Interim storage facility, encapsulation plant and final repository for spent nuclear fuel

Background material for consultations according to the Espoo (EIA) Convention

Updated January 2008

SKB

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Preface

If an activity is likely to have a significant environmental impact in another country, the Swedish Environmental Protection Agency shall, according to the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo, 1991), known as the Espoo (EIA) Convention, "inform the competent authority in that country about the planned activity or measure and give the country concerned and the citizens who are affected the opportunity to take part in a consultation procedure concerning the application and the environmental impact assessment" (Environmental Code Chap. 6 Sec. 6).

Svensk Kärnbränslehantering AB, SKB (the Swedish Nuclear Fuel and Waste Management Co.), has been assigned the task of managing and disposing of the radioactive waste from the Swedish nuclear power plants. In order to dispose of the spent nuclear fuel, SKB plans to build an encapsulation plant, where the spent nuclear fuel is encapsulated in copper canisters, and a final repository at a depth of about 500 metres in the bedrock.

The encapsulation plant is planned to be built adjacent to the existing interim storage facility for spent nuclear fuel (Clab) in Oskarshamn. Investigations have been conducted in Forsmark and Oskarshamn to explore the prospects for siting of the final repository. Data from the investigations are at present compiled and analysed. Both Oskarshamn and Forsmark are situated on the Baltic Sea coast in southern Sweden.

The purpose of this document is to provide an overview of SKB's plans for disposal of the spent nuclear fuel and the consequences this activity is likely to have. Detailed information about: safety and radiation protection, the long term safety for a KBS-3 repository and the general structure of the EIS document for the final repository system are enclosed as appendences. Additional information can be found on SKB's website and in SKB's reports, the most important of which are available in English.

Introduction

Nuclear power in Sweden

Sweden has twelve nuclear power reactors at four sites, ten of which are in operation. At Ringhals there are three pressurized water reactors and one boiling water reactor with a combined capacity of 3,600 MW, at Forsmark three boiling water reactors with a combined capacity of 3,200 MW, at Oskarshamn three boiling water reactors totalling 2,200 MW, and at Barsebäck two boiling water reactors of 600 MW each.

The plants were commissioned between 1972 and 1985. The Riksdag (Swedish parliament) has decided to begin a phase-out of nuclear power. One of the two reactors in Barsebäck was shut down in 1999. The other reactor was shut down on 31 May 2005.

Dates for closure of the remaining reactors have not been fixed. The plans for disposal of the radioactive waste are based on a scenario with 50 years of operation of the reactors in Forsmark and Ringhals and 60 years of operation for the reaktors in Oskarshamn.

SKB's mission

The radioactive waste in Sweden comes mainly from nuclear power. Under Swedish law the reactor owners bear full technical and financial responsibility for the waste from nuclear power. Together, they have formed Svensk Kärnbränslehantering AB, SKB (the Swedish Nuclear Fuel and Waste Management Co), which has been given the task of managing the country's spent nuclear fuel so that both the environment and human health are protected, in both the short and long term.

The Nuclear Activities Act requires that SKB prepare a programme for the comprehensive research and development and whatever other measures are needed to manage and dispose of the waste in a safe manner. In keeping with the requirements of the law, SKB submits reports to the regulatory authorities and the Government on the progress of this work. This is done every three years in RD&D programmes (Research, Development and Demonstration). So far SKB has presented ten RD&D programmes, including two supplements requested by the Government. The most recent report was submitted in September 2007.

Existing waste system

The radioactive waste from nuclear power can be divided into different categories based on life and activity level. With reference to requirements on management and final disposal, the Swedish waste is divided into three main categories. The first is *short-lived low- and intermediate-level waste (LILW)*. This category includes spent components, filters etc. from operation, maintenance and decommissioning of the nuclear power plants. The second category consists of *high-level waste (HLW)* in the form of spent nuclear fuel. It comprises a smaller fraction of the volume, but contains most of both the short- and long-lived radionuclides. The third main category, *long-lived LILW*, consists of e.g. spent components from the reactor core.

The short-lived LILW is disposed of in SFR in Forsmark (Final repository for radioactive operational waste). The spent nuclear fuel is interim-stored in Clab in Oskarshamn (Central interim storage facility for spent nuclear fuel). Furthermore, there is a system for transportation of the various waste types from the nuclear power plants to the waste facilities, see Figure 1.

What remains to be done in order to dispose of the waste from the nuclear power plants is:

- to build an encapsulation plant and a final repository for spent nuclear fuel
- to build a final repository for long-lived LILW

Long-lived LILW is generated mainly when the nuclear power plants are decommissioned. It is planned to be disposed of at a depth of several hundred metres in the bedrock. Siting and construction will not begin for another 30 years. SKB's current efforts are focused on final disposal of the spent nuclear fuel.

