume 1.7 m^3, porosity waste assumed 15%, void=279 m^3 (average per caisson for steel packaging in Reference waste).
14 caissons	20,902	6,683	If filled with moulds, i.e 864 moulds per caisson
Concrete grout in caissons			
One caisson	217	65	If filled with moulds, i.e 864 moulds
14 caissons	3,034	910	If filled with moulds, i.e 864 moulds per caisson
Macadam/Rock fill			
Bottom (below caissons, out to vault walls)	1,882	565	Calculated 246.3·(19.2–2·0.05)·0.4
Sides (beside caissons)	6,000	1,800	Calculated 246.3·(19.2–16.2–2·0.05)·8.4
Between caissons	2,654	796	Calculated 13·1.5·16.2·8.4
Top (above caissons)	30,890	9,267	Calculated 90%·246.3·(19.2–2·0.05)·(310/19.2–0.05–8.4–0.4) (the top is assumed to be filled to 90%))
Bottom at inner zone	36	11	Calculated 4.7·(19.2–2·0.05)·0.4
Macadam inner zone (TT)	1,268	380	Calculated 90%·4.7·(19.2–2·0.05)·(310/19.2–0.05–0.4) (assumed to be filled to 90%))
Bottom at reloading zone	183	55	Calculated 24·(19.2–2·0.05)·0.4
Macadam reloading zone (BST)	6,475	1,943	Calculated 90%·24·(19.2–2·0.05)·(310/19.2–0.05–0.4) (assumed to be filled to 90%))
Total macadam/rock fill	49,388	14,816	
Non filled volume			
Top (empty space above top macadam)	3,432	3,432	Calculated 10%·246.3·(19.2–2·0.05)·(310/19.2–0.05–8.4–0.4) (the top is assumed to be filled to 90%))
Top of inner zone	141	141	Calculated 10%·4.7·(19.2–2·0.05)·(310/19.2–0.05–0.4) (assumed to be filled to 90%))
Top of reloading zone	719	719	Calculated 10%·24·(19.2–2·0.05)·(310/19.2–0.05–0.4) (assumed to be filled to 90%))
Total non filled volume	4,293	4,293	
Totals			
Total waste section, i.e.246.3 m	76,353	24,682	
Total rock vault	85,250	27,953	

* Assumed porosities: Shotcrete and grout 0.3, construction concrete 0.15 and macadam/rock fill 0.3.

Table A-5. Estimated volumes and void including porosity in materials in 1BTF.

