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# Feasibility study of waste containers and handling equipment for SFL

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# Feasibility study of waste containers and handling equipment for SFL

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# Abstract

The main purpose of the work presented in this report is to identify suitable waste containers for the Swedish long-lived low and intermediate level waste to be disposed of in SFL. An inventory of existing waste and forecasts on future waste, including existing waste packages, serves as basis for the study. Various alternatives for transport and handling of the long-lived low and intermediate level waste are discussed and presented.

The existing steel tank (or BFA tank) is currently used for storage of mainly core components from maintenance at the nuclear power plants. The steel tank forms part of a system that has been used by Swedish nuclear power plant operators for lifting out segmented core components for dry storage. The steel tanks are available in different models with different wall thickness that can be chosen based on the activity of the waste. Due to the good radiation-shielding properties of the steel, the steel tank is proven to be a well-suited package for handling and storage of core components.

The study presents five new containers for transport and handling of long-lived low and intermediate level waste. These containers can handle various fractions of the existing waste, and together they are able to provide for the vast majority of the Swedish long-lived low and intermediate level waste. The containers share the same footprint and can thus be handled and transported in an efficient way. These containers are:

- Container for standard moulds, carrying four standard moulds.
- Container for standard 200-litre drums, carrying 16 standard drums.
- Container for 280-litre protection drums, carrying 16 protection drums.
- Shielded container, for intermediate level waste.
- Long-term durable container, which can be credited with a safety function in an assessment of the long-term safety of the repository.

The containers for drums and moulds are based on a straightforward design which provides for safe transport and handling. These containers are made of a framework provided with corrugated metal sides. The void in the waste containers will be filled with grout prior to transport. These containers have therefore no need for a separate steel lid.

The shielded container is preliminarily made from welded 100 mm thick steel plates and is fitted with a bolted lid. This container provides for safe transport and handling of intermediate level waste, such as segments of core components. This container thus offers similar functions as the existing steel tank and may supersede the steel tanks as storage container for core components.

The long-term durable container is manufactured using a method that provides for joints that are completely welded through the full thickness of the material, including the weld between the lid and the body of the container.

A waste transport container for steel tanks – ATB 1T – is currently being developed by SKB. This waste transport container will be licensed as a B(U) container according to the IAEA transport regulations.

Two additional transport containers are presented: ATB 1L for the transport of one shielded container or one long-term durable container and ATB 2L for the transport of two containers for drums or moulds. ATB 2L may possibly be classified as a IP 2 container but ATB 1L need to be licensed as a B(U) container.

In the report also method and equipment for segmentation of BWR control rods are presented.

# Sammanfattning

Huvudsyftet med arbetet som presenteras i denna rapport är att identifiera lämpliga avfallsbehållare för det svenska långlivade låg- och medelaktiva avfall som ska slutförvaras i SFL. En inventering av befintligt avfall och prognoser om framtida avfall, inklusive befintliga avfallskollin, utgör underlag till studien. Olika alternativ för transport och hantering av det långlivade låg- och medelaktivt avfallet diskuteras och presenteras.

Befintlig ståltank (eller BFA-tank) används idag för mellanlagring av främst härdkomponenter från underhåll vid kärnkraftverken. Ståltanken ingår i ett system som har använts av de svenska kärnkrafts-operatörerna för att lyfta ut segmenterade härdkomponenter för torr mellanlagring. Ståltankarna finns i olika modeller med olika väggtjocklek som kan väljas baserat på aktiviteten hos avfallet. De goda strålskärmande egenskaperna hos stål gör att ståltanken visat sig vara en väl lämpad behållare för hantering och mellanlagring av härdkomponenter.

I rapporten presenteras fem nya behållare för transport och hantering av långlivat låg- och medel-aktivt avfall. Dessa behållare kan hantera olika fraktioner av det aktuella avfallet, och tillsammans kan de hantera en klar majoritet av svenskt långlivat låg- och medelaktivt avfall. Behållarna har samma mått i basplanet och kan således hanteras och transporteras på ett effektivt sätt. Dessa behållare är:

- Behållare för kokiller, för fyra stycken kokiller.
- Behållare för standard 200-litersfat, för 16 stycken standardfat.
- Behållare för 280-liters skyddsfat, för 16 stycken skyddsfat.
- Skärmad behållare, för medelaktivt avfall.
- Långtidsbeständig behållare, som kan tillskrivas en säkerhetsfunktion vid en analys av den långsiktiga säkerheten av slutförvaret.

Behållarna till fat och kokiller baseras på en enkel konstruktion som ger säker transport och hantering. Dessa behållare tillverkas av en ram försedd med korrugerade metallsidor. Tomrummet i avfallsbehållarna fylls med kringgjutningsbruk före transport. Dessa behållare har därför inget behov av ett separat lock.

Den skärmade behållaren tillverkas preliminärt av svetsade 100 mm tjocka stålplåtar och är utrustad med ett bultat lock. Denna behållare ger säker transport och hantering av medelaktivt avfall, till exempel segmenterade delar av härdkomponenter. Denna behållare erbjuder därmed liknande funktioner som befintlig ståltank och skulle kunna ersätta ståltanken som behållare för mellanlagring av härdkomponenter.

Den långtidsbeständiga behållaren tillverkas med en metod som ger svetsfogar som går genom hela tjockleken på materialet, inklusive svetsen mellan locket och behållaren.

En transportbehållare för ståltankar – ATB 1T – håller på att utvecklas av SKB. Denna transport-behållare kommer att licensieras som en B(U)-behållaren enligt IAEA:s transportföreskrifter.

Två transportbehållare presenteras: ATB 1L för transport av en skärmad behållare eller en långtids-beständig behållare och ATB 2L för transport av två behållare för fat eller kokiller. ATB 2L kan förmodligen klassificeras som en IP 2-behållare men ATB 1L måste licensieras som en B(U)-behållare.

I rapporten presenteras även metod och utrustning för segmentering av BWR styrstavar.

# Contents

# 1 Introduction

## 1.1 Background

The Swedish power industry has been generating electricity by means of nuclear power for about 40 years. The Swedish system for managing and disposal of the waste from operation of the reactors has been developed during that period of time to handle the different types of nuclear waste with separate repositories for different types of waste. When finalized, the Swedish system will comprise three repositories: the repository for short-lived radioactive waste (SFR), the repository for long-lived waste (SFL), and the Spent Fuel Repository.

SKB currently operates SFR in Östhammar municipality, and an extension of SFR is planned, mainly to permit the disposal of decommissioning waste from the nuclear power plants and SKB's facilities. The system for disposal of the spent nuclear fuel consists today of the storage facility for spent nuclear fuel in Oskarshamn municipality (Clab) and will be completed by the construction and commissioning of the Encapsulation Plant adjacent to Clab and the Spent Fuel Repository in Forsmark, Östhammar municipally. The current Swedish system also includes a ship (m/s Sigrid) and casks for transport.

SKB plans to dispose of the long-lived low and intermediate level waste in SFL. The waste comprises waste from the operation and decommissioning of the Swedish nuclear power plants, legacy waste from the early research in the Swedish nuclear programmes, and smaller amounts of waste from hospitals, industry and research.

The project *SFL Concept study* was initiated with the objective of identifying and developing methods of conditioning and disposal of the long-lived low and intermediate level waste. The aim of the study is to highlight and evaluate all possible alternatives and at the same time compile the premises, requirements and constraints that form the basis for the evaluation. Following the evaluation, a system for the management and disposal of long-lived low and intermediate level waste is proposed to be further assessed with respect to long-term safety. The outcome of the assessment will determine whether the system meets the requirements on post-closure safety and may constitute SKB's main alternative for the future development and planning of SFL.

## 1.2 Purpose and scope

The main purpose of the work presented in this report has been to identify suitable waste containers for the long-lived low and intermediate level waste to be disposed of in SFL and includes two main objectives:

- Identification of a set of waste containers that can provide for safe transport and handling of long-lived low and intermediate level waste, including neutron-induced intermediate level waste from the nuclear power plants and legacy waste.
- Identification of a long-term durable container which can provide for safe transport and handling of all types of long-lived low and intermediate level waste, and which also has properties that enable it to be credited with a safety function in an assessment of the long-term safety of the repository.

The scope also includes describing the waste containers to such a level that the feasibility of the design, production, handling, lifting and transportation can be evaluated.

Furthermore, the work includes the making of an inventory of alternatives for safe transport and handling of long-lived low and intermediate level waste. The inventory will identify needs and support the formulation of prerequisites for the conceptual design of waste containers.

The study should also identify a set of suitable waste transport containers for the waste containers presented in this report.

As prerequisite for the study, information provided by the nuclear power plants, AB SVAFO and Studsvik Nuclear AB regarding the waste inventory planned for SFL is used. The waste inventory from the nuclear power plants is reported by Herschend (2013).

## 1.3 Outline of the report

Chapter 2 reports on the waste inventory for SFL, focusing on the different waste packages currently used. The waste itself and existing waste packages are important prerequisites for the study.

Chapter 3 holds a brief investigation of handling alternatives for transport and handling of long-lived low and intermediate level waste. The work includes the mapping of existing equipment for transport and handling of long-lived low and intermediate level waste as well as the identification of missing system and containers.

Chapter 4 summarizes the most important prerequisites for the study and also accounts for the identified design considerations.

Chapter 5 presents a set of containers for transport and handling of long-lived low and intermediate level waste.

Chapter 6 presents a long-term durable container for intermediate level waste.

Chapter 7 presents the waste transport containers for transport of the waste containers presented in Chapters 5 and 6.

Chapter 8 summarizes the report.

Appendix 1 presents general consideration for the design of the waste containers, such as standards, classification etc.

Appendix 2 presents a method and suggested equipment for segmentation of BWR control rods.

Appendix 3 presents the packing of BWR control rod segments into waste containers.

Appendix 4 presents flow charts illustrating the waste management chain for long-lived low and intermediate level waste.

# 2 Long-lived low and intermediate waste for SFL

## 2.1 General

Long-lived low and intermediate level waste planned for disposal in SFL comprises four main categories:

- waste from early research in the Swedish nuclear programmes (currently managed by AB SVAFO),
- neutron-irradiated components such as reactor internals, core components and PWR pressure vessels from maintenance and dismantling of the Swedish nuclear power plants,
- BWR control rods from operation of the Swedish nuclear power plants, and
- waste from other sources such as industries, hospitals and research facilities including waste from operations in Studsvik.

The first category – the legacy waste – was produced during the development of the Swedish nuclear programmes in the 1960s and early 1970s and comprises about 40% of the long-lived low and intermediate level waste that is planned to be disposed of in SFL. This waste is currently stored on the Studsvik site.

The second and third categories – waste from operation, maintenance and dismantling of nuclear power plants including the BWR control rods – consist of components installed in the nuclear reactor vessel close to the reactor core. These components are mainly made of steel and contain about 99% of the activity in the future SFL. A more detailed compilation of the quantities and types of waste from the operation, maintenance and decommissioning of nuclear power facilities is presented in Herschend (2013).

The fourth category, which also is the smallest, comprises long-lived waste from non-nuclear facilities within medicine, research and industry, and also waste from research and operations in Studsvik.

Figure 2-1 shows the estimated timetable for when the waste for SFL will be produced and the corresponding estimated repository volume required. The total volume of SFL waste is estimated to about 16,000 $m^3$ of which about 8,500 $m^3$ has already been produced.

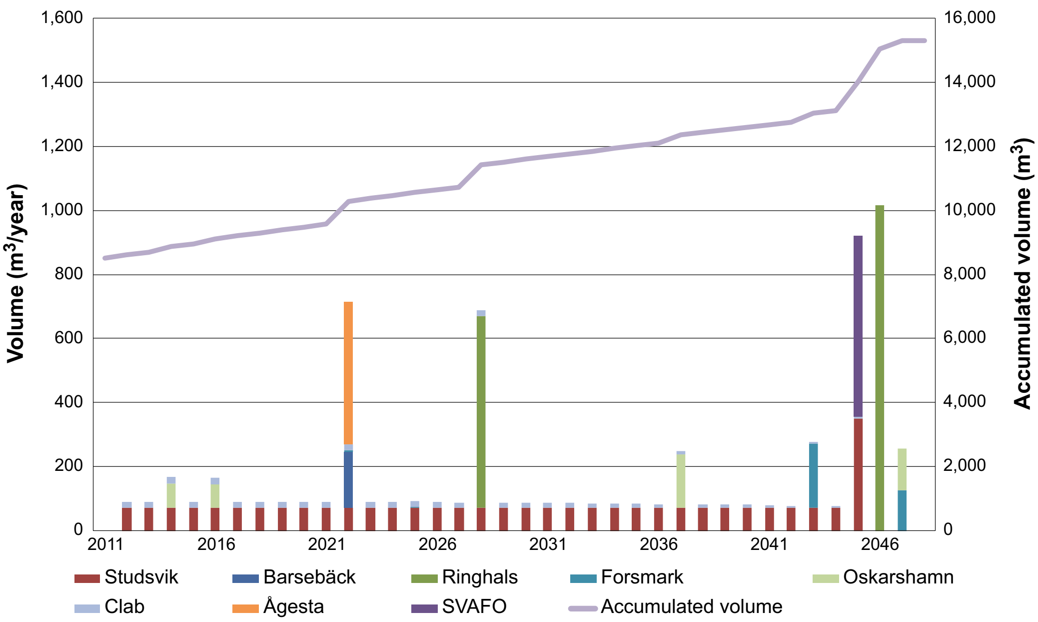


***Figure 2-1.*** *An estimated timetable for when the waste for SFL will be produced and the corresponding estimated repository volume required (SKB 2013).*

## 2.2 Legacy waste

This waste category mainly consists of legacy waste from early research in the Swedish nuclear programmes and is currently managed by AB SVAFO.

Large part of the waste is placed in 200-litre drums and stabilized using grout. However, due to the prolonged storage they have now been placed in 280-litre drums as overpack to provide for safe storage and handling on the Studsvik site. The 200-litre drums can be retrieved from the 280-litre drums. Figure 2-2 shows the yellow 280-litre protection drums in the storage building.

Legacy waste is also stored in steel containers called Berglöf boxes, which are extensively used in conventional workshops and industries, in ISO containers, and in unique containers. Figure 2-3 shows a photograph of the waste storage in a rock cavern in Studsvik with low and intermediate level waste showing Berglöf boxes, glove boxes in concrete and 400-litre drums.

## 2.3 Waste from the nuclear power plants

The waste from the nuclear power plants comprises components with a significant content of long-lived radioactive isotopes. These components are typically located close to the core itself, where the neutron flux creates induced activity in the component material. The elevated levels of long-lived nuclides make the core components unsuitable for disposal in SFR. For a PWR, also the pressure vessel wall in the vicinity of the reactor core is subject to high neutron flux. The wall material in the core region will have too high induced activity for disposal in SFR.

### 2.3.1 PWR pressure vessels

The largest components aimed for disposal in SFL are the reactor pressure vessels from the three PWRs operated by Ringhals AB and the reactor pressure vessel from Ågesta. The reactor pressure vessels from Ringhals 2–4 weigh close to 330 tonnes each (not including reactor internals), and are made of steel with a lining of stainless steel.

