Technical Report

TR-09-23

Plan 2008

Costs starting in 2010 for the radioactive residual products from nuclear power

Basis for fees and guarantees in 2010 and 2011

Svensk Kärnbränslehantering AB

December 2008

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

Plan 2008

Costs starting in 2010 for the radioactive residual products from nuclear power

Basis for fees and guarantees in 2010 and 2011

Svensk Kärnbränslehantering AB

December 2008

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 (referred to in this document as the Financing Act with associated Ordinance). 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-seventh annual plan report, gives an updated version of these costs. As in previous years' reports, the costs are shown both for the system as a whole, including management and disposal of radioactive operational waste plus certain waste deriving from facilities belonging to others than SKB's owners, and for the part of the system that is covered by the regulatory framework mentioned above. The former costs have been based on a scenario concerning reactor operation that is based on the nuclear power plant owners' current planning, while the latter have been based on the operating time of the reactors that is stipulated in the regulatory framework.

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 basic 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 and is the primary purpose of the report.

Stockholm, December 2008

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 of fees to a fund by the licensees, primarily during the period the reactors are in operation, but also later if need be.

The details of this financing are regulated in the so called Financing Act (2006:647) with associated Ordinance (2008:715)[1]. 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 fees based on electricity produced. Reactor owners today are Forsmark Kraftgrupp AB, OKG Aktiebolag and Ringhals AB. A licensee of the latter category, today Barsebäck Kraft AB, pays the fee in the form of an annual amount if a Government decision has decreed that additional fees have to be paid into the fund.

SKB has the task of calculating and compiling the future costs for the four licensees mentioned above. According to the regulatory framework, such a cost accounting shall be submitted to the regulatory authority at given intervals. Earlier regulations prescribed annual cost compilations. In the years to come this shall be done every three years, but during a transition period every other year. Plan 2008, which concerns the basis for fees and guarantees for 2010–2011, will thus be followed by Plan 2010 (2012–2014) and then Plan 2013 (2015–2017).

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 planning around it 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 2007 and the most recent activity plan. 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 to fuel equivalent to 6,000 copper canisters.

Preparations are currently being made by SKB for selection of the site for the final repository for nuclear fuel. The goal is that one of the two sites where the site investigations (now almost completed) have been carried out will be chosen. The cost calculations are based on the assumption of Forsmark as the site in the reference scenario. This choice has been for optimal illumination of different cost aspects and must not be regarded as a commitment on the part of SKB (for example, costs for sea transport of encapsulated nuclear fuel are included and analyzed in this way).

The reference calculation and the figures on which it is based are presented in the report as background information. The Financing Act does not require this presentation. But since this information serves as a basis for other calculations, SKB has found it of value to include it (Chapter 2). Cost estimates required by the Financing Act are presented in Chapter 3.

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 low- and intermediate-level operational waste, SFR.
- Laboratories for development of encapsulation and final disposal technology.

[1] Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities and Ordinance (2008:715) on Financial Measures for the Management of Residual Products from Nuclear Activities.

The reference scenario also includes the following additional facilities:

- canister factory and encapsulation plant for spent nuclear fuel,
- final repository for spent nuclear fuel, SFK,
- interim storage facility for core components, BFA,
- final repository for long-lived low- and intermediate-level waste, SFL, and
- final repository for decommissioning waste (extension of SFR).

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, EIA, overall safety matters, etc. Other costs include costs for decommissioning and dismantling of reactor plants as well as at-plant facilities for interim storage or final disposal of low- and intermediate-level waste.

The Financing Act, along with the Ordinance, stipulates a number of conditions that have an effect on the scope of the reference scenario as well as on the calculation model used by SKB. Such conditions include the reactor operating time on which the estimate of the quantity of waste products is based, as well as the fact that uncertainties with regard to future developments in different areas have to be taken into account. In addition, the calculation should only include waste products, which, according to the Financing Act's definition of residual products, excludes the management of operational waste. Among other things, the existing facility at SFR is excluded from the calculations.