Material 1BTF	Volume [m^3]	Void+pore volume* [m^3]	Comment
Shotcrete			
Shotcrete (waste section+walls, i.e.130.6 m)	210	63	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 130.6·(2·(129/14.7–0.05)+14.7)·0.05.
Shotcrete inner zone	6	2	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 3.6·(2·(129/14.7–0.05)+14.7)·0.05.
Shotcrete reloading zone	41	12	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 25.8·(2·(11.8–0.05)+14.7)·0.05.
Total shotcrete	257	77	
Concrete structures			
Floor (waste section+walls, i.e.130.6 m)	477	72	Calculated 130.6·(14.7–2·0.05)·0.25
Prefabricated lid	712	107	Calculated (130·13.7·0.4 (above waste)
Lid	762	114	Calculated (130·(14.7–2·0.05)·0.4 (above prefabricated lid)
Walls (both sides)	50	7	Calculated 2·0.3·(4.9+0.4+0.4)·(14.7–2·0.05)
Floor inner zone	13	2	Calculated 3.6·(14.7–2·0.05)·0.25
Floor reloading zone	94	14	Calculated 25.8·(14.7–2·0.05)·0.25
Total concrete structres	2,108	316	
Waste			
Concrete tanks	3,878	1,400	Reference waste inventory: 393 concrete tanks, outer volume 9.867 m^3, inner volume 6 m^3, porosity waste assumed 40%, porosity tank walls 15%, void = 381 m^3.
Concrete moulds	249	76	Reference waste inventory: 144 concrete moulds, outer volume 1.728 m^3, inner volume 1 m^3, porosity waste assumed 15%, porosity mould walls 15%, void = 46 m^3.
Drums	1,956	366	Reference waste inventory: 8,116 drums, outer volume 0.241 m^3, inner volume 0.238 m^3, inner porosity 15%, void 0.011 m^3/drum.
Other	191	74	Reference waste inventory: 40 Cortén boxes, outer volume (1.5·1.5·1.5), assumed total void and pore space 20%, Reactor vessel lid outer volume 55 m^3, volume calculated from 65,000 kg and density of steel 7,800 kg/ m^3 remaining space is void.
Total waste	6,273	1,916	
Concrete grout			
Concrete grout (waste section)	3,109	933	Calculated 130·(14.7–0.05)·(4.9+0.4)–6,273–712.
Macadam/Rock fill			
Bottom (waste section+walls, i.e.130.6 m)	858	257	Calculated 130.6·(14.7–2·0.05)·(0.3+0.15)
Top (waste section)	3,991	1,197	Calculated 90%·130.6·(14.7–2·0.05)·(129/14.7–0.05–0.4–0.4 –4.9–0.25–0.15–0.3) (assumed to be filled to 90%)
Bottom at inner zone	24	7	Calculated 3.6·(14.7–2·0.05)·(0.15+0.3)
Bottom at reloading zone	170	51	Calculated 25.8·(14.7–2·0.05)·(0.15+0.3)
Macadam inner zone	370	111	Calculated 90%·3.6·(129/14.7–0.05)·(14.7–2·0.05)–6–13–24 (assumed to be filled to 90%)
Macadam reloading zone	2,653	796	Calculated 90%·25.8·(129/14.7–0.05)·(14.7–2·0.05)–41–94–170 (assumed to be filled to 90%)
Total macadam/rock fill	8,065	2,419	
Non filled volume			
Top (waste section)	443	443	Calculated 10%·130.6·(14.7–2·0.05)·(129/14.7–0.05–0.4–0.4 –4.9–0.25–0.15–0.3) (assumed to be filled to 90%)
Top of inner zone	46	46	Calculated 90%·3.6·(129/14.7–0.05)·(14.7–2·0.05) (assumed to be filled to 90%)
Top of reloading zone	329	329	Calculated 90%·25.8·(129/14.7–0.05)·(14.7–2·0.05) (assumed to be filled to 90%)
Total non filled volume	818	818	
Totals			
Total waste section, i.e.130.6 m	16,885	5,110	
Total rock vault	20,640	6,479	

* Assumed porosities: Shotcrete and grout 0.3, construction concrete 0.15 and macadam/rock fill 0.3.

Table A-6. Estimated volumes and void including porosity in materials in 2BTF.

Material 2BTF	**Volume [m^3]**	**Void+pore volume* [m^3]**	**Comment**
Shotcrete			
Shotcrete (waste section+walls, i.e.130.6 m)	210	63	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 130.6·(2·(129/14.7–0.05)+14.7)·0.05.
Shotcrete inner zone	6	2	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 3.6·(2·(129/14.7–0.05)+14.7)·0.05.
Shotcrete reloading zone	41	12	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 25.8·(2·(11.8–0.05)+14.7)·0.05.
Total shotcrete	257	77	
Concrete structures			
Floor (waste section+walls, i.e.130.6 m)	477	72	Calculated 130.6·(14.7–2·0.05)·0.25
Prefabricated lid	712	107	Calculated (130·13.7·0.4 (above waste)
Lid	762	114	Calculated (130·(14.7–2·0.05)·0.4 (above prefabricated lid)
Walls (both sides)	50	7	Calculated 2·0.3·(4.9+0.4+0.4)·(14.7–2·0.05)
Floor inner zone	13	2	Calculated 3.6·(14.7–2·0.05)·0.25
Floor reloading zone	94	14	Calculated 25.8·(14.7–2·0.05)·0.25
Total concrete structres	2,108	316	
Waste			
Concrete tanks	7,193	2,547	Reference waste inventory: 729 concrete tanks, outer volume 9.867 m^3, inner volume 6 m^3 (porosity waste assumed 40%, porosity tank walls 15%, void= total void in 2BTF – void in steel tanks).
Steel tanks	178	36	Reference waste inventory: 18 steel tanks, outer volume 9.867 m^3, assumed total void and pore space 20%.
Total waste	7,371	2,583	
Concrete grout			
Concrete grout (waste section)	2,011	603	Calculated 130·(14.7–0.05)·(4.9+0.4)–7,371–712
Macadam/Rock fill			
Bottom (waste section+walls, i.e.130.6 m)	858	257	Calculated 130.6·(14.7–2·0.05)·(0.3+0.15)
Top (waste section)	3,991	1,197	Calculated 90%·130.6·(14.7–2·0.05)·(129/14.7–0.05–0.4 –0.4–4.9–0.25–0.15–0.3) (assumed to be filled to 90%)
Bottom at inner zone	24	7	Calculated 3.6·(14.7–2·0.05)·(0.15+0.3)
Bottom at reloading zone	170	51	Calculated 25.8·(14.7–2·0.05)·(0.15+0.3)
Macadam inner zone	370	111	Calculated 90%·3.6·(129/14.7–0.05)·(14.7–2·0.05)–6–13–24 (assumed to be filled to 90%)
Macadam reloading zone	2,653	796	Calculated 90%·25.8·(129/14.7–0.05)·(14.7–2·0.05)–41–94–170 (assumed to be filled to 90%)
Total macadam/rock fill	8,065	2,419	
Non filled volume			
Top (waste section)	443	443	Calculated 10%·130.6·(14.7–2·0.05)·(129/14.7–0.05–0.4 –0.4–4.9–0.25–0.15–0.3) (assumed to be filled to 90%)
Top of inner zone	46	46	Calculated 90%·3.6·(129/14.7–0.05)·(14.7–2·0.05) (assumed to be filled to 90%)
Top of reloading zone	329	329	Calculated 90%·25.8·(129/14.7–0.05)·(14.7–2·0.05) (assumed to be filled to 90%)
Total non filled volume	818	818	
Totals			
Total waste section, i.e.130.6 m	16,884	5,447	
Total rock vault	20,640	6,817	