### 2.3.2 Core components and internal parts

The core components from the BWRs planned for disposal in SFL include the core support structure (moderator tank, moderator tank cover, core grid and the upper part of the control rod guide tubes) and the core spray. Also included are neutron detectors, guide tubes, boron plates and fuel boxes (including spacers etc.). The steam separators are planned for disposal in SFR.

The waste from the PWRs includes all reactor internals.

Core components and internal parts that have been replaced during power upgrades of reactors in Oskarshamn and Forsmark have been placed in steel tanks for dry storage. The steel tanks are available in different models with different wall thicknesses that can be chosen based on the activity of the waste. Figure 2-4 shows examples of placement of material in cassettes for steel tanks with a wall thickness of 50 mm and 100 mm.

### 2.3.3 BWR control rods

Used BWR control rods are stored today in the central storage facility for spent nuclear fuel (Clab) or in the pools at the nuclear power plants. The entire programme will result in approximately 4,000 BWR control rods.

BWR control rods contain a large amount of induced activity in the form of long-lived radionuclides and are thus planned for disposal in SFL. Control rods from PWR reactors are included in the fuel bundles and will be disposed of together with the spent fuel in the repository for spent nuclear fuel.

The control rods from BWR reactors have a length of 4.2 m and consist of 0.27 m × 0.27 m wide crosses. The control rods consist of stainless steel and neutron-absorbing material such as boron carbide.


***Figure 2-2.** Current storage of drums at AB SVAFO after rebuilding of the storage and placing drums into 280-litre protection drums (Photo: SVAFO/Fredrik Ekenborg).*

***Figure 2-3.** Photograph of waste packages in the storage in Studsvik (Photo: SVAFO/Fredrik Ekenborg).*

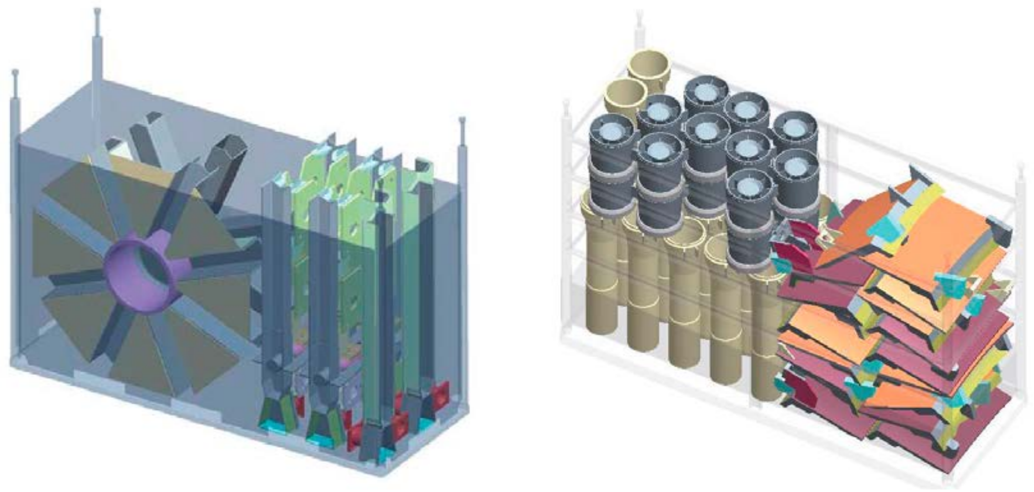

*Figure 2-4. Packing plan for segments of core components packed into cassettes for steel tanks. T-50B with segments from moisture separators, SFR waste (left). T-100 with the moderator tank lid and steam separator segments, SFL waste (right).*

## 2.4 Waste from industries, hospitals and research facilities

The waste from Swedish industry, hospitals, universities and research facilities is handled by Studsvik Nuclear AB, which prepares the waste for disposal and stores it until a repository is available. This waste fraction includes the waste stemming from Studsvik Nuclear AB's own operations. This waste is mainly stored in 200-litre drums.

Future operational waste and waste from the dismantling of the facilities in Studsvik will render additional waste for SFL.

# 3 Alternatives for transport and handling of SFL waste

Treatment and conditioning processes are used to convert radioactive waste materials into a form that is suitable for its subsequent management, such as transportation, storage and disposal. Treatment and conditioning of waste are aimed at enhancing safety or reducing costs or both by changing the characteristics of the waste – for example by volume reduction, removal of radionuclides from the waste, or changing its composition – or by producing a waste package suitable for handling, transport, storage and/or disposal. Since all handling of the waste entails a risk for increased dose load, the handling chain should be planned as a whole. The benefits in terms of safety and handling must be weighed against the dose load to personnel during treatment and conditioning. In this study, the term *conditioning* is used to denote all processing, pre-treatment, treatment, and conditioning of waste.

The different waste types planned to be deposited in SFL have different properties. Neutron-irradiated components from the nuclear power plants consist primarily of steel and stainless steel. The control rods consist of stainless steel and neutron-absorbing material such as boron carbide. Both contain long-lived activation products created by neutron-irradiation. The legacy waste is largely already conditioned by embedding in cement and contains other long-lived radionuclides, such as uranium and fission products.

This chapter contains an inventory of alternatives for safe transport and handling that may be suitable for the long-lived low and intermediate level waste in question. The feasibility of the handling alternatives is assessed.

The chapter is structured based on the following waste categories:

- Legacy waste, section 3.1.
- Metallic waste from nuclear power plants, section 3.2.
- BWR control rods, section 3.3.
- Waste from industries, hospitals and research facilities, section 3.4.

The handling alternatives and conditioning methods are described, and the benefits and consequences of the methods are elaborated on.

In this report the main focus when evaluating the handling alternatives has been on technological aspects. Aspects related to cost and long-term safety of the repository have not been considered.

## 3.1 Legacy waste

The legacy waste from early research in the Swedish nuclear programmes is to a large extent already conditioned. The waste is currently placed in different types of containers such as drums, moulds, large tanks and smaller boxes, as shown in Chapter 2.

Four main alternatives can be formulated for the legacy waste, which is already conditioned:

- Handling without further conditioning, section 3.1.1.
- Repacking into new containers, section 3.1.2.
- Retrieval and sorting, section 3.1.3.
- Other options, section 3.1.4.

This section describes the handling alternatives assessed for the legacy waste.

### 3.1.1 Handling without further conditioning

The most straightforward conditioning method is to deposit the waste in SFL in its current state and form, such as it is described in Chapter 2. The dose burden on the personnel is expected to be limited, by minimizing the conditioning needed.

In reality, however, parts of the waste are still expected to require emplacement in suitable containers in order to ensure safe transport and handling.

#### *Method*

The waste is accepted for disposal in SFL in its current state and form. Requirements on the waste packages are only imposed by the needs of safe transportation and handling.

#### *Prerequisites*

**Waste container**

No new waste container will be required due to that the waste will be deposited in the container in which it is currently stored.

**Transport container**

The transport of a majority of the existing waste packages – drums and moulds – can be handled within SKB's current transportation and handling system. For other waste packages, special arrangements within the current system will be needed, unless new transport containers are to be designed.

#### *Consequences*

**Requirements on the repository**

The strength of individual packages must be taken into consideration when packing and stacking different types of packages in a disposal room.

**Dose impact during handling**

Handling of individual drums and waste packages of various sizes is time-consuming and inappropriate from a handling viewpoint. The dose to the personnel is dependent on the high level of manual labour required to carry out this method. The dose impact is thus likely to be higher than if the waste is handled in a more efficient way.

### 3.1.2 Repacking into new containers

This conditioning method is aimed at creating an efficient and safe system for handling, transport, storage and disposal.

#### *Description*

The legacy waste currently stored in moulds and drums is packed into new containers. The waste packages are stabilized with grout in the container. The new containers will serve as overpacks for the moulds and drums and provide the mechanical strength needed for safe transport and handling of the waste.

#### *Prerequisites*

**Waste container**

Repacking of waste will require that new containers are developed. Today, no suitable container that can be used as over-pack for the waste currently stored in drums and moulds is available. The dimensions of these containers should be such that a suitable number of drums or moulds can be placed in each container. Preferably the dimensions of the containers should be equal independent on the type of container that the waste is currently stored in.

**Repacking facility**

This method requires that a repacking facility is available. The facility needs to handle the legacy waste containers, which will be placed in standardized containers and stabilized for safe handling and transportation.

**Transport container**

A new set of transport containers needs to be designed for the new waste containers for SFL. The external dimensions and weights of these containers must comply with SKB's current transportation and handling system.

#### *Consequence*

**Dose impact during handling**

Since handling of the waste is expected to be more efficient, once the original waste packages have been emplaced in the new containers, the dose to the personnel is likely to be lower than if the waste is handled without further conditioning.

### 3.1.3 Retrieval and sorting

The method entails that the existing waste packages with conditioned waste are opened and the waste separated from the grout and sorted prior to further handling. Thanks to this method, a number of well-characterized waste fractions will be obtained, that can be placed in suitable containers.

The sorting procedure is similar to the one undertaken by AB SVAFO during the period 1986–2002 to empty the storage facility AT in Studsvik.

#### *Description*

The containers are opened and the grout is crushed in an enclosed area. The waste is then sorted into a predetermined number of fractions by remote-controlled equipment. The waste may then be further processed by means of other conditioning methods described in this chapter, e.g. packing into new containers.

#### *Prerequisites*

Sorting of the legacy waste is expected to be a time-consuming activity. However, provided sufficient capacity is made available, the technical challenge will be less daunting. The prerequisite for sorting of the legacy waste is discussed below.

**Facility for conditioning of waste**

Sorting of the waste requires a conditioning facility with equipment for remote handling. A hot cell must be available for handling certain fractions of the legacy waste. Since the waste is currently stored in drums and is thus already segmented into small pieces, it is not expected that any equipment for additional segmentation of the waste components will be required.

The hot cell facility managed by AB SVAFO in Studsvik is an example of a facility with suitable capability. However, due to the large volumes of legacy waste, a new plant needs to be built in order for this alternative to be feasible.

**Waste container**

The sorted waste can be placed in any type of container that fits SKB's transportation and handling system. Which type of container that is used will be determined by the waste type and the level of activity.

**Transport container**

Since the waste container fits SKB's transportation and handling system, there is no need for design of new transport containers.

***Consequence***

**Dose impact during handling**

As with all other types of handling of radioactive material, it is expected that personnel operating the conditioning facility will be exposed to some radiation dose. However, the dose to personnel is expected to be kept low since this work is expected to be done in a hot cell or similar.

### 3.1.4 Other options

In section 3.1.3 a method for retrieval and sorting of the legacy waste is described. However, in addition to sorting, it is also possible to further treat the waste using different methods in order to e.g. reduce the volume of the waste further or to increase the stability of the waste form in order to improve the long-term safety of the repository. However, these methods are not within the scope of this study and will not be treated further in this report.

## 3.2 Metallic waste from nuclear power plants

The metallic waste from the nuclear power plants – core components, reactor internals, PWR pressure vessels etc., but not BWR control rods – adds up to approximately 2,500 tonnes of steel and stainless steel. The activity of the neutron-irradiated components influences handling alternatives. The most demanding radionuclide from a radiation safety viewpoint during the first 70 years is Co-60. All handling requires radiation shielding, and any segmentation of these components is therefore preferably done in the pools at the nuclear power plants.

In the case of metallic waste from the nuclear power plants, four main alternatives can be formulated for handling and conditioning:

- Disposal of whole components, section 3.2.1.
- Segmentation and loading into steel tanks, section 3.2.2.
- Segmentation and loading into new containers, section 3.2.3.
- Other options, section 3.2.4.

This section describes these four different handling alternatives assessed for the metallic waste from the nuclear power plants.

### 3.2.1 Disposal of whole components

In keeping with the ALARA principle, components may be handled in one piece rather than being segmented. The extensive handling associated with segmentation of, for example, a reactor pressure vessel may not be justified in terms of dose burden, and should be carefully evaluated against the option of handling the reactor pressure vessel in one piece.

In practice, this approach is considered a viable option only for sufficiently large components, which need extensive segmentation efforts. For smaller components, where segmentation is less extensive, segmentation and loading in containers is the preferred option due to the benefits in subsequent handling, transportation, storage and disposal.

As of now, Ringhals AB is planning to deposit intact PWR pressure vessels in SFL (including reactor internals). This option is discussed in this section.

### *Description*

PWR pressure vessels are removed from the reactor containment, transported to the repository and deposited in the repository in one piece. In order to provide for safe transport and handling, radiation shielding, preferably a metallic shield, has to be applied to each of the vessels prior to any handling. In the case that the reactor internals are not removed prior to transport, they will need to be securely fastened inside the reactor pressure vessel.

### *Prerequisites*

Handling of radioactive components of the size of a reactor pressure vessel will be a challenging task. The prerequisites for handling of the vessels according to the described method are presented briefly in this section.

#### Installation of the radiation shield

As a first task in this process the reactor pressure vessels must be provided with a radiation shield in order to provide radiation protection during all subsequent handling steps. The shield is preferably a thick steel liner that is attached to the PWR pressure vessel in the core region by means of a suitable but not yet determined method.

#### Lifting of the reactor pressure vessels

The reactor pressure vessel can be removed from the reactor containment by means of a large crane. Even though this involves lifting of an object weighing about 540 tonnes (reactor internals and shielding included), it is considered technically feasible as national and international experience exists from this kind of work.

#### Stabilizing the reactor internals

In order to provide for safe transport of the pressure vessel with reactor internals still in their original position, these will have to be securely fastened. A few options including grouting and welding can be identified but this work will require great efforts and risks for personnel performing this work.

#### Overland transport

Overland transport is preferably done by self-propelled modular trailers which can carry heavy loads and can be tailored to each individual transport. There is national and international experience of this kind of operation and the task is considered relatively simple.

#### Sea transport

Sea transport requires a ship with a big enough cargo capacity. Considering the relatively limited size of the reactor pressure vessels and international experience from sea transport of large objects, the task is considered relatively straightforward, although special arrangements will be needed.

#### Transport tunnels in the repository

In order to transport intact reactor pressure vessels through the transport tunnel down to disposal depth, the dimensions of the tunnel will have to be increased. The cross-sectional area of the tunnel has to be roughly doubled, compared to if the objects were segmented at the nuclear power plant site and transported in containers.

**Rock cavern in the repository**

A separate rock cavern needs to be built for PWR pressure vessels, similar to the rock cavern for BWR pressure vessels in the planned extension of SFR. The dimensions of the rock cavern will need to be commensurate with the dimensions of the reactor pressure vessel.

**Filling of the reactor pressure vessels in the repository**

In order to create a stable and alkaline environment inside the reactor pressure vessels, they will probably have to be filled with grout. This process is not technically challenging but requires careful planning and logistics. One of the main difficulties may be managing the gas that is expelled from the vessel when it is filled with grout. This gas may contain radioactive gases or particles that have to be prevented from contaminating the repository.

**Radiation shielding in the repository**

Radiation shielding will probably be required in the rock cavern. One suggestion is to build a concrete shield before disposal of the PWR pressure vessels.

#### *Consequence*

**Dose impact during handling**

It is likely that personnel will have to work in the vicinity of the reactor pressure vessels during many steps of this operation. Careful planning is needed to manage the handling chain from removal of the reactor pressure vessel at the nuclear power plant site to the backfilled rock cavern.