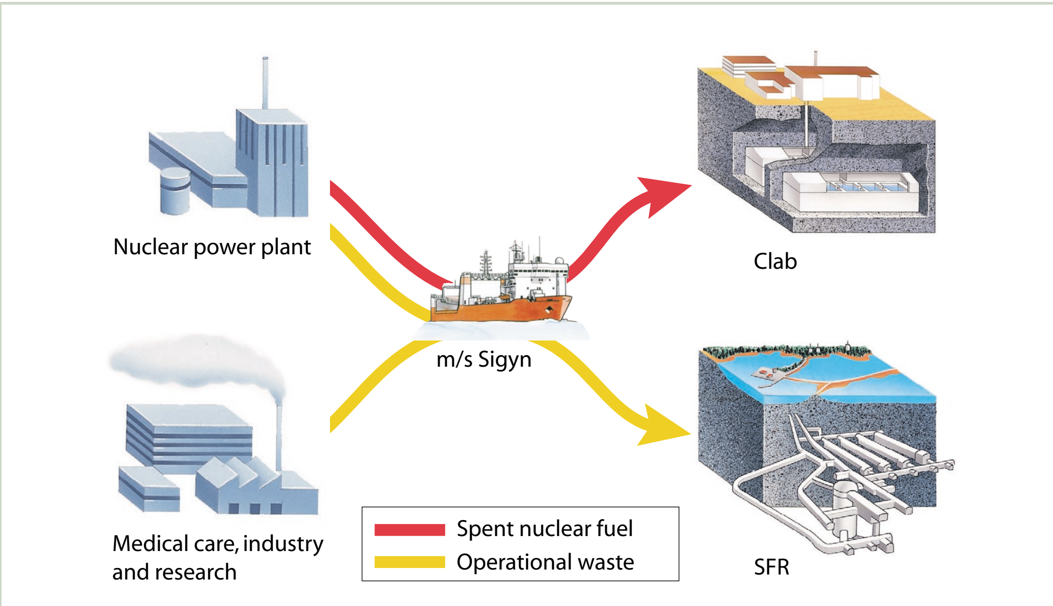


***Figure 1**. Existing facilities for management and disposal of radioactive waste.*

Final disposal of spent nuclear fuel

Choice of strategy and method

The general requirements governing disposal of spent nuclear fuel are found in international agreements and Swedish legislation. Reviews of different strategies and methods for disposal of spent nuclear fuel have been presented on a number of occasions, including in connection with the supplement to RD&D-Programme 1998, (Integrated account of method, site selection and programme prior to the site investigation phase. SKB report TR-01-03. Svensk Kärnbränslehantering AB, 2000.)

Internationally, a broad consensus exists that geological disposal is the strategy that is best suited to disposal of long-lived radioactive waste. The method which SKB proposes for final disposal is called KBS-3, where KBS stands for KärnBränsleSäkerhet (Nuclear Fuel Safety), see Figure 2.

The method entails that:

- the spent nuclear fuel is encapsulated in copper canisters with cast iron inserts
- the canisters are emplaced at a depth of approximately 500 metres in the bedrock
- the canisters are surrounded by a buffer of bentonite clay

The KBS-3 method requires construction of two new nuclear installations: an encapsulation plant and a final repository. Both facilities require permits under both the Nuclear Activities Act and the Environmental Code.

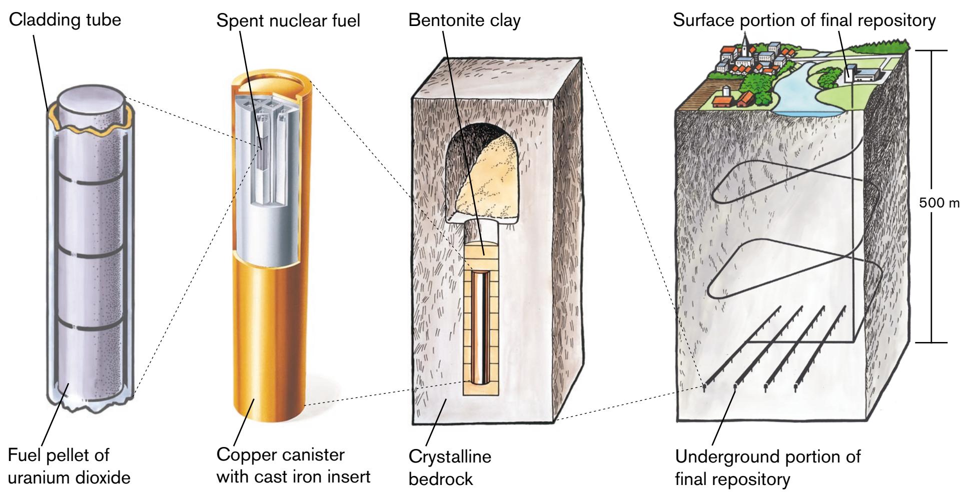


Figure 2. *The KBS-3 method is based on multiple barriers (canister, buffer and rock) that prevent the radionuclides in the fuel from harming man and the environment.*

Long-term safety

Safety aspects are of vital importance in connection with the management of spent nuclear fuel. Safety must be ensured both during repository operation and long after repository closure. The Swedish crystalline bedrock is between one and two billion years old and comprises a stable environment, where changes take place very slowly.