The quantity of spent nuclear fuel and radioactive waste to be disposed of is linked to the operating time of the reactors, and this fee-determining operating time is stipulated in the regulatory framework. The fee calculation is then based on the electricity production that is expected during the same time. The fee-determining operating time should be 40 years for the reactors that are 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.

Aside from the payment of fees, a reactor owner must pledge two kinds of guarantees. One guarantee must cover the fees that have not yet been paid and that relate to the remaining fee-determining operating time. This guarantee declines gradually as the reactor's operating time approaches 34 years but then levels out at a minimum time of six years 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 waste products that exist when the calculation starts (31 December 2009).

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 of reactors all of which 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 results of the calculation are presented below. The amounts pertain to future costs from 2010 and relate to the January 2008 price level.

Remaining basic cost[2]	SEK 75.6 billion
Basis for financing amount	SEK 68.9 billion
Supplementary amount[3]	
– at 80% confidence level[4]	SEK 12.4 billion

[2] The remaining basic cost and the basis for the financing amount are calculated as the median of the results obtained in the risk analysis.

[3] Pertains to Forsmark, Oskarshamn and Ringhals. Barsebäck is not obligated to report a supplementary amount.

[4] The confidence level indicates the probability that the amount will not be exceeded.

Contents

1 The Financing Act and SKB's calculation model 9
1.1 The Financing Act 9
1.2 Amounts to report under the Financing Act 10
1.3 SKB's calculation model 11

2 Costs according to the reference scenario 15
2.1 General system description 15
2.2 Special premises as a basis for the plan calculation 18
2.2.1 Operating scenarios for the nuclear power plants and waste quantities 18
2.2.2 Overall timetable for execution 20
2.2.3 Siting of future facilities 20
2.2.4 Decommissioning of nuclear power plants 21
2.3 Description of facilities in the Nuclear Fuel Programme 22
2.3.1 Research, development and demonstration – RD&D 22
2.3.2 Clab – Central interim storage facility for spent nuclear fuel 24
2.3.3 Encapsulation of spent nuclear fuel 25
2.3.4 Final repository for spent nuclear fuel 28
2.4 Description of facilities in the programme for low- and intermediate-level waste (LILW) 32
2.4.1 Final repository in SFR for short-lived radioactive operational waste 32
2.4.2 Final repository in SFR for short-lived radioactive waste from decommissioning 33
2.4.3 Facilities at the nuclear power plants for interim storage or deposition of low- and intermediate-level waste 34
2.4.4 Final repository for long-lived low- and intermediate-level waste, SFL 35
2.5 Description of the transportation system 35
2.6 Calculation methodology 37
2.7 Costs 37
2.7.1 Future costs 37
2.7.2 Incurred and budgeted costs 39

3 Costs according to the Financing Act 41
3.1 Operating scenarios for the reactors and energy production and waste quantities 41
3.2 Changes in the system compared with the reference scenario 41
3.3 Calculation methodology 43
3.3.1 The successive principle – a probabilistic calculation method 43
3.3.2 Brief description of the applied methodology 43
3.4 Variations and uncertainties taken into account in the calculation 45
3.4.1 General 45
3.4.2 Variations and uncertainties in the group "Society" 47
3.4.3 Variations and uncertainties in the group "Economics" 47
3.4.4 Variations and uncertainties in the group "Execution" 48
3.4.5 Variations and uncertainties in the group "Organization" 49
3.4.6 Variations and uncertainties in the group "Technology" 49
3.4.7 Variations and uncertainties in the group "Calculation" 50
3.5 Costs 51
3.5.1 General 51
3.5.2 Remaining basic cost 51
3.5.3 Basis for financing amount 54
3.5.4 Supplementary amount 54