### 3.2.2 Segmentation and loading of waste into steel tanks

This conditioning method is aimed at creating an efficient and safe system for handling, transport, storage and disposal. The neutron-irradiated steel components are segmented and placed in steel tanks. The use of the existing handling system, of which the steel tank is a component, is warranted by the ALARA principle – the waste is handled remotely and finally emplaced in robust containers that can be handled remotely.

The alternative implies that the steel tanks currently used for storage will be disposed of in SFL. The steel tanks form part of a system that has been used by Swedish nuclear power plant operators for lifting out segmented core components for dry storage. The steel tanks are available in different models with different wall thicknesses that can be chosen based on the activity of the waste. Due to the good radiation-shielding properties of the steel, the steel tank is proven to be a well-suited package for handling and storage of core components. One option is to stabilize the waste with grout before the tanks are placed in the repository.

#### *Description*

The neutron-irradiated components are segmented using different techniques, usually in the pools on the nuclear power plant sites. The segmented parts are placed in the waste cassette, which is placed at the bottom of the pool. A radiation protection hood is used to lift and transport the filled waste cassette from the segmentation pool to the steel tank which is located in a transport box on the pool side. A vacuum drying cover is then placed on the steel tank and connected to a pump unit to remove water from the steel tank. When the content of the steel tank is dry, the cover is removed and the tank lid is moved in place onto the tank. When the tank lid is bolted to the tank, the transport box is closed and transported to storage or disposal.

Today, there are segmented components from maintenance stored either under dry conditions in steel tanks on the nuclear power plant sites or under wet conditions in the pools in Clab or on the nuclear power plant sites, see section 2.3. The method implies that waste currently stored in pools is segmented and placed in steel tanks. During dismantling of the reactors, the neutron-irradiated components will be segmented in the same way as during maintenance.

This waste category includes reactor core instrumentation. It should be noted that the LPRM (Local Power Range Monitoring) probes contain very small amounts of fissile material. Special care has to be taken when these probes are handled to avoid contamination of the pool.

#### *Prerequisites*

**Waste container**

This method entails the use of steel tanks for storage and disposal of the segmented metallic components from the nuclear power plants. There is thus no need for the development of new containers.

**Transport container**

Transport containers need to be suited for transport of the waste in its current state. A transport container – ATB 1T – is under development for external transportation of steel tanks. ATB 1T is required for transportation of steel tanks with segmented parts that have not been stabilized with grout or similar.

**Facility for conditioning**

If the waste needs to be stabilized before disposal, one or more conditioning facilities need to be available. The facilities must provide for stabilizing of the waste in the existing steel tanks. The tanks need to be opened and filled with grout.

#### *Consequences*

**Dose impact during handling**

Since waste will not be treated outside the waste containers, the dose to the personnel is expected to be limited. The dose load to personnel is dependent on the decay time of the waste before handling.

### 3.2.3 Segmentation and loading of waste into new containers

This conditioning method is aimed at creating an efficient and safe system for handling, transport, storage and disposal. The neutron-irradiated steel components are segmented and placed in new containers, other than the steel tanks used in section 3.2.2. The use of shielded containers is warranted by the ALARA principle – the waste will be fixed in robust shielded containers that can be handled remotely.

#### *Description*

Segmentation of neutron-irradiated components is performed according to the methods described in section 3.2.2, and placed in the container. The waste is stabilized with grout in the container.

Neutron-irradiated components currently stored in pools are segmented to fit into the new containers. The waste is placed in the containers and stabilized with grout in the container.

The neutron-irradiated components, which are currently stored in steel tanks, are lifted out of the tanks and placed in new shielded containers. The waste is stabilized with grout in the container.

#### *Prerequisites*

Repacking of intermediate level waste into new containers for SFL will be a rather straightforward process as long as segmentation of the waste is not required. In this section the most important prerequisites for the loading and repacking of the waste into new containers are discussed.

**Waste container**

This alternative requires that new waste containers for the metallic waste from the nuclear power plants are developed. These containers should provide the same level of radiation shielding as the currently used steel tanks and thus be made of thick steel sheets.

**Handling equipment**

This handling alternative requires that equipment for lifting out segmented core components from the nuclear power plant pools based on the new shielded container is available.

**Repacking facilities**

This method requires that one or more repacking facilities are available. The facilities must provide for repacking and stabilizing of waste already stored in steel tanks into new containers. Segmentation is expected to be needed, although for a limited amount of the waste in existing steel tanks. Since intermediate level waste, in particular the core components, will be treated outside the containers, this facility needs to include a hot cell or water pool to provide for radiation shielding during operation.

**Transport container**

A new set of transport containers need to be designed for the new waste containers. The external dimensions and weights of these containers must comply with SKB's current transportation and handling system.

***Consequences***

**Handling of secondary waste**

Repacking of the waste will lead to the formation of secondary waste in the form of slightly surface-contaminated containers, such as the steel tanks for core components. These steel tanks need to be decontaminated prior to reuse or recycling. Since the expected level of contamination is low, it is presumed that this procedure can be undertaken for example at the present facility operated by Studsvik Nuclear AB at the Studsvik site. The amount of secondary waste stemming from this conditioning method that must ultimately be disposed of is judged to be very small.

**Dose impact during handling**

Since waste will be treated outside the waste containers during repacking of waste in existing steel tanks, it is not unlikely that the dose to the personnel will be higher than for the handling alternative involving the steel tank (section 3.2.2). The dose load to personnel is above all dependent on the decay time of the waste before handling. However, as it is expected that the repacking will be done in a hot cell or water pool the dose is expected to be low.

### 3.2.4 Other options

In the previous sections, different alternatives for handling and packing of the metallic waste from the nuclear power plants have been discussed. However, in addition to these, it is also possible to further treat the waste using different methods in order to e.g. reduce the volume of the waste further or increase the stability of the waste form in order to improve the long-term safety of the repository. However, these methods are not within the scope of this study and will not be treated further in this report. A separate report on the feasibility of melting metallic intermediate level waste has been produced within the SFL concept study (Huutoniemi et al. 2012).

## 3.3 BWR control rods

Used BWR control rods are stored today in the central storage facility for spent nuclear fuel (Clab) or in the pools at the nuclear power plants. All handling requires radiation shielding, and the most demanding radionuclide from a radiation safety viewpoint during the first 70 years is Co-60.

Two handling alternatives for the BWR control rods have been identified:

- Disposal of whole control rods, section 3.3.1.
- Segmentation and loading into containers, section 3.3.2.

The handling alternatives are described in this section, and the benefits and consequences of the methods are discussed.

### 3.3.1 Disposal of whole control rods

The most straightforward handling alternative for BWR control rods is to deposit the control rods in their current state and form. This method is justified by the ALARA principle, since by minimizing the handling steps needed, the dose burden on the personnel is expected to be lower.

The handling alternative entails BWR control rods to be placed in copper canisters and deposited in the planned repository for spent nuclear fuel.

#### *Method*

BWR control rods are transferred from their current location in Clab to the Encapsulation Plant in a similar way as is planned for the spent nuclear fuel. The BWR control rods are emplaced in copper canisters and subsequently follow the same route as the spent nuclear fuel to disposal in the Spent Fuel Repository.

#### *Prerequisite*

**Adaptation of the Encapsulation Plant**

The Encapsulation Plant needs to be adapted to handle BWR control rods as well. The BWR control rods will be placed in copper canisters that are sealed in a similar fashion as is planned for the spent fuel.

**Waste container**

This alternative requires only that additional copper canisters are manufactured to host the control rods.

#### *Consequences*

**BWR control rods in the repository for spent nuclear fuel**

The BWR control rods need to be emplaced in the repository for spent nuclear fuel, which will increase the disposal volume required in the planned repository for spent nuclear fuel. There are approximately 4,000 BWR control rods in the entire nuclear programme. Assuming that 12 BWR control rods can be fitted into a copper canister, there will be approximately 350 additional canisters to be disposed of in the planned repository for spent nuclear fuel. The possibility of increasing the packing density is discussed in section 3.3.2. Canisters with BWR control rods can likely be deposited with a smaller distance compared to canisters with spent fuel, since the heat generation is negligible.

**Dose impact during handling**

Dose impact during handling is expected to be limited.

### 3.3.2 Segmentation and loading into containers

The physical dimensions of the BWR control rods restrict dense packing in containers. In order to increase the packing density, the control rods can be segmented. There are several different methods available for segmentation, but this section focuses on one particular method and the prerequisites and consequences are briefly outlined. For a more thorough description of the method, please refer to Appendix 2.

#### *Description*

The method involves three steps, as shown in Figure 3-1:

1. Removal of the stem of the control rod.
2. Segmentation of the control rod into four blades.
3. Optional further segmentation of the individual blades into shorter parts, which will fit into a container suitable for SFL.

The first cut involves removal of the stem in order to prepare the control rod for further segmentation. This procedure is preferably done by means of a saw.

The second cut is along the centre of the cruciform-shaped control rod to create four blades, each about 4 metres long and about 0.14 metre wide. This operation can be done without the release of any boron carbide.

The third step involves segmenting the steel blade into two or several equally long parts. Release of boron carbide is anticipated during this step, since one or several channels filled with boron carbide will be punctured.

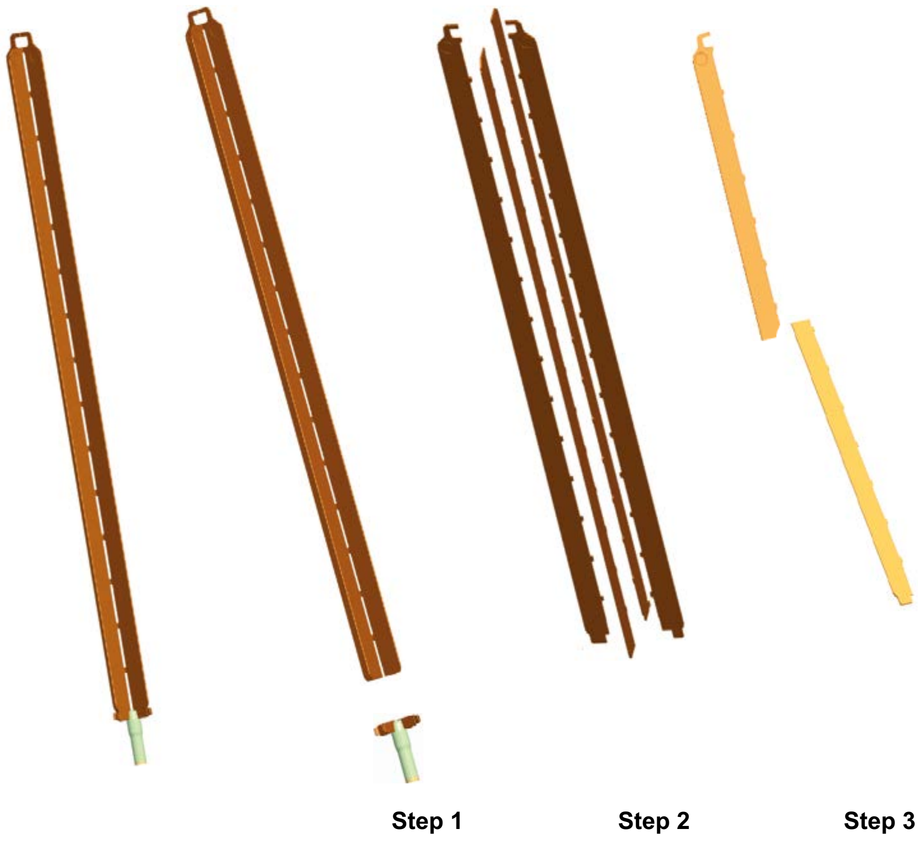


***Figure 3-1.*** *Schematic illustration of the proposed method for segmentation of BWR control rods: 1) Removal of the stem of the control rod, 2) segmentation of the control rod into four blades, and 3) (optional) further segmentation of the individual blades into shorter parts.*

After segmentation, the control rods are placed in suitable containers. Depending on whether the segmentation comprises two or three steps the requirements on the dimensions of the waste containers will vary.

### *Prerequisites*

Segmentation of the control rods will require the development of new equipment, but also a facility in which this process can be carried out. Due to the high activity of the control rods, segmentation is likely to be done under water in a pool or in a hot cell but apart from that no major technical obstacles are expected. The following prerequisites have to be fulfilled:

#### Equipment for segmentation

Equipment for removal of the stem, segmentation of the control rod into four separate blades, and finally for the segmentation of each individual blade is needed.

#### Facility for conditioning of waste

The most important consideration in designing the facility is probably whether segmentation should be performed in a dry hot cell or under water in a pool.

#### Waste container

The requirements on the waste containers is dependent the dimensions of the segments of the control rods. For segments with the length of the entire blades the copper canisters can be used, see section 3.3.1. For shorter segments other containers need to be developed.

#### Adaptation of the Encapsulation Plant

If the segmented blades are to be emplaced in copper canisters for disposal using the KBS-3 method, the Encapsulation Plant needs to be adapted to handle BWR control rod blades as well. The BWR control rod blades will be placed in copper canisters that are sealed in a similar fashion as is planned for the spent fuel.

#### Transport container

A new set of transport containers need to be designed for the new waste containers for SFL. The external dimensions and weights of these containers must comply with SKB's current transportation and handling system.

### *Consequences*

#### Dose impact during handling

Segmentation of control rods will probably entail the release of radioactive substances, at least during the third and final step of this process, during which at least one of the boron carbide-filled channels is punctured and the release of both boron carbide and tritium gas must therefore be expected. Methods for handling the release of powder and gas into the pool water are commercially available.

#### Packing density

Segmentation of the control rods will increase the packing density in the waste containers significantly, and as a consequence the required repository volume for the control rods will also be reduced. It can be estimated that about 90 BWR control rods can be fit into one copper canister (with modified cast iron insert), which implies that the approximately 4,000 BWR control rods in the entire nuclear programme will need an estimated 50 canisters.

**BWR control rods in the repository for spent nuclear fuel**

If the segmented blades are to be emplaced in copper canisters for disposal using the KBS-3 method the disposal volume required in the planned repository for spent nuclear fuel will increase. Canisters with BWR control rods can likely be deposited with a smaller distance compared to canisters with spent fuel since the heat generation is negligible.

## 3.4 Waste from industries, hospitals and research facilities

This waste category includes operational and decommissioning waste from Studsvik Nuclear AB, operational and decommissioning waste from AB SVAFO, as well as waste from industries, hospitals, universities and research facilities, which is also managed by Studsvik Nuclear AB. Parts of the waste is stored in Studsvik today, parts are estimated future waste from operations and decommissioning.

Two main alternatives can be formulated for this waste category:

- Handling without further conditioning, section 3.4.1.
- Loading into new containers, section 3.4.2.

This section describes the handling alternatives assessed for this waste category.

### 3.4.1 Handling without further conditioning

The most straightforward conditioning method is to deposit the waste in SFL in its current state and form, such as it is described in Chapter 2. The dose burden on the personnel is expected to be limited, by minimizing the conditioning needed.

#### *Method*

The waste is accepted for disposal in SFL in its current state and form. Requirements on the waste packages are only imposed by the needs of safe transportation and handling.

#### *Prerequisites*

**Waste containers**

This alternative does not require the development of any new waste containers.

**Transport containers**

The transport of the existing waste packages – drums and moulds – can be handled within SKB's current transportation and handling system.

