Technical Report

TR-11-05

# Plan 2010

## Costs starting in 2012 for the radioactive residual products from nuclear power

### Basis for fees and guarantees during the period 2012–2014

Svensk Kärnbränslehantering AB

December 2010

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ISSN 1404-0344
SKB TR-11-05

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# Preface

According to the current regulatory framework, it is the responsibility of the holder of a licence to own or operate a nuclear power reactor to prepare a calculation of the costs for all measures that are needed for the management and disposal of spent nuclear fuel that has been used in the reactors and other radioactive waste products and to decommission and dismantle the reactor plants. The regulatory framework comprises the Act (2006:647) and the Ordinance (2008:715) on Financial Measures for the Management of Residual Products from Nuclear Activities (hereinafter referred to as the Financing Act and the Financing Ordinance, respectively). This cost calculation shall be submitted periodically to the Government or the authority designated by the Government. SKB's owners have assigned SKB the task of preparing such a cost calculation jointly for the licensees of the Swedish nuclear power plants.

The present report, which is the twenty-eighth annual plan report, gives an updated compilation of these costs. As in previous years' reports, the costs are shown for two cases. The first case concerns the system as a whole, including management and disposal of radioactive operational waste plus certain waste deriving from other facilities than those belonging to SKB's owners. This case has been based on a scenario concerning reactor operation that is based on the nuclear power plant owners' current planning. The second case concerns the system with the restrictions that follow from the regulatory framework, which stipulates the time for operation of the reactors that is supposed to serve as a basis for fees.

The report is divided into three parts:

**Chapter 1** provides background information regarding the Financing Act and SKB's calculation model.

**Chapter 2** provides information on the underlying calculation, which is based on current plans for reactor operation and SKB's activities.

**Chapter 3** presents the cost estimates required by the Financing Act that are the primary purpose of the report.

Stockholm, December 2010

Svensk Kärnbränslehantering AB

Claes Thegerström

# Summary

A company that has a licence to own a nuclear power plant is responsible for adopting whatever measures are needed for safe management and disposal of spent nuclear fuel and radioactive waste deriving from it and for decommissioning and dismantling of the reactor plants after they have been taken out of service. The most important measures are to plan, build and operate the facilities and systems that are needed for this, and to conduct related research and development. The financing of these measures is based on payment by the licensees of nuclear waste fees to a state-administered fund, primarily during the period the reactors are in operation, but also later if need be. In addition to these fees, the licensees must pledge certain guarantees to the state.

The system of nuclear waste fees and guarantees is regulated in the Financing Act (2006:647) with associated Ordinance (2008:715). This regulatory framework distinguishes between licensees for one or more reactors of which at least one is in operation and licensees all of whose reactors have been permanently taken out of operation after 31 December 1995. A licensee in the former category is called a reactor owner and pays waste fees based on electricity produced (öre/kWh). Today there are three reactor owners in this category: Forsmark Kraftgrupp AB, OKG Aktiebolag and Ringhals AB. A licensee in the latter category, today Barsebäck Kraft AB, can be charged waste fees in the form of a certain annual amount.

SKB has been tasked by the nuclear power companies jointly to calculate and compile the future costs for the measures for which they are responsible. According to the regulatory framework, such a cost accounting shall be submitted to the regulatory authorities at given intervals. From now on this is to be done every three years, but has been done every other year during a transition period. Plan 2010, which succeeds Plan 2008, will thus be followed by Plan 2013.

The future costs are based on SKB's current planning regarding the design of the system and the timetable for its execution. The current design is called the reference design, while the overall execution plan is called the reference scenario. This report is based on the proposed plan of the activities that has been presented in SKB's RD&D Programme 2010. The quantity of spent nuclear fuel to be managed in this scenario is based on an operating time of 50 years for each of the Forsmark and Ringhals reactors and 60 years for the Oskarshamn reactors. Rounded off, this is equivalent to 6,000 copper canisters.

The cost calculation for the reference scenario and the figures on which it is based are presented in the present report. The regulatory framework does not require that such a cost accounting be submitted to the authority, but since it serves as a basis for the other calculations, SKB has found it of value to include it in the report. This is done in Chapter 2. The cost estimates required by the Financing Act are presented in Chapter 3. In addition, a separate set of tables is submitted to the authority with the detailed figures the authority needs for its review and its calculations. Among other things, the tables show how the costs are distributed among the four nuclear power companies.

The reference scenario includes the following facilities and systems in operation:

- Transportation system for radioactive waste products.
- Central interim storage facility for spent nuclear fuel, Clab.
- Final repository for short-lived radioactive waste, currently SFR.
- Laboratories for development of encapsulation and final disposal technology.

The reference scenario also includes the following additional facilities or facility parts:

- Canister factory and encapsulation plant for spent nuclear fuel.
- Final repository for spent nuclear fuel, the Spent Fuel Repository.
- Extension of SFR to hold short-lived waste from decommissioning of the NPPs and a small amount of operational waste and to make space available for interim storage of long-lived radioactive waste.
- Final repository for long-lived radioactive waste, SFL.

The costs according to the reference scenario also include costs for research, development and demonstration (RD&D), as well as SKB's central functions. The latter include general functions such as corporate management, business support, communications, environment, overall safety matters, etc. Other costs include costs for decommissioning of the reactor plants as well as at-plant facilities for interim storage or final disposal of radioactive waste.

The Financing Act, along with the Ordinance, stipulates a number of conditions that have an effect on the scenario that determines the scope of the calculation model used by SKB to arrive at the basis for fees etc. This applies above all to the operating time of the reactors, which is supposed to serve as a basis for determining the quantity of spent nuclear fuel and radioactive waste, as well as the requirement that uncertainties regarding future developments in different areas must be estimated. The latter requirement suggests that a probability-based uncertainty analysis of the type SKB applies is necessary. The regulatory framework also stipulates that the calculation should only include residual products which, according to the definition in the Financing Act, excludes the management of operational waste. The costs of SFR in its current function as a final repository for operational waste are then excluded.

The quantity of spent nuclear fuel and radioactive waste to be disposed of is linked to the operating time of the reactors. The fee-determining operating time stipulated in the regulatory framework is 40 years. A minimum limit is stipulated entailing that a remaining operating time of at least six years shall be applied unless there is reason to assume that operation may cease before then. In the present calculation, this rule entails operation at least up to and including 2017. The fee calculation, which is done by the Radiation Safety Authority, is then based on a forecast regarding the remaining electricity production during the same time.

Aside from the payment of fees, a reactor owner must pledge two kinds of guarantees. One guarantee covers stipulated fees that have not yet been paid. This guarantee declines gradually as the reactor's operating time approaches 34 years but subsequently levels out at the minimum time of six years which then ensues as described above. The basis for this guarantee is called the financing amount. The calculation is done in principle as for the fee basis, but the costs are limited to management and disposal of the residual products that exist when the calculation begins (in this report on 31 December 2011).

The second guarantee pertains to the case where it can be assumed that the assets in the Nuclear Waste Fund will not suffice due to unplanned events, at the same time as the option of increasing the fee payments and adjusting the aforementioned guarantee is for some reason not available. The basis for this guarantee is called the supplementary amount.

For a licensee whose reactors are permanently shut down, in our case Barsebäck Kraft AB, only the first type of guarantee is applicable when it comes to the cost basis to be submitted to the regulatory authority. The supplementary amount below thus applies only to Forsmark, Oskarshamn and Ringhals.

The results of the calculation are presented below. The amounts pertain to future costs from 2012 and relate to the January 2010 price level.

| | |
|---|---|
| Remaining basic cost | SEK 89.8 billion |
| Basis for financing amount | SEK 83.6 billion |
| Supplementary amount<br>– at 80% confidence level | SEK 13.1 billion |

# Contents

# Definitions

| | |
|---|---|
| BFA | Rock cavern for waste. |
| BWR | Boiling water reactor. |
| Clab | Central interim storage facility for spent nuclear fuel. |
| Clink | Clab and the encapsulation plant as an integrated facility. |
| RD&D | Research, Development and Demonstration. |
| NPP | Nuclear power plant. |
| Spent Fuel Repository | Final repository for spent nuclear fuel. |
| PWR | Pressurized water reactor. |
| SFL | Final repository for long-lived radioactive waste. |
| SFR | Final repository for short-lived radioactive operational and decommissioning waste. |
| SSM | Swedish Radiation Safety Authority. |
| TWh | Terawatt-hour. Unit of energy equal to a billion kWh. |
| MWh | Megawatt-hour. Unit of energy equal to a thousand kWh. |
| MWd | Megawatt-day. Unit of energy equal to 24,000 kWh. |
| Tonnes of uranium or tU | Quantity of spent nuclear fuel defined as the weight of uranium contained in the fuel assemblies when they are placed in the reactor (prior to irradiation). |
| Capacity factor | The ratio, expressed as a percentage, of the energy generated during the year to the energy that could theoretically have been generated if the nuclear power unit had been operated at full capacity during every hour of the year (normally between 75% and 90%). |
| Burnup | A value which here gives the quantity of energy obtained from the fuel, normally expressed in MWd per kg of uranium (MWd/kgU). |
| Residual products | "Nuclear material that will not be reused and nuclear waste that does not constitute operational waste" according to the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities. Nuclear material is in this case spent nuclear fuel. Operational waste is radioactive waste that is managed and disposed of during operation or immediately after when the reactor is permanently shut down. |

# 1 The Financing Act and SKB's calculation model

## 1.1 The Financing Act

A company that has a licence to own a nuclear power plant is responsible for adopting whatever measures are needed for safe management and disposal of spent nuclear fuel and radioactive waste deriving from it and for decommissioning and dismantling of the reactor plants after they have been taken out of service. The most important measures are to plan, build and operate the facilities and systems that are needed for this, and to conduct related research and development. The financing of these measures is based on payment by the licensees of nuclear waste fees to a state-administered fund, primarily during the period the reactors are in operation, but also later if need be. In addition to these fees, the licensees must pledge certain guarantees to the state.

The fees are paid to the Nuclear Waste Fund, which deposits the assets in an interest-bearing account at the National Debt Office, in treasury bills or in debt instruments issued in accordance with the Covered Bonds Issuance Act (2003:1223). Paid-in fees shall be used to reimburse the costs the fees are intended to cover. In practice, this means that the licensee is entitled to obtain compensation from the fund for his costs to meet his obligations as described in the above paragraph.

The system of nuclear waste fees and guarantees is regulated in the Financing Act (2006:647) with associated Ordinance (2008:715).[1] The content of both of these statutes is hereinafter called the *regulatory framework.*

The regulatory framework distinguishes between licensees for one or more reactors of which at least one is in operation and licensees all of whose reactors have been permanently taken out of operation after 31 December 1995. A licensee in the former category is called a reactor owner and pays fees based on electricity produced (öre/kWh). Today there are three reactor owners in this category: Forsmark Kraftgrupp AB, OKG Aktiebolag and Ringhals AB. A licensee in the latter category, today Barsebäck Kraft AB, can be charged waste fees in the form of a certain annual amount. In this document the term "licensee" is used as a collective designation for the four aforementioned nuclear power companies[2].

The regulatory framework further distinguishes between residual products on the one hand and radioactive operational waste on the other. Residual products are defined as *"nuclear material that will not be reused and nuclear waste that does not constitute operational waste"*. The nuclear waste fee shall cover costs for management and final disposal of residual products, but not costs for management and final disposal of operational waste. Those costs are borne directly by the licensee.

Besides licences to operate the reactor plants, the reactor owners have separate licences, or plan to have them in the future, for smaller facilities that are situated on the power plant site. Such facilities are interim storage facilities for waste packages or repositories for very low-level operational waste. These facilities are only used by the power plant licensee. The costs for construction and operation of these smaller facilities are regarded as costs for the day-to-day operation of the nuclear power plant and are therefore not included in the calculations pursuant to the regulatory framework surrounding the Financing Act. However, the costs for future decommissioning of these facilities are included in the calculations, since these costs are temporally and materially associated with the decommissioning of the NPPs.

A licensee shall, in consultation with the other licensees, calculate the costs for management and disposal of the spent nuclear fuel and the radioactive waste, as well as for decommissioning of the reactor plants. The licensees have commissioned SKB to carry out and compile these calculations.

[1] Act (2006:647) on Financial Measures for the Management of Waste Products from Nuclear Activities and Ordinance (2008:715, most recently amended 2009:324) on Financial Measures for the Management of Waste Products from Nuclear Activities.

[2] If the term "licensee" is used about anyone else, this is stipulated.

The Government has decided that the calculations shall be submitted to the Swedish Radiation Safety Authority, which prepares proposals for fees and guarantees based on these figures. Decisions on the size of fees and guarantees are made by the Government. An exception is the guarantee pledged by Barsebäck Kraft AB. This guarantee is determined by the Swedish Radiation Safety Authority. Fees shall be charged and guarantees pledged as needed both during the time the reactors are in operation and after permanent shutdown up until the reactor plants have been dismantled and all residual products disposed of.

The quantity of spent nuclear fuel and radioactive waste to be disposed of is dependent on the operating time of the reactors. The regulatory framework stipulates that the cost calculations shall assume an operating time of 40 years for each reactor that is currently in operation. A minimum limit is stipulated entailing that a remaining operating time of at least six years shall be applied unless there is reason to assume that operation may cease before then. For Plan 2010, which is intended to serve as a basis for fees and guarantees from 2012, this means that all ten currently operating reactors are assumed to be in operation up to and including 2017. At that time, four of the reactors will have been operating more than 40 years[3].

Aside from the payment of fees, a licensee must pledge two kinds of guarantees. One type of guarantee covers fees that have not yet been paid in. The other type of guarantee relates to unplanned events. The guarantees become payable if the licensees fail to fulfil their obligation to pay fees and the assets in the fund are deemed to be insufficient.

For a licensee of reactors that are permanently shut down, i.e. Barsebäck Kraft AB, only the first type of guarantee is applicable.

According to the regulatory framework, the cost accounting shall be submitted to the regulatory authority at certain intervals. It was prescribed that the calculations should be submitted every year up to and including 2008 and then during a transition period every other year. Subsequently this shall be done every three years. Plan 2010, which begins where Plan 2008 left off, will thus be followed by Plan 2013.

## 1.2 Amounts to report under the Financing Act

As a basis for calculating fees and judging the need for guarantees, three amounts shall be reported to the authority:

- the remaining basic cost (basis for fees),
- basis for financing amount (basis for determining the amount of the guarantee that relates to fees stipulated but not yet paid),
- supplementary amount (basis for determining the amount of the guarantee that relates to unplanned events and that becomes payable if fee payments are not made and the guarantee according to the second bullet point is not sufficient).

Beyond that there are regulations concerning a more detailed accounting for the next few years including not just costs but also energy production. This information must be submitted to the regulatory authority in addition to the plan report.

The remaining basic cost shall include all future costs for managing and disposing of the residual products that are expected to arise during the fee-determining operating time of 40 years (or at least six remaining years of operation). For Plan 2010, this pertains to costs from 2012. The amount shall also cover costs for decommissioning the reactors and conducting the necessary research and development. The remaining basic cost includes an allowance for unforeseen factors and risk to a given level. These contingency amounts are obtained by means of a probability-based uncertainty analysis which SKB uses and which is described in Chapter 3. The total basis for fees is finally obtained by adding an additional amount relating to certain costs for regulatory supervision and other items, called extra costs. These amounts are added by the regulatory authority in connection with the calculation of fees and are not included in the present report.

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[3] Up to and including 2017, the operating time for O1 will be 45.9 years, for O2 43.0 years, for R1 42.0 years and for R2 42.7 years.

The basis for the financing amount shall include costs calculated in the same way as the remaining basic cost but with the limitation that the quantity of spent nuclear fuel and radioactive waste refers to the quantities projected to exist at the time the calculation begins. For Plan 2010, this reconciliation date is 31 December 2011. Based on these quantities, the total financing amount is then obtained in the same way as the fee basis, i.e. certain additions are made for unforeseen items and risk and for extra costs, the latter by the regulatory authority. The difference between the financing amount and the current content of the Nuclear Waste Fund, plus expected return, provides a basis for estimating the size of the guarantee to be pledged for fees determined but not yet paid. This estimate is made by the regulatory authority.

The supplementary amount constitutes the difference between costs included in the remaining basic cost and the upper limit for costs for which the reactor owner is currently required to pledge a guarantee. According to the regulatory framework, this upper limit shall be based on "*a reasonable estimate of costs …… that can arise due to unplanned events.*" (Regarding SKB's interpretation of the concept "reasonable", see Section 3.5.4.) In SKB's model, this upper limit is not just based on the uncertainties that serve as a basis for the fee, but also on a number of exceptional events with greater consequences than what is included in the basic cost. Otherwise, the same probability-based calculation method is employed. The supplementary amount constitutes the basis for determining the size of the guarantee for unplanned events.

## 1.3 SKB's calculation model

The cost calculations are carried out in four steps, schematically illustrated in Figure 1-1.

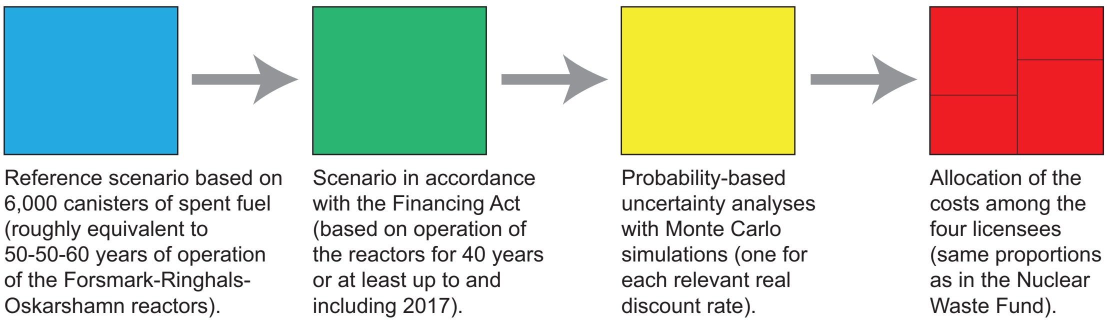



***Figure 1-1.*** *The four steps in SKB's calculation model.*

**Step 1** (blue box)

The future costs are based on SKB's current planning regarding the design and execution of the system. The current design is called the reference design while its execution – which includes timetables, waste quantities and other planning – is called the reference scenario. The reference scenario is based on the proposed plan of the activities that has been presented in SKB's RD&D Programme 2010. It is made clear there that the quantity of spent nuclear fuel and radioactive waste is to be based on an operating time of 50 years for each of the Forsmark and Ringhals reactors and 60 years for the Oskarshamn reactors. The quantity of nuclear fuel is rounded off to the equivalent of 6,000 copper canisters.