References 55

Appendix 1 List of spent nuclear fuel and radioactive waste to be disposed of according to the reference scenario with operation of the reactors for 50 and 60 years, respectively, and the regulatory scenario (40 years) 57

Definitions

BFA	Rock cavern for waste.
Burnup	A value which here gives the quantity of energy that has been obtained from the fuel when it is taken out of the reactor for transport to Clab, normally expressed in MWd per kg of uranium (MWd/kgU).
BWR	Boiling Water Reactor.
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%).
Clab	Central interim storage facility for spent nuclear fuel.
HLW	High-level waste.
ILW	Intermediate-level waste.
LILW	Low- and intermediate-level waste.
LLW	Low-level waste.
MWd	Megawatt-day. Unit of energy equal to 24,000 kWh.
MWh	Megawatt-hour. Unit of energy equal to a thousand kWh.
NPP	Nuclear Power Plant.
PWR	Pressurized Water Reactor.
RD&D	Research, Development and Demonstration.
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.
SFK	Final repository for spent nuclear fuel.
SFL	Final repository for long-lived low- and intermediate-level waste.
SFR	Final repository for short-lived radioactive operational and decommissioning waste.
SSM	Swedish Radiation Safety Authority.
tU	Tonne of uranium. Quantity of spent fuel defined as the weight of uranium contained in the fuel assemblies when they are placed in the reactor (prior to irradiation).
TWh	Terawatt-hour. Unit of energy equal to a billion kWh.

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 the nuclear reactors and for decommissioning and dismantling the reactors 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 of fees to a fund by the licensees, primarily during the period the reactors are in operation, but also later if need be.

Paid-in fees are transferred to the Nuclear Waste Fund, whose assets are deposited in an interest-bearing account at the National Debt Office or invested in treasury bills. Investments with a maturity of more than one year are made on the market in ordinary treasury bonds. The licensee is entitled to obtain compensation from the fund for expenditures in connection with his obligations as described above.

The details of this financing are regulated in the so called Financing Act (2006:647) with associated Ordinance (2008:715)[5], here called the regulatory framework. 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. According to the definition in the Financing act, a licensee in the former category is a reactor owner and pays fees based on electricity produced. Reactor owners today are Forsmark Kraftgrupp AB, OKG Aktiebolag and Ringhals AB. A licensee of the latter category, today Barsebäck Kraft AB, pays the fee in the form of an annual amount if further funds have to be paid into the Fund according to a Government decision. The collective designation that will be used in this report for all four nuclear power companies is "the licensees".

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 geographically associated with a given power plant area. Such facilities are interim storage facilities for waste packages or repositories for very low-level operational waste. With few exceptions, these facilities are used only by the licensee on whose power plant site the facility is located. The costs for construction and operation of these facilities do not fall under the Financing Act, since they are operating costs which are paid directly by the licensee. Decommissioning of these facilities, when the time comes, takes place simultaneously with the reactor plants, and the costs for this are reported in the present report as a part of the cost for decommissioning of the nuclear power plants.

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 and dismantling of the reactor plants. 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 the submitted calculations. On the basis of the submitted cost figures,the Government determines the fees to be charged either on produced electricity or annually, as well as the guarantees which the licensee must pledge for future costs that are not covered by already paid-in funds. 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 waste products disposed of.

The quantity of spent nuclear fuel and radioactive waste to be disposed of is linked to the operating time of the reactors, and this fee-determining operating time is stipulated in the regulatory framework. The size of the fees is determined on the basis of the electricity production that is expected during the same time. *The fee-determining operating time* is 40 years for the reactors that

[5] Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities and Ordinance (2008:715) on Financial Measures for the Management of Residual Products from Nuclear Activities.

are 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 the present account, this entails that all reactors are in operation at least until 2015. Three reactors are affected by this minimum limit[6].