#### *Consequences*

**Requirements on the repository**

The strength of individual packages must be taken into consideration when packing and stacking different types of packages in a disposal room.

**Dose impact during handling**

Handling of individual drums is time-consuming and inappropriate from a handling viewpoint. The dose to the personnel is dependent on the high level of manual labour required to carry out this method. The dose impact is thus likely to be higher than if the waste is handled in a more efficient way.

### 3.4.2 Loading into new containers

This conditioning method is aimed at creating an efficient and safe system for handling, transport and disposal. The waste can be loaded into the containers either directly or by loading primary waste packages, such as drums or moulds, into the containers. This waste category has similar waste packages as the legacy waste and would benefit from the same solutions as the legacy waste.

#### *Description*

The waste is packed into new containers. The waste or waste packages are stabilized with grout in the container. The new container will provide the mechanical strength needed for safe transport and handling of the waste.

#### *Prerequisites*

**Waste container**

Repacking of waste will require new containers to be developed. The requirements are similar to the requirements posed by the legacy waste (section 3.1.2).

**Transport container**

A new set of waste transport containers needs to be designed for the new waste containers. The external dimensions and weights of these containers must comply with SKB's current transportation and handling system.

#### *Consequence*

**Dose impact during handling**

Since handling of the waste is expected to be more efficient using a common system for waste handling, the dose to the personnel is likely to be lower than if the waste is handled without further conditioning.

# 4 Conditions for the study

## 4.1 General prerequisites for the study

The main purpose of the work – as outlined in section 1.2 – is to identify suitable waste containers for the long-lived low and intermediate level waste to be disposed of in SFL and includes:

- Identification of a set of waste containers that can provide for safe transport and handling of long-lived low and intermediate level waste, including neutron-induced intermediate level waste from the nuclear power plants and legacy waste.
- Identification of a long-term durable container which can provide for safe transport and handling of all types of long-lived low and intermediate level waste, and which also has properties that enable it to be credited with a safety function in an assessment of the long-term safety of the repository.

There are two important prerequisites to consider in this work given by the waste in question:

- The total volume of the waste planned for SFL is small – only about 16,000 $m^3$. This implies that the external dimensions of the containers should be similar, independent on the type of container and waste in the container, to constitute an efficient transport and handling systems.
- A large fraction of the waste planned for SFL has already been conditioned in containers, such as moulds and drums with different dimensions, and cannot be reconditioned without significant efforts.

The existing waste packages that have been identified to be considered in this study for the development of new containers are presented in section 4.3.

## 4.2 Guiding principles for the design of containers

Given the small amounts of waste planned for SFL, the study has formulated an additional objective to develop a set of containers whose foot print dimensions (width × depth) as well as lifting brackets are identical in order to facilitate and streamline the transport and handling system. The set of waste containers to be pursued will be based on a modular system that allows rational handling, transport and disposal of the waste containers in SFL.

The following design considerations have been identified:

- The waste containers will be designed for stabilization of the emplaced waste and waste packages using for example grout. The internal dimension of the waste containers will thus allow for grouting. In this study the weight calculations are based on the assumption that the grout that will be used inside the waste containers has a density of 2,000 $kg/m^3$.
- The waste containers will be designed to allow for grouting of the void between the containers prior to closure of the repository.
- The waste containers will be designed to allow for stacking in the repository.
- The waste containers will not be designed for any accident drop cases. Safety will be achieved by secured lifting. This means that hoists and lifting equipment are assumed to be dimensioned with over-strength or that redundant lifting devices are used.

In the development work the following limitations set by the present transport system have been identified:

- The total weight of the waste transport container including the waste containers is limited to 120 tonnes, which is the maximum total weight accepted by the current transport system.
- Waste containers shall be designed to meet the requirement of radiation protection during handling and transport in order to fulfil IAEA’s transport regulations (IAEA 2012).

In practice, the legacy waste, which is already conditioned and which represents a significant part of SFL waste, has guided the dimensioning of the new waste containers for SFL.

## 4.3 Existing waste packages considered in the study

The following waste packages exist and are considered in this study.

### *Standard concrete or steel mould*

| | |
|---|---|
| Width × Depth | 1,200 × 1,200 mm |
| Height | 1,200 mm |
| Weight including waste matrix, maximum | 5,000 kg |

### *Tray for four standard drums*

| | |
|---|---|
| Width × Depth, external measurement | 1,205 × 1,205 +2/0 mm |
| Width × Depth, internal measurement | 1,197 × 1,197 +2/0 mm |
| Thickness of the bottom plate | 4 mm |
| Weight of the empty tray | 66 kg |

### *Drum according to SIS 846202*

| | |
|---|---|
| Nominal diameter over the bottom ring | 581.5 mm |
| Maximum diameter over the locking ring | 613 mm |
| Height of the drum | 875 mm |
| Volume of the drum | 208 litres |
| Weight of the drum including waste matrix | 500 kg |

### *Drum according to DIN 6644 Type D18*

| | |
|---|---|
| Nominal diameter over the bottom ring | 581.5 mm |
| Maximum diameter over the locking ring | 613 mm |
| Height of the drum | 883 mm |
| Volume of the drum | 216 litres |
| Weight of the drum including waste matrix | 500 kg |

### *Protection drum*

| | |
|---|---|
| External diameter | 650 mm |
| External height | 960 mm |
| Volume of the drum | 280 litres |
| Weight of the drum including waste matrix | 525 kg |

### *Steel tank for core components*

The steel tank is used for storage of mainly core components from maintenance at the nuclear power plants. A handling system has been developed, which allows for loading of the tank under safe conditions in the reactor hall (SKB 2007, 2010).

The outer dimensions of the steel tank is 3.3 × 1.3 × 2.3 $m^3$ (*length* × *width* × *height*) giving an outer volume of about 10 $m^3$. There are tanks available with wall thickness 50, 100, 150 and 200 mm. The choice of wall thickness is determined by the activity and dose rate of the waste in question. The thickness of the bottom and lid is less than of the walls. The internal dimensions and weights are shown in Table 4-1.

The cassette is designed for loading of 12 tonnes of waste. However, experience from the nuclear power plants in Oskarshamn and Forsmark indicates that most of the tanks contain only about 3 tonnes with a maximum of 6–7 tonnes. In order to improve the packing density additional segmentation would be required.

**Table 4-1. Main data for steel tanks with various wall thickness.**

| Type of tank | Inner length (m) | Inner width (m) | Inner height (m) | Inner volume ($m^3$) | Tank weight, empty (tonnes) | Cassette weight (tonnes) | Waste weight (tonnes) | Weight of tank and waste (tonnes) | Total tank weight including grout (tonnes) |
|---|---|---|---|---|---|---|---|---|---|
| T50 | 3.2 | 1.2 | 2.2 | 8.45 | 10.25 | 2.82 | 12.0 | 25.1 | 38.2 |
| T100 | 3.1 | 1.1 | 2.2 | 7.50 | 18.51 | 3.57 | 12.0 | 34.1 | 45.1 |
| T150 | 3.0 | 1.0 | 2.2 | 6.60 | 25.60 | 5.46 | 12.0 | 43.1 | 51.8 |
| T200 | 2.9 | 0.9 | 2.15 | 5.61 | 33.20 | 5.81 | 12.0 | 51.0 | 57.7 |

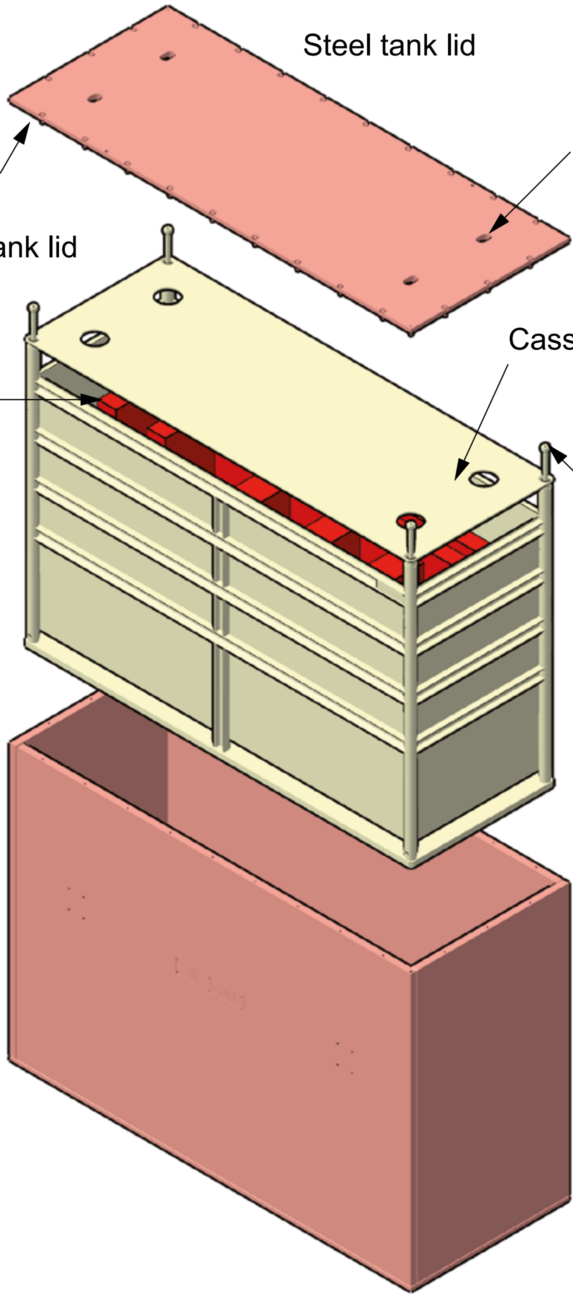


*Figure 4-1. Schematic illustration of the steel tank for neutron-irradiated components. The steel tank has external dimensions 3.3 × 1.3 × 2.3 $m^3$ (length × width × height). The waste is placed in a cassette which is placed in the tank. A lid is bolted to the tank. The thickness of the steel walls can be adjusted to comply with the requirements determined by the activity level of the waste.*

# 5 Design of waste containers

In Chapters 2, 3 and 4 the waste to be disposed of in SFL, the handling alternatives for the different waste categories and the containers in which parts of the waste is currently stored have been presented and discussed. In this chapter a set of waste containers for SFL which has been developed based on the conclusions made in the previous chapters is presented. Besides descriptions of the containers, a description of the lifting tools and lifting brackets on the containers is presented. General design considerations for the waste containers are summarized in Appendix 1.

## 5.1 Lifting brackets and lifting tools

In order to be able to use the same lifting tool for all types of containers independently of whether the container has a lid or not, a new type of lifting brackets has been developed. These brackets are placed in each corner of the container and consist of a bent plate which also acts as a guide for stacking the containers and for guiding the lifting tool, Figure 5-1.The lifting brackets are designed equally for all waste containers and dimensioned for the heaviest waste container.

Figure 5-2 shows the principle of the proposed lifting tool. The tool consists of a frame provided with four horizontal pins located in the corners. The pins are hydraulically operated.

The lifting tool is designed with over-strength, i.e. the lifting tool is able to carry the load even with only two (diagonal) out of four pins functioning.

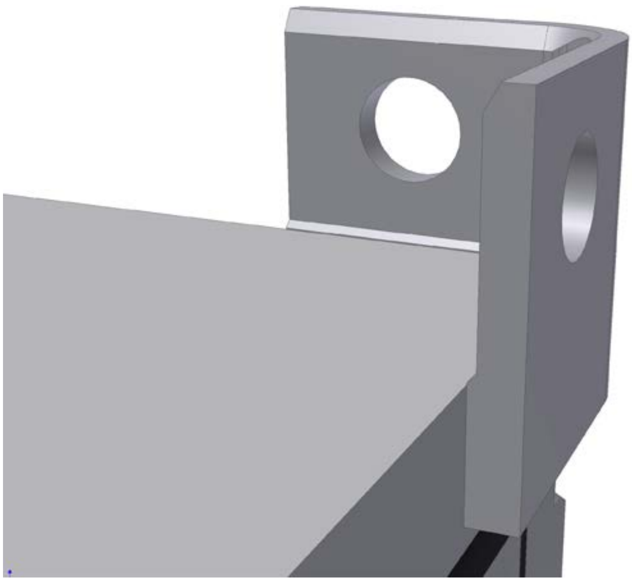

***Figure 5-1.*** *Preliminary design of the lifting bracket.*

*Figure 5-2. Preliminary design of lifting tool.*

## 5.2 Waste container for standard moulds

The waste container for four standard moulds consists of a welded framework of square tubes, with sides made of corrugated steel panels that are designed to withstand the forces from grouting of the waste, see Figure 5-3. The bottom plate consists of a flat plate with stiffeners arranged like a cross inside the waste container, see Figure 5-4. The stiffening plates also guide for the moulds when they are placed in the waste container. Guides for the moulds are also provided along the inner walls of the waste container.

**Table 5-1. Data for the waste container for standard moulds.**

| | |
|---|---|
| Outer dimensions (length × width × height) | 2,690 × 2,690 × 1,296 $mm^3$ |
| Inner dimensions (length × width × height) | 2,490 × 2,490 × 1,284 $mm^3$ |
| Outer dimensions (length × width) over the lifting lugs | 2,750 × 2,750 $mm^2$ |
| Total height from base to top of the lifting lugs | 1,450 mm |
| Square tube | 100 × 100 × 6.3 $mm^3$ |
| Side plate thickness | 4 mm |
| Bottom plate thickness | 12 mm |
| Outer volume | 9.38 $m^3$ |
| Inner volume | 8.60 $m^3$ |
| Volume of the four moulds/waste | 6.91 $m^3$ |
| Void for grout | 1.69 $m^3$ |
| Weight of empty container | 1,755 kg |
| Weight of waste | 20,000 kg |
| Weight of grout | 3,377 kg |
| Total weight (rounded value) | 25,200 kg |

*Figure 5-3. 3D-view of waste container loaded with standard moulds. Reinforcement bars on top of the moulds also shown.*

*Figure 5-4. 3D-view of waste container for standard moulds when empty. The stiffening plates for the bottom plate and guides for the moulds are visible.*

In order to facilitate grouting, the waste container has been designed to fulfil the following conditions:

- Distance between moulds: 50 mm
- Distance mould to waste container wall: 20 mm
- Distance from top of mould to top of waste container: 80 mm

The waste container for moulds will not be provided with a steel lid but only filled with grout to the top of the container. The grout surface will level with the top of the steel frame. Reinforcement bars will be placed on top of the moulds to prevent cracking of the top-most layer of the grout, see Figure 5-3.

## 5.3 Waste container for standard 200-litre drums

The design of the waste container for standard 200-litre drums is similar to the waste container for standard moulds, see Figure 5-5. The difference is the height of the container which is adapted to the height of the drums. In order to be able to handle the drums in a rational manner they are placed on trays – four drums on each tray – which are then placed in the waste container. For that reason, the guides are adapted for the trays, see Figure 5-6. The nominal distance between the trays is about 40 mm in order to facilitate grouting. The waste container for standard 200-litre drums will not be provided with a steel lid but only filled with grout to the top of the container. The grout surface will therefore level with the top of the steel frame. Reinforcement bars will be placed on top of the drums to prevent cracking of the top-most layer of the grout, see Figure 5-5.