SKB's planning includes in several cases alternative proposals for solutions, for example in cases where development work or collection of factual data as a basis for decisions is under way. In the reference scenario, however, a specific solution must be formulated in order for a clear and concrete basis for the cost calculations to be obtained. This formulation should nevertheless not be regarded as a final commitment on the part of SKB. Examples of such reference data, specific for the plan calculation, are given in Section 2.2.

The reference design and the reference scenario, and the costs associated with them, are presented in Chapter 2.

**Step 2** (green box)

The Financing Act and the associated Ordinance stipulate a number of conditions whose effect is that the scope of the programme is limited somewhat in comparison with the reference scenario. This applies above all to the operating time for the reactors, which comprises the basis for the estimate of the quantity of spent nuclear fuel and radioactive waste. A minor limitation also follows from the fact that the cost calculation shall pertain to the management and disposal of residual products, which, according to the definition in the Financing Act, excludes operational waste. Among other things, the cost of today's SFR is not included in the calculations.

According to the regulatory provisions, the fee-determining operating time of the reactors shall be 40 years, but with a minimum of six remaining years of operation. In Plan 2010 the latter entails operation up to and including 2017.

The deviations from the reference scenario (step 1), as well as the costs for the system that are obtained in this manner and that are to be covered by the Financing Act, are described in Chapter 3 of this report.

**Step 3** (yellow box)

The regulatory framework prescribes that the cost accounting should pertain to both expected costs and additional costs to cover the possible effect of unplanned events. This means that some form of uncertainty analysis based on probability theory should be carried out. Since the mid-90s, SKB has used a method called "The successive principle" or simply "successive calculation". The method and the uncertainties that are taken into account in the analysis are presented in Chapter 3.

**Step 4** (red box)

Payments to the Nuclear Waste Fund are made under four main headings, one for each licensee.[4] The future costs must therefore be divided among them. The procedure for this, as well as the results of the division, are not described in this report but submitted to the regulatory authority in a separate set of tables.

### *Connection between different calculations – a summary*

A number of calculations of varying scope and with somewhat different assumptions are carried out during the course of the process. Some of them intend to provide the amounts stipulated in the Financing Plan, while others are carried out as a basis for SKB's development and planning work, or for the financial accounting in SKB's owner companies. The calculations that are of relevance for reporting under the Financing Act are shown by Figure 1-2.

The reference calculation (blue in Figure 1-2) is dealt with fully in Chapter 2. The calculation called *Calculation 40 (real)* (green) as well as the uncertainty analysis (yellow) are dealt with in Chapter 3. The other two are not treated further in this report, except that the outcome of *Calculation Dec. 2011 (real)* is presented. This is the basis for calculating the financing amount. The allowance for unforeseen factors and risk for these other calculations is taken from the uncertainty analysis performed in *Calculation 40 (real)* (proportioned). All calculations are corrected to account for an assumed real cost trend.

[4] A fifth main heading concerns fees under the Studsvik Act, but costs under this Act are not dealt with in this report.

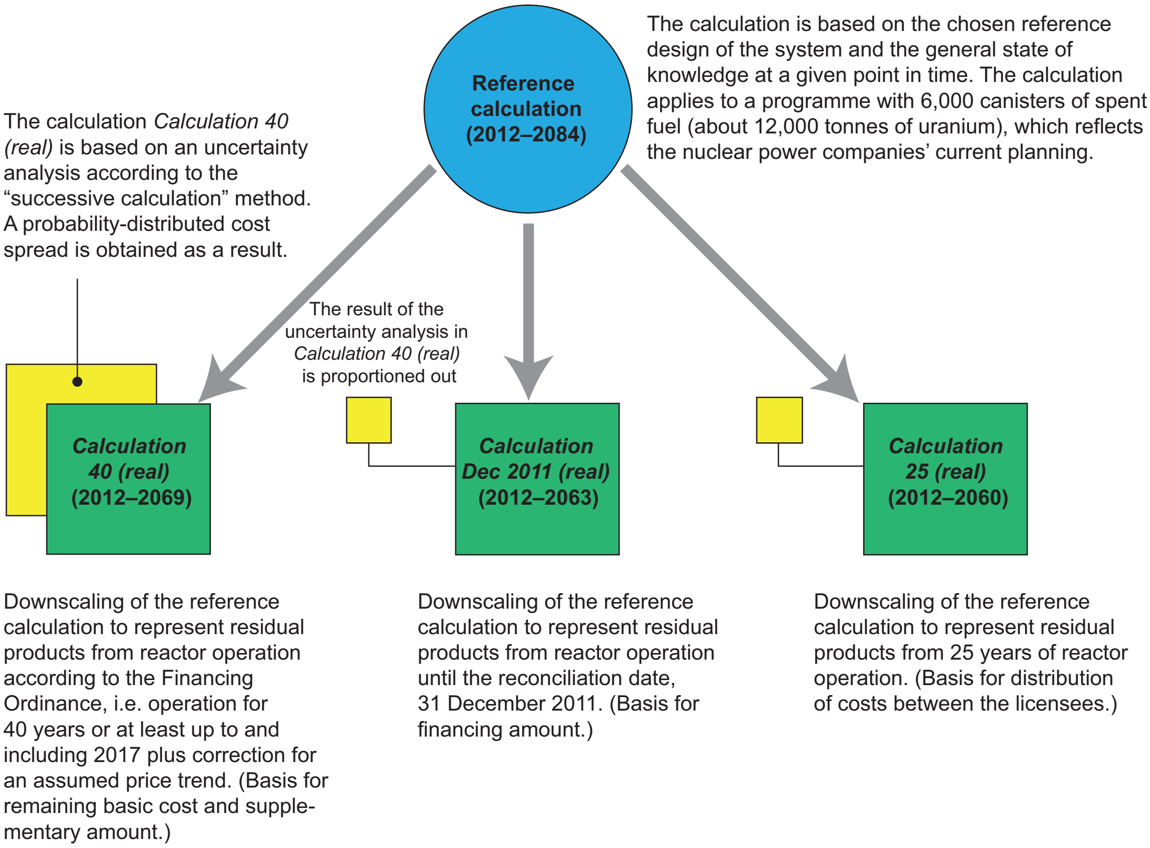



***Figure 1-2.*** *Relationship between the calculations that are set up.*

# 2 Costs according to the reference scenario

## 2.1 General system description

A cost calculation based on the current state of planning within SKB serves as a basis for the costs presented in the plan report. This primarily applies to the design of the system which today constitutes the main alternative in SKB's development work and is referred to as the reference design, but here also includes assumptions concerning future events where decisions have not yet been made. These assumptions are necessary in order for a complete cost calculation basis to be compiled. They are presented in greater detail in the next section.

The reference design, together with these assumptions, comprises what we call the reference scenario. This in turn serves as the basis for the calculation of the reference cost.

The facilities which SKB operates or is planning for in the future are intended for disposal of residual products and radioactive operational waste from the Swedish nuclear power plants. At the same time, SKB must, in return for compensation, also dispose of smaller quantities of radioactive waste from industrial plants, research facilities and other institutions in these facilities. The volumes required to handle these quantities, on the scale we know today, are included in the reference scenario. They are not, however, included in the costs under the Financing Act (Chapter 3), since they are financed from other sources than from the licensees' fund shares.

The term "residual products" is currently defined as follows in the Financing Act: "By residual products is meant in this Act nuclear material that will not be reused and nuclear waste that does not constitute operational waste". With this definition, the products to be disposed of can be classified as shown by Table 2-1.

A total picture of the Swedish system for disposal of the residual products of nuclear power and other radioactive waste is shown by Figure 2-1. The figure illustrates the flow of residual products and radioactive waste from the nuclear power plants or other institutions via interim storage facilities and treatment plants to different types of final repositories. With the exception of the interim storage facilities or near-surface repositories located at the plants where the waste is generated, all disposal facilities are planned, built, operated and decommissioned under SKB's auspices.

SKB is also responsible for transportation of the residual products and the waste between the facilities. In Sweden, all existing facilities are located on the coast, and the future facilities are planned to be sited there as well. The transportation system is therefore based on sea shipments by a specially-built ship (m/s Sigyn) as the central unit.

A rough breakdown of the different subsystems included in the system for disposal of the residual products of nuclear power and other radioactive waste is currently made by SKB into the two programmes being conducted: The Nuclear Fuel Programme and the LILW (low- and intermediate-level waste) Programme. To this can be added a number of auxiliary systems.

**The Nuclear Fuel Programme**

Interim storage, encapsulation and final disposal of spent nuclear fuel. This includes Clab, the encapsulation plant (with canister factory) and the Spent Fuel Repository. The encapsulation plant is planned to be integrated with Clab, and the integrated plant will then be called Clink.

**LILW Programme**

Interim storage, treatment and final disposal of low- and intermediate-level radioactive waste. This includes several facilities, some intended for short-lived waste and others for long-lived waste.[5]

[5] By "short-lived nuclear waste" is meant material with a significant content of radionuclides with a half-life of less than 31 years. Other waste is designated long-lived nuclear waste.

Facilities for short-lived operational and decommissioning waste include local interim storage facilities and SFR. The facilities for long-lived waste are interim storage facilities, located either at the NPPs or in SFR, and SFL, the final repository for long-lived radioactive waste.

**Auxiliary systems**

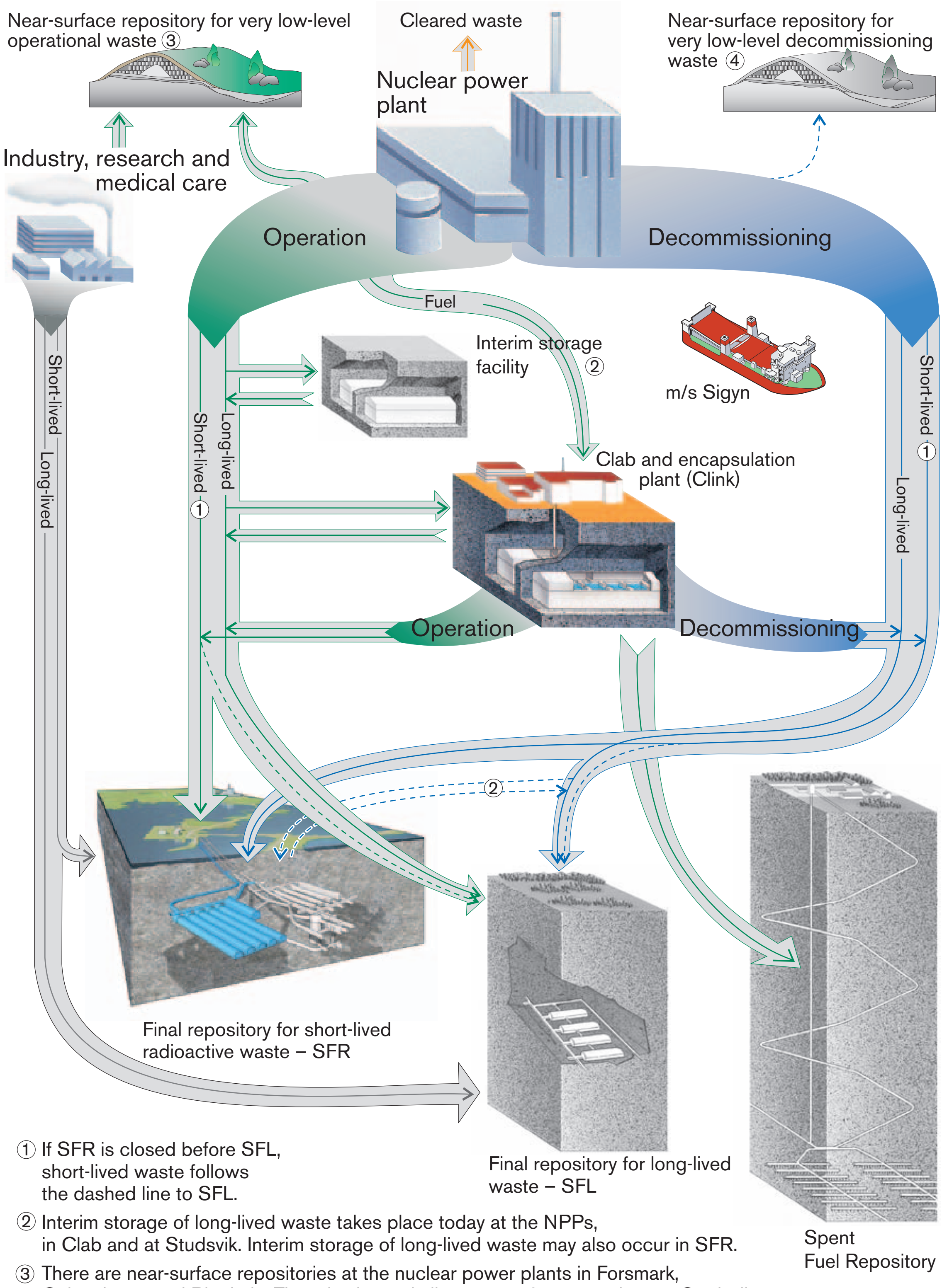
- The transportation system based on the specially designed ship m/s Sigyn with terminal vehicles for loading and unloading of the cargo plus transport casks and containers for different types of residual products and operational waste.
- Facilities for research, development and demonstration of technical solutions. This includes above all the Äspö HRL (Hard Rock Laboratory) next to the Oskarshamn Nuclear Power Plant, where a bentonite laboratory is also situated, and the canister laboratory in Oskarshamn.
- SKB's central functions with management and business support plus special units for communications and for environmental and safety matters.

Several of the facilities are in operation, which provides a good basis for the cost calculations. The future facilities are in different stages of development and design, and the cost calculations for these facilities have been based on the drawings, specifications, personnel plans and other documents that have been prepared as well as on experience from the manufacture and utilization of prototype equipment. The facilities are described in Section 2.3.

Besides the above costs for the subsystems, the total calculation also includes the costs of decommissioning of the nuclear power plants. Decommissioning does not comprise a part of SKB's obligation, but is a matter for the individual nuclear power company. SKB responsibilities are limited to the management and disposal of the radioactive waste from decommissioning (part of the LILW Programme), and at present also studies and estimates of the future costs of decommissioning. The special premises that apply to this decommissioning are presented in the next section.

**Table 2-1. Types of residual products and other radioactive waste for management and disposal.**

| Financing / Type of waste | **Financing directly by the licensees (operational waste) or by another stakeholder who purchases space in SKB's facilities.** The costs are included in the costs reported in Chapter 2 of this report. | **Financing within the framework of the Financing Act (only residual products according to the definition in the Financing Act).** Financing takes place via the Nuclear Waste Fund. The costs are dealt with in Chapter 3 of this report. |
|---|---|---|
| **Short-lived very low-level waste** | Operational waste, compressed or in containers of concrete or steel. Interim-stored where the waste is produced (local interim storage). Disposed of either in at-plant near-surface repositories or in SFR. | Operational and decommissioning waste from the interim storage facilities and treatment plants that fall under the Financing Act (Clab, encapsulation plant) and decommissioning waste from the reactor plants. Interim-stored locally. Disposed of in SFR. |
| **Short-lived low- and intermediate-level waste** | Operational waste from the NPPs or other stakeholders, in containers of concrete or steel. Interim-stored locally. Disposed of in SFR. | Same as above. |
| **Long-lived low- and intermediate-level waste** | Operational and decommissioning waste from other stakeholders. Interim-stored locally. Disposed of in SFL. | Operational and decommissioning waste from the reactor plants, including replaced reactor internals. Interim-stored in Clab, in SFR or locally (at-plant interim storage is directly financed). Disposed of in SFL. |
| **Long-lived high-level residual products** | Spent nuclear fuel from SVAFO (Ågesta) and Studsvik. Encapsulated in the same copper canisters as other spent nuclear fuel. Disposed of in the Spent Fuel Repository. | Spent nuclear fuel encapsulated in copper canisters. Disposed of in the Spent Fuel Repository. |




① If SFR is closed before SFL, short-lived waste follows the dashed line to SFL.

② Interim storage of long-lived waste takes place today at the NPPs, in Clab and at Studsvik. Interim storage of long-lived waste may also occur in SFR.

③ There are near-surface repositories at the nuclear power plants in Forsmark, Oskarshamn and Ringhals. There is also a similar near-surface repository at Studsvik, to which some waste from industry, research and medical care is sent.

④ Possible alternative for very low-level decommmissioning waste. A decision has not yet been made on this.

***Figure 2-1.*** *Overview of the Swedish system for management and disposal of the residual products of nuclear power and other radioactive waste.*

## 2.2 Special premises as a basis for the plan calculation

### 2.2.1 Operating scenarios for the nuclear power plants and quantities of spent fuel and radioactive waste

The reference scenario is based on the reactor owners' current plans for future reactor operation. In these plans it is assumed that the reactors at Forsmark and Ringhals will be operated for a total of 50 years and the reactors in Oskarshamn for 60 years.

It is highly probable that the production data for the individual reactors will change during the long time remaining. These changes may involve power increases due to new technology or other reasons, as well as changed fuel types or burnups. The reference scenario does not take this into account, however; it is based on historical data and an extrapolation of today's situation. Any future changes will be incorporated when the decisions have been made and licences obtained.

Table 2-2 shows historical data concerning the total energy production and the average capacity factor up to and including 2010 (the last months of 2010 are a forecast).

Table 2-3 shows the reactors' operating data with estimated future electricity production and quantity of spent nuclear fuel. The quantity of fuel is given in tonnes of uranium.[6] The table reports data based on 50 and 60 years' operation of the reactors, respectively. In the reference design and the cost calculations, this is approximated to amounting to 6,000 canisters of spent nuclear fuel.

The quantity of encapsulated spent nuclear fuel and radioactive waste is compiled in Table 2-4, with stipulation of the volumes for which space must be allocated in the different final repositories. The table does not include the waste quantities that are placed in near-surface repositories on the NPP sites. The volumes pertain to encapsulated spent nuclear fuel and the containers with radioactive waste that are ready for final disposal. In most cases these containers consist of concrete cubes (moulds) 1.2 metres on a side, but there are also 200-litre steel drums and larger containers.

Finally, the block diagram in Figure 2-2 shows the quantities and illustrates schematically how the spent nuclear fuel and the radioactive waste pass through the storage and treatment facilities and are ultimately deposited in the appropriate final repository.

**Table 2-2. Energy production and average capacity factors for the past ten years.**

| Year | Energy production TWh | Capacity factor % | Comment |
|---|---|---|---|
| 2001 | 69.2 | 83 | |
| 2002 | 65.8 | 84 | Oskarshamn 1, which was shut down for renovation, is excluded from the calculation of the capacity factor. |
| 2003 | 65.6 | 78 | |
| 2004 | 75.2 | 92 | Barsebäck 2 was taken out of service on 31 May 2005. |
| 2005 | 69.6 | 87 | |
| 2006 | 65.0 | 83 | |
| 2007 | 64.3 | 82 | |
| 2008 | 61.3 | 78 | |
| 2009 | 50.0 | 63 | |
| 2010 | 57.1 | 72 | |

[6] The actual weight of the fuel in the form of complete fuel assemblies is much greater. One BWR assembly weighs about 300 kg, of which 180 kg consists of uranium. After burnup the uranium weight has decreased slightly. For a PWR assembly the corresponding weights are about 560 kg and 460 kg, respectively.