The spent nuclear fuel is hazardous (radiotoxic) for a very long time, and imposes special demands on management and disposal. The goal is to minimize the risks by isolating the fuel from man and the environment as long as it is hazardous. The short-lived substances (nuclides) with high radioactivity decay within the course of a few decades. Subsequently, cesium-137 and strontium-90 dominate the radiotoxicity of the fuel. After a thousand years, radiotoxicity is dominated by a few nuclides, the actinides and their decay products. After around 100,000 years, the radiotoxicity of the spent fuel has declined to the same level as the quantity of uranium ore from which the fuel was fabricated. The radiotoxicity of such uranium minerals, as well as eventually that of the spent fuel, is dominated by radiation from decay products of the uranium (radium, radon, polonium, etc).

Radiological *long-term safety* after closure of the final repository are dealt with in a special safety report, in which various scenarios are presented describing the evolution of the repository one million years into the future.

The safety report is regulated and reviewed by the regulatory authorities: the Swedish Radiation Protection Authority (SSI) and the Swedish Nuclear Power Inspectorate (SKI).

The most recent safety assessment, SR-Can, was submitted in November 2006. SR-Can is a preparatory step for the SR-Site safety assessment, which is planned to be published in 2009.

Important aspects to be described are:

- methodology of the assessment
- the repository system at closure – fuel, canister, buffer, rock and biosphere
- processes that alter the repository over time
- external impact in the event of a release of radionuclides due to canister damage

Radiological *safety during operation* of the encapsulation plant and the final repository is described and examined in preliminary safety reports. Before the facilities are taken into operation, the safety reports are supplemented by analyses and experience from the design phase, construction and commissioning.

The siting work

A step-by-step siting process for *the final repository* according to the KBS-3 method began in 1992, see Figure 3. By means of general siting studies, SKB explored the general siting prospects in different parts of the country. The feasibility studies comprised evaluation of the siting prospects in a total of eight municipalities: Storuman, Malå, Östhammar, Nyköping, Oskarshamn, Tierp, Älvkarleby and Hultsfred. In 2000, SKB proposed sites and program for geological investigations. In 2002, site investigations began in the Forsmark area in Östhammar Municipality and the Simpevarp area in Oskarshamn Municipality, see Figure 4, after supportive decisions by the Government and the municipalities. The site investigations have recently been finished. Data from the investigations are at present compiled and analysed.

Forsmarks Kraftgrupp AB, FKA, has three light-water nuclear power reactors in the Forsmark area. SFR (Final repository for radioactive operational waste), which was commissioned in 1987 and is owned by SKB, is also located in Forsmark.

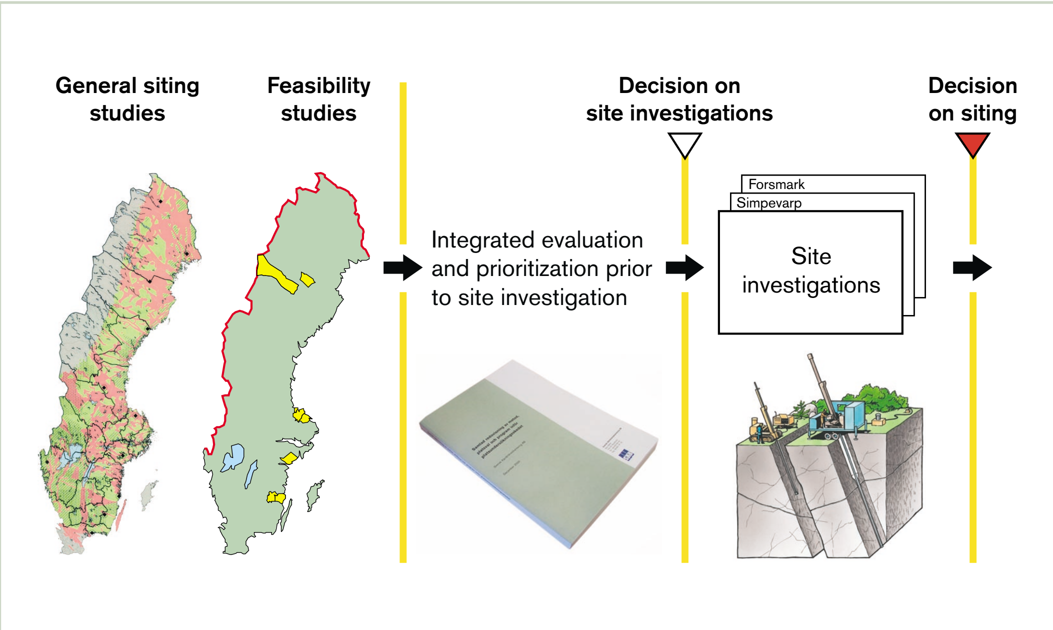


Figure 3. The siting work for a final repository for spent nuclear fuel is being conducted through general siting studies, feasibility studies and site investigations.