* Assumed porosities: Shotcrete and grout 0.3, construction concrete 0.15 and macadam/rock fill 0.3.

Table A-7. Estimated volumes and void including porosity in materials in the silo.

Material Silo	Volume [m^3]	Void+pore volume* [m^3]	Comment
Concrete structures			
Bottom	538	81	Calculated π·(27.6/2)^2·0.9
Outer wall	3,540	531	Calculated π·(27.6/2)^2·52.55–π·((27.6–2·0.8)/2)^2·52.55
Inner walls	5,518	828	Calculated inner volume – total inside shaft
Lid	531	80	Calculated π·((27.6–2·0.8)/2)^2·1
Total concrete structure	10,127	1,519	
Inside in shafts			
Shafts full-size	19,014		Calculated 57·2.55·2.55·51.3
Shafts half-size – B, C, D	2,119		Calculated 12·2.55·1.35·51.3
Shafts quarter-size – E	347		Calculated 4·1.3·1.3·51.3
Small shafts – F, G	239		Calculated 8·(0.75·0.64+1/2·(0.91–0.64)·0.75)·51.3
Total inside shafts	21,718		
Waste			
Concrete moulds	8,161	2,478	Reference waste inventory: 4,723 concrete moulds, outer volume 1.728 m^3, inner volume 1 m^3, porosity waste assumed 15%, porosity mould walls 15%, void=1,475 m^3.
Steel moulds	7,327	1,358	Reference waste inventory: 4,240 steel moulds, outer volume 1.728 m^3, inner volume 1.7 m^3, porosity waste assumed 15% except for dried bituminised ion-exchange resins in bitumen (i.e. 825 steel moulds with bitumenised waste from Forsmark), void=573 m^3.
Steel drums	722	183	Reference waste inventory: 2,996 drums, outer volume 0.241 m^3, inner volume 0.238 m^3, inner porosity 15%, void 90 m^3.
Total waste	16,210	4,019	
Concrete grout			
Concrete grout (waste section)	5,561	1,668	Calculated total inside shaft – total waste volume + upper layer for leveling (21,718–16,210+53)
Bentonite			
Surronding conrete silo	4,126	2,517	Calculated π·(29.4/2)^2·51.2–π·(27.6/2)^2·51.2, bentonite porosity 61%
Sand bentonite			
Bottom	1,018	255	Calculated π·(29.4/2)^2·1.5, sand-bentonite porosity 25%
Top	1,492	373	Calculated π·(31/2)^2·1.5 + π·(31/2)^2·2.3–π·(27.6/2)^2·2.3, sand-bentonite porosity 25%
Total sand bentonite	2,510	628	
Additional materials			
Bottom – Cast coarse concrete for drainage system [m]	68	20	Calculated π·(29.4/2)^2·0.1, porosity as concrete grout
Bottom – Concrete plate with drainage system	136	41	Calculated π·(29.4/2)^2·0.2, porosity as concrete grout
Bottom – Thin concrete layer	30	9	Calculated π·((27.6/2)^2·0.05, porosity as concrete grout
Top lid – Sand layer above concrete grout	27	8	Calculated π·((27.6–2·0.8)/2)^2·0.05, porosity 30%
Top lid – Sand above concrete part of lid	53	16	Calculated π·((27.6–2·0.8)/2)^2·0.1, porosity 30%
Backfill – Friction material in cupola	6,347	1,904	90% of remaing volume in cupola, porosity 30%
Backfill – Cement-stabilised sand in cupola	705	212	10% of remaining volume in cupola, porosity 30%
Totals			
Total concrete silo including waste	31,978	7,231	
Total	45,900	12,561	