**Table 2-3. Operating data plus electricity production and fuel quantities based on 50 years' operation (Forsmark and Ringhals) and 60 years' operation (Oskarshamn).**

| Start commercial operation | | | Thermal capacity/ net capacity MW | Energy production through 2010 TWh | mean value from 2011 TWh/y | Fuel through 2010 tU | Total for reference scenario Operation through | Energy production TWh | Spent fuel tU |
|---|---|---|---|---|---|---|---|---|---|
| F1 | (BWR) | 10/12 1980 | 2,928 / 978 | 206 | 8.4 | 758 | 9/12 2030 | 373 | 1,191 |
| F2 | (BWR) | 7/7 1981 | 2,928 / 990 | 197 | 7.9 | 742 | 6/7 2031 | 359 | 1,204 |
| F3 | (BWR) | 22/8 1985 | 3,300 / 1,170 | 217 | 9.9 | 748 | 21/8 2035 | 461 | 1,380 |
| O1 | (BWR) | 2/6 1972 | 1,375 / 473 | 96 | 3.5 | 449 | 5/2 2032 | 169 | 575 |
| O2 | (BWR) | 15/12 1974 | 1,800 / 638 | 144 | 6.3 | 552 | 14/12 2034 | 296 | 887 |
| O3 | (BWR) | 15/8 1985 | 3,900 / 1,400 | 201 | 11.2 | 721 | 14/8 2045 | 590 | 1,697 |
| R1 | (BWR) | 1/1 1976 | 2,540 / 855 | 163 | 6.4 | 634 | 31/12 2025 | 259 | 893 |
| R2 | (PWR) | 1/5 1975 | 2,652 / 866 | 181 | 7.2 | 588 | 30/4 2025 | 284 | 844 |
| R3 | (PWR) | 9/9 1981 | 3,135 / 1,051 | 182 | 8.3 | 574 | 8/9 2031 | 355 | 1,080 |
| R4 | (PWR) | 21/11 1983 | 2,775 / 935 | 178 | 7.1 | 566 | 20/11 2033 | 341 | 1,045 |
| B1 | (BWR) | 1/7 1975 | 1,800 / 600 | 93 | | 425 | 30/11 1999 | 93 | 425 |
| B2 | (BWR) | 1/7 1977 | 1,800 / 600 | 108 | | 455 | 31/5 2005 | 108 | 455 |
| BWR total | | | 22,371 / 7,704 | 1,426 | 54 | 5,485 | | 2,708 | 8,708 |
| PWR total | | | 8,562 / 2,852 | 541 | 23 | 1,728 | | 980 | 2,969 |
| All NPPs total | | | 30,933 / 10,556 | 1,967 | 76 | 7,213 | | 3,689 | 11,677 |

**Table 2-4. Encapsulated nuclear fuel and radioactive waste to be disposed of.**

| | Quantity to be disposed of | Final repository |
|---|---|---|
| Spent BWR fuel<br>Spent PWR fuel<br>Other spent nuclear fuel (MOX, Ågesta, Studsvik) | 6,000 canisters | Spent Fuel Repository |
| Operational waste from NPPs | 50,500 $m^3$ | SFR |
| Decommissioning waste from NPPs | 133,000 $m^3$ | SFR |
| Operational and decommissioning waste from NPPs (near-core components) | 3,800 $m^3$ | SFL |
| Operational waste from Clab and encapsulation plant | 4,300 $m^3$ | SFR |
| Decommissioning waste from Clab and encapsulation plant | 3,300 $m^3$ | SFR |
| Operational waste from SVAFO and Studsvik | 12,600 $m^3$ | SFR |
| Decommissioning waste from SVAFO and Studsvik | 5,000 $m^3$ | SFR |
| Waste from SVAFO and Studsvik | 6,000 $m^3$ | SFL |
| Total short-lived radioactive waste | 208,700 $m^3$ | SFR |
| Total long-lived radioactive waste | 9,800 $m^3$ | SFL |

### 2.2.2 Overall timetable for execution

The plans for the Nuclear Fuel Programme and the LILW Programme were presented in RD&D Programme 2010. Based on these plans, rough timetables have been prepared for all future facilities. These timetables show, for example, that the encapsulation plant and the Spent Fuel Repository will be built so that deposition of encapsulated fuel can begin in 2025. This will initially involve a small number of canisters per year and gradually increase to reach the regular capacity of 160 canisters per year. Towards the end of the operating period, the deposition rate will decrease to 100 canisters per year, since over the longer term the deposition rate should be adapted to the annual inflow of spent nuclear fuel.

As far as the LILW Programme is concerned, the extension of SFR is supposed to be finished in 2020 so that short-lived decommissioning waste can be received from Barsebäck. Deposition of decommissioning waste will continue until the last reactor has been decommissioned. It is planned that SFL will receive waste from the mid-2040s until all long-lived decommissioning waste from the NPPs has been deposited.

A general timetable is shown of the flow of payments and the individual facilities in Section 2.7, Costs.

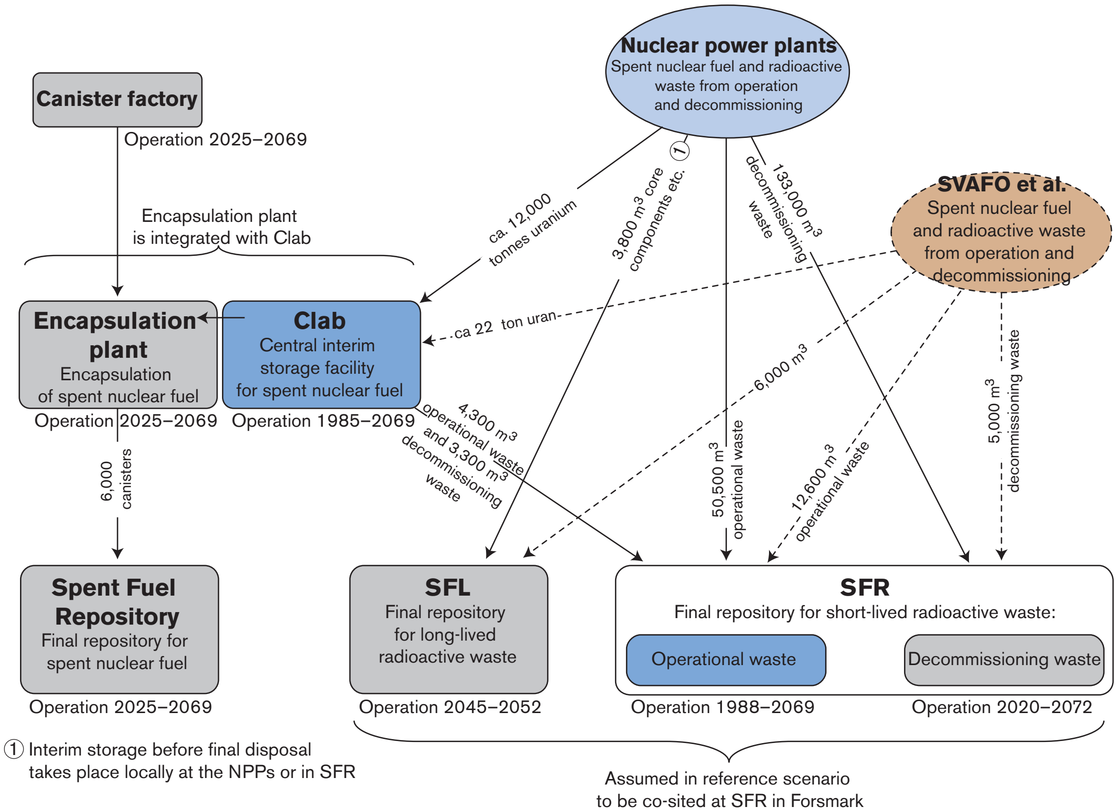



***Figure 2-2.*** *Block diagram with transport flows showing management of the residual products from nuclear power and other radioactive waste as a basis for the reference scenario.*

### 2.2.3 Siting of future facilities

SKB has submitted an application for a licence to build the encapsulation plant integrated with Clab. SKB will submit a licence application for the Spent Fuel Repository in the spring of 2011, with siting in Forsmark.

SKB has not yet made any final decision regarding the siting of SFL. But in order to carry out the cost calculation, an assumption must be made. The uncertainty in this assumption is dealt with later in the uncertainty analysis that is performed to arrive at the amounts called for in the Financing Act.

SFL will be built fairly far in the future. Long-lived radioactive waste cannot be deposited in SFR, since the waste has to be kept isolated for a long time and must therefore probably be disposed of at greater depth in the bedrock. The premise for the reference scenario is that the repository is sited at Forsmark and that it is built by starting from the existing construction and transport tunnels in SFR and excavating further a couple of hundred metres down in the rock.

The canister factory is not a nuclear facility and has been regarded as a normal industrial siting activity where different alternatives are evaluated with regard to economics, safety and environmental impact. SKB has decided that the factory will be located in the Oskarshamn area.

### 2.2.4 Decommissioning of nuclear power plants

The measures required for managing and disposing of the radioactive residual products from nuclear power also include decommissioning of the nuclear power plants. Decommissioning begins after a reactor plant has been permanently shut down and lasts until dismantling has reached a point where it can be assumed that the remaining parts of the plant can be released from regulatory control (cleared). What then remains is exempted from the requirements of the Nuclear Activities Act, and it is assumed that continued dismantling can be done under the same terms as for other industrial activities. How far dismantling is then to be carried for these remaining facility parts varies between the power plants depending on plans for further use of the site.

The timetable for decommissioning the reactor plants is influenced by a number of different factors. Dismantling can be carried out safely a short time after shutdown, but there may in certain cases be advantages to deferred dismantling. The earliest time for dismantling, after the different reactors have been shut down and the spent nuclear fuel has been transported to Clab, is linked to the construction of facilities for management of the decommissioning waste and the processing of licence applications. Dismantling will begin with the reactors in Barsebäck, where it is expected that the dismantling work can commence when the extension of SFR is completed in 2020. SFR will then have the capacity required to receive decommissioning waste.

With regard to resource utilization and the receiving capacity of interim storage facilities and final repositories, it is desirable to stagger the start of dismantling of different reactor plants. With the exception of the two reactors in Barsebäck, which will be dismantled simultaneously, it is assumed that the start of dismantling of reactors on the same site will be staggered by at least one year. Two integrated reactor units cannot begin to be dismantled until both have been shut down and all nuclear fuel has been removed.

During the period from when the reactor has been taken out of service until the start of dismantling, fuel is removed, decontamination[7] takes place and preparations are made for dismantling. This period is called defuelling operation as long as nuclear fuel is left in the plant and shutdown operation thereafter. During the shutdown operation period, the workforce will be reduced. The length of the shutdown operation depends on when dismantling is begun. The actual dismantling work is expected to take seven years per reactor and employ an average of a couple of hundred persons. The principle is illustrated by Figure 2-3.

The radioactive waste from decommissioning is all LLW and ILW. However, the activity level varies considerably between different parts. The waste with the highest activity consists of the internal parts of the reactor vessel.

The short-lived waste will be transported directly to SFR and be deposited there (see Section 2.4.1). The long-lived waste, which includes the reactor internals, will be interim-stored either locally at the NPPs or in temporarily utilized parts of SFR. This waste will later be deposited in SFL, which is assumed in the reference scenario to be finished in the mid-2040s (see Section 2.4.3).

A large quantity of the decommissioning waste can be released after treatment for unrestricted use and thereby be handled according to the rules that apply to demolition waste from industry in general.

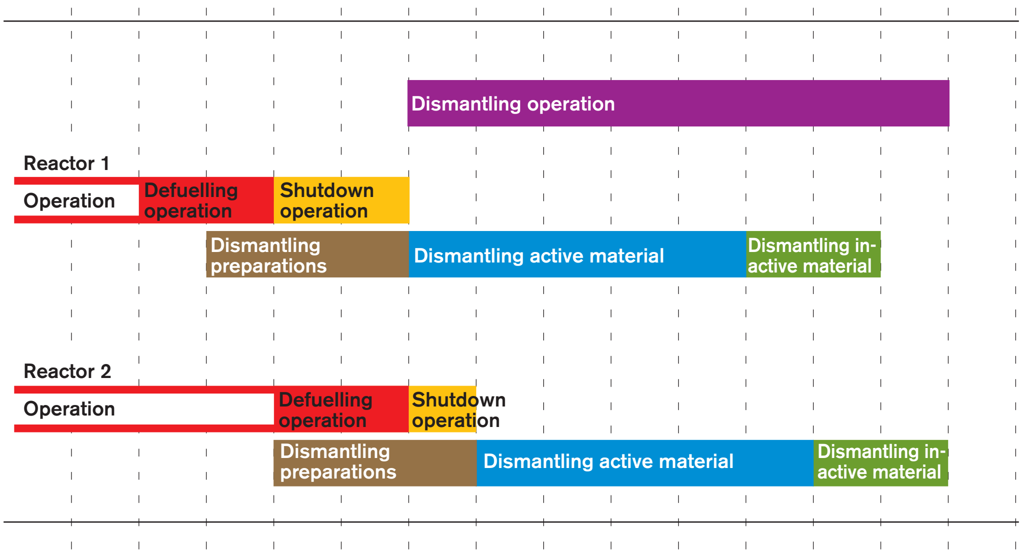



***Figure 2-3.*** *Schematic illustration showing the main activities included in the decommissioning of two interconnected reactor plants.*

[7] Washing or other manner of cleaning to remove superficial radioactive contamination.

## 2.3 Description of facilities in the Spent Fuel Programme

### 2.3.1 Research, development and demonstration – RD&D

SKB's work with research, development and demonstration (RD&D) is aimed at gathering the necessary knowledge, material and data to realize the final disposal of spent nuclear fuel and long-lived radioactive waste. A programme for this work is presented by SKB every three years. The most recent programme, RD&D Programme 2010, was submitted to the Government in September 2010.

RD&D has so far mainly been focused on the management of spent nuclear fuel. However, an increasingly large portion is being devoted to the LILW Programme and to method studies and follow-up of experience from decommissioning of reactor plants. Within the LILW Programme, the RD&D is above all being focused on management of the long-lived waste.

Since most of the RD&D-related activities are included in the Nuclear Fuel Programme, RD&D is described in the section concerning this programme.

The long-term safety of a final repository is evaluated by means of safety assessments, where scientific methodology is used and knowledge concerning long-term changes is obtained from research. At present, SKB is carrying out safety assessments in support of the applications to build the Spent Fuel Repository in Forsmark and the applications concerning an extension of SFR.

The goal of the research on long-term safety which SKB is conducting is to understand the processes (long-term changes) that occur in a final repository and how they affect the repository's ability to prevent or retard the escape of radioactive substances.

An important component in the RD&D work is the Äspö Hard Rock Laboratory (HRL). An illustration of the HRL is shown in Figure 2-4. The HRL is used to test, verify and demonstrate the investigation methods that have been used in the site investigations and that will later be used for detailed characterization of the Spent Fuel Repository in Forsmark. The Äspö HRL is also used to study and verify the function of different components in the final repository system.

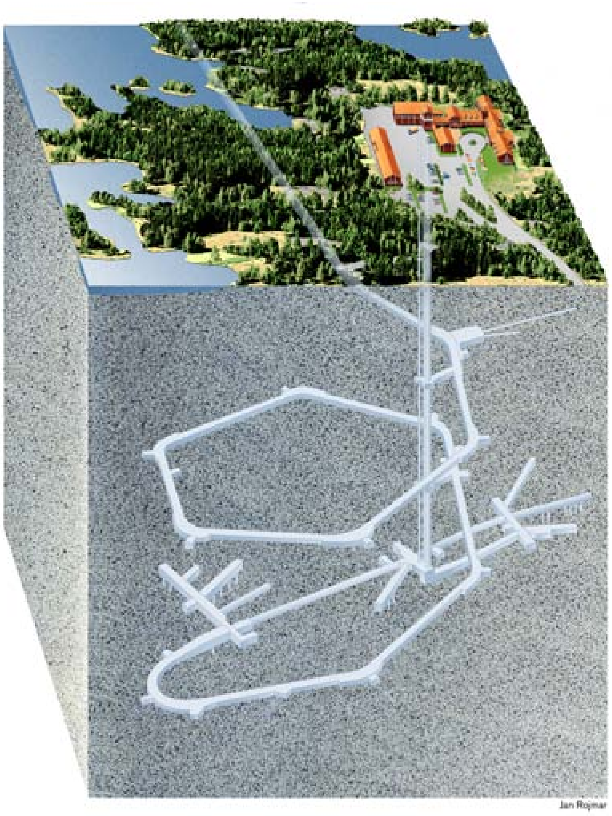



***Figure 2-4.*** *Äspö HRL.*


***Figure 2-5.*** *Deposition machine for handling of canisters in the final repository.*

Another important purpose is to develop and demonstrate methods for building and operating the Spent Fuel Repository. As a part of this work, SKB has carried out trials of a prototype deposition machine, development of the horizontal deposition alternative, testing of the method for lowering of bentonite buffer and canisters in the bored deposition holes, and backfilling and plugging of deposition tunnels. A full-scale prototype repository has been built, and a test of retrieval of a canister from a deposition hole has been carried out. Figure 2-5 shows the latest design of the deposition machine for handling of canisters with spent nuclear fuel.

In the future, the laboratory will be used to train the personnel who will work in the Spent Fuel Repository.

Another important component in the RD&D activities is the Canister Laboratory, where development of methods for sealing and inspection of the copper canister is carried out. Different types of canister handling equipment are also tested and verified on a full scale in the laboratory. The laboratory will also be used for training of personnel prior to the commissioning of the encapsulation plant.

Trial fabrication of canister components such as copper tubes, lids, bottoms and inserts with lids has been going on since 1996. Different fabrication methods are being tested at a number of companies in Sweden and abroad.

SKB has been conducting research and development at the Bentonite Laboratory in Oskarshamn since 2007. The facility is situated adjacent to the Äspö HRL and supplements the experiments being conducted there. In the Bentonite Laboratory, SKB tests the properties of the bentonite and develops methods for backfilling the tunnels of the Spent Fuel Repository with backfill material and building plugs to seal the deposition tunnels.

In the reference scenario it is assumed that research, development and demonstration will continue on Äspö until deposition is commenced. Development and training will be pursued at the Canister Laboratory until the encapsulation plant is put into operation.

Costs for early activities within the Spent Fuel Repository project such as site investigations, design and detailed characterization are presented in the cost compilation under the heading “Spent Fuel Repository”.