Aside from the payment of fees, a reactor owner must pledge two kinds of guarantees. One guarantee must cover the possibility that fees will never be paid because a reactor is shut down before the end of the fee-determining operating period, i.e. before the reactor has reached an operating period of 40 years. This guarantee declines gradually as the reactor's operating time approaches 34 years but then levels out at a minimum time of six year as described above. The second guarantee pertains to the case where 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 increasing the aforementioned guarantee is for some reason not available.

For a licensee of reactors all of which 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.

SKB has the task of calculating and compiling the future costs for the four licensees mentioned above. According to the regulatory framework, such a cost accounting shall be submitted to the regulatory authorities at given intervals. In the long term this shall be done every three years, but during a transition period every other year. Plan 2008, which concerns the basis for fees and guarantees for 2010–2011, will thus be followed by Plan 2010 (2012–2014) and then Plan 2013 (2015–2017).

1.2 Amounts to report under the Financing Act

As a basis for calculating fees and judging the need for guarantees, three amounts are to 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 fee payments during the remaining fee-determining operating time),
- 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).

The remaining basic cost must include all future costs for managing and disposing of the waste 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 2008, this pertains to costs from 2010. The amount is also supposed to cover costs for decommissioning and dismantling 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 calculation method which SKB uses and which is described in Chapter 3. The total basis for fees is finally obtained by adding an amount to cover certain costs for regulatory supervision and other items, called extra costs. These costs are added by the regulatory authority in connection with the calculation of fees and are not itemized in the present report.

The basis for the financing amount is supposed to 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, in other words at the start of the first fee year covered by the calculations. For Plan 2008, this point in time is 31 December 2009. The total financing amount is then obtained in the same way as the fee basis, i.e. certain additions are made by the regulatory authority. The difference between the financing

[6] Oskarshamn 1 has a total operating time of 37 years and should therefore add three more years to the fee-determining operating time, which is then 43 years. Oskarshamn 2 has a total operating time of 35 years and should therefore add one more year to the fee-determining operating time. Ringhals 2 has just passed the limit and gets an addition of a couple of months.

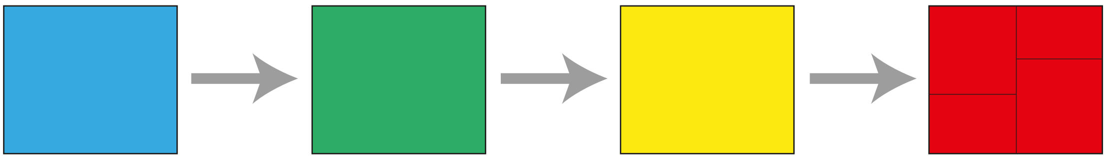
amount and the current content of the Nuclear Waste Fund, plus expected return, provides a basis for estimating the size of the guarantee to be pledged for fees not yet paid during the remaining fee-determining operating time. This estimate is made by the regulatory authority.

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 Ordinance, this upper limit shall be based on "*a reasonable estimate of costs …… that can arise due to unplanned events.*" In SKB's calculation model, this upper limit covers uncertainties with a lower probability of occurring and with greater consequences than 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.

Regarding SKB's interpretation of the concept "reasonable", see section 3.5.4.

1.3 SKB's calculation model

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



Reference scenario based on 6,000 canisters of spent fuel (roughly equivalent to 50/50/60 years of operation of the Forsmark-Ringhals-Oskarshamn reactors).

Scenario in accordance with the Financing Act (based on 40 years of operation of the reactors).

Risk analysis involving evaluation of uncertainties and Monte Carlo simulations (one for each relevant real discount rate).

Allocation of the costs among the four licensees (same proportions as in the Nuclear Waste Fund).

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 of the system, including the timetable for its execution. The current design is called the reference design, while the planning around it 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 2007 and the most recent activity plan. The quantity of spent nuclear fuel and radioactive waste to be disposed of is 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 to enable 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 design and the costs for the reference scenario are presented in Chapter 2 of this report.