* Assumed porosities: Shotcrete and grout 0.3, construction concrete 0.15 and macadam/rock fill 0.3.

Table A-8. Estimated volumes and void including porosity in materials in 1BLA.

Material 1BLA	Volume [m^3]	Void+pore volume* [m^3]	Comment
Shotcrete			
Shotcrete (waste section, i.e.146.3 m)	279	84	Assumed 0.05 m thickness on walls and roof (2·average height+width. Calculated 146.3·(2·(11.8–0.05)+14.7)·0.05.
Shotcrete inner zone	7	2	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 3.7·(2·(11.8–0.05)+14.7)·0.05.
Shotcrete reloading zone	19	6	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 10·(2·(11.8–0.05)+14.7)·0.05.
Total shotcrete	306	92	
Concrete structures			
Floor (waste section, i.e. 146.3 m)	501	75	Calculated 146.3·13.7·0.25.
Floor inner zone	13	2	Calculated 3.7·13.7·0.25.
Floor reloading zone	34	5	Calculated 10·13.7·0.25.
Total concrete	548	82	
Waste			
ISO-containers	10,858	6,426	Reference waste inventory: 18 half height 10 ft outer volume 7.74, inner volume 7.5. 447 half height 20 ft outer volume 15.24 and inner volume 15. 129 full height 20 ft outer volume 30.28 and inner volume 30 (void+pore volume assumed 60%·inner volume).
Concrete grout			
Waste section	0	0	No backfill surrounding waste.
Macadam/Rock fill			
Bottom (waste section, i.e.146.3 m)	961	288	Calculated 146.3·(14.7–2·0.05)·(0.3+0.15).
Bottom inner zone	24	7	Calculated 3.7·(14.7–2·0.05)·(0.3+0.15).
Bottom reloading zone	66	20	Calculated 10·(14.7–2·0.05)·(0.3+0.15).
Macadam/rock fill reloading zone	1,438	431	Calculated 90%·(10·173)–19–34–66 (assumed to be filled to 90%).
Total macadam/rock fill	2,489	747	
Non filled volume			
Empty space outside ISO-containers (waste section, i.e.146.3 m)	12,711	12,711	Calculated 146.3·173–279–501–10,858–961.
Inner zone	596	596	Calculated 3.7·173–7–13–24.
Top of reloading zone	173	173	Calculated 10%·10·173 (assumed to be filled to 90%).
Total non filled volume	13,480	13,480	
Totals			
Total waste section, i.e.146.3 m	25,310	19,584	
Total rock vault	27,680	20,827	

* Assumed porosities: Shotcrete 0.3, construction concrete 0.15 and macadam/rock fill 0.3.

Table A-9. Estimated volumes and void including porosity in materials in 2–5BLA.