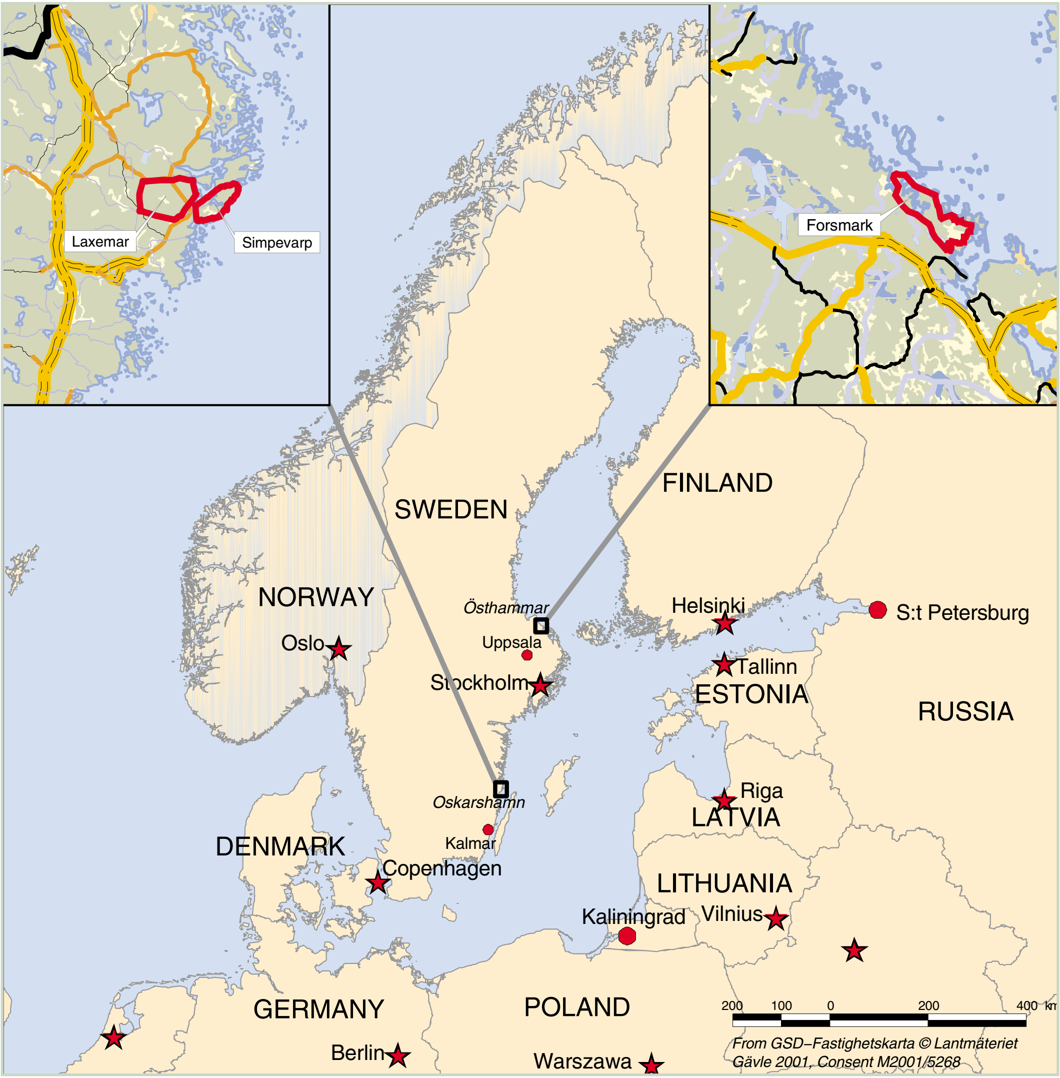
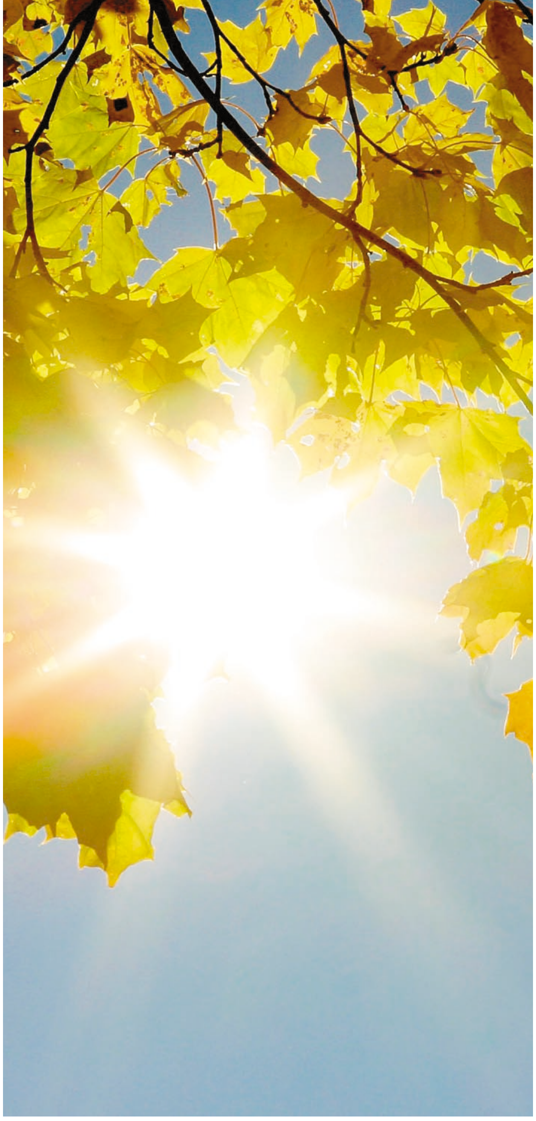