### 2.3.2 Clab – Central interim storage facility for spent nuclear fuel

Clab is situated adjacent to the Oskarshamn Nuclear Power Plant. The facility, which started operation in 1985, was originally designed to store some 3,000 tonnes of fuel (uranium weight) in four pools. The introduction of new storage canisters that can be more densely packed has increased the capacity of these pools to about 5,000 tonnes. A new rock cavern with storage pools was recently put into operation, increasing the storage capacity of the facility to 8,000 tonnes.

At year-end 2010, the facility is expected to contain fuel equivalent to 5,240 tonnes of uranium spent weight (about 5,490 tonnes of uranium initial weight). Core components and reactor internals that will eventually be deposited in SFL are also kept in the facility.

Clab consists of an above-ground or surface part for receiving fuel and an underground part with storage pools. The surface part also contains equipment for ventilation, water purification and cooling, waste handling, electrical systems etc. plus premises for administration and operating personnel. Reception and all handling of fuel takes place under water in pools.

The storage pools are located in rock caverns and made of concrete with a stainless steel lining. The pools are designed to withstand earthquakes.

SKB operates the facility with its own personnel. The permanent workforce during operation is currently about 100 persons.

After all fuel and other waste has been removed from Clab, the above-ground facilities will be dismantled along with those parts of the storage pools that have become radioactive. The radioactive decommissioning waste will be transported to SFR.

The costs for Clab are based on experience to date and renewed appraisals of the facility's future needs for maintenance and reinvestments.

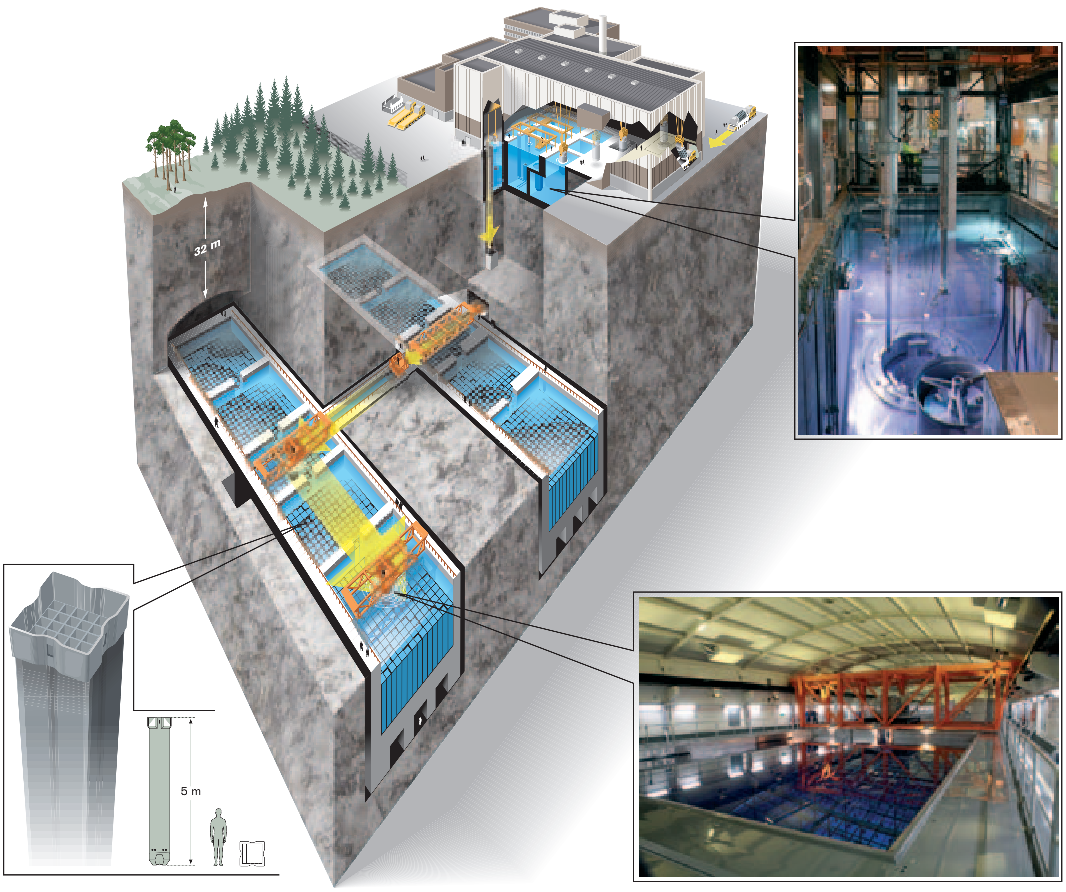



***Figure 2-6.*** *Clab.*

### 2.3.3 Encapsulation of spent nuclear fuel

#### *Canister factory*

By "canister factory" is meant a plant where the different parts of the canister are finish-machined and assembled to a finished canister.

The reference design of the canister consists of an outer 5 cm thick corrosion barrier of copper in the form of a tube with lid and bottom, see Figure 2-7. The specified copper grade is a high-purity oxygen-free copper with a small addition of phosphorus.

Four methods have been tried for fabricating copper tubes. In one method, a copper plate is rolled to tube halves, which are then welded together by longitudinal electron beam welding (EBW). The other methods are based on fabricating the copper tubes in one piece by either pierce and draw processing, extrusion or forging. Copper lids and bottoms are fabricated by finish-machining of preformed forged blanks. The reference design is based today on extrusion of tubes.

Inside the copper tube is the cast iron insert with channels for the fuel assemblies. The insert also serves as the pressure-bearing component in the design. The insert is made of nodular iron. Today the inserts have been cast and rough-machined at several foundries both in Sweden and abroad. The lid for the insert is made of rolled steel plate. Blanks for insert lids are cut out of the rolled steel plate and finish-machined.

Components such as tubes, lids and bottoms of copper as well as inserts of nodular iron with steel lids are delivered to the canister factory, where they are finish-machined to the right final size. After dimensional inspection the copper bottom is welded onto the copper tube. Nondestructive testing methods such as ultrasound and radiography are used to inspect the weld. After cleaning the insert is lifted down into the copper tube, and together with the steel lid and the copper lid this package is delivered to the encapsulation plant. A detailed delivery certificate accompanies the canister with documentation of material and fabrication.

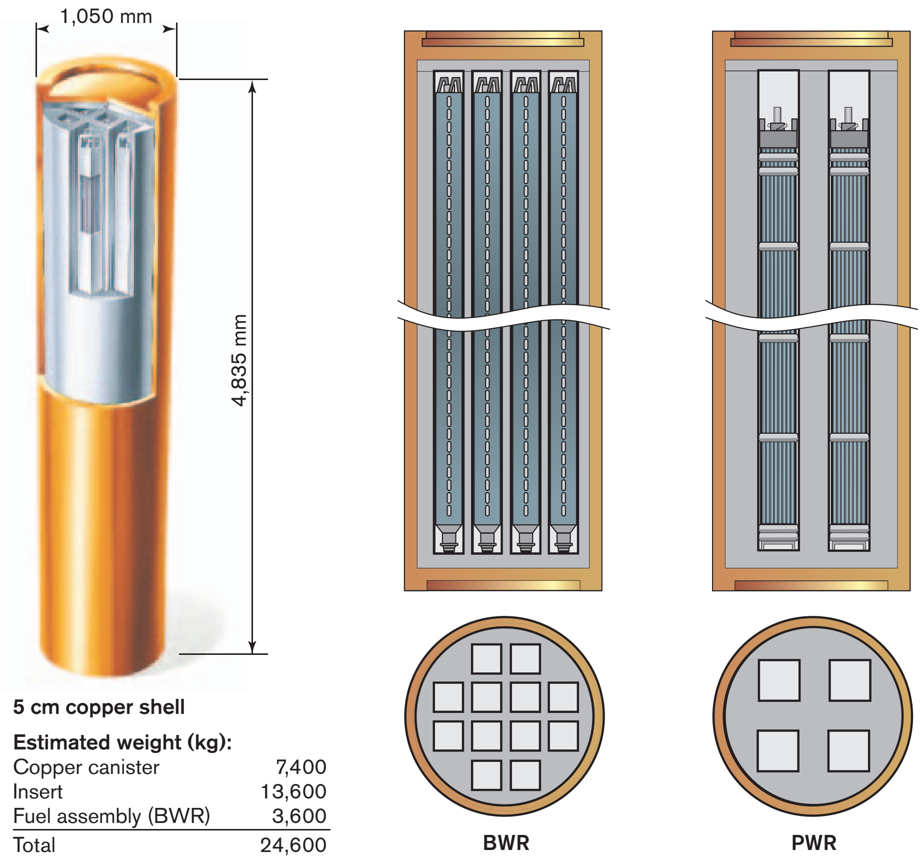



***Figure 2-7.*** *Copper canister with cast iron insert.*

The canister factory is planned to be housed in a building of about 7,000 $m^2$ with premises for maintenance workshop, offices and inspection laboratory. The staff requirement is estimated at 20 persons.

### *Encapsulation plant*

Before the spent nuclear fuel is placed in the final repository, it will be encapsulated in the canister described above. The canister holds up to 12 BWR assemblies or 4 PWR assemblies. Encapsulation is planned to take place in a new plant integrated with Clab, see Figure 2-8. The encapsulation plant and Clab will be operated as an integrated facility under the name Clink.

The encapsulation plant will contain the following functions:

- Arrival section with quality inspection of delivered canister parts.
- Encapsulation section with the following steps:
  - Verification of decay heat, documentation and sorting of the fuel from the storage pools. Transloading of fuel assemblies to a transfer canister.
  - Drying of fuel and lowering of individual fuel assemblies into the insert plus fitting of steel lid onto the insert.
  - Change of atmosphere in the insert, whereby air is replaced by an inert gas. Cleaning of joint surface, fitting of copper lid onto copper canister.
  - Welding of canister lid by means of friction stir welding.
  - Nondestructive testing of weld joint and cooling of canister. Testing is planned to be done after welding and after machining.
  - Machining of weld joint.
- Dispatch section for finished canisters. Transport from the plant to the final repository will take place in radiation-shielded transport casks.
- Auxiliary systems with cooling and ventilation systems as well as electrical and control equipment.
- Personnel and office premises plus storeroom.

The plant is designed for an annual production capacity of 200 canisters. The long-term production rate at the plant is, however, limited by the fuel input rate, which is in turn limited by the minimum storage time in Clab needed for the fuel to decay to a suitable level. In the reference scenario with a total of 6,000 canisters, the production rate for most of the operating period will be around 160 canisters per year, decreasing to 100 towards the end.

***Figure 2-8.*** *Encapsulation plant for spent nuclear fuel integrated with Clab.*

Encapsulation will mainly be done in the daytime. The synergies in terms of organization and manpower gained by integrating the encapsulation plant with Clab have been taken into account in estimating the staff requirement.

Encapsulation of spent nuclear will begin in 2025 with trial operation lasting until 2027 and including around 180 canisters. Routine operation will then begin in 2028.

After completed encapsulation, the plant will be decommissioned and radioactive decommissioning waste will be transported to SFR.

### 2.3.4 Spent Fuel Repository

According to SKB's plans, the Spent Fuel Repository will be located on a site southeast of the Forsmark nuclear power plant called Söderviken, Figure 2-9. The facility consists of an above-ground or surface part and an underground part.

#### *Underground part*

The underground part consists of a central area and a repository area plus connections to the surface part in the form of shafts for elevators and ventilation and a ramp for vehicle transport. According to the KBS-3 method, the final repository will be located at a depth of 400–700 m below the ground surface. In order to avoid conductive structures and limit rock stresses, the repository depth has been set at 470 m. The repository area is situated within a delimited area of rock known as a tectonic lens, with favourable rock properties.

Figure 2-9 shows the extent of the repository area based on the results of the site investigations. The spacing between the canisters and between the deposition tunnels is determined by the temperature expected to develop around the canister, especially the temperature in the surrounding bentonite. Bentonite is a clay that swells on absorbing water, and its purpose is to protect the canister and retard radionuclide transport if the canister's surface layer should be penetrated. The function of the bentonite is dependent on the temperature not getting too high. The spacing between the canisters is therefore determined by the fuel's decay heat, the thermal properties of the rock and the bentonite, and the initial temperature of the rock. Based on the given premises, a canister spacing of 6.0 m and a tunnel spacing of 40 m have been chosen in the reference scenario. The extent of the repository depicted in the figure also includes 13% spare capacity to allow for deposition holes that cannot be used for some reason.

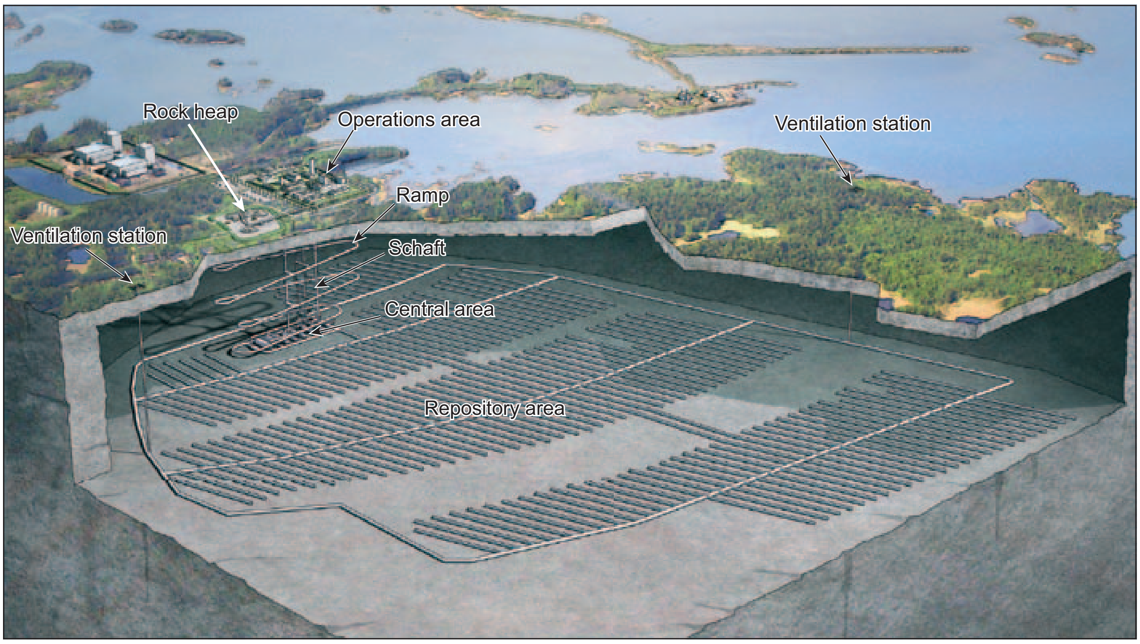



***Figure 2-9.*** *The main parts of the Spent Fuel Repository.*

The reference design is based on the alternative with a consolidated operations area above ground and a spiral ramp for transporting heavy and bulky goods. In addition there are a number of shafts for transport, utilities and ventilation. In order to shorten the construction period, a skip shaft for rock spoil in the form of a sunk shaft is driven in parallel with the blasting of the ramp. During the operating period, the skip shaft will be utilized for transport of rock spoil and backfill. Transport casks with canisters will be transported on the ramp, which is the main use of the ramp.

The central area contains openings with functions for operation of the underground part and is situated directly beneath the operations area on the ground surface. It consists of a series of parallel halls with different functions. The halls are interconnected by the tunnels that serve as the transport pathways in the central area, as well as local tunnels for communication and service.

### *Surface part*

The surface part includes operations area, rock heap, ventilation stations and storage building, see Figure 2-10. Most of the facility parts are collected in an operations area, which is divided into an inner and an outer operations area. Nuclear activities on the surface are conducted in the inner operations area. The outer operations area contains the production plant for buffer and backfill and a number of buildings intended for operating functions, service and maintenance, and personnel.

The inner operations area contains the buildings with access pathways to the underground part and is therefore a guarded area with a special entrance building for entrance and exit control. The inner operations area also contains a terminal building that serves as a reception and transloading station for canister transport casks. In the reference scenario, these casks are transported from the encapsulation plant by m/s Sigyn to the harbour in Forsmark at SFR. They are then transported further to the terminal building by terminal vehicles. The transport casks are stored in this building before being transported down to the underground part for emptying.

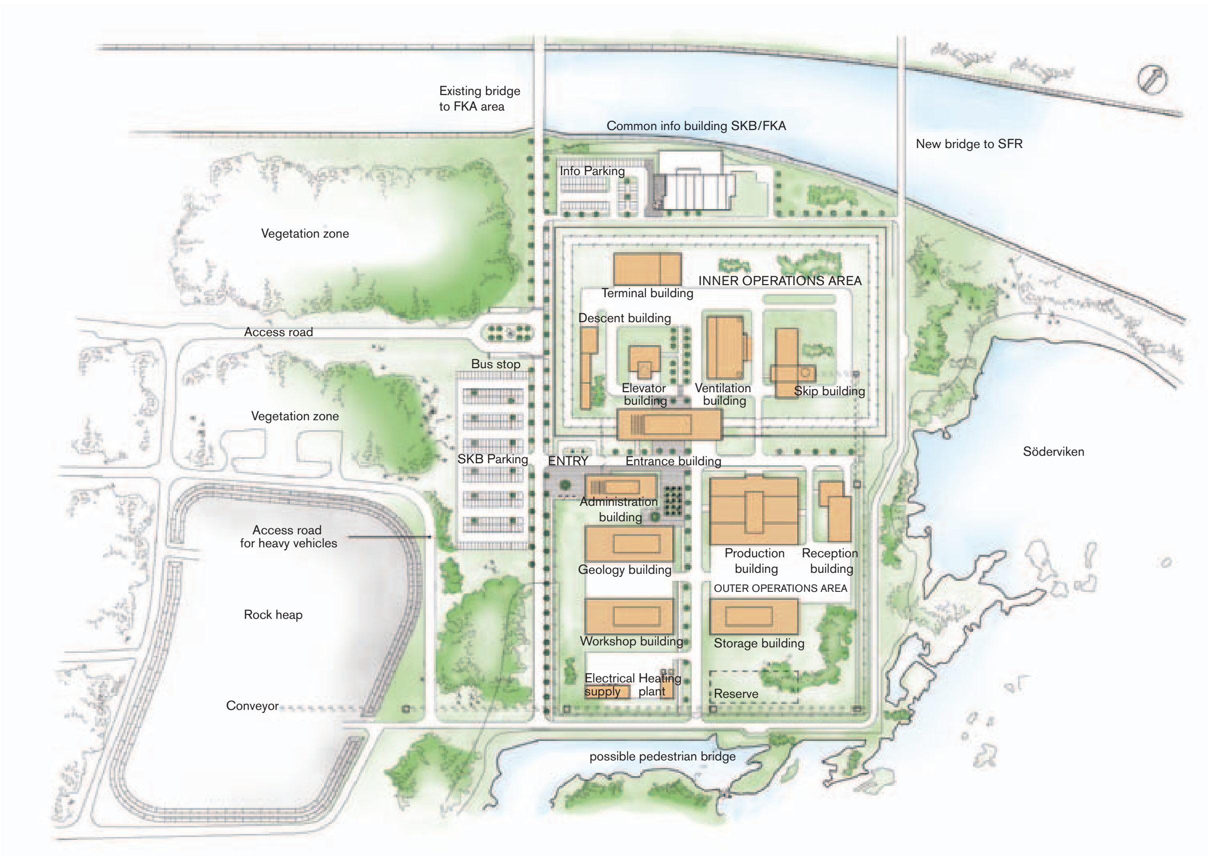



*Figure 2-10. Spent Fuel Repository in Forsmark – surface part.*

The rock heap is used to store rock spoil from blasting until it can be disposed of. The rock heap is located near the operations area and the rock spoil is transported to the rock heap by conveyors from the skip building in the inner operations area.