**Table 5-2. Data for the waste container for standard 200-litre drums.**

| | |
|---|---|
| Outer dimensions (length × width × height) | 2,690 × 2,690 × 980 $mm^3$ |
| Inner dimensions (length × width × height) | 2,490 × 2,490 × 968 $mm^3$ |
| Outer dimensions (length × width) over the lifting lugs | 2,750 × 2,750 $mm^2$ |
| Total height from base to top of the lifting lugs | 1,134 mm |
| Square tube | 100 × 100 × 6.3 $mm^3$ |
| Side plate thickness | 4 mm |
| Bottom plate thickness | 12 mm |
| Outer volume | 7.09 $m^3$ |
| Inner volume | 6.48 $m^3$ |
| Volume of the 16 standard 200-litre drums | 3.33 $m^3$ |
| Void for grout | 3.16 $m^3$ |
| Weight of empty container | 1,602 kg |
| Weight of waste | 8,000 kg |
| Weight of grout | 6,312 kg |
| Total weight (rounded value) | 16,000 kg |

*__Figure 5-5.__ 3D-view of waste containers loaded with four trays with four drums each. Reinforcement bars on top of the drums also shown.*

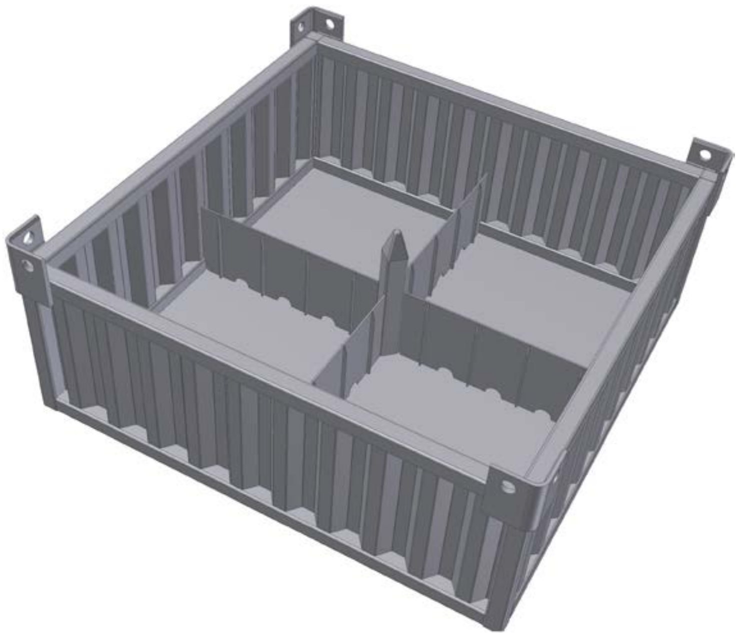

***Figure 5-6.*** *3D-view of an empty waste container for standard 200-litre drums, showing the stiffening plates for the bottom plate and guides for the trays.*

## 5.4 Waste container for 280-litre protection drums

The design of the waste container for 280-litre protection drums is similar to the waste container for standard 200-litre drums. The difference are the height of the container and the inner dimensions, which are adapted to the height and diameter of the 280-litre protection drums, see Figures 5-7 and 5-8. It should be noted that before grouting of the waste, the lids of the 280-litre protection drums will be removed in order to fill the void between the 280-litre protection drums and the 200-litre drums containing the waste with grout. The waste container for 280-litre protection drums will not be provided with a steel lid but only filled with grout to the top of the container. The grout surface will therefore level with the top of the steel frame. Reinforcement bars will be placed on top of the drums to prevent cracking of the top-most layer of the grout, see Figure 5-7.

**Table 5-3. Data for the waste container for 280-litre protection drums.**

| | |
|---|---|
| Outer dimensions (length × width × height) | 2,690 × 2,690 × 1,050 $mm^3$ |
| Inner dimensions (length × width × height) | 2,630 × 2,630 × 1,038 $mm^3$ |
| Outer dimensions (length × width) over the lifting lugs | 2,750 × 2,750 $mm^2$ |
| Total height from base to top of the lifting lugs | 1,204 mm |
| L-profile | 60 × 30 × 7 $mm^3$ |
| Side plate thickness | 4 mm |
| Bottom plate thickness | 12 mm |
| Outer volume | 7.60 $m^3$ |
| Inner volume | 7.34 $m^3$ |
| Volume of the waste | 3.33 $m^3$ |
| Void for grout | 4.02 $m^3$ |
| Weight of empty container | 1,480 kg |
| Weight of waste | 8,400 kg |
| Weight of grout | 8,031 kg |
| Total weight (rounded value) | 18,000 kg |

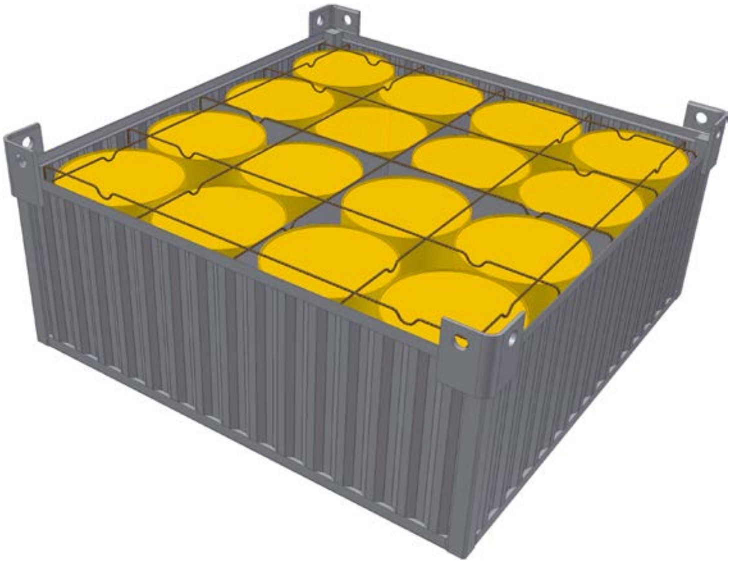

*Figure 5-7. 3D-view of the waste containers loaded with 280-litre protection drums. Reinforcement bars on top of the drums also shown.*

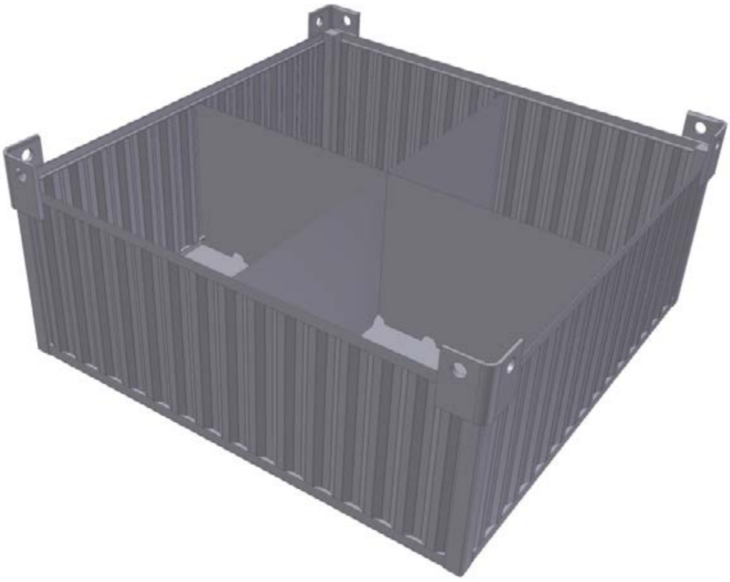

*Figure 5-8. 3D-view of the waste containers for 280-litre protection drums when empty.*

## 5.5 Shielded waste container

The existing intermediate level waste planned for disposal in SFL has not been finally conditioned, and can thus be retrieved. This means that there are no strict dimensional requirements from conditioned waste on the dimensions of the shielded container. Following the design principles set up in Chapter 4, the shielded waste containers is designed to have the same outer dimensions as the container for standard moulds.

Preliminary, all sides of the waste container will have a wall thickness of 100 mm steel. In future design work, also other values on the wall thickness may be considered to meet the requirements posed by waste with different activity and dose rate. The container will be fitted with a bolted lid, see Figure 5-9. The interior height is reduced compared to the container for standard moulds because of the thicker bottom and thicker lid. The number of bolts shown in the figures is only an assumption for this study; the exact number requires more detailed analysis.

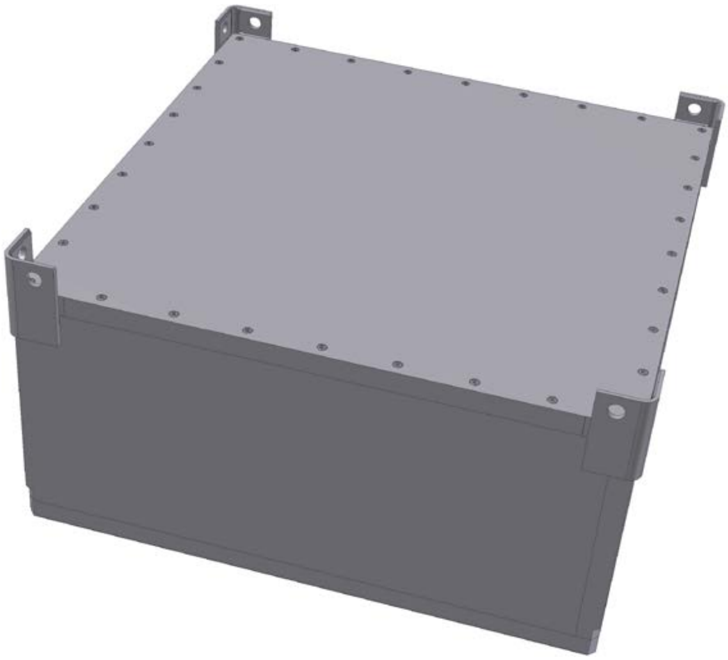

***Figure 5-9.*** *3D-view of the shielded waste container with the bolted lid in place.*

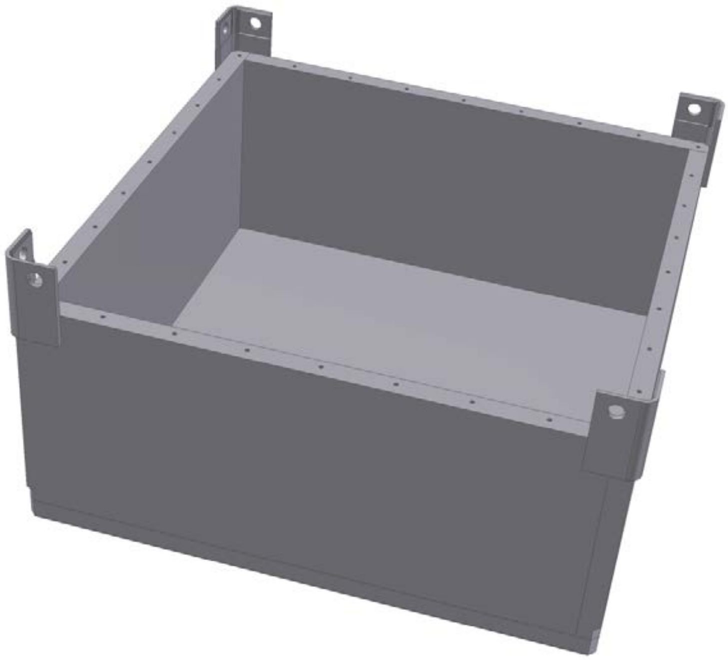

***Figure 5-10.*** *3D-view of the shielded waste container when empty.*

The side plates and base of the waste container are joined by welding. Based on experience from welding of similar structures it is assumed that the welds can be performed as conventional fillet welds and V-joints in the order of 10–15 mm, see Figure 5-11. Due to the thickness of the steel plates the welding must be done at an elevated temperature (100–200 °C) and with normal subsequent annealing for stress relief at 550–650 °C.

After completed welding operations, the support surface for the lid is facemilled to create a smooth surface and ensure a tight seal between the lid and the body of the container. No seal is foreseen between the lid and the body of the container. The sealing surface is steel to steel.

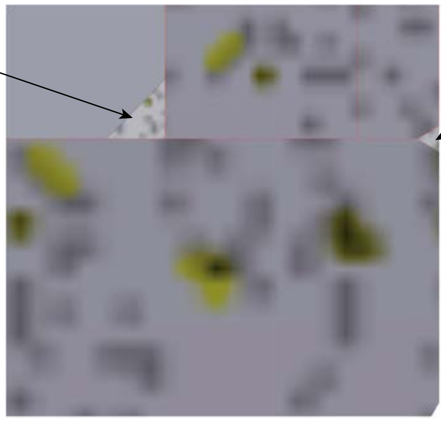


***Figure 5-11.*** *Welding design between the side plates and bottom plates. The same design is used for joining the side plates to each other.*

After the waste has been placed in the container it will be filled with grout up to the level of the lid after which the lid is bolted to the container. The lid is handled with removable lifting bolts during installation of the lid.

If the waste must be handled under water a cassette suited for the waste container will be required. Preliminary external dimensions of such a cassette is 2,450 × 2,450 × 1,090 $mm^3$ *(length × width × height)* with internal dimensions estimated to 2,350 × 2,350 × 1,040 $mm^3$ *(length × width × height)*. The weight of the cassette is estimated to be about 1,200 kg. The handling of the cassette also requires a lifting tool. The weight of the cassette and the waste is limited to 20,000 kg.

**Table 5-4. Data for the shielded waste container.**

| | |
|---|---|
| Outer dimensions (length × width × height) | 2,690 × 2,690 × 1,296 $mm^3$ |
| Inner dimensions (length × width × height) | 2,490 × 2,490 × 1,096 $mm^3$ |
| Outer dimensions (length × width) for the lifting lugs | 2,750 × 2,750 $mm^2$ |
| Total height from base to top of the lifting lugs | 1,450 mm |
| Plate thickness | 100 mm |
| Outer volume | 9.38 $m^3$ |
| Inner volume | 6.80 $m^3$ |
| Capacity for waste | 2.55 $m^3$ |
| Void for grout | 4.25 $m^3$ |
| Weight of empty container | 20,300 kg |
| Weight of waste | 20,000 kg |
| Weight of grout | 8,495 kg |
| Total weight (rounded value) | 48,800 kg |

# 6 Design of long-term durable container

The principal difference between the shielded container described in section 5.5 and the long-term durable container described in this section is that the long-term durable container is designed to have properties that enable it to be credited with a safety function in an assessment of the long-term safety of the future repository. The dimensions and other data of the long-term durable container will thus be equal to those of the shielded container (see Table 5-4) but the manufacturing method and sealing of the lid will differ.

All sides of the waste container will be of 100 mm steel plates and it will be fitted with a welded lid. In future design work, also other values on the wall thickness may be considered to meet the requirements posed by waste with different activity and dose rate. All welds shall have full penetration and the weld material should have the same corrosion properties as the base material. The arrangement of the welds is shown in Figure 6-1.

The lifting brackets for the container are welded to the lid. In order to be able to handle the waste container before the lid is mounted, lifting brackets will be arranged inside of the container, see Figure 6-2. When handling, a bayonet lifting tool is used, see Figure 6-3. It is suggested that the lifting tool will be designed so that it can be connected to the lifting tool for the container.