Figure 4. *Two sites – Forsmark in Östhammar Municipality and Simpevarp/Laxemar in Oskarshamn Municipality – are being investigated for siting of the final repository.*

The site investigations in Oskarshamn were initially focused on two candidate areas: Simpevarp and Laxemar. The investigations were later focused on the south-west part of Laxemar. Oskarshamns Kraftgrupp AB, OKG, which has three light-water nuclear power reactors, is located on the Simpevarp Peninsula. Clab (Central interim storage facility for spent nuclear fuel), which is owned by SKB, is also situated on the Simpevarp Peninsula. Clab, which was commissioned in 1985, receives spent nuclear fuel from all of Sweden's nuclear power plants. The descent tunnel to the Äspö HRL (Hard Rock Laboratory) is also located on the Simpevarp Peninsula. The Äspö HRL is SKB's research facility for a final repository and is situated at a depth of 460 metres in the bedrock.

SKB has also studied and compared different alternatives for siting of the *encapsulation plant*. Our proposal is to build it adjacent to Clab in Oskarshamn Municipality. The alternative for siting of the encapsulation plant is adjacent to the nuclear installations in Forsmark. This alternative will only be considered if the final repository is also sited at Forsmark.



Timetable

Consultations

Early consultations in accordance with the Environmenatal Code on the final repository and the encapsulation plant were carried out during the period 2002 – 2003. The extended consultations began in 2003. Joint meetings for the encapsulation plant and the final repository are being held in both Oskarshamn and Forsmark. The extended consultations will continue until a few months before the applications are submitted in 2009.

The application process

The current timetable for the application process is in short as follows:

2006 SKB applied for a permit under the Nuclear Activities Act for the encapsulation plant. An EIS (environmental impact statement) was appended to the application. At the same time, a safety assessment focusing on the performance of the canister in the final repository (SR-Can) was submitted to SKI, along with a system analysis focusing on the encapsulation plant's role in the KBS-3 system and an account of the planned canister shipments.

2009 SKB applies for a permit under the Nuclear Activities Act for the final repository and for permits under the Environmental Code for the interim storage facility, the encapsulation plant and the final repository, i.e. the entire KBS-3 system.

This proposal gives the Government an opportunity to make simultaneous decisions on permits under the Nuclear Activities Act and the Environmental Code for all parts of the KBS-3 system.

Construction and operation of the facilities

The scenario on which SKB's planning is based is that the ten reactors that are still in operation, i.e. all except Barsebäck 1 and 2, are shut down after 50–60 years of operation. This gives a total quantity of spent fuel of about 12,000 tonnes of uranium, which is equivalent to about 6,000 canisters of the type that will be used according to the current reference design. The programme permits both larger and smaller fuel quantities to be managed, the main consequences being modifications on the total operating time and the space require of the final repository.

The plan is that construction of the encapsulation plant and the final repository will start in 2012 and trial operation in 2020. The whole final repository programme is expected to be completed in 2070. By that time the final repository will have been backfilled and sealed, the above-ground facilities dismantled and the land restored. SKB's general planning is illustrated by Figure 5.