Figure 2-9 also shows the projected locations of two ventilation stations for the exhaust air from the rock caverns.

In addition to the aforementioned surface parts, storerooms for bentonite and backfill material are situated at the receiving harbour in Hargshamn, about 30 km south of Forsmark. Material for production of buffer and backfill is transloaded and stored there prior to transport to the production plant.

#### *Activities and functions*

When the facility has been built and conditions for commissioning have been fulfilled and approved by the regulatory authorities, the nuclear activity starts with an initial phase called trial operation. The principal operating activities are rock works, deposition and production/transport of buffer and backfill material. These activities entail that the canisters are deposited in a part of the repository where buffer and backfill are also emplaced, at the same time as new deposition tunnels are blasted out in another part.

The deposition tunnels are blasted out as deposition proceeds. However, deposition can be commenced immediately when trial operation begins, since a number of deposition tunnels with associated transport and main tunnels have been prepared during the construction of the facility. The main tunnels are the transport and handling tunnels that are located immediately adjacent to the deposition tunnels and interconnect them. The deposition rate is progressively increased after the trial operation phase to approach the rate that will prevail during routine operation. The results of the trial operation phase will be evaluated as a basis for obtaining a permit for routine operation.

A total of 220 persons will be employed at the final repository.

#### *Rock works*

By “rock works” is meant all activities required to blast out tunnels and bore deposition holes, including preparations and detailed characterization. The term also includes providing tunnels with temporary installations for ventilation, electricity, lighting and drainage. Rock works will be carried out using the drill-and-blast method with standardized equipment for the most part. An apparatus developed specially for the purpose is used for boring of deposition holes. The rock works in a deposition tunnel are considered to be finished when the tunnel is ready for canister deposition.

The rock spoil is hauled by dumptrucks from the blasting site in the repository area to the rock loading station’s discharge hopper in the central area. The rock spoil passes through the rock loading station’s crusher and silo and is then transported by the skip up to the operations area and further to the rock heap.

#### *Deposition*

Deposition includes preparations for deposition, placement of bentonite buffer in the deposition hole, deposition of the canister, and backfilling and plugging of the deposition tunnel, see Figure 2-11.

Backfilling of the deposition tunnel is begun when the last canister has been deposited in the tunnel. In simplified terms, backfilling entails filling the tunnel with blocks of swelling clay. The space nearest the rock surface is filled with pellets of the same material as the blocks. When the deposition tunnel has been backfilled completely, it is sealed by casting a concrete plug in the mouth of the tunnel. These concrete plugs have no long-term function after the entire final repository has been closed and sealed.

#### *Buffer and bentonite*

The buffer surrounds the deposited canister and is one of the barriers in the final repository. The buffer consists of compacted bentonite. Beneath and above the canister the buffer consists of blocks, and along the mantle surface of the canister it consists of rings. In addition there are pellets or granules of bentonite for filling the gaps between the blocks/rings and the rock in the deposition hole.

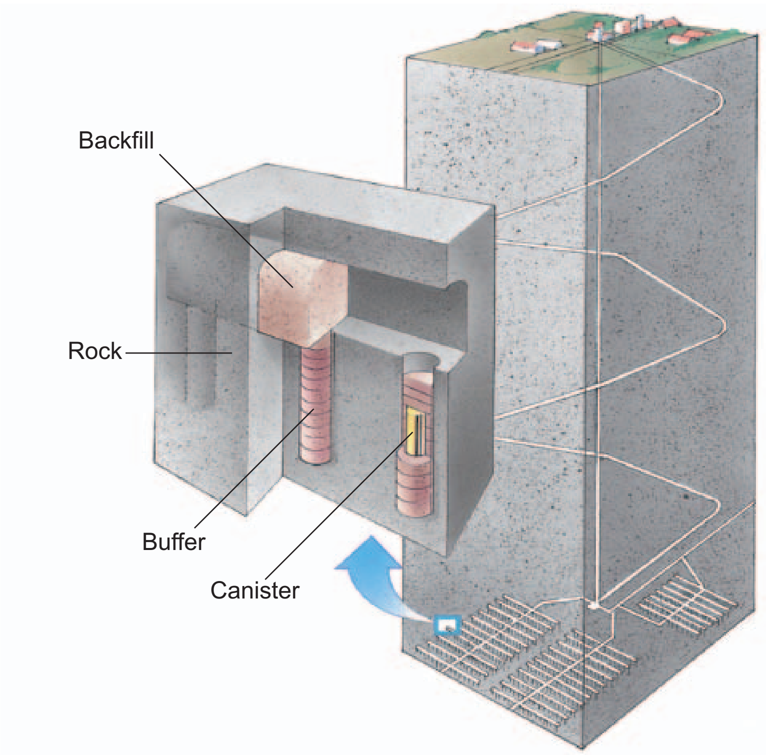



*Figure 2-11.* *KBS-3 with vertical deposition.*

The backfill replaces the excavated rock in the deposition tunnels. It consists of compacted blocks of clay that are stacked in the tunnels. Pellets of the same material are used to fill the gap between blocks and tunnel wall.

Bentonite and backfill material is brought in by ship to the harbour at Hargshamn, where it is stored in bulk in storerooms. From there the material is transported to the production building in the outer operations area, where fabrication of buffer takes place by compaction of the bentonite to blocks, rings and pellets of high density.

The finished buffer and backfill blocks are transported to the inner operations area via the entrance building and on to the skip building. Transport down to the central area takes place by skip, and from there by vehicle out to the point of use in the deposition tunnel.

## 2.4 Description of facilities in the LILW Programme

### 2.4.1 SFR – final repository for short-lived radioactive waste

A final repository for operational waste from the nuclear power plants, called SFR, has been in operation since 1988 adjacent to the Forsmark Nuclear Power Plant. The repository is located beneath the Baltic Sea, covered by about 60 metres of rock. Two access tunnels, each about one kilometre in length, lead from the harbour in Forsmark out to the repository area. Radioactive waste from Clab and similar radioactive waste from non-electricity-producing activities, including Studsvik, is also disposed of in SFR. The repository will soon be extended to be able to receive radioactive decommissioning waste as well, initially from Barsebäck where the dismantling will start in around 2020.

SFR consists today of four 160 metre long rock vaults and one 70 metre high cylindrical rock cavern containing a concrete silo. The waste containing most of the radioactive substances is placed in the silo. Figure 2-12 shows a sketch of SFR with pictures from different disposal chambers. Figure 2-13 shows the future extension, which is planned to be completed in 2020.

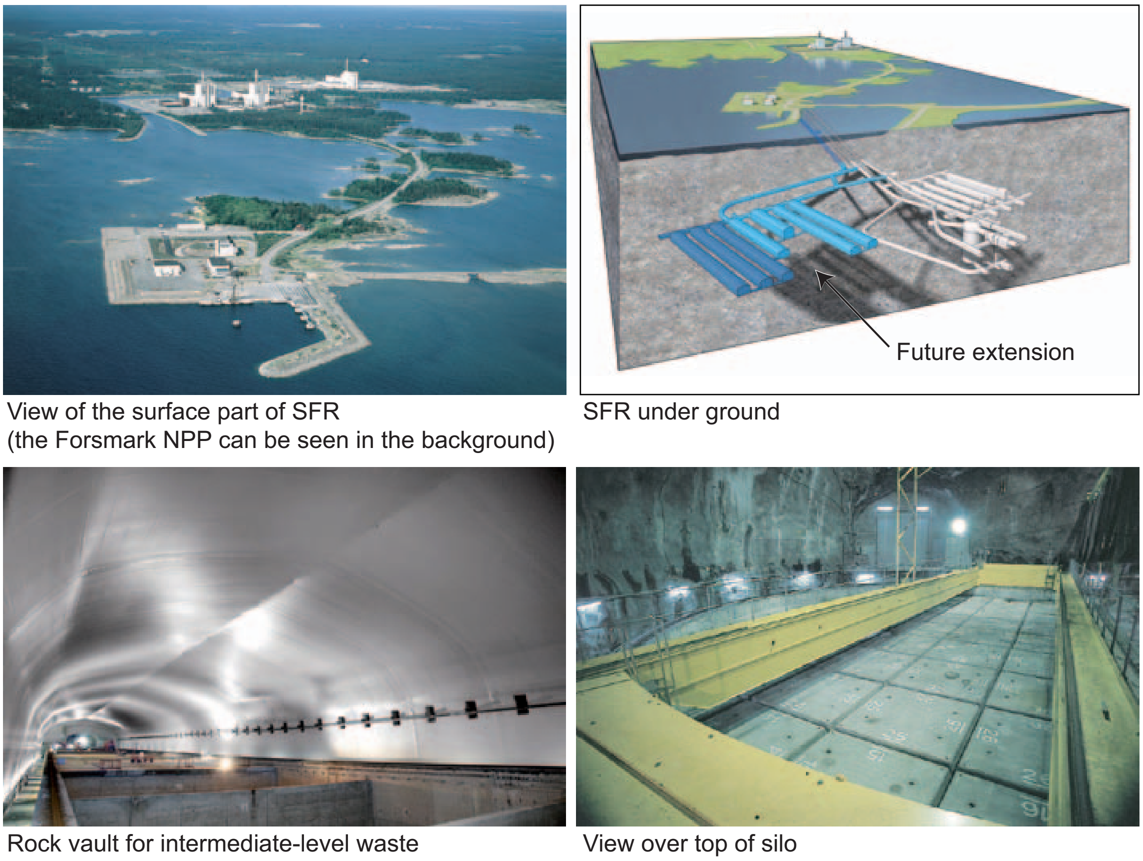



***Figure 2-12.*** *SFR.*

***Figure 2-13.*** *SFR with planned extension.*

The concrete silo stands on a bed of sand and bentonite. Internally it is divided into vertical shafts into which the waste is lowered and embedded in porous concrete. The space between the silo and the rock wall is filled with bentonite. When the silo is full, the space above the silo will be filled with a sand-bentonite mixture and with sand and crushed rock.

Certain waste categories placed in rock vaults are embedded in cement after deposition. It is also possible to encase the waste in concrete when the facility is closed.

Handling of intermediate-level waste packages, which are placed either in the silo or in one of the rock vaults, is done by remote control. Low-level waste, which is placed in the other rock vaults, is handled by forklift truck.

For the reference scenario with 50 years of operation of the reactors in Forsmark and Ringhals, and 60 years in Oskarshamn, it is estimated that SFR will receive a total of about 65,000 $m^3$ of operational waste, including radioactive waste from non-nuclearpower related activities as described in Section 2.1. The capacity of the present-day SFR is about 60,000 $m^3$. An extension is needed for operational waste, and is included as a part of the extension that is planned for decommissioning waste.

It is assumed that most of the decommissioning waste can be packed in standard containers and then transported to SFR and placed in rock vaults. It is estimated that a total of about 140,000 $m^3$ waste will be stored in this manner. A smaller portion of the decommissioning waste consisting of core components and reactor internals is planned to be deposited in SFL, which the reference scenario assumes will be in connection with SFR, although at greater depth, see Section 2.4.3. It is assumed in the reference scenario that SFL will be put into operation only after all reactors have been shut down.

SKB took over operation of SFR in 2009. This was previously contracted out to Forsmarks Kraftgrupp AB. An operations group consisting of about 20 persons is in charge of operation and maintenance. Outside contractors are engaged for parts of the maintenance work. Altogether, it is estimated that between 20 and 30 full-time equivalents per year will be needed for operation and maintenance of SFR. This includes operation of SFL when it becomes operative in the mid-2040s.

It is assumed in the planning premises in the reference scenario that SFR and SFL will be sealed and closed at the same time after all decommissioning waste from Clab and the encapsulation plant, i.e. Clink, has been disposed of.

Approximately 33,900 $m^3$ of waste are expected to have been deposited in SFR by year-end 2010.

### 2.4.2 Facilities at the nuclear power plants for interim storage or deposition of short-lived radioactive waste

The facilities that exist today at our nuclear power plant sites for management of short-lived low- and intermediate-level waste include those covered by the licence to own the reactor plant and those where a special licence is issued. The former are not included in the cost calculations for the reference scenario.

Those that are operated with a special licence are currently:

- A near-surface final repository for very low-level operational waste at Forsmark.
- An interim storage facility for core components at Forsmark.
- A near-surface final repository for very low-level operational waste at Oskarshamn.
- A dry rock interim storage facility at Oskarshamn for short-lived operational waste from OKG and for long-lived waste (core components) from all NPPs. The interim storage facility goes under the designation BFA.
- A near-surface final repository for very low-level operational waste at Ringhals.
- An interim storage facility for operational waste at Ringhals. The interim storage facility is called the mould store.

### 2.4.3 SFL – Final repository for long-lived radioactive waste

The final repository for long-lived radioactive waste, called SFL, is mainly intended to contain core components and reactor internals, plus long-lived radioactive waste from SVAFO and Studsvik[8].

SFL may be co-sited with one of the other final repositories. For calculation purposes, a co-siting with SFR is assumed in the reference scenario, see Section 2.2.3. The repository will be located at a depth of 300 metres with connection to existing ramps.

In the current preliminary design, the repository consists of rock vaults in which the waste is stacked in concrete shafts and encased in porous concrete. The shafts are then covered with concrete planks and cast over. All handling is done by remote-controlled overhead crane. In conjunction with repository closure, the space between the concrete shafts and the rock is filled with crushed rock and the rock cavern's openings are sealed with concrete plugs.

See Section 2.4.1 regarding the workforce during operation.

## 2.5 Description of the transportation system

A distinction is made in the calculation between sea transport with associated terminal handling and overland transport by road. The former is presented under the heading "Transportation system" while the latter is included in the concerned facilities.

"Transportation system" refers to the system for sea transport. It consists of three main components: the ship m/s Sigyn, the transport casks and containers, and the terminal vehicles. The system is designed to be used for spent nuclear fuel and all types of nuclear waste.

M/s Sigyn is built for ro-ro handling and has a payload capacity of 1,400 tonnes. Loading and unloading by crane is also possible. Operation and maintenance of the ship is entrusted to the shipping line Destination Gotland.

A new ship is currently in the process of being procured, with planned delivery in 2013.

By year-end 2010, a total of about 5,240 tonnes of fuel spent weight (5,490 tonnes initial weight), is expected to have been transported from the nuclear power plants to Clab and about 33,900 $m^3$ of short-lived radioactive waste to SFR.

Casks designed to meet stringent requirements on radiation shielding and to withstand large external stresses are used for shipments of spent nuclear fuel and core components to Clab. One such cask holds about 3 tonnes of fuel. Radiation-shielded steel containers are used for transporting ILW to SFR. They hold about 20 $m^3$ of waste, and the maximum transport weight per container is 120 tonnes. Standard freight containers can be used for LLW from operation as well as for most of the decommissioning waste. At present, the system includes ten transport casks for spent fuel and two for core components, plus 27 radiation-shielded containers for ILW.

During loading and unloading, the casks/containers are transported short distances between storage facilities and the ship by special terminal vehicles, see Figure 2-14. At present, five such vehicles are used.

Transport of canisters with spent nuclear fuel from the encapsulation plant at Clab to the Spent Fuel Repository is assumed in the reference scenario to take place by sea to the harbour in Forsmark. Further transport to the operations area takes place directly by terminal vehicle. The encapsulated nuclear fuel is carried in transport casks of a type similar to those used for the fuel today.

The costs for the transportation system are based on experience to date. The future costs take into account recurrent needs for new ships, vehicles and transport casks/containers.

[8] It is assumed that the long-lived waste from the nuclear power plants will be interim-stored in containers, whereby decay will facilitate further handling. Interim storage can be arranged in different ways, but in the reference scenario this is assumed to occur in the extended SFR.

***Figure 2-14.** Terminal vehicle with transport cask.*

## 2.6 Calculation methodology

The calculation for the reference cost is done in the traditional way using a deterministic method. By this is meant a method based on given, fixed assumptions. Normally a percentage allowance is added for unforeseen factors in such a calculation, but not in SKB's case. Instead, all types of uncertainties are treated separately in the uncertainty analysis, which is described in Chapter 3.

The calculation is based on functional descriptions of each facility, resulting in layout drawings, equipment lists, staffing forecasts, etc. For facilities and systems that are in operation, this information is highly detailed and well known, while the level of detail is lower for future facilities.

For construction and installation costs in connection with the construction of future facilities, a base cost is calculated for each cost item, including:

- quantity-related costs
- non-quantity-related costs
- secondary costs.

Quantity-related costs are costs that can be calculated directly with the aid of design specifications and with knowledge of unit prices, for example for concrete casting, rock blasting and operating personnel. Experience gained from the previous construction of the nuclear facilities, such as the NPPs, Clab and SFR, has been drawn on in estimating both quantities and unit prices.

All details are not included on drawings or otherwise specified in the early stages. But their magnitude can be estimated with good accuracy based on experience from other similar projects. The costs for these, the non-quantity-related costs, or normally obtained by means of an experience-based percentage allowance called "allowance for unspecified items"[9].

[9] This should not be confused with allowance for unforeseen factors, which is not included in the reference calculation. Unforeseen factors are assumed to comprise a part of the total uncertainty that is handled in the uncertainty analysis, see further Chapter 3.

The final item included in the base costs is secondary costs. These include costs for administration, design, procurement and inspection as well as the costs for temporary buildings, machines, housing, offices and the like. These costs are also relatively well known and have been calculated based on the estimated service requirement during the construction phase.

## 2.7 Costs

### 2.7.1 Future costs

The costs for different facilities are presented in Table 2-5 under the items *investment*, *operation and maintenance, backfilling* and *decommissioning and closure*. Backfilling pertains only to the deposition tunnels. Normally, only the costs that arise before a facility or a part of a facility is commissioned, or major reinvestments when a facility has reached a considerable age (for example today for Clab), are allocated to *investment*. However, in the final repository for spent nuclear fuel, where build-out of the deposition tunnels will proceed continuously during the deposition phase (the operating phase), the costs for this work are also included in *investment*. The costs in Table 2-5 are a best cost estimate based on current data for the reference scenario.