Step 2 (green box)

The Financing Act and the Financing Ordinance stipulate a number of conditions that have an effect on the scope of the reference scenario as well as on the calculation model used by SKB. This applies above all to the operating time for the reactors, which comprises the basis for the estimate of the quantity of residual products. In addition, the calculation should only include waste products, which, according to the definition of residual products in the Financing Act, excludes operational waste. Among other things, the existing facility at SFR is excluded from the calculations.

Regarding the operating time for the reactors, the regulatory provisions concerning the fee-determining operating time apply, in other words 40 years of operation with a minimum of six remaining years of operation.

These deviations from the reference scenario that was calculated under 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 also prescribes that the cost accounting should in most cases pertain to expected costs, which means that the result has to take into account the uncertainties that exist regarding future developments in various areas. SKB does this by means of a probability-based calculation method (risk analysis). The requirement to submit an estimate of the supplementary amount, i.e. the cost effect of unplanned events, further underscores the need for such an analysis.

The risk analysis method that is employed goes under the name of "The successive principle" or "successive calculation". The method and the uncertainties that have been taken into account are presented in detail in Chapter 3.

Step 4 (red box)

Allocation of assets to the Nuclear Waste Fund takes place under four main headings, one for each licensee.[7] 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 collection of tables.

Interconnection 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 Act, 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 basic calculation (blue in Figure 1-2) is dealt with fully in Chapter 2. The calculation "Ref. 40" (green) as well as the risk analysis (yellow) are dealt with in Chapter 3. The other two are not treated further in this report, except that the outcome "basis for financing amount" is presented. This amount is the result of the calculation "Ref. today". The allowance for unforeseen factors and risk is taken from the risk analysis for "Ref. 40" (proportioned).