Two welding methods have been suggested for the manufacturing of the long-term durable containers: the *Narrow gap method* and the *J-joint method*.

***Figure 6-1.*** *3D-view of the long-term durable waste container with lid. The welds are shown (black).*

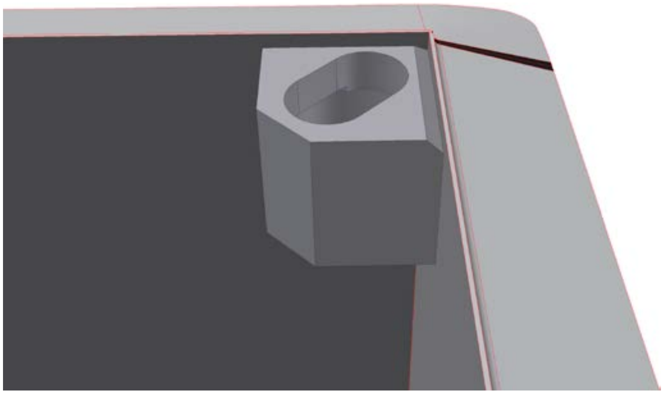

***Figure 6-2.*** *Illustration of a lifting bracket welded inside the long-term durable waste container.*

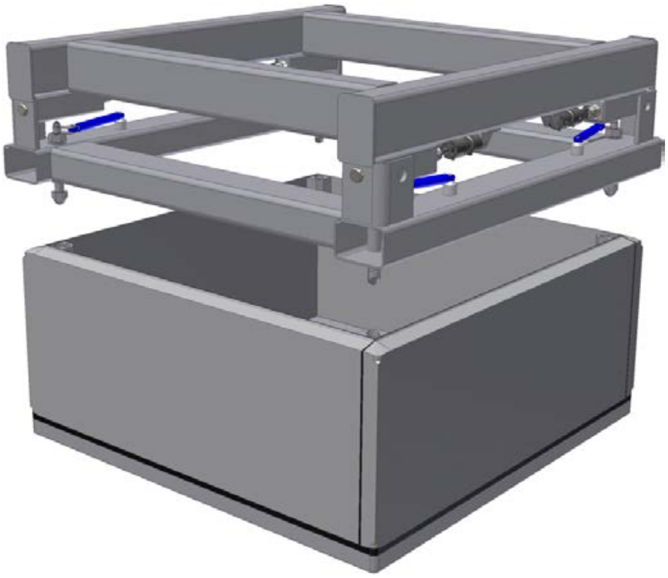

*Figure 6-3. Proposed design for lifting tools for the long-term durable container before the lid is welded to the container.*

The narrow gap method is characterised by a low consumption of welding material rendering a smaller welding deformation and lower residual stresses in the weld. However, even though the narrow gap method could be made suitable for joining the sides of the container with minor adjustments (see Figure 6-4), it is considered less suitable for welding of the base of the container to the side plates and also for attaching of the lid.

As an alternative to the narrow gap method it is proposed that the welding of the lid and base plate should be performed with a more traditional weld profile, for example J-joint (see Figures 6-5 and 6-6) according to SS-EN ISO 9692-1:2004 using a robotic metal inert gas (MIG) welding equipment.

Due to the large thickness of the steel plates in the container it is required that welding is made at an elevated operating temperature (100–200 °C) to minimize the risk of hydrogen embrittlement. The welding should preferably also be followed by annealing at 550–650 °C for stress relief.

However, annealing is not possible after welding of the lid when the waste container is loaded with waste and grout. It is instead suggested that the elevated operating temperature is retained some time after welding, to obtain a favourable cooling and to reduce the risk of phase transformations in the material. It is estimated, however, that lack of annealing does not affect corrosion properties of the material. After welding operations have been completed, non-destructive testing techniques will be used to verify the quality of the weld.

It should be noted that the grout inside the container must be fully cured before the lid can be mounted and welded. The time aspects of this will need further investigation.

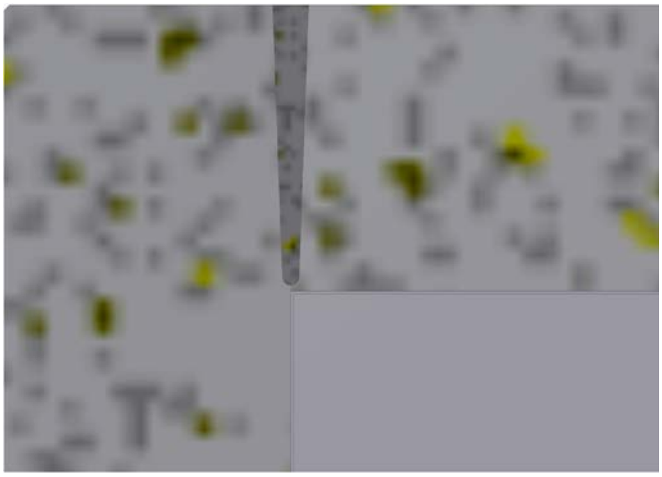

***Figure 6-4.** Illustration of narrow gap weld joining side plates. The wall thickness is 100 mm.*

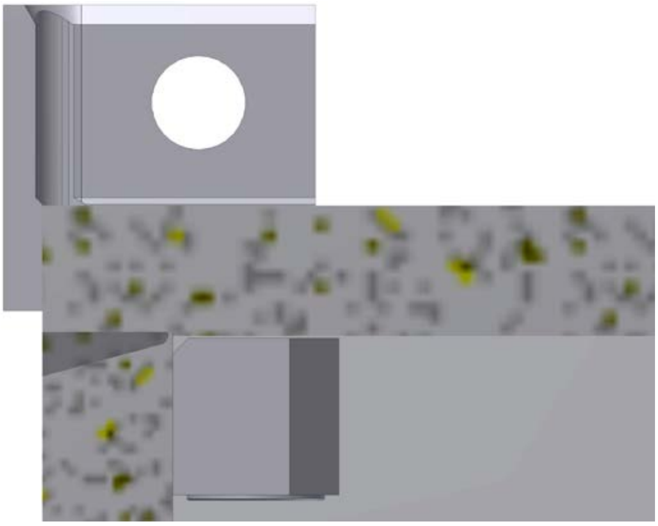

***Figure 6-5.** Welding of the lid to the container walls creating a J-joint.*

***Figure 6-6.** Welding of the bottom to the container side plates creating a J-joint.*

# 7 Design of waste transport containers

The weight of the waste transport containers (ATBs) to SFR for which existing terminal vehicles have been designed is limited to 120 tonnes. Considering this weight limitation, two containers for moulds or drums can be transported in one waste transport container, or a single shielded or long-term durable container.

Following this, the internal dimensions of the waste transport containers will be according to Table 7-1. A clearance of 100 mm has been adopted between waste containers and the inside of the ATB and between waste containers for guides in the ATB as well as space for the lifting tool. The ATB for containers for moulds and drums is denominated ATB 2L and the ATB for the shielded or long-term durable containers is denominated ATB 1L, respectively. These new type of ATB must fulfil the IAEA transport regulations. ATB 2L may be classified as a IP 2 container but ATB 1L must be licensed as a B(U) container.

A waste transport container for steel tanks (section 4.3) is currently being developed in a separate project. This waste transport container – ATB 1T – will be licensed as a B(U) container according to the IAEA transport regulations. Some data on the ATB 1T is included in this chapter for comparison.

Based on experience, it is further assumed that ATB 2L will have a wall thickness of 100 mm. ATB 1L will have a wall thickness of at least 160 mm, equivalent to ATB 1T. However, the final wall thickness will be decided on when the activity and surface dose rates of waste containers to be transported are known. In order not to exceed a total shipping weight of 120 tons, the maximum wall thickness for the ATB 2L should not exceed 120 mm. The corresponding value for ATB 1L is 190 mm. Based on the assumptions made of the wall thickness, the external dimensions of the ATBs presented in Table 7-2 are obtained.

In Table 7-3 a summary of the transport weights for these ATBs is presented, based on the dimensions given in Table 7-2 and a weight of 9,000 kg for the support stand.

**Table 7-1. Internal dimensions for ATB 2L, ATB 1L and ATB 1T.**

| | ATB 2L | ATB 1L | ATB 1T |
|---|---|---|---|
| Length (mm) | 5,680 | 2,890 | 3,330 |
| Width (mm) | 2,890 | 2,890 | 1,320 |
| Height (mm) | 1,500 | 1,500 | 2,325 |

**Table 7-2. External dimensions for ATB 2L, ATB 1L and ATB 1T.**

| | ATB 2L | ATB 1L | ATB 1T |
|---|---|---|---|
| Length (mm) | 5,880 | 3,210 | 3,700 |
| Width (mm) | 3,090 | 3,210 | 1,710 |
| Height (mm) | 1,700 | 1,700 | 2,695 |

**Table 7-3. Summary of weight information for ATB 2L, ATB 1L and ATB 1T.**

| | ATB 2L | ATB 1L | ATB 1T |
|---|---|---|---|
| Total weight (kg) | 50,200 | 49,900 | 55,000 |
| Weight, transport stand (kg) | 9,000 | 9,000 | 9,000 |
| Weight, waste packages (kg) | 2 × 25,500 | 48,000 | 52,000 |
| Total transport weight (kg) | 109,600 | 107,700 | 116,000 |

In order to comply with the IAEA transport regulations it is likely that shock absorbers will be needed for ATB 1L. The weight of shock absorber has not been estimated in this study and has to be included in the final design of the ATB.

Table 7-4 reports estimated dimension of the transport profiles for ATB 2L, ATB 1L as well as ATB 1T.

The total length of the transport stand is 7,230 mm for all types of ATB as is determined by the locking arrangement of the ATB in the cargo room of SKB's ship m/s Sigrid.

Preliminary design of ATB 2L is shown in Figure 7-1 and the preliminary design of ATB 1L is shown in Figure 7-2.

**Table 7-4. Transport profiles for ATB 2L, ATB 1L and ATB 1T.**

| | ATB 2L | ATB 1L | ATB 1T |
|---|---|---|---|
| Width (mm) | 3,310 | 3,470 | 3,340 |
| Height (mm) | 3,100 | 3,200 | 4,300 |

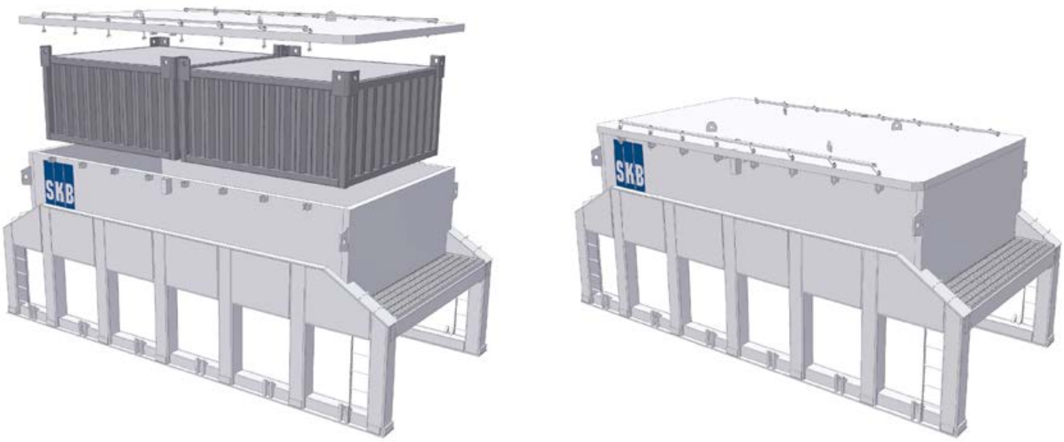

***Figure 7-1.*** *Preliminary design of ATB 2L.*

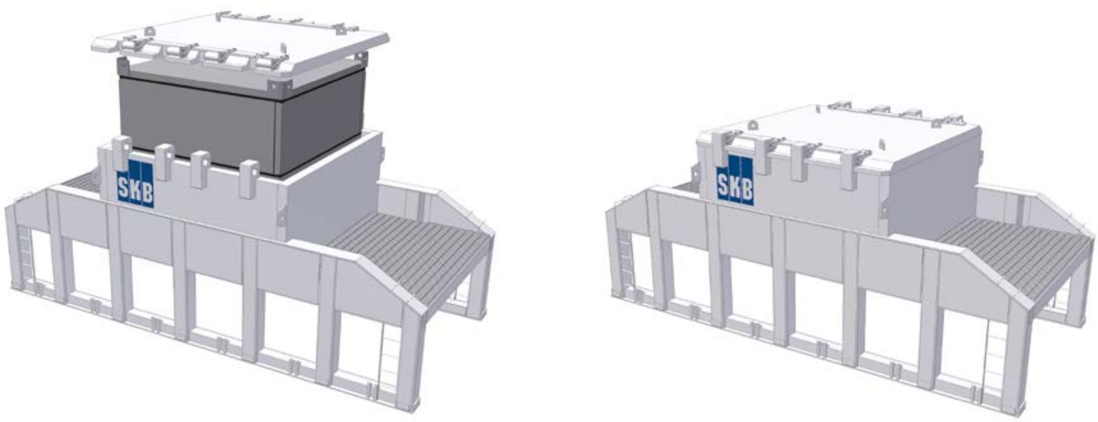

***Figure 7-2.*** *Preliminary design of ATB 1L without shock absorbers.*

# 8 Summary and future work

The main purpose of the work presented in this report is to identify suitable waste containers for the Swedish long-lived low and intermediate level waste to be disposed of in SFL. An inventory of existing waste and forecasts on future waste, including existing waste packages, serves as basis for the study. Various alternatives for transport and handling of the long-lived low and intermediate level waste are discussed and presented.

The existing steel tank is currently used for storage of mainly core components from maintenance at the nuclear power plants. The steel tank forms part of a system that has been used by Swedish nuclear power plant operators for lifting out segmented core components for dry storage. The steel tanks are available in different models with different wall thickness that can be chosen based on the activity of the waste. Due to the good radiation-shielding properties of the steel, the steel tank is proven to be a well-suited package for handling and storage of core components.

The study presents five new containers for transport and handling of long-lived low and intermediate level waste. These containers can handle various fractions of the existing waste, and together they are able to provide for the vast majority of the Swedish long-lived low and intermediate level waste. The containers share the same footprint and can thus be handled and transported in an efficient way. These containers are:

- Container for standard moulds, carrying four standard moulds.
- Container for standard 200-litre drums, carrying 16 standard drums.
- Container for 280-litre protection drums, carrying 16 protection drums.
- Shielded container, for intermediate level waste.
- Long-term durable container, which can be credited with a safety function in an assessment of the long-term safety of the repository.

The containers for drums and moulds are based on a straightforward design which provides for safe transport and handling. These containers are made of a framework provided with corrugated metal sides. The void in the waste containers will be filled with grout prior to transport. These containers have therefore no need for a separate steel lid.

The shielded container is preliminarily made from welded 100 mm thick steel plates and is fitted with bolted lid. This container provides for safe transport and handling of intermediate level waste, such as segments of core components. This container thus offers similar functions as the existing steel tank and may supersede the steel tanks as storage container for core components.

The long-term durable container is manufactured using a method that provides for joints that are completely welded through the full thickness of the material, including the weld between the lid and the body of the container. However, significant effort is expected in the development of welding method and quality control for the long-term durable container.