The reference cost amounts to a total of SEK 92.0 billion. Of these costs, SEK 69.7 billion fall within SKB's sphere of activity and are thereby common costs for the licensees, known as joint costs. The remaining costs are for activities where each licensee has his own cost responsibility, known as separable costs.

Figure 2-15 shows the reference cost distributed over time. For information purposes, a simplified timetable is also shown for the different facilities to give an idea of their influence on the cost flow. It shows, for example, that the two cost peaks in the chart stem on the one hand from the investment in the encapsulation plant and the Spent Fuel Repository, and on the other from the decommissioning of the nuclear power plants.

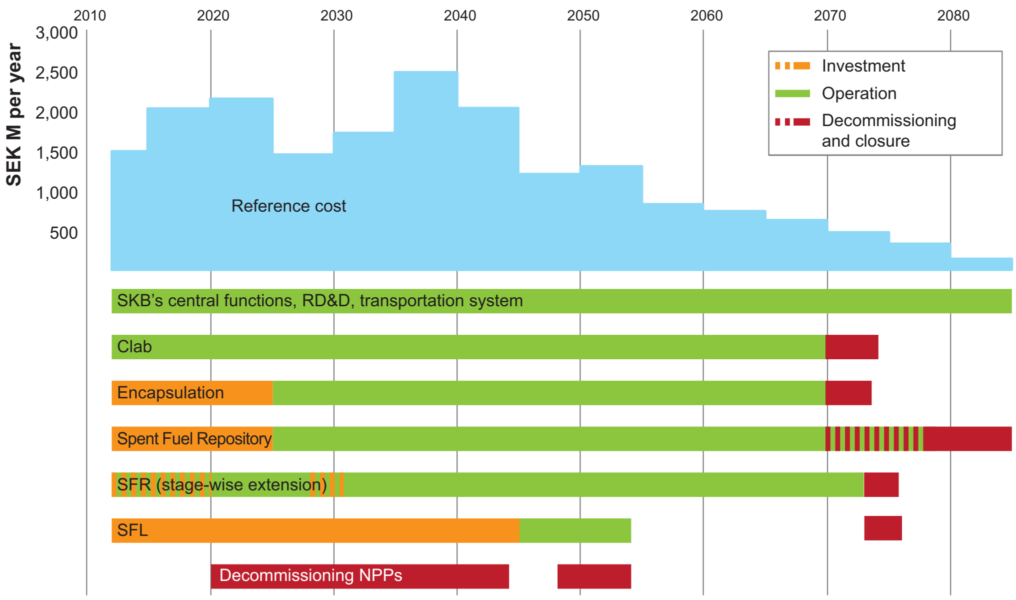



***Figure 2-15.** Distribution in time of the future costs for the reference scenario and rough timetables for the facilities.*

**Table 2-5. Future costs for the reference scenario up to and including 2012, January 2010 price level.**

| | | Cost per cost category, SEK M | Cost per facility, SEK M |
|---|---|---|---|
| **SKB's central functions and RD&D** | | 10,430 | 10,430 |
| **Transportation** | investment | 1,860 | 3,430 |
| | operation and maintenance | 1,570 | |
| **Clab** | investment | 2,000 | 9,620 |
| | operation and maintenance | 6,980 | |
| | decommissioning | 640 | |
| **Encapsulation plant and canister factory** | investment | 2,980 | 13,750 |
| | operation and maintenance | 10,570 | |
| | decommissioning | 200 | |
| **Spent Fuel Repository** | | | |
| **– Off-site facilities** | investment and operation | 260 | 260 |
| **– Operations areas above ground** | investment | 8,690 | 15,980 |
| | operation and maintenance | 7,110 | |
| | decommissioning | 180 | |
| **– Facilities below ground** | investment | 6,100 | 10,480 |
| | operation and maintenance | 320 | |
| | backfilling | 1,720 | |
| | decommissioning and closure | 2,340 | |
| **Final repository for long-lived radioactive waste, SFL** | investment | 820 | 1,500 |
| | operation and maintenance | 320 | |
| | decommissioning and closure | 360 | |
| **Interim storage facility and near-surface repositories at the nuclear power plants** | investment | 0 | 130 |
| | operation and decommissioning | 130 | |
| **Final repository for short-lived radioactive operational waste, SFR** | investment | 250 | 1,000 |
| | operation and maintenance | 750 | |
| | decommissioning and closure | | |
| **Final repository for short-lived radioactive decommissioning waste, SFR** | investment | 1,260 | 3,250 |
| | operation and maintenance | 1,750 | |
| | decommissioning and closure | 240 | |
| **Decommissioning of reactor plants** | defuelling operation | 1,650 | 22,170 |
| | decommissioning | 20,520 | |
| **Total reference cost (excluding allowance for unforeseen factors and risk)** | | | 92,000 |

### 2.7.2 Incurred and budgeted costs

Table 2-6 shows, in current money terms, incurred costs through 2009, the forecast cost outcome for 2010 and budgeted costs for 2011. (The reference cost reported in Section 2.7.1 includes the costs from 2012.)

The costs for reprocessing that occurred in an early phase are not included.

The distribution of the total cost, incurred and future, among different facilities is illustrated by Figure 2-16. The distribution is based on the January 2010 price level, whereby incurred costs have been adjusted upwards with the consumer price index, CPI.

**Table 2-6. Incurred costs through 2009, the forecast cost outcome for 2010 and budgeted costs for 2011, current money terms.**

| | Incurred through 2009 SEK M | Outcome 2010 (forecast) SEK M | Budget 2011 SEK M | Total through 2011 SEK M |
|---|---|---|---|---|
| SKB's central functions | 2,325 | 311 | 312 | 2,948 |
| RD&D | 5,745 | 396 | 378 | 6,519 |
| Transport | | | | |
| – investment/reinvestment | 225 | 10 | 45 | 280 |
| – operation | 763 | 38 | 40 | 841 |
| Clab | | | | |
| – investment/reinvestment | 3,644 | 112 | 158 | 3,914 |
| – operation | 1,892 | 158 | 163 | 2,213 |
| Encapsulation plant | | | | |
| – investment | 321 | 25 | 27 | 373 |
| Spent Fuel Repository (siting, site investigations and design) | 3,104 | 156 | 185 | 3,446 |
| SFR and LILW | | | | |
| – investment/reinvestment | 1,073 | 63 | 25 | 1,161 |
| – operation | 757 | 80 | 124 | 961 |
| Total | 19,849 | 1,349 | 1,457 | 22,654 |

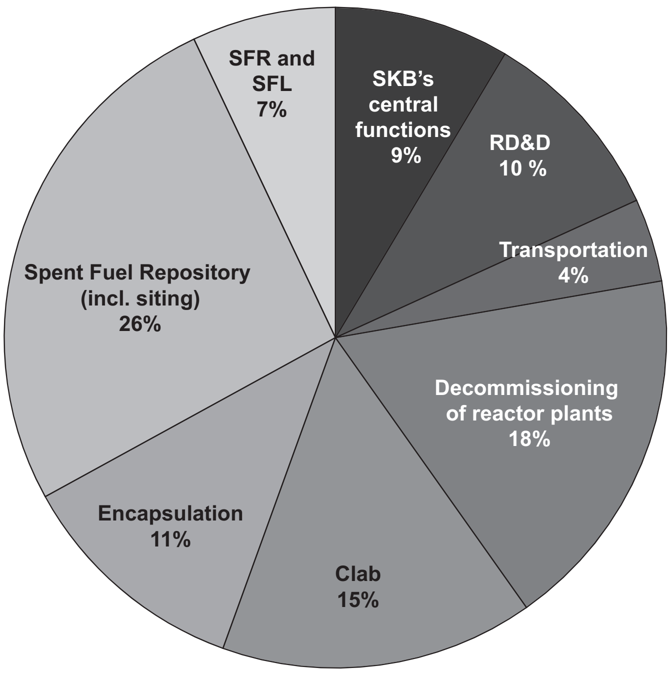



*Figure 2-16. Distribution of the total cost (incurred and future) for the reference scenario entailing operation of reactors in Forsmark and Ringhals for 50 years and in Oskarshamn for 60 years. January 2010 price level.*

# 3 Costs according to the Financing Act

## 3.1 Operating scenarios for the reactors and quantities of spent nuclear fuel and radioactive waste

As was evident from the overviews in Chapter 1, a number of calculations of differing scope and with different premises need to be done in order to arrive at the amounts required by the regulatory framework. All of these calculations are based on the reference calculation, i.e. the one based on the reference scenario described in Chapter 2. A downscaling and transformation is then carried out so that the different calculations conform to the requirements made by the regulatory framework.

The most important key parameters are the operating times of the reactors and the quantities of fuel that follow from this. The reference scenario follows the current plans in place for the power companies, but for the cost calculations under the Financing Act the regulatory framework prescribes what operating times are to apply as a basis for calculations of costs and fees. Two operating scenarios are above all of interest and will be described here. A third, which is not presented, is used to distribute the costs among the licensees.

The one operating scenario concerns the basis for calculation of fees. There it is prescribed that the cost calculations shall be done assuming that the reactors in operation today will be operated for 40 years. A minimum time of six years must be assumed, however, if there is no concrete reason to assume an earlier shutdown. For Plan 2010, the minimum rule entails that all reactors will be operated at least up to and including 2017.

The other operating scenario serves as a basis for the financing amount with a reconciliation at the start of the first fee year covered by the calculation, which in our case means 31 December 2011. By reconciliation is meant that an inventory is made of the quantity of spent nuclear fuel that exists at the stipulated date, including the fuel present in the reactor cores. The costs are then calculated for this quantity. As always, costs for decommissioning of the nuclear power plants are also included in the different calculations.

The calculation for the financing amount is treated with in principle the same level of detail as the calculation for the fee basis as regards the influence of the quantity of nuclear fuel on costs and timetables, but more approximately as regards changes in the quantity of radioactive waste.

Operating data and fuel quantities for the scenario with 40 years of operation are presented in Table 3-1. Table 3-2 also shows the quantities in the reference scenario for the sake of comparison.

The cost accounting further on in the chapter is carried out in relatively great detail for the 40-year scenario (Section 3.5.2). Only the total amount is given for the reconciliation at 31 December 2011 (Section 3.5.3).

## 3.2 Changes in the system compared with the reference scenario

The consequences for the system of the changes in fuel and waste quantities that are made compared with the reference scenario are primarily dependent on the operating time for the facilities. The rate of deposition of the spent fuel canisters is also affected, due to the fact that the proportion of “old” fuel relative to the total quantity increases, which makes it easier to keep the temperature around the canister after deposition within the specified limit.

Other changes are a consequence of the fact that facilities or facility parts for management of operational waste or volumes intended for waste from another party are to be omitted from the cost calculation under the Financing Act. Such changes are, however, of less cost-related importance than those associated with changed fuel and waste quantities.

**Table 3-1. Operating data plus electricity production and fuel quantities at the nuclear power plants.**

| Start commercial operation | | | Thermal capacity/ net capacity MW | Energy production through 2010 TWh | Energy production mean value from 2011 TWh/y | Fuel through 2010 tU | Total for basic cost: Operation through | Total for basic cost: Energy production TWh | Total for basic cost: Spent fuel tU |
|---|---|---|---|---|---|---|---|---|---|
| F1 | (BWR) | 10/12 1980 | 2,928 / 978 | 206 | 8.1 | 758 | 9/12 2020 | 287 | 970 |
| F2 | (BWR) | 7/7 1981 | 2,928 / 990 | 197 | 8.1 | 742 | 6/7 2021 | 282 | 971 |
| F3 | (BWR) | 22/8 1985 | 3,300 / 1,170 | 217 | 9.8 | 748 | 21/8 2025 | 361 | 1,111 |
| O1 | (BWR) | 6/2 1972 | 1,375 / 473 | 96 | 3.5 | 449 | 31/12 2017 | 120 | 517 |
| O2 | (BWR) | 15/12 1974 | 1,800 / 638 | 144 | 6.1 | 552 | 31/12 2017 | 187 | 658 |
| O3 | (BWR) | 15/8 1985 | 3,900 / 1,400 | 201 | 11.2 | 721 | 14/8 2025 | 365 | 1,120 |
| R1 | (BWR) | 1/1 1976 | 2,540 / 855 | 163 | 6.3 | 634 | 31/12 2017 | 208 | 746 |
| R2 | (PWR) | 1/5 1975 | 2,652 / 866 | 181 | 7.0 | 588 | 31/12 2017 | 230 | 704 |
| R3 | (PWR) | 9/9 1981 | 3,135 / 1,051 | 182 | 8.3 | 574 | 8/9 2021 | 272 | 830 |
| R4 | (PWR) | 21/11 1983 | 2,775 / 935 | 178 | 7.1 | 566 | 21/11 2023 | 269 | 827 |
| B1 | (BWR) | 1/7 1975 | 1,800 / 600 | 93 | – | 425 | 30/11 1999 | 93 | 425 |
| B2 | (BWR) | 1/7 1977 | 1,800 / 600 | 108 | – | 455 | 31/5 2005 | 108 | 455 |
| BWR total | | | 22,371 / 7,704 | 1,426 | 53 | 5,485 | | 2,011 | 6,973 |
| PWR total | | | 8,562 / 2,851 | 541 | 22 | 1,728 | | 771 | 2,361 |
| All NPPs total | | | 30,933 / 10,556 | 1,967 | 76 | 7,213 | | 2,782 | 9,334 |

**Table 3-2. Encapsulated nuclear fuel and radioactive waste to be disposed of.**

| | Quantity to be disposed of | | Final repository |
|---|---|---|---|
| Spent BWR fuel<br>Spent PWR fuel<br>Other spent nuclear fuel (MOX, Ågesta, Studsvik) | 4,500 canisters | (6,000) [1] | Spent Fuel Repository |
| Operational waste from NPPs | 43,500 $m^3$ | (50,500) $m^3$ | SFR |
| Decommissioning waste from NPPs | 133,000 $m^3$ | (133,000) $m^3$ | SFR |
| Operational and decommissioning waste from NPPs (near-core components) | 3,300 $m^3$ | (3,800) $m^3$ | SFL |
| Operational waste from Clab and encapsulation plant | 3,400 $m^3$ | (4,300) $m^3$ | SFR |
| Decommissioning waste from Clab and encapsulation plant | 3,300 $m^3$ | (3,300) $m^3$ | SFR |
| Operational waste from SVAFO and Studsvik | 11,600 $m^3$ | (12,600) $m^3$ | SFR |
| Decommissioning waste from SVAFO and Studsvik | 5,000 $m^3$ | (5,000) $m^3$ | SFR |
| Waste from SVAFO and Studsvik | 6,000 $m^3$ | (6,000) $m^3$ | SFL |
| Total short-lived radioactive waste | 199,800 $m^3$ | (208,700) $m^3$ | SFR |
| Total long-lived radioactive waste | 9,300 $m^3$ | (9,800) $m^3$ | SFL |

[1] Figures with brackets refer to the reference scenario as defined in Chapter 2.

In summary, the most important changes compared with the reference scenario are:

- The number of canisters with spent nuclear fuel declines from the 6,000 included in the reference scenario. The remaining basic cost is based on 4,500 canisters and the financing amount on 3,542 canisters. The total operating time for the Spent Fuel Repository and Clink decreases by 15 and 21 years, respectively. The shortening of the timetable also affects other facilities, mainly SFL.
- Operational waste that is disposed of during ongoing operation of the reactors should not be included in the calculation in terms of costs (does not fall under the heading of residual products). It is above all SFR in its current scope that is excluded, but this also has consequences for the transportation system, where the costs for the shipments to SFR are also excluded, along with a proportional share of the costs for SKB's central functions.

- The volumes in SKB's facilities that are occupied by radioactive waste from others besides the licensees (SVAFO and others) should be excluded when calculating costs. This waste is financed from other sources than via the licensees' fund shares.

## 3.3 Calculation methodology

### 3.3.1 Future real price changes

The costs that are reported under the Financing Act are adjusted to take future real price changes into account. These changes are dependent on factors in society at large over which SKB has no control. They are referred to as external economic factors (EEFs) and include the trend in payroll costs (including productivity), costs of input materials and machinery, as well as currency exchange rates. By "real" price increases is meant price increases in addition to the general rate of inflation as expressed by the consumer price index, CPI. The real price and cost trend is defined in the calculation by a trend line for each EEF. The trend lines are plotted based on historical data. The following areas are considered:

- Price and productivity trend for **payroll costs in the services sector**.
- Price and productivity trend for **payroll costs in the construction industry**.
- Price trend for **machinery**.
- Price trend for **building materials**.
- Price trend for **consumable supplies**.
- Price trend for **copper**.
- Price trend for **bentonite**.
- Price trend for **energy**.
- **Exchange rate** in USD for directly imported goods and machinery.

### 3.3.2 The successive principle – a probabilistic calculation method

A probability-based (probabilistic) calculation method that uses standard statistical methods to make allowance for the variations and uncertainties that must be taken into account in estimating the cost of a project, especially in an early phase, is employed for calculation of the amounts to be reported under the Financing Act (see Chapter 1). The method is based on a calculation principle called "the successive principle", which has been developed specially as a tool for management of uncertainties of this type. It is also called "successive calculation". The method is described thoroughly in *Proactive Management of Uncertainty using the Successive Principle*, Steen Lichtenberg, 2000.

Each cost item or variation/uncertainty is regarded as a variable that can assume different values with a varying degree of probability (stochastic variable). A suitable function that defines this probability distribution (probability function) is chosen for each cost item and variation/uncertainty.

A central aspect of the application of the "successive principle" is the methodology for structuring the calculation and setting up probability distributions for the variations/uncertainties included in the analysis. This is done by means of judgements made by a team specially composed for this purpose. SKB has chosen to call this team the "analysis group". The existence and composition of the analysis group and how they work is one of the things that distinguishes "the successive principle" from other probability-based uncertainty analyses.

According to the creator of the method, the group should consist of persons with different qualifications and should otherwise be heterogeneously composed with regard to age, profession, etc. This is to obtain an optimal interaction in the group and minimize the risk of systematic misjudgements or bias in the conclusions it arrives at. The number of participants can vary according to the nature of the project. SKB has found that 16 participants is optimal for the work.

The total cost is then obtained by adding up all the cost items according to the rules that apply to addition of stochastic variables. The result that is obtained is also a stochastic variable, which means that each amount that can be determined is associated with a given probability. In our case, this association is expressed as the "probability that a given amount will not be exceeded". This is designated in the model as the "confidence level" for the amount. A confidence level of 50% means, for example, that the probability that the actual value will not exceed the predicted value is 50%.

The confidence level for the different amounts to be determined under the Financing Act is a matter for the regulatory authorities to decide. From the time the probability-based calculation method was introduced in the mid-1990s, the fees have been calculated based on an amount with a confidence level of 50%. (There is an equal probability that the actual amount will be more or less than the calculated amount.) This confidence level also constitutes the basis for the amounts reported below.