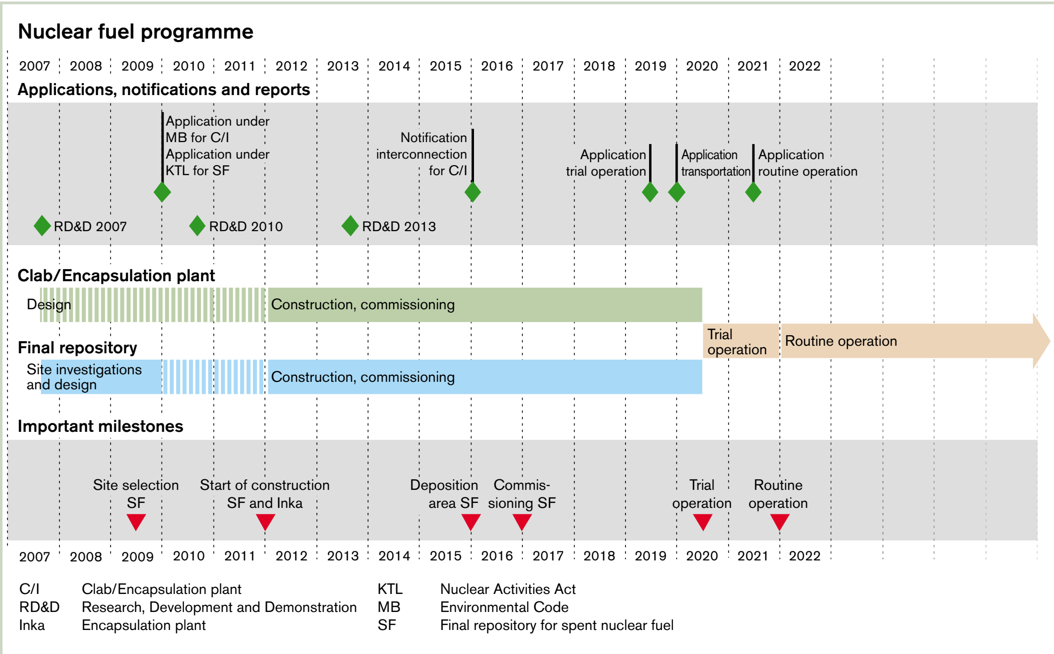
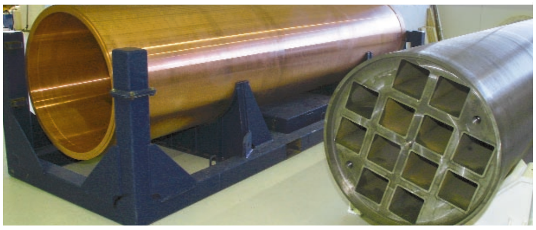


Figure 5. Main features of SKB's long-term plan.



Encapsulation plant

Siting

The encapsulation plant can be sited either at Clab (Central interim storage facility for spent nuclear fuel) in Oskarshamn, at the final repository, at another existing nuclear installation, or at a brand new site. SKB suggests that the encapsulation plant should be built adjacent to Clab, regardless of where the final repository is built. However, it is also possible to build a free-standing encapsulation plant, and a siting at Forsmark is being investigated as an alternative. There is plenty of space to build the encapsulation plant next to the nuclear power plant at Forsmark

Facility and activities

In Oskarshamn, the encapsulation plant can be built directly adjacent to Clab. The encapsulation plant will be about 70 x 100 metres and consist of three storeys below and seven above ground level, see Figure 6. The facility will be designed to allow integration with the systems and organization at Clab.

Prior to encapsulation the fuel is transported from the storage pools in Clab via a fuel elevator to a pool in the encapsulation plant, where the radiation is measured and the fuel is sorted. The fuel is then lifted up out of the water and into a radiation-shielded handling cell, where it is vacuum-dried. After drying it is placed in the canister. When a canister has been filled with fuel assemblies, the canister insert's lid is fitted. The copper lid is then placed on the canister and the canister is sealed by welding. The reference welding method for the encapsulation plant is Friction Stir Welding (FSW).

The encapsulated fuel is placed in a transport cask for shipment to the final repository. If the final repository is located at Oskarshamn, the transport cask will be shipped the short distance from the encapsulation plant to the repository by road.

Figure 6. Possible layout of the encapsulation plant located adjacent to Clab.

If the encapsulation plant is located in Forsmark, all spent nuclear fuel will be sorted, measured and dried at Clab prior to shipment. The fuel will be transported to the final repository by the specially designed ship m/s Sigyn (or an equivalent other/new ship), which transports the fuel from the nuclear power plants to Clab today. The shipments will go from the harbour at Simpevarp to the Forsmark nuclear power plant's harbour. Encapsulation of the fuel will then take place in roughly the same way as described above.

The canister

The canister that will contain the spent nuclear fuel is nearly five metres long and has a diameter of over one metre, see Figure 7. It weighs between 25 and 27 tonnes when filled with fuel. The outer shell is five centimetres thick and made of copper, which protects against corrosion. Inside the copper shell, an insert of cast iron provides the necessary strength.