Material 2–5BLA	Volume [m^3]	Void+pore volume* [m^3]	Comment
Shotcrete			
Shotcrete (waste section, i.e.243 m)	544	163	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 243·(2·(13.5–0.05)+17.9)·0.05.
Shotcrete inner zone	18	5	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 8·(2·(13.5–0.05)+17.9)·0.05.
Shotcrete reloading zone	54	16	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 24·(2·(13.5–0.05)+17.9)·0.05.
Total shotcrete	616	185	
Concrete structures			
Floor (waste section, i.e. 243 m)	1,701	255	Calculated 243·14·0.5
Longitudinal walls	2,100	315	Calculated (243·8.64·0.5)·2 for support of ISO-containers during operation
Floor inner zone	56	8	Calculated 8·14·0.5
Floor reloading zone	168	25	Calculated 24·14·0.5
Total concrete	4,025	604	
Waste			
ISO-containers	16,459	9,720	Assumed 1,080 half height 20 container outer volume 15.24 and inner volume 15 (void+pore volume assumed 60%·inner volume)
Concrete grout			
Waste section	0	0	No backfill surrounding waste
Macadam/Rock fill			
Bottom (waste section, i.e.243 m)	1,730	519	Calculated 243·(17.9–2·0.05)·0.4
Bottom inner zone	57		Calculated 8·(17.9–2·0.05)·0.4
Bottom reloading zone	171		Calculated 24·(17.9–2·0.05)·0.4
Macadam inner zone	1,611	483	Calculated 90%·8·242–18–56–57 (assumed to be filled to 90%)
Macadam reloading zone	4,834	1,450	Calculated 90%·24·242–54–168–171 (assumed to be filled to 90%)
Total macadam/rock fill	8,404	2,453	
Non filled volume			
Empty space outside ISO-containers (waste section, i.e.243 m)	36,272	36,272	Calculated 243·242–544–1,701–16,459–1,730
Top of inner zone	194	194	Calculated 10%·8·242 (assumed to be filled to 90%)
Top of reloading zone	581	581	Calculated 10%·24·242 (assumed to be filled to 90%)
Total non filled volume	37,046	37,046	
Totals			
Total waste section, i.e.243 m	58,806	47,244	
Total rock vault	66,550	50,008	

* Assumed porosities: Shotcrete 0.3, construction concrete 0.15 and macadam/rock fill 0.3.

Table A-10. Estimated volumes and void including porosity in materials in BRT.

Material BRT	Volume [m^3]	Void+pore volume* [m^3]	Comment
Shotcrete			
Shotcrete (waste section, i.e.207 m)	400	120	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 207·(2·(178/15–0.05)+15)·0.05.
Shotcrete zone at 2TT	3	1	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 1.5·(2·(178/15–0.05)+15)·0.05.
Shotcrete zone at 2BST	3	1	Assumed 0.05 m thickness on walls and roof (2·average height+width). Calculated 1.5·(2·(178/15–0.05)+15)·0.05.
Total shotcrete	406	122	
Concrete structures			
Floor (waste section, i.e. 207 m)	1,325	199	Calculated 207·12.8·0.5
Floor zone at 2TT	10	1	Calculated 1.5·12.8·0.5
Floor zone at 2BST	10	1	Calculated 1.5·12.8·0.5
Total concrete	1,344	202	
Waste			
Reactor pressure vessels filled with grout	5,418	1,401	Outer volume calculated from dimensions given i Inventory report. Concrete volume 4,670 m^3 from Inventory report (given as void).
Concrete grout			
Concrete grout waste section	9,320	2,796	Calculated 207·8·8.9–5,418
Macadam/Rock fill			
Bottom (waste section, i.e.207 m)	1,451	435	Calculated 207·(15–2·0.05)·0.4+207·((15–2·0.05)–12.8)·0.5
Sides (waste section)	12,712	3,814	Calculated 207·((15–2·0.05)–8)·8.9
Top (waste section)	5,598	1,679	Calculated 90%·207·(15–2·0.05)·(178/15–0.05–8.9–0.5–0.4) (assumed to be filled to 90%)
Bottom at 2TT	11	3	Calculated 1.5·(15–2·0.05)·0.4+1.5·((15–2·0.05)–12.8)·0.5
Bottom at 2BST	11	3	Calculated 1.5·(15–2·0.05)·0.4+1.5·((15–2·0.05)–12.8)·0.5
Macadam zone at 2TT	214	64	Calculated 90%·1.5·(178/15–0.05)·(15–2·0.05)–3–10–11 (assumed to be filled to 90%)
Macadam zone at 2BST	214	64	Calculated 90%·1.5·(178/15–0.05)·(15–2·0.05)–3–10–11 (assumed to be filled to 90%)
Total macadam/rock fill	20,209	6,063	
Non filled volume			
Top (waste section)	622	622	Calculated 10%·207·(15–2·0.05)·(178/15–0.05–8.9–0.5–0.4) (assumed to be filled to 90%)
Top zone at 2TT	26	26	Calculated 10%·1.5·(178/15–0.05)·(15–2·0.05)
Top zone at 2BST	26	26	Calculated 10%·1.5·(178/15–0.05)·(15–2·0.05)
Total non filled volume	675	675	
Totals			
Total waste section, i.e.207 m	36,846	11,066	
Total rock vault	37,380	11,258	

* Assumed porosities: Shotcrete and grout 0.3, construction concrete 0.15 and macadam/rock fill 0.3.