The guarantee that has to be pledged for unplanned events is determined on the basis of a much higher confidence level. The level used in this cost accounting is 80% (Section 3.5.4).

The method also provides indications of where the major uncertainties are. They can then be broken down and analyzed in greater detail, after which the calculation is repeated, leading to reduced uncertainty. This "successive" convergence towards an increasingly accurate result has given the method its name.

### 3.3.3 Brief description of the applied methodology

Certain aspects of our unique project warrant a departure from the theoretical formulas for addition of stochastic variables. Instead, SKB uses an iterative method controlled by a random number generator. The method, which is used widely in various contexts, normally goes under the name of Monte Carlo simulation. The method provides a high degree of flexibility, which is very well suited to the special problems that must be addressed. Examples of such problems are:

- The calculation extends over a very long time. In a present value calculation, the effects of various events will differ depending on the chosen discount rate and when the event occurs.
- There are dependencies between some of the stochastic variables that are identified by the analysis group.
- The calculation is very large and includes a large number of variations and uncertainties. The Monte Carlo simulation gives us a means to follow and record the calculation procedure in detail, which is desirable for checking and understanding how different events can affect the outcome.
- Certain events are so momentous that they fundamentally alter the calculation basis. Such events must be handled in a two-step process: The probability that an event will occur and then what the possible outcomes are.

Monte Carlo simulation entails running through the calculation a number of times, called cycles or iterations. In each cycle, the outcome for each variable is determined on the basis of the chosen probability distribution by letting a random number, specific for each variable, determine the confidence level. The set of random numbers is renewed for each cycle. One cycle in the model can thus be said to represent one "execution" of the project. The final result consists of the probability distribution given by all calculation cycles taken together. The simulation in the plan calculation encompasses 2,000 cycles, which has been judged to provide sufficient accuracy in the result.

The application of the method is illustrated schematically in Figure 3-1. The following description relates to the drawings in the figure.

The system is broken down into a number of "calculation objects". These objects correspond roughly to the different cost categories: investment, operation, decommissioning, backfilling and closure for different facilities.

The input values in the calculation consist of the "probable" cost for each calculation object and for the total amount **(1)**. The probable costs are normally taken from the scaled-down reference calculation, which does not include an allowance for unforeseen factors and risk.

The next step is to determine what variations and uncertainties are to be included in the uncertainty analysis. They may be of such a nature that affect different calculation objects in several parts of the system **(3)**, for example changed timetable or changed number of canisters, or they may only affect single calculation objects **(2)**, for example uncertainty in workforce or canister cost. Each variation is defined in terms of its

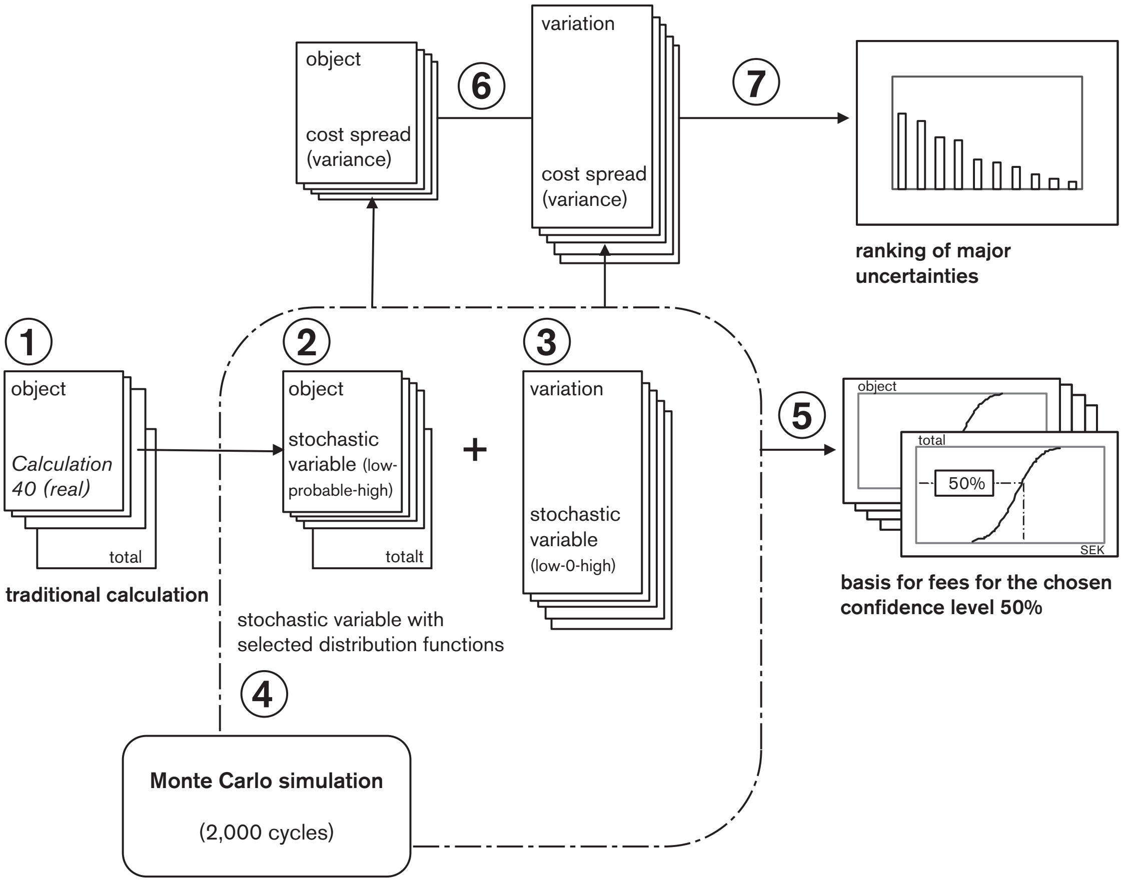



***Figure 3-1.*** *Schematic description of calculation steps (numbers refer to description in text).*

scope (low and high alternative) and an assessment is made of which calculation objects are affected by the variation. The low and high alternatives are given together with their confidence levels.

Subsequently, the cost impact on different calculation objects of the variations and uncertainties chosen to be included is evaluated. Since both the calculation objects and the variations and uncertainties have been defined not only with their probable reference costs but also with a range of values (lowest and highest cost related to confidence levels), the component cost items can be described as stochastic variables with associated distribution functions. The functions are chosen so that the probability distribution fits the character of the variation as closely as possible. Special properties of the variation, such as a pronounced skewed distribution of the outcome or an either-or value (discrete distribution), may affect the choice of probability function.

Finally, the outcome is calculated and summed in the Monte Carlo simulation.

For each object as well as for the system as a whole, the result gives a distribution function **(5)** from which the cost can be obtained for the chosen confidence level. In addition, partial results **(6)** are drawn off during the course of the calculation procedure which enable the uncertainties in the analysis to be evaluated and ranked **(7)**.

Since several of the variations included in the calculations greatly influence the timetable, the final result varies with different discount rates.[10] The calculations are therefore carried out for each discount rate of interest.

The basis for the supplementary amount is calculated in the same way as the basis for the remaining basic cost but includes more exceptional variations with a theoretical system or timetable impact.

[10] For example, an uncertainty allowance that is 20% without discounting at a 50% confidence level may be 15% after discounting at a certain discount rate. This is due to the fact that great uncertainties that lie far in the future lose importance when discounted.

## 3.4 Variations and uncertainties taken into account in the calculation

### 3.4.1 General

As was described in the preceding section, variations and uncertainties are handled according to the successive principle by first being taken out and treated separately. This is done by means of a definition of "general conditions", which establish the calculation premises in the "normal case". In a second step, variations around these general conditions are defined and costed. This is done by means of a three-point estimation where low value, probable value and high value are estimated. Both of these steps are carried out by the specially composed analysis group. Finally, a statistical summation is made of the uncertainties, in SKB's case by means of Monte Carlo simulation.

The three-point estimation in the application used by SKB is done by specifying a low value and a high value around the probable value. Both the low value and the high value are linked to a certain probability. If there are special reasons for choosing another one, the probability 1:10 is used.[11] It should be emphasized that the low and high values are not limit values. The limit values, in other words the extreme minimum and maximum values, follow from the probability function set up on the basis of the three-point estimation and can differ considerably from the low and high values.

In the description below, the probability of the low or the high value is only given if it deviates from the normal 1:10.

It should be pointed out that it is not normally possible to clearly identify a low and a high alternative for variations that affect the timetable. The cost effect of the variation is affected by discounting. Postponing activities normally leads to increased costs, since intervening activities are prolonged, and postponement could then be considered a high alternative. However, the purpose of the calculation is to provide a basis for estimating the fee requirement, and discounted costs play an important role in that analysis. With a positive real interest rate, the postponement of activities can, due to the present value effect, lead to a reduction of the basis for fees and thereby a low alternative. But since it is necessary in the calculation model that the designations low and high consistently relate to a certain course of events rather than certain relative amounts, SKB uses a convention whereby the situation after discounting of the future costs determines the designation.

Certain calculation premises are fixed and should thus not be questioned or evaluated by the analysis group. Determinations of which premises are fixed are made by SKB's management, usually in consultation with the regulatory authority. They are designated "fixed premises" in the successive calculation. Examples of such fixed premises can be:

- The social system and its institutions will endure throughout the calculation period.
- The Nuclear Fuel Programme does not include reprocessing as an alternative.
- Only the KBS-3 method (in different variants) is considered.
- Fuel quantities are fixed by the reactor operation time stipulated in the Financing Act.
- The calculation considers the real price trend and is set up at today's price level.

All the fixed premises identified in the plan calculation apply in the uncertainty analysis that underlies the determination of the remaining basic cost and the basis for the financing amount. Certain of the fixed premises do not, however, apply in the uncertainty analysis that is done to determine the supplementary amount. Instead, these premises are converted to general conditions and can thereby be varied. As a result, the uncertainty analysis for the supplementary amount includes more uncertainties (variations) than the calculation for the remaining basic cost and the basis for the financing amount.

An example of a fixed premise that does not apply for the supplementary amount is the siting of the Spent Fuel Repository. In the calculation of the remaining basic cost and the basis for the financing amount, a siting in Forsmark applies as a fixed premise. In the calculation of the supplementary

[11] The probability 1:10 entails that there is a 10% probability that the outcome will not exceed the low value and a 90% probability that it will not exceed the high value.

amount, on the other hand, siting constitutes an uncertainty, so the analysis group takes into account the risk that a new siting process may be required.

Two sets of general conditions with associated variations have thereby been identified in the plan calculation. The complete list is very extensive, more or less comprehensive. The first set (category 1) consists of variations that are included in all calculation bases, i.e. the remaining basic cost, the basis for the financing amount and the supplementary amount. The second set (category 2) is only included for the supplementary amount.

For the sake of clarity, both in this report and for the work of the analysis group, the uncertainties have been divided into a number of groups:

- **Society**. This group includes uncertainties over which SKB has very little or no influence. Examples are legislation, regulatory matters and politics in general. This includes the question of how value shifts in society with regard to nuclear power can affect the execution and costs of the project. Question of a socioeconomic nature are, however, dealt with separately in the "Economics" group.
- **Economics**. This group is of the same character as the first group, "Society", but with the emphasis on economic conditions such as the real price trend for wages and input materials, business cycle factors and currency risks.
- **Execution**. This includes timetable strategies, siting questions, strategy for decommissioning of the reactor plants, etc.
- **Organization**. This mainly concerns how the future construction or decommissioning projects should be executed and managed in organizational terms.
- **Technology**. All purely technical questions are included in this group. For natural reasons, the greatest uncertainties pertain to the future facilities for management of both nuclear fuel and radioactive waste. A very large group within this area consists of most object-specific variations or uncertainties (explained below).
- **Calculation**. This group considers the risks of misjudgements in the actual calculation work. They can consist of both overestimation of the difficulties (pessimistic judgements) or underestimation (optimistic judgements).

**Object-specific variations** consist of specified or more standardized variations that affect the probable cost for each object (a total of 64 objects). This thus includes variations that remain after all variations around the general conditions have been taken into account. Examples of such variations are changes in building volume or operating organization for individual objects, or varying requirements on execution (for example deposition). For certain objects a standardized variation is assumed without being able to point to any specific cost factor.

Object-specific variations are usually within the interval –20% to +30%, but may have a much wider range for certain objects. This applies above all to certain objects included in the dismantling of the reactor plants as well as less cost-demanding objects where even small disturbances can have a large percentage effect.

One object-specific uncertainty of interest concerns the investment in SFL. The repository is in a very early stage of development, which means that uncertainty regarding its final design is great. The variation around the probable value has been given a relatively large span: low value –30% and high value +100%.

It should be reiterated that if nothing else is specified, the stipulated low and high values are linked to a probability of 1:10.

An account of the variations and uncertainties for the different groups above is given in the following sections. Within each group, the ones that belong to category 1 are described first, and then the ones that belong to category 2 and are thus only included in the basis for the supplementary amount.

### 3.4.2 Variations and uncertainties in the group "Society"

It is assumed that changed **legislative and regulatory requirements** could have a great impact on costs, and in particular there is a great probability that these requirements will increase, resulting in cost increases. In the evaluation of uncertainty, a distinction is made between requirements that apply to nuclear activities and requirements that apply to construction and industrial activities in general. The former are assumed to influence both investment and operation, while the latter are assumed to only influence the investment costs. The influence lies in the interval –5% to +30%.

#### *Additional variations and uncertainties in the basis for the supplementary amount*

**Value shifts** in society regarding people's attitude to nuclear power are assumed to have a potential effect on costs, above all with respect to legislation and licensing processes, but also with respect to general requirements. The impact on costs can lead to both higher and lower costs compared with the probable value. The effect is simulated in the model as an annual decrease or increase of the operating cost for the system by –5% or +30% per year, respectively.

**The operating time for the reactors** does not normally affect the system, since this is a fixed premise given by the regulatory framework. There is an exception, however: the timetable for decommissioning of the nuclear power plants. This timetable is based on the reference scenario and thus given by 50 or 60 years of operation of all reactors (except Barsebäck).

An earlier shutdown (on average for all reactors) means either that dismantling is brought forward or that extra costs are incurred for shutdown operation during the period between shutdown and dismantling. A later shutdown, on the other hand, means that the cost of the whole dismantling process is postponed. Given a positive real interest rate, this results in an increased return on the assets in the Nuclear Waste Fund. The low alternative is based on an average operating time of 70 years. The high alternative is based on operation up to and including 2018.

### 3.4.3 Variations and uncertainties in the group "Economics"

The calculation is based on assumptions concerning **the real price and cost trend** within a number of areas, and the uncertainty in these assumptions is included in the uncertainty analysis. The real price and cost trend is defined in the calculation with trend lines, which are based wherever possible on historical data, see Section 3.3.1. The analysis group evaluates possible discrepancies in these trend lines.

**The impact of business cycle fluctuations** on the costs is one of the uncertainties in the group "Economics". In the long term it can be assumed that cyclical fluctuations even out, but they can be of importance during short, cost-intensive periods. Two such periods have been identified. Firstly the investment phase for the Spent Fuel Repository and the encapsulation plant, between 2015 and 2025, and secondly the period during which most of the nuclear power plants are being dismantled, which will start in the 2030s and extend into the 2040s. For the facilities within the Nuclear Fuel Programme, cyclical fluctuations are assumed to have an impact of between –15% and +25%. The equivalent effect for dismantling is –25% to +20%. The reason the dismantling costs are affected in a more favourable direction is that it is assumed to be possible to some extent to adapt the timetables for dismantling to the economic situation.

### 3.4.4 Variations and uncertainties in the group "Execution"

In the probable case it is assumed **that the licensing process for the Spent Fuel Repository and the encapsulation plant** will take about five years. In the low and high alternatives, the length of the licensing process is assumed to be four and ten years, respectively. However, the delay entails a longer decay period for the spent nuclear fuel, and with a moderate increase in the deposition rate the final date can be retained despite the delay.

**The time required for construction of the Spent Fuel Repository** is estimated in the probable case to be ten years. After that the facility can be put into operation and deposition commenced. The construction time is assumed in the variation to be between nine and 16 years. Here again it is assumed that the deposition rate can be increased in the event of a delay.

**Operating disturbances due to damage and theft etc.**. It is assumed that the operating disturbances can be made up for by overtime or extra shifts. A general cost increase of 5% in the operation of the encapsulation plant and the Spent Fuel Repository is assumed to cover the extra costs. (Any bodily injury or material damage is covered by insurance and is not included in the calculation. However, the insurance premiums are included as a part of the operating cost.)

**The time it takes to dismantle the NPPs** affects time-dependent costs such as physical security and maintenance of the reactor plant, but not the costs of the dismantling work itself. It is assumed in the variation that this time is shortened or prolonged by two years.

**The time taken by defuelling operation**, i.e. from shutdown of the reactor until the spent fuel has been removed, varies between one and five years. In the probable case, this time is estimated at two years.

**The date when deposition starts at the extended SFR** affects not only the investment cost, but also the date when dismantling of the Barsebäck reactors can start. A delay of five years is assumed in the variation, which means that the extended SFR will be commissioned in 2025.

**The date when deposition starts in SFL** is relatively far ahead in time in SKB's planning premises: 2045. In the variation, it is assumed in the low alternative that the plant is built so that deposition can begin in 2053. Deposition of the long-lived waste is then finished at the same time as that of the short-lived waste. In the high alternative, deposition is assumed to begin in 2030.

**Strategy for waste management during dismantling of the NPPs.** By means of a more efficient strategy for waste management, it is assumed that the time required for dismantling can be reduced by two years. Possible efficiency improvements are a common waste treatment plant for the NPPs and the option of depositing very low-level waste in local near-surface repositories.

### *Additional variations and uncertainties in the basis for the supplementary amount*

**General delays in the commissioning of the encapsulation plant and the Spent Fuel Repository**. This uncertainty differs from delays in the licensing process described above in that the cause here is more general and above all linked to political decisions. A delay of 15 years is assumed. Like the delay in the licensing process, the effect on the final date is limited due to decay of the fuel and the possibility of increasing the deposition rate.

**Disturbances in operation due to serious technical problems, accidents etc**. are assumed to only affect operating conditions. (Any bodily injury or material damage is covered by insurance and is not included in the calculation. However, the insurance premiums are included as a part of the operating cost.) The damage is assumed to be of such a scope that it results in an interruption in operation lasting a total of five years. The damage is furthermore assumed to occur at a relatively late stage so that the lost time cannot easily be made up. It is assumed that a full workforce is maintained constantly during the stoppage, indicating that it is not known in advance how long the interruption will be.

**The siting of the Spent Fuel Repository** includes a variation where the selected site at Forsmark is not accepted and a new siting process has to be started. The probability of this happening is set at 1:20. The cost effect of the variation is varied with respect to the delay in the programme that arises with the chosen extreme cases of seven and 25 years and with respect to whether the repository can be sited at the coast or further inland.