***Figure** 7. Copper canister with spent nuclear fuel.*

Final repository

Siting

SKB has recently finished site investigations in Forsmark and Oskarshamn in order to determine the prospects for siting of the final repository. Alpresent, data from the investigations are compiled and analysed. SKB's objective is that one of the sites will constitute the main alternative for siting of the final repository in the permit application.

There is ample space to accommodate the final repository's above-ground buildings in both Forsmark and Oskarshamn. If the final repository is located at Forsmark, the main alternative is siting it close to the power plant; there is also suitable space there for a possible rock heap.

The site investigations in the Oskarshamn area were focusing on two subareas: the Simpevarp Peninsula with environs and the Laxemar area. The investigations were later focused on the south-west part of Laxemar. There are suitable land areas for the buildings and for the rock heap in this part of Laxemar.

Facility and activities

Design of the facility

The final repository's underground part must be located in an area with suitable geological properties considering the repository's long-term safety. The above-ground parts of the facility should be located as close to the underground part as possible to ensure good coordination between the above-ground operations area and the central area under ground, see Figures 8 and 9.

The connections between the ground surface and the repository consist of a ramp for canister transport and shafts for rock spoil and bentonite and for elevator and ventilation.

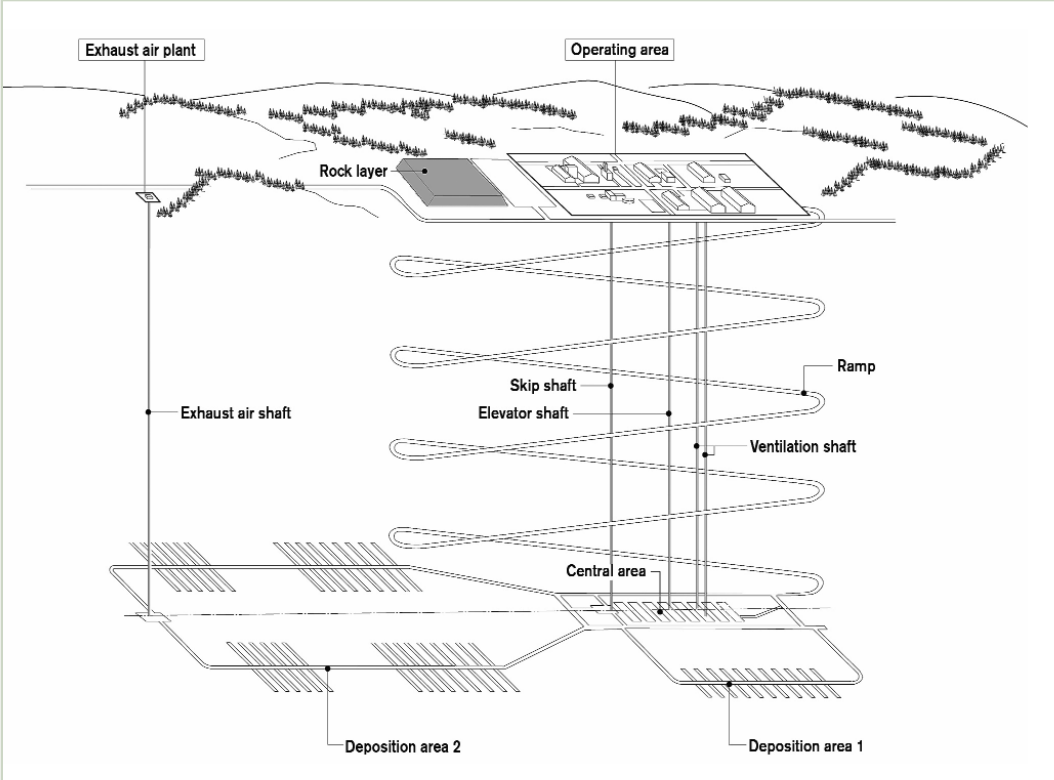


***Figure 8**. Schematic design of the final repository.*

Buildings, roads, the tunnel portal and the rock heap will occupy 0.2–0.4 km^2. The deposition area extends over an area of 2–4 km^2, at a depth of approximately 500 metres below the surface.

Construction and operation

The construction phase amounts to about 7 years and is divided into two sub-phases consisting of different building activities. During the construction phase, the shafts and ramp will be driven down to repository level, about 500 metres, and the excavation of the repository area will begin. The work in the form of blasting, rock haulage and construction activities will be most intensive during the latter half of the period.

The operating phase extends over approximately 45 years and consists of sequences of construction of deposition tunnels, deposition of canisters and backfilling of tunnels. During the operating phase, the speed of the excavation work will be determined by the desired rate of deposition, which means that the intensity will be much lower than during the construction phase.

The operating phase is also divided into two phases, trial operation and routine operation. When the encapsulation plant and the first part of the final repository are finished, *trial operation* will take place during a period of a few years.