A waste transport container for steel tanks – ATB 1T – is currently being developed by SKB. This waste transport container will be licensed as a B(U) container according to the IAEA transport regulations.

Two additional transport containers have been suggested in this study: ATB 1L for the transport of one shielded container or one long-term durable container and ATB 2L for the transport of two containers for drums or moulds. ATB 2L may possibly be classified as a IP 2 container but ATB 1L need to be licensed as a B(U) container.

A method for segmentation of BWR control rods and placing the cut material in shielded containers is presented in Appendices 2 and 3. Flow charts presenting overviews of the main steps in the process of waste conditioning, storage, transport and disposal are presented in Appendix 4. The two presented alternatives are examples, and other alternatives or combinations are feasible.

This study summarizes some aspects related to handling and transport of the waste planned for SFL. Further work will include studies of the possibilities and consequences of various handling alternatives and detailed design of equipment. Further studies relate to:

- Repacking facility for the legacy waste.
- Conditioning facility for the waste from the nuclear power plants.
- Facility and method for segmentation of BWR control rods.
- Final design of the transport containers for the waste containers, ATB 1L and ATB 2L.
- Manufacturing technique for the long-term durable container.

# References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.


**Herschend B, 2013.** Long-lived intermediate level waste from Swedish nuclear power plants: Reference inventory. SKB R-13-17, Svensk Kärnbränslehantering AB.

**Huutoniemi T, Larsson A, Blank E, 2012.** Melting of metallic intermediate level waste. SKB R-12-07, Svensk Kärnbränslehantering AB.

**IAEA, 2012.** Regulations for the safe transport of radioactive material, 2012 Edition. Vienna: International Atomic Energy Agency. (Safety Standards Series SSR-6)

**SKB, 2007.** RD&D programme 2007. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste. SKB TR-07-12, Svensk Kärnbränslehantering AB.

**SKB, 2010.** RD&D programme 2010. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste. SKB TR-10-63, Svensk Kärnbränslehantering AB.

**SKB, 2013.** RD&D programme 2013. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste. SKB TR-13-18, Svensk Kärnbränslehantering AB.

## Appendix 1

# General design considerations for the waste containers

### *Swedish standards*

For waste containers and lifting equipment, the following standards apply:

- KBM (Quality regulations for mechanical equipment).
- TBM (Technical regulations for mechanical devices).
- TBY (Technical regulations for surface treatment).
- Eurocode 3 (Steel structures).
- KIKA TS (Crane users in nuclear plant – Technical specification).
- For all welds, specific welding procedures (WPS) must be established according to SS-EN ISO 15609 for the welding operation in question. The welding procedures shall be based on approved WPQR (Welding Procedure Qualification Record) according to the applicable part of the SS-EN ISO 15614-series or SS-EN ISO 15613.

### *Classification*

The following classification is assumed to apply for waste containers:

- Safety class 4.
- Quality class 4.
- Class 3 according to KIKA.
- Welding class WB according to SS-EN ISO 5817:2007.

### *Dimensioning*

The following partial coefficients have been used for dimensioning calculations of for waste containers. In this study, only simple scoping calculations are performed for verification of the design.

- Risk coefficient gn = 1.25 according to KIKA TS.
- Material gm = 1.0.
- Dead weight gg = 1.0.
- Load gq = 1.35.

Waste containers do not need to be dimensioned with regard to fatigue as the number of stress cycles is << 1,000 during the lifetime of the component.

### *Material*

All waste containers will be manufactured using carbon steel. Materials should be selected based on strength and ease of welding. There are no specific requirements on impact resistance. Unless stated otherwise, the following material is used:

- Square tubes: S355J2H
- Steel plate: S355J2G3

### *Surface treatment*

As the waste containers will be surrounded by concrete in the repository no specific requirements for surface treatment is necessary, other than to prevent surface corrosion before placement in SFL. A surface coating will be applied to the container in order to prevent surface corrosion but the final treatment will be determined at a later stage.

### *Lifting brackets and lifting tool*

In order to facilitate the use of the same lifting tool for all types of containers they must all be provided with identical lifting brackets independent of the design of the container.

## Appendix 2

# Method for segmentation of BWR control rods

The described method concerns segmentation of BWR control rods under water. Prior to transportation from the nuclear power plant the main part of the control rod stem must be removed. The remaining part of the control rod is a 4.2 m long cruciform-shaped part, about 0.27 × 0.27 m in size, as shown in Figure A2-1.

### *Method*

The method involves three steps, as shown in Figure A2-2:

1. Removal of the stem of the control rod.
2. Segmentation of the control rod into four blades.
3. Optional further segmentation of the individual blades into shorter parts, which will fit into a container suitable for SFL.

The first cut involves removal of the stem in order to prepare the control rod for further segmentation. This procedure is preferably done by means of a saw. The removed stem is grabbed by a lifting tool and placed in a suitable cassette.

The second cut is along the centre of the cruciform-shaped control rod to create four blades, each about 4 metres long and about 0.14 metre wide. This operation can be done without the release of any boron carbide. The separated blades are grabbed by a lifting tool and transported to a storage position in the pool or to a suitable container.

The third step involves segmenting the steel blade into two or several equally long parts. Release of boron carbide is anticipated during this step, since one or several channels filled with boron carbide will be punctured.

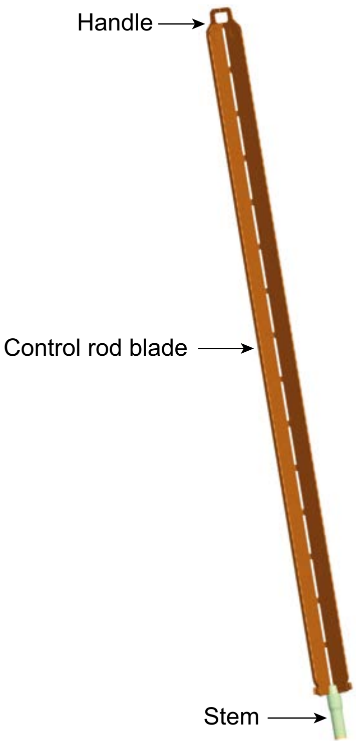


***Figure A2-1.*** *Principle design of a BWR control rod. The main part of the control rod stem has been removed.*

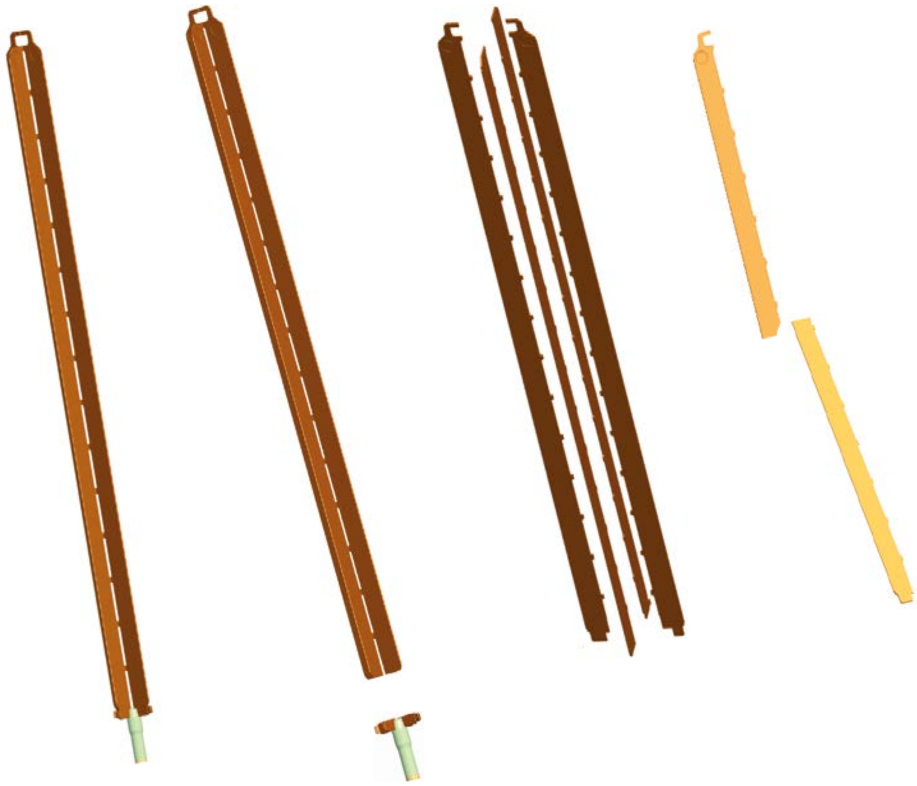


*Figure A2-2. Schematic illustration of the proposed method for segmentation of BWR control rods: 1) Removal of the stem of the control rod, 2) segmentation of the control rod into four blades, and 3) (optional) further segmentation of the individual blades into shorter parts.*

### Equipment

Figure A2-3 shows the conceptual design of a cutting equipment with two stations – one for removal of the stem and one for segmentation of the control rod into four blades. These stations correspond to step 1 and 2 in the cutting sequence, respectively. Figures A2-4, A2-5 and A2-6 show details of the two stations. The BWR control rod segmentation equipment shown below is developed by Westinghouse Electric Company Sweden.

To perform the optional third step and segment the individual blades into shorter segments, either a saw or a powerful hydraulic cutting tool can be used. Cutting using a hydraulic cutting tool is faster and considered easier from a handling perspective. However, the material in the control rods is hard and brittle due to the neutron irradiation, and the hydraulic cutting tool may cause cracks in the material. Sawing does not have the same side effects, but is slower and demands more consumables.

After segmentation, the control rods are placed in suitable containers. Depending on whether the segmentation comprises two or three steps, the requirements on the dimensions of the waste containers will vary.

### Requirements

The proposed method requires the following:

- A suitable pool for segmentation. This pool can be adjacent to the Central storage for spent nuclear fuel (Clab) or elsewhere.
- Lifting equipment for control rods, control rod segments, cutting equipment and containers for transportation.
- System for filtering of water and cleaning.

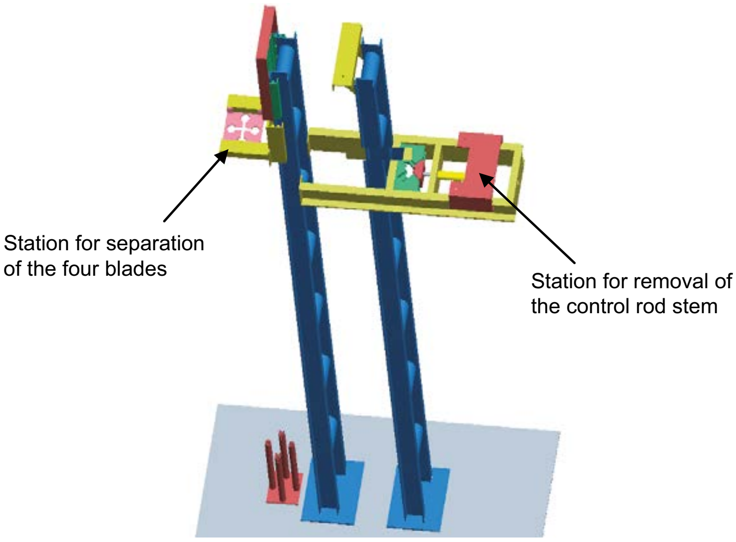


*Figure A2-3. Arrangement of cutting equipment for segmentation of BWR control rods. The cutting equipment comprise two stations – one for removal of the stem (right) and one for segmentation of the control rod into four blades (left). These stations correspond to step 1 and 2 in the cutting sequence, respectively.*

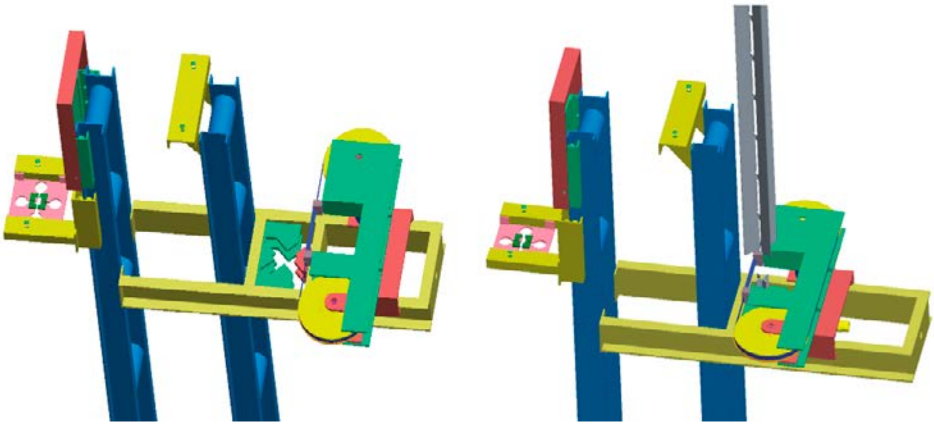

*Figure A2-4. Detail of the station for removal of the control rod stem. Before loading of the control rod into the band saw (left) and after removing the stem (right).*

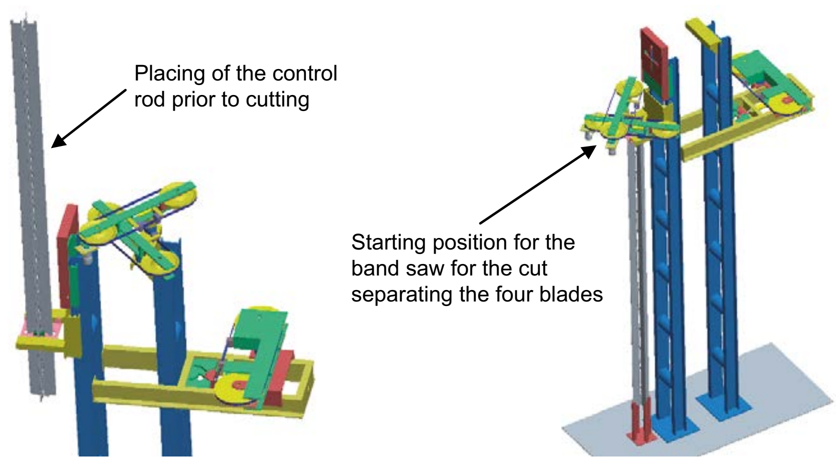


*Figure A2-5. Station for segmentation of control rods into four blades. The figure shows the placement of the cruciform-shaped control rod into the station prior to cutting (left) and the starting position for the double band saw for the cut separating the four blades (right).*

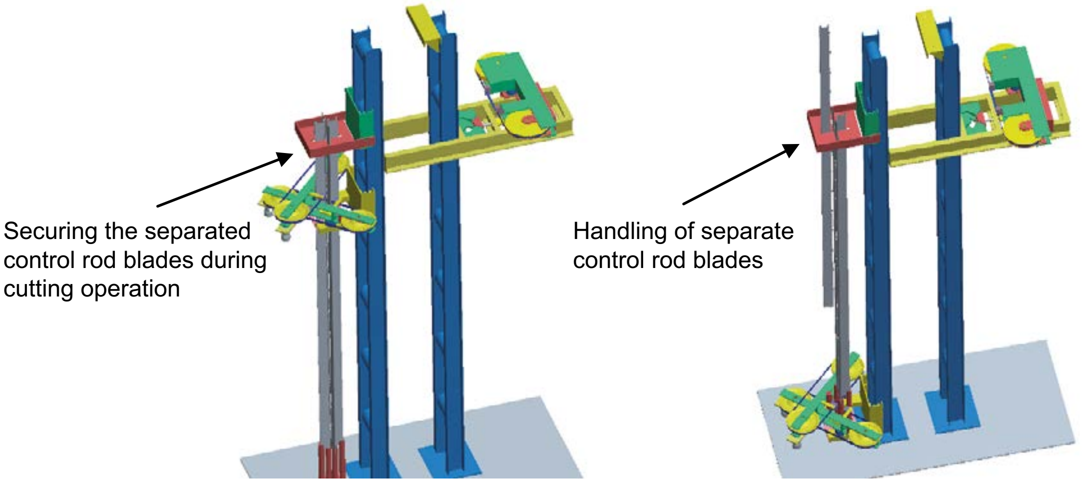


***Figure A2-6.*** *Station for segmentation of control rods into four blades. The figure shows the cutting operation (left) where the separated blades are secured during the cutting operation using a holder at the top of the equipment. The figure also shows (right) the unloading of separate control rod blades after completed cutting sequence.*

#### *Release of radionuclides*

Cutting of BWR control rods designed by ABB Atom/Westinghouse is considered relatively easy as they consist of 8–10 mm thick plates, in which the horizontal holes have been drilled to allow containment of boron carbide powder or hafnium. When cutting the third step, one to two drilled holes will be punctured and a limited amount of boron carbide can be released into the water. However, the material is brittle due to neutron irradiation and there is a risk that several holes are affected if the blade fractures. Tests made show that there is no overpressure in the control rods.