**The siting of the encapsulation plant includes a variation where the facility is located at the site for the Spent Fuel Repository (Forsmark)**. This alternative entails increased operating costs and the elimination of external canister shipments, to be replaced by fuel transport from Clab to the encapsulation plant. The probability of this happening is set at 1:20.

**The siting of SFL** includes a variation where the repository is sited separately from other final repositories. This is a high alternative entailing costs for separate descents to the deposition level, with a separate supply and operating organization, and with an expanded siting and site investigation programme. The probability of this happening is set at 1:20.

### 3.4.5 Variations and uncertainties in the group "Organization"

The importance of **the efficiency and competence** of the project organization is judged to lie within an interval of –10% to +15% of the investments. The variation is limited to the Spent Fuel Repository and the encapsulation plant.

How **the design of the Spent Fuel Repository and the encapsulation plant** is carried out is assumed to affect the investment costs within an interval of –10% to +20%. The impact includes the period up to commissioning of the facilities.

**The learning effect associated with the decommissioning of the twelve reactor plants** is a question that concerns the actual procedure surrounding the decommissioning of a nuclear power plant. The learning effect when it comes to the dismantling methodology and the dismantling work mainly falls under the external economic factors (EEFs), where it is included in the concept of the productivity trend. The reference calculation is set up without reference to such a learning effect. A low value is assumed entailing that efficiency in the handling of the process increases by 35% from the time the first reactor is dismantled until the last one.

### 3.4.6 Variations and uncertainties in the group "Technology"

Aside from many of the object-specific variations and uncertainties, it is mainly layout and execution principles for the Spent Fuel Repository that are taken into account in the area of technology. There are above all four factors that include uncertainties of significance.

**Adaptation to local conditions.** SKB has selected Forsmark as the site of the Spent Fuel Repository. Even though the site selection and the associated investigations have reduced the uncertainties concerning local conditions, detailed characterization remains to be done. One important uncertainty concerns the fracture structure and other properties of the rock. This is assumed to influence the layout of the underground parts of the facility since the extent of the repository is affected by the block structure in the rock. An example of a low value is a reduction of the extent of the repository due to the assumption that 5% of the canister positions are rejected (probable value is 13%). An equivalent high value is an increase in the extent of the repository due to the assumption that 30% of the canister positions are rejected. Another variation addresses the uncertainty surrounding the design of the repository accesses, i.e. ramp and shafts. In a low alternative it is assumed that the ramp is omitted and an additional shaft for canister transport is included. Two ramps are required in the high alternative. To these variations must be added uncertainties regarding handling equipment etc. which influence the dimensions of rock caverns and tunnels.

The **thermal conditions** constitute another factor of importance for the Spent Fuel Repository. This affects both the fuel, i.e. its decay heat, and the thermal properties of the buffer and the surrounding rock. These conditions influence the spacing between the canisters, which is adjusted so that the temperature limit with regard to the bentonite is not exceeded. The risk of high temperatures can, however, be countered by other measures, such as by limiting the decay heat in the canister either by a lower filling degree (fewer assemblies in a canister) or by a more drawn-out deposition process. This latter method is used as a variable in the model with a variation of the total operating time by a reduction of three years or an increase of four years.

The third factor concerns the conditions surrounding **backfilling of deposition tunnels and closure of the repository**. The low and high alternatives are not expressed in terms of concrete alternatives to the method and materials assumed in the probable case, since this is not possible without extensive studies. The uncertainty is instead expressed in terms of cost impact, where the low alternative entails a cost reduction of 50% while the high alternative entails a cost increase of 60%. In the case of rock caverns that are not in direct contact with the deposition area the cost span is assumed to be –60% to +50%.

Finally, the fourth factor concerns the possibility of a **more cost-effective method for emplacement of the canisters** with associated buffer in the final repository. The reference design is based on deposition of the canisters one by one in holes bored in the tunnel floor. One alternative involves the technique of emplacing the canisters horizontally in long bored holes, each hole containing a large number of canisters. In this way the relatively costly deposition tunnels can be eliminated. The probability of this alternative has been judged to be increasingly high in recent years as the development work has yielded promising results. In this year's calculation the probability is set at 40%.

**Method for rock excavation**. The reference scenario is based on drill-and-blast, with stringent requirements on exposed surfaces and limitation of disturbances in the form of fracturing that spreads into the rock. An alternative method could be full-face boring using TBM (Tunnel Boring Machine) technology. All in all, the uncertainty is deemed to result in a cost span for rock excavation from –20% to +20% in relation to the probable cost.

#### *Additional variations and uncertainties in the basis for the supplementary amount*

**The temperature on the canister surface** is a restriction in the current system. It may not exceed 100°C, but with the desired safety margin the upper limit is set at 90°C. If it could be shown that this restriction can be removed or raised, the deposition period could be shortened. An increase in the deposition rate from 160 canisters per year is relatively simple, since the facilities will be designed for a capacity of 200 canisters per year. An increase in the maximum temperature to 110°C is assumed for this variation, which makes it possible to shorten the operating period for encapsulation and disposal by four years.

### 3.4.7 Variations and uncertainties in the group "Calculation"

**Allowance for unspecified items** is added regularly in the calculation work to cover costs for building parts or other items that experience shows must be included but that are not specified on the drawings or in the specifications on which the calculation is based. This allowance is not to be confused with the allowance for unforeseen factors that is normally included in the deterministic calculations and that refers to events that may occur but may also fail to occur. The allowance for unspecified items is a percentage allowance. The uncertainty in the assessment is set at about 50% in either direction, which results in changes in the costs for building investments by 5% and for rock works by 10%.

**Realism in cost estimates** refers to the fact that the individuals who price the components in the calculation judge complexity and difficulties in execution with a varying attitude. This attitude is normally referred to as pessimism (overestimation of difficulties) or optimism (underestimation of difficulties). The uncertainty is personal and is therefore divided among the areas of responsibility of the different calculators. This normally coincides with different technical areas relating to construction, rock works, process, operation, decommissioning etc. The uncertainty varies between different calculators depending on the complexity of what they estimate, but is in most cases between –20% and +35%.

## 3.5 Costs

### 3.5.1 General

The costs in this chapter refer to the amounts which licensees are obliged to report to the regulatory authority under the current regulatory framework. What is included has been described in previous sections, but two things should be highlighted again to underscore the difference between the amounts given here and those reported in Chapter 2:

- The costs refer only to the licensee's future costs from 2012 for managing and disposing of spent nuclear fuel and such radioactive waste that is not operational waste. The price level is January 2010. The amounts include adjustment for real price changes according to the method for application of external economic factors, EEFs.
- Allowance for unforeseen factors and risk has been added to the total amounts. This allowance has been calculated using the method described in Section 3.3. The allowance has been obtained by choosing a given confidence level and applying it to the probability distribution that is the result of the risk analysis. The confidence level that has been used is described below in connection with the amount in question.

The reason the allowance for unforeseen factors and risk is added only to the total amount is because the calculation method used evaluates the total uncertainty. It also coincides with the way the Nuclear Waste Fund is divided up. If each object were to be analyzed separately in the calculations, the "statistical" effect of the low probability that negative or positive events will occur simultaneously for most or all of the objects would be lost.

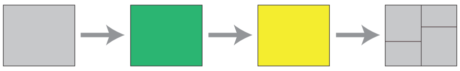
Moreover, an allowance for unforeseen factors and risk calculated in this way cannot be tied to individual objects except by some kind of standard apportionment (for example by proportioning). If it turns out to be expedient to do this for some purpose where the apportionment is more important than the correct calculation outcome, this relatively simple operation is left up to the user of the results.

Regarding the total picture of costs for management and disposal of residual products and other radioactive waste, including incurred costs and budgeted costs for the current year, see the preceding chapter.

### 3.5.2 Remaining basic cost

Table 3-3 shows the future costs attributable to remaining basic cost, which constitutes the basis for calculation of fees.

**Table 3-3. Remaining basic costs from 2012, price level January 2010.**

|  | | Cost per cost category, SEK M | Cost per facility, SEK M |
|---|---|---|---|
| **SKB's central functions and RD&D** | | 9,680 | 9,680 |
| **Transportation system** | investment | 1,180 | 2,440 |
| | operation and maintenance | 1,260 | |
| **Clab** | investment | 1,430 | 7,820 |
| | operation and maintenance | 5,630 | |
| | decommissioning | 760 | |
| **Encapsulation plant and canister factory** | investment | 2,910 | 10,700 |
| | operation and maintenance | 7,590 | |
| | decommissioning | 200 | |
| **Spent Fuel Repository** | operation and maintenance | 5,540 | 5,540 |
| **– Off-site facilities** | investment and operation | 230 | 230 |
| **– Operations areas above ground** | investment | 6,890 | 7,070 |
| | decommissioning | 180 | |
| **– Facilities below ground** | investment | 4,820 | 8,070 |
| | backfilling | 1,200 | |
| | decommissioning and closure | 2,050 | |
| **Final repository for long-lived radioactive waste, SFL** | investment | 770 | 1,480 |
| | operation and maintenance | 340 | |
| | decommissioning and closure | 370 | |
| **Interim storage facility and near-surface repositories at the nuclear power plants** | investment | 0 | 0 |
| | operation and decommissioning | 0 | |
| **Final repository for short-lived radioactive operational waste, SFR** | investment | 0 | 0 |
| | operation and maintenance | 0 | |
| | decommissioning and closure | 0 | |
| **Final repository for short-lived radioactive decommissioning waste, SFR** | investment | 1,140 | 2,920 |
| | operation and maintenance | 1,560 | |
| | decommissioning and closure | 220 | |
| **Decommissioning of reactor plants** | defuelling operation | 1,780 | 22,060 |
| | decommissioning | 20,280 | |
| **Total Cost *Calculation 40 (real)* (excluding allowance for unforeseen factors and risk)** | | | 78,010 |
| **Allowance for unforeseen factors and risk** | | | 11,800 |
| **Total remaining basic cost** | | | 89,810 |

The costs reported in the table at the object level do not include an allowance for unforeseen factors and risk. This allowance is reported at the total level at the bottom of the table.

The costs for different facilities are presented under the items *investment, operation and maintenance, backfilling* and *decommissioning and closure* (backfilling refers only to backfilling of deposition tunnels). Normally, only the costs that arise before a facility or a part of a facility is commissioned, or major reinvestments when a facility has reached a considerable age (for example for Clab), are allocated to *investment*. However, in the final repository for spent nuclear fuel, where build-out of the deposition tunnels will proceed continuously during the deposition phase (the operating phase), the costs for this work are also included in investment.

The remaining basic cost amounts to a total of SEK 89.8 billion. Of this, SEK 11.8 billion is allowance for unforeseen factors and risk. Of this amount, approximately 72% falls within SKB's sphere of activity and is thereby borne in common by the licensees (joint costs). The remainder, about 28%, comprises costs for activities where each licensee has his own cost responsibility and does not share the costs with other licensees (separable costs). The separable costs pertain to the decommissioning of the licensee's reactor plants. However, management of the radioactive decommissioning waste falls within SKB's sphere of responsibility.

Figure 3-2 shows the costs according to Table 3-3 distributed over time. The allowance for unforeseen factors and risk is not included in the chart, since it can only be distributed over time by means of an approximate method (this is not done here). The distribution over time is only associated with the scaled-down reference calculation, see Section 1.3.

Figure 3-2 also shows a simplified timetable for the different facilities to give an idea of their influence on the cost flow. It shows, for example, that the two cost peaks in the chart stem in part from the investment in the encapsulation plant and the Spent Fuel Repository, and in part from the decommissioning of the nuclear power plants.

The graph in Figure 3-3 shows the present value of the remaining basic cost for different values of the discount rate. Since the graph shows the total amount, it includes the allowance for unforeseen factors and risk. This is made possible by carrying out Monte Carlo simulations for each discount rate of interest. The graph is based on simulations for each integral discount rate from 0 to 5 percent.

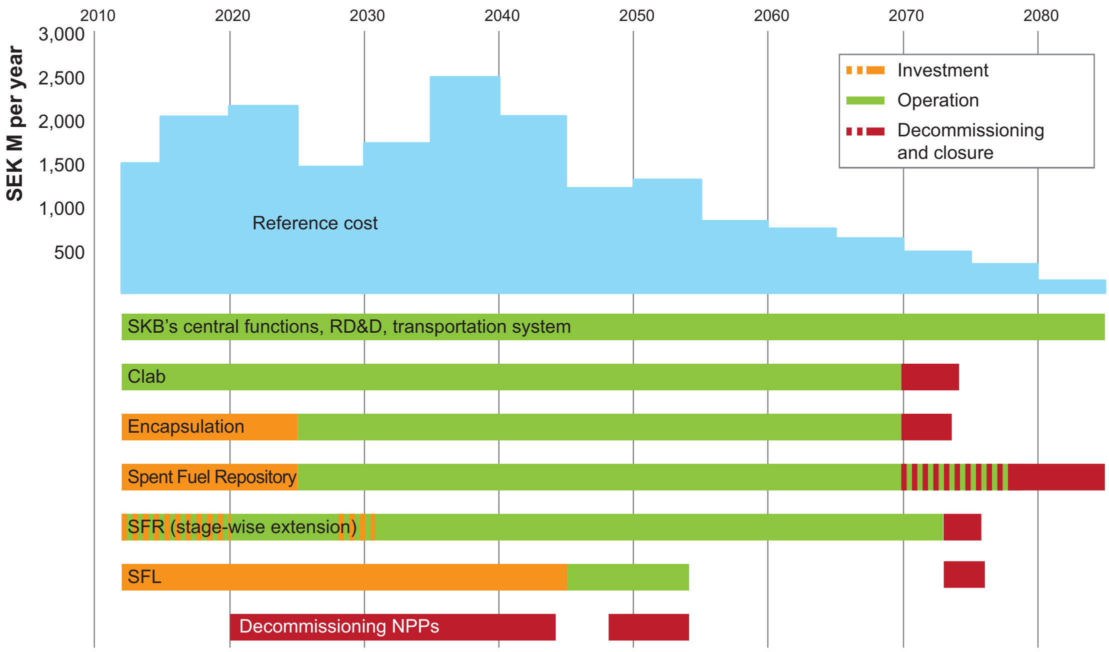



***Figure 3-2.*** *Remaining basic cost, excluding allowance for unforeseen factors and risk, distributed over time and associated timetable for the facilities, price level January 2010.*

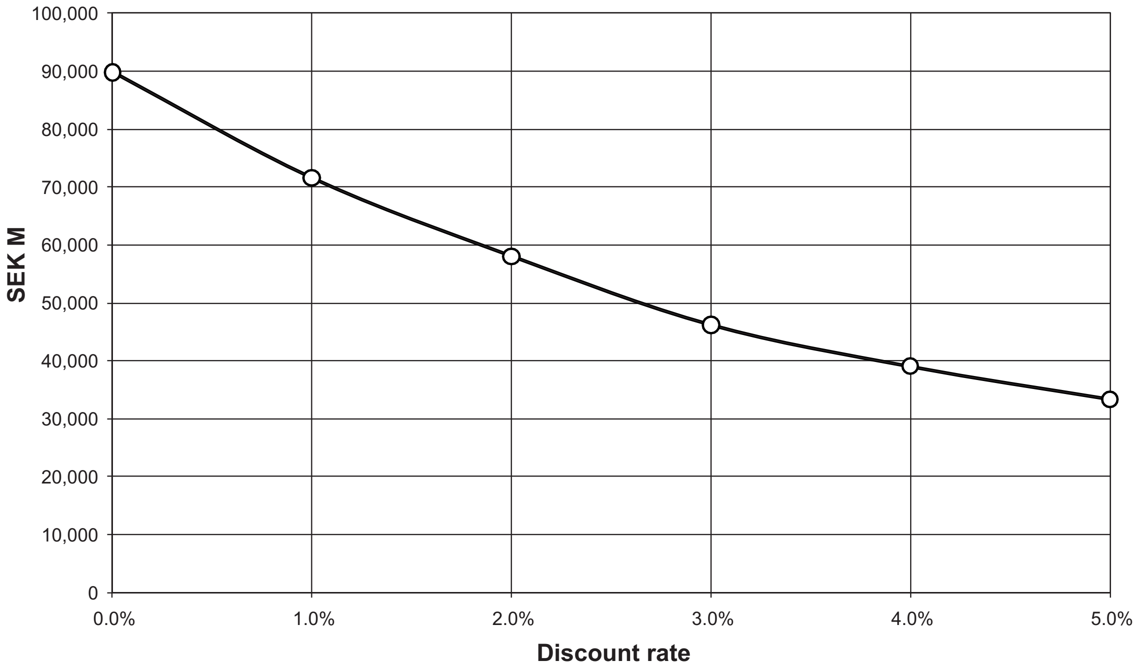



*Figure 3-3. The present value of the remaining basic cost as a function of the discount rate, price level January 2010.*

### 3.5.3 Basis for financing amount

The financing amount serves as the basis for one of the guarantees which the licensees must pledge in addition to fee payments. The amount is calculated in the same way as the remaining basic cost in the preceding section but should, when it comes to residual products, only include those that exist at the end of the year before the year when the calculation begins. In our case, this means the residual products that exist on 31 December 2011. This means that the number of canisters decreases from 4,500 to 3,542.

The basis for the financing amount is SEK 83.6 billion, which is SEK 6.2 billion lower than the remaining basic cost. (The total financing amount is calculated by the regulatory authority by adding the so-called extra costs to the basis for financing amount reported by SKB.)

### 3.5.4 Supplementary amount

The supplementary amount is the basis for one type of guarantee which the licensees have to pledge in addition to fee payments and in addition to the guarantee mentioned in the preceding section. This amount is also calculated in basically the same way as the remaining basic cost, but with three important differences:

- The amount serves as a basis for guarantees intended to cover reasonable costs for unplanned events. The uncertainty analysis therefore includes events and uncertainties that are assumed to be of a considerably greater scope and of a more fundamental nature than those included in the calculation of the other amounts. See the compilation of variations and uncertainties in Section 3.4.
- The supplementary amount is obtained as the difference between an amount that represents this upper reasonable limit and the remaining basic cost. The higher amount is obtained from the uncertainty analysis at a higher confidence level than the 50% chosen for the remaining basic cost. SKB considers a confidence level of 80% to be a level that corresponds to the “reasonableness” stipulated by the regulatory framework.
- The supplementary amount only concerns those parts of the total system that belong to the reactor owners Forsmarks Kraftgrupp AB, OKG Aktiebolag and Ringhals AB. In its capacity as “other licensee”, Barsebäck Kraft AB is not subject to the obligation to report a supplementary amount.

The supplementary amount for the three reactor owners has been calculated at a confidence level of 80% to be SEK 13.1 billion.