Trial operation will be evaluated before a decision is made to proceed with *routine operation*, when up to 200 canisters per year will be deposited. A total of about 6,000 canisters will be deposited during trial and routine operation

After deposition is concluded, the buildings on the surface can be dismantled and the land restored or prepared for other activities. There are no restrictions on the use of the restored site, except for the fact that deep drilling is prohibited.

Figure 9. *In this sketch, the final repository's surface facilities are placed in the industrial area, where the Forsmark plant's residential area is located today.*

Handling of rock spoil

In the construction of the tunnels needed for the final repository, a total of about 3 million m^3 of rock (loose measure) will be excavated and hauled to the ground surface.

Approximately one-third of the total volume of rock spoil will be taken out during the construction phase. This spoil is not needed for backfilling of the final repository, but can be used as a resource for other construction activities, for example roadbuilding or other civil engineering projects. The spoil can be placed in a temporary heap pending removal from the area by truck.

The second one-third of the total volume of the rock spoil is taken to the production building to be crushed and mixed with bentonite. It is then transported down into the underground facility to be used as backfill in the deposition tunnels.

The remaining one-third of the rock spoil is used for backfilling of tunnels and shafts in the final repository. The rock spoil is stored temporarily in a rock heap.

Another possibility is to use Friedland clay, instead of rock spoil and bentonite, for the backfilling. In this case, a larger amount of rock spoil can be used as a resource for other construction activities.

Transportation

During regular operation, one canister can be deposited per day. How the canisters are transported from the encapsulation plant depends on where the final repository is located.

Furthermore, the traffic will include shipments of bentonite, rock spoil, backfill materials and building materials, as well as personell transport.

The transport activity will be most noticeable during the latter half of the construction phase, a period of approximately 3.5 years, when 1 million m^3 of rock spoil will be shipped out. The increase in traffic during the operation of the facility will be marginal in relation to the situation today.

Environmental impact

Environmental impact assessment

The applications for permits under the Nuclear Activities Act and the Environmental Code will be accompanied by an environmental impact statement (EIS). This document will describe the environmental impact of the encapsulation plant and the final repository with associated activities. The EIS covers the entire period of time from the start of construction of the facilities up to and including backfilling and closure of the underground tunnels and cleanup and restoration of the surface site.

The establishment of the encapsulation plant and the final repository for spent nuclear fuel will affect the people who live and work in the area. In addition to environmental impact, effects on human health and the community will therefore also be studied.

Impacts and consequences

The *radiological impact* of the encapsulation plant in the form of releases to water and air will be very small, on the order of a few ten-thousandths of what is permitted from a nuclear installation. No releases with radiological impact are expected to take place in connection with the shipments of encapsulated fuel to the final repository or the deposition of canisters in the final repository.

The main environmental impact is expected to be of a non-radiological character and is caused by handling and transport of the rock spoil, giving rise to local pollution of air and water.

During construction of the facilities, increased traffic to and within the area gives rise to *atmospheric emissions*. Furthermore, the blasting work and rock crushing at the final repository give rise to particulate emissions. Both the increased traffic and the blasting contribute locally to emissions of nitrogen oxides and carbon monoxide.

Drainage water from the rock works during construction of the encapsulation plant and the final repository will contain particles, oil and contaminants. The water will be cleaned before being discharged to the Baltic Sea. The *leachate* from rock heaps will be tested and cleaned if necessary.

Construction of tunnels, shafts and the underground part of the final repository causes a local lowering (drawdown) of the *groundwater level*. After repository closure, the natural groundwater level will be restored, but this may take several decades.

Noise and vibration are caused mainly by rock works, transport and the ventilation fans. Elevated sound levels will be noticed a few kilometres from the facilities and along the roads.

Safety and radiation protection

The safety work for SKB's nuclear facilities is based on legislation and regulatory requirements. SKB performs several different types of assessments and reports regarding safety and radiation protection for the encapsulation plant, Clab, the final repository and the transportation system.

A facility's safety analysis report describes how safety and radiation protection in a nuclear facility are arranged to protect human health and the environment.

Since transportation of spent nuclear fuel is classified as a nuclear activity, special permits are required from SKI and SSI according to the Nuclear Activities Act.

Development of the KBS-3 method for final disposal of spent nuclear fuel has been going on since the late 1970s. Over the course of the years SKB has carried out several analyses of the long-term safety of the final repository.

Transboundary environmental impact

The main environmental impacts due to the Encapsulation plant and the Final repository for spent nuclear fuel will be non-radiological consequences related to increase in traffic, transportations (noise, light, vibrations) due to handling of rock spoil and impact on groundwater level. Noise is judged to be the aspect that can have an impact furthest away. Elevated sound levels will be noticed a few kilometres from the facilities and along the roads.

The only possible activities or measures that might have an impact in other countries are related to release of radionuclides from the final repository. SR-Can is a safety analysis focusing on a first evaluation of the long-term safety for KBS-3 repositories at Forsmark and Laxemar.

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