The design of the GE control rods is fundamentally different since they consist of vertical tubes filled with boron carbide powder, which are wrapped in a stainless steel casing. Since vertical pipes are cut off in the third step, probably a larger amount of boron carbide will be released into the water compared to design with horizontal holes.

As a result of the irradiation of the boron carbide powder, there is a risk that the control rod blades emit a small amount of tritium when they are cut off. Experience shows that the release of tritium as a result of cutting used control rods is relatively low.

# Appendix 3

## Packing of segments of BWR control rods

After segmentation of the control rods the segments need to be placed in storage boxes for safe and efficient handling. The dimensions of these boxes are dependent on whether they must fit into a cassette in Clab or if they can be placed directly into a waste container for SFL.

With the prerequisite that a storage box for half blades (segmentation in three steps) must fit into a Clab cassette it is suggested that the storage boxes should have the outer dimensions 150 × 740 × 2,400 $mm^3$. Each storage box could preliminary hold the blades from nine control rods. These boxes can later be placed in shielded containers for disposal in SFL.

With the specified dimensions of the shielded container (section 5.5), it would be possible to place a total of 21 storage boxes with control rod blades in each shielded container. Given the estimated total number of BWR control rods (4,000), a total of 22 shielded containers would be required to accommodate all BWR control rods.

Besides the blades also the remaining stems of the control rods are placed in specially designed boxes. These boxes should have the dimensions 740 × 740 × 2,400 $mm^3$. It is estimated that each box could hosts approximately 90 stems (Figure A3-1), adding up to a total of 45 storage boxes for the stems from all BWR control rods.

With a total of three storage boxes with control rod stems in each container, a total of 15 shielded containers will be required to host all control rod stems. However, as these containers can be filled with six additional storage boxes with blades from the control rods each (see Figure A3-2), the total number of containers with parts from the control rods can be reduced.

In summary, it is estimated that 32 shielded containers would be required to host all BWR control rods from the Swedish nuclear programme.

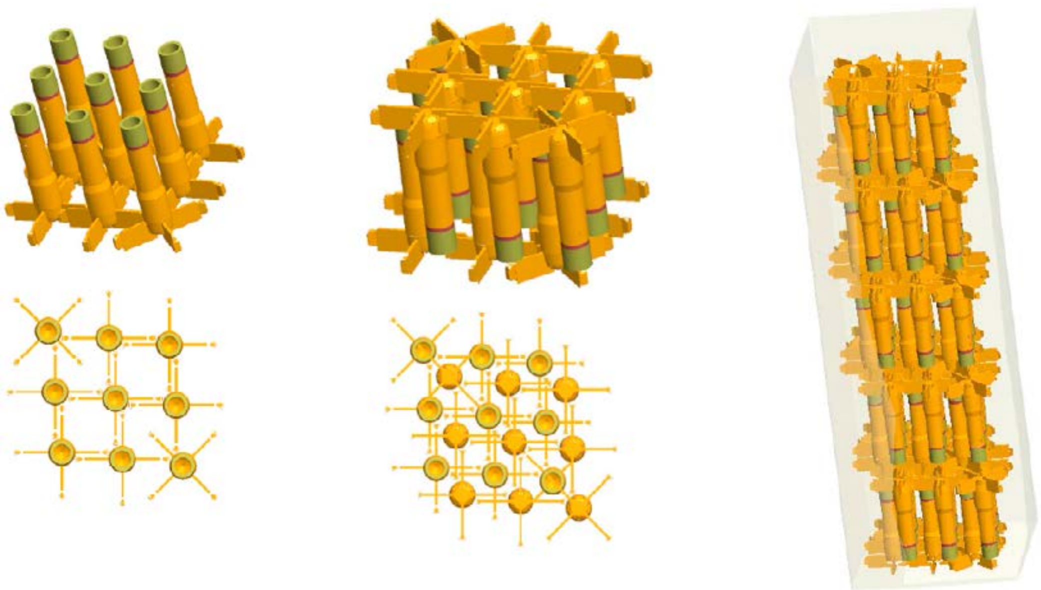

***Figure A3-1.*** *3D illustration of the placement of the control rod stems in a storage box designed to fit inside a Clab cassette.*

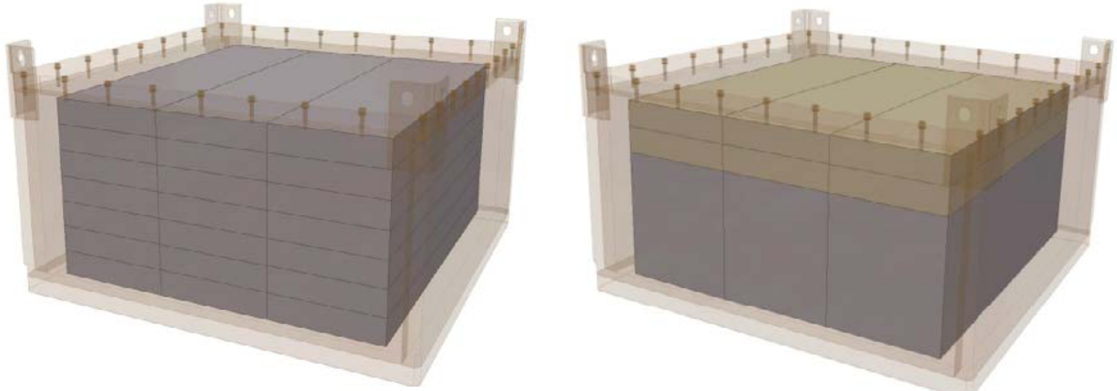

***Figure A3-2.*** *Shielded container with 21 storage boxes of cut control rod blades (left) and a shielded container with three storage boxes for control stems and six storage boxes for control rod blades (right).*

# Appendix 4

## Flow charts for handling of long-lived low and intermediate level waste

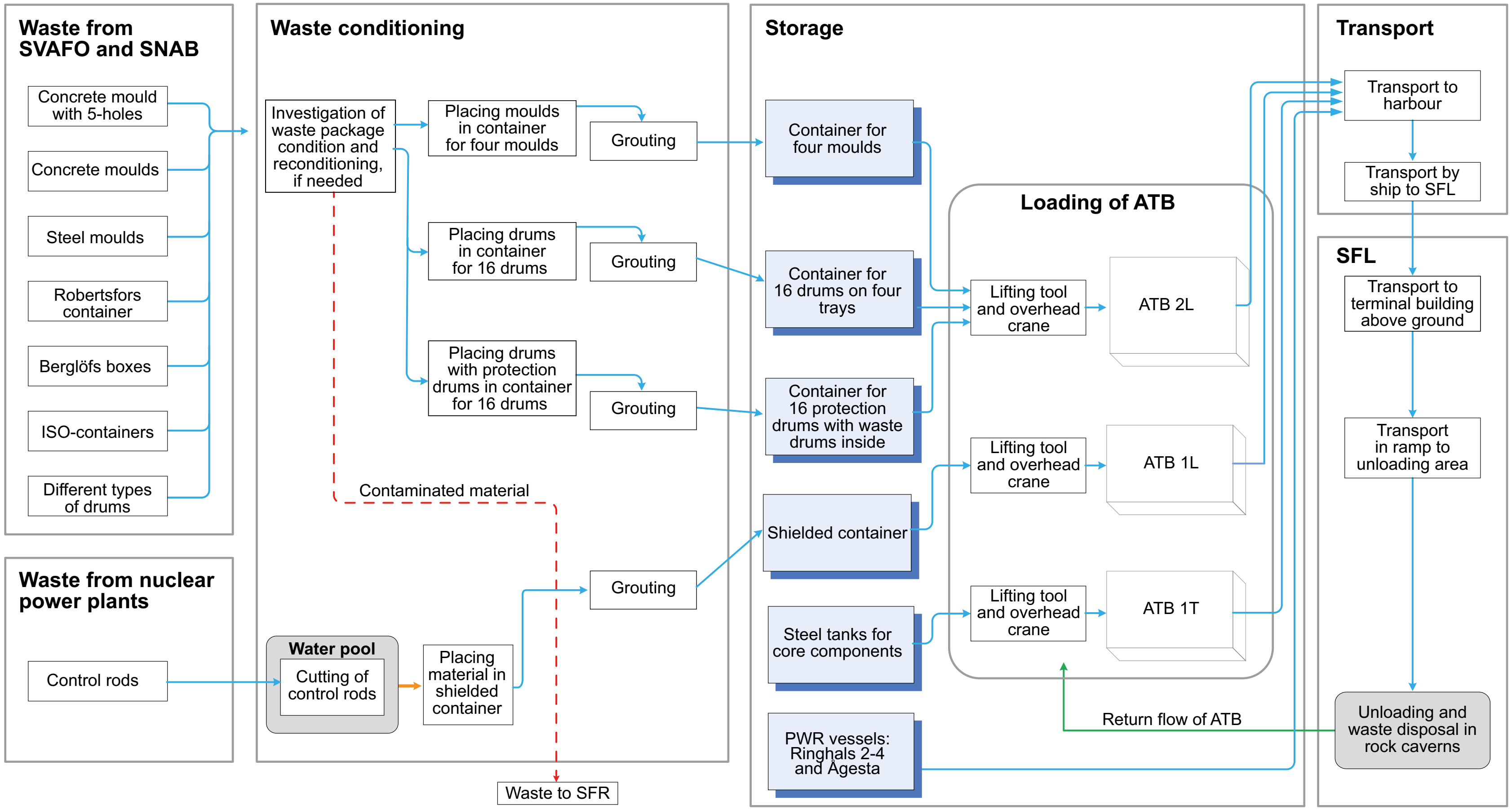


*Figure A4-1. Flow chart for an alternative with a mixture of new waste containers, steel tanks and PWR pressure vessels as containers for disposal.*

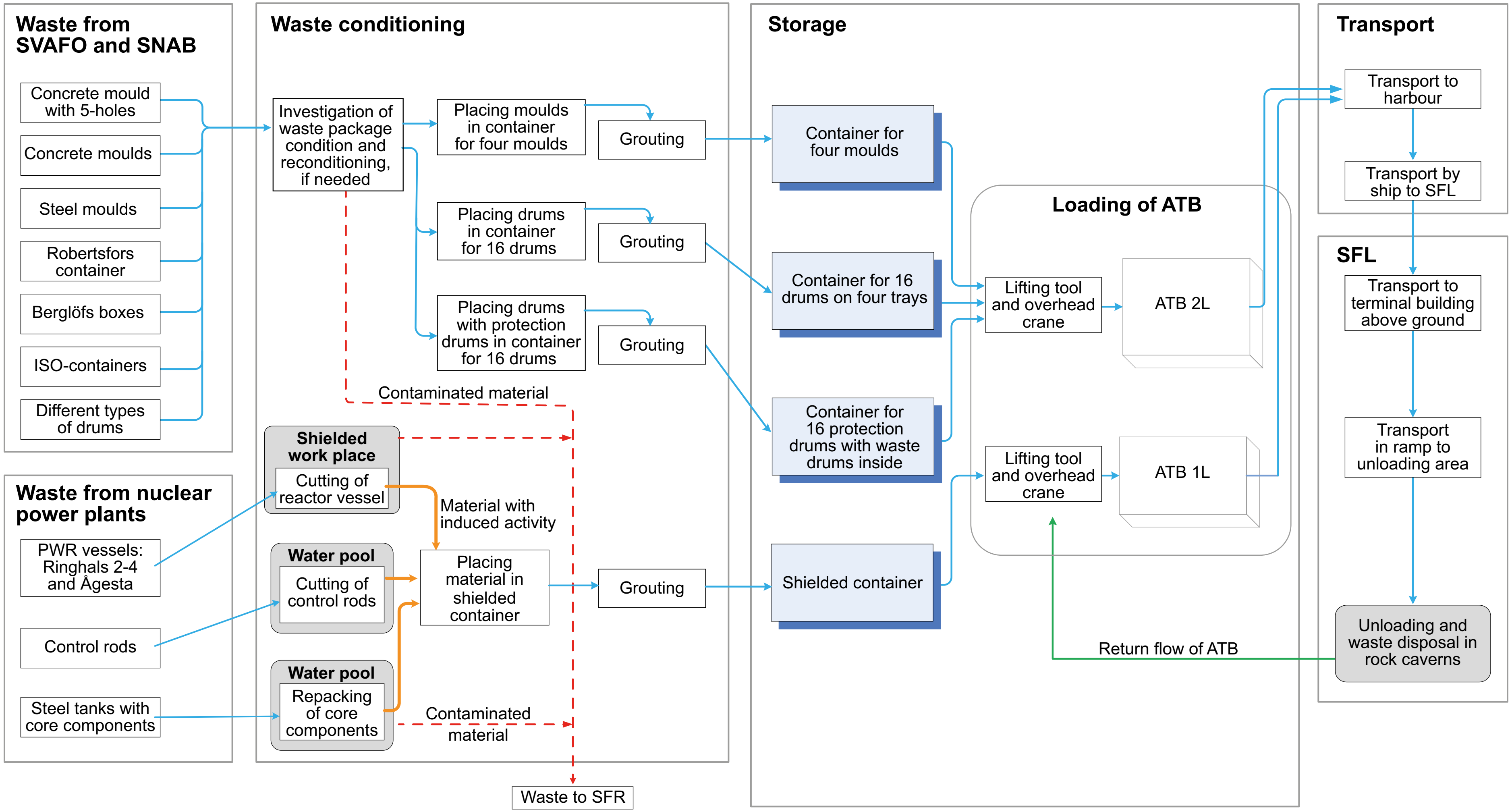


***Figure A4-2.*** *Flow chart for the alternative when all waste is placed in the new family of containers for disposal.*