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

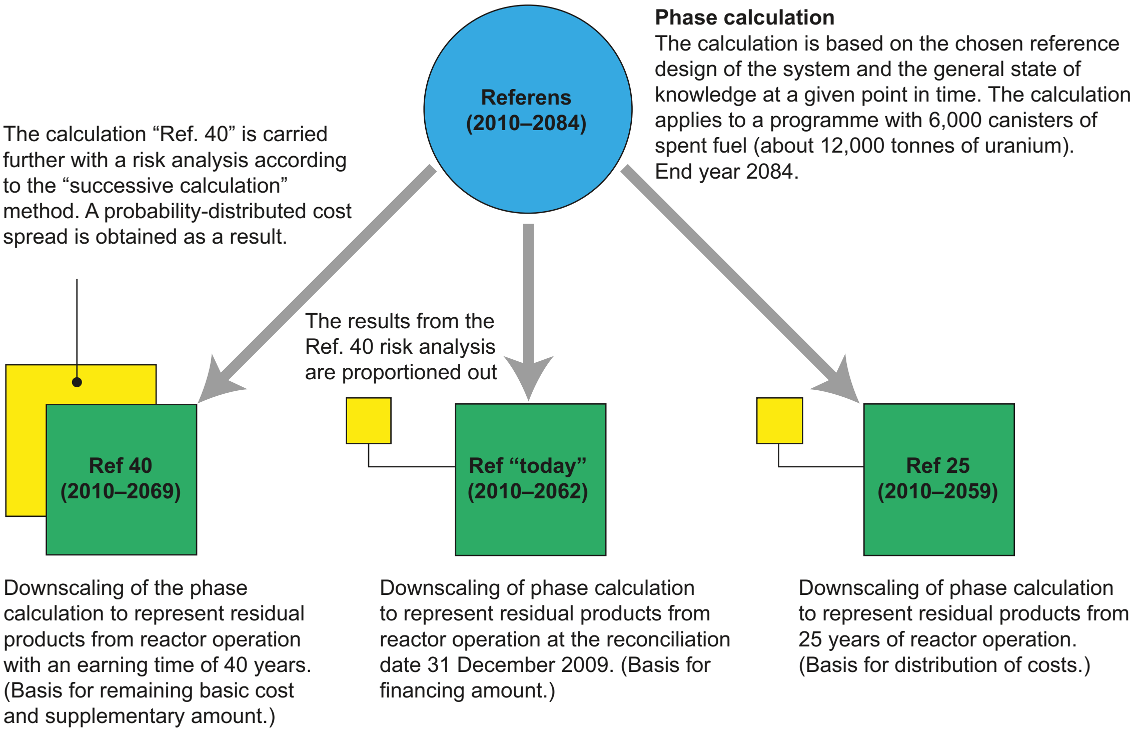


Figure 1-2. *Relationship between the calculations that are set up.*

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, which are presented in greater detail in the next section, are necessary in order for a complete cost calculation basis to be compiled.

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

The facilities which SKB operates or is planning for in the future are intended for disposal of residual products and operational waste from the Swedish nuclear power plants. At the same time these facilities must, in return for compensation, also receive smaller quantities of radioactive waste from industrial plants, research facilities and other institutions. 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 waste products of nuclear power and other radioactive waste is shown by Figure 2-1. The figure illustrates the flow of waste 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 waste 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 waste products of nuclear power and other radioactive waste is currently made by SKB in the two programmes being conducted: The Programme for spent nuclear fuel and the Programme for low and intermediate level waste. To this can be added a number of auxiliary systems as listed below.

Programme for spent nuclear fuel

Interim storage, encapsulation and final disposal of spent nuclear fuel. This includes the following facilities: Clab, the encapsulation plant (with canister factory) and the final repository for spent nuclear fuel (SFK).

Programme for low and intermediate level waste

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.[8] Facilities for short-lived operational and decommissioning waste include local interim storage facilities and SFR. The facilities for long-lived waste are the interim storage facility (BFA, rock cavern for waste) and the final repository long-lived low- and intermediate-level waste (SFL).

[8] By "short-lived nuclear waste" is meant material with a significant content of radionuclides with a half-life of less than 30 years. Other waste is designated long-lived nuclear waste.

Table 2-1. Types of waste products and other radioactive waste to manage and dispose of.

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. 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 decommissioning of the reactor plants. Disposed of in SFR, as long as this is in operation, and later in the final repository for long-lived low- and intermediate-level waste (SFL), which in the reference case is assumed to be located at SFR at great depth in the rock (final site selection not made).
Short-lived low- and intermediate-level waste	Operational waste from the NPPs or other institutions, in containers of concrete or steel. Disposed of in SFR. Interim-stored where the waste is produced (local interim storage).	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 decommissioning of the reactor plants. Interim-stored locally. Disposed of in SFR, as long as this is in operation, and later in the final repository for long-lived low- and intermediate-level waste (SFL).
Long-lived low- and intermediate-level waste	Costs for local interim storage of operational waste from the reactor plants. Operational waste from other stakeholders, mainly Studsvik. Final disposal in the repository for long-lived low- and intermediate-level waste (SFL).	Operational and decommissioning waste from the reactor plants, including replaced reactor internals. Operational waste is interim-stored in Clab or BFA (Oskarshamn). Interim storage facility for decommissioning waste not determined. Disposed of in the repository for long-lived low- and intermediate-level waste (SFL).
Long-lived high-level waste products	Spent fuel and other high-level waste, mainly from Ågesta and Studsvik. Assumed in the reference scenario to be encapsulated in the same copper canisters as other fuel and emplaced in the final repository for spent fuel (SFK).	Spent fuel encapsulated in copper canisters. Emplaced in the final repository for spent fuel (SFK), which is assumed in the reference scenario to be located at Forsmark (final site selection not made).

Auxiliary systems

- The transportation system based on the specially designed ship m/s Sigyn and terminal vehicles for loading and unloading of the cargo.
- 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 and the Canister Laboratory in Oskarshamn.
- SKB's central functions with management and business support plus special units 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 various facilities are described in section 2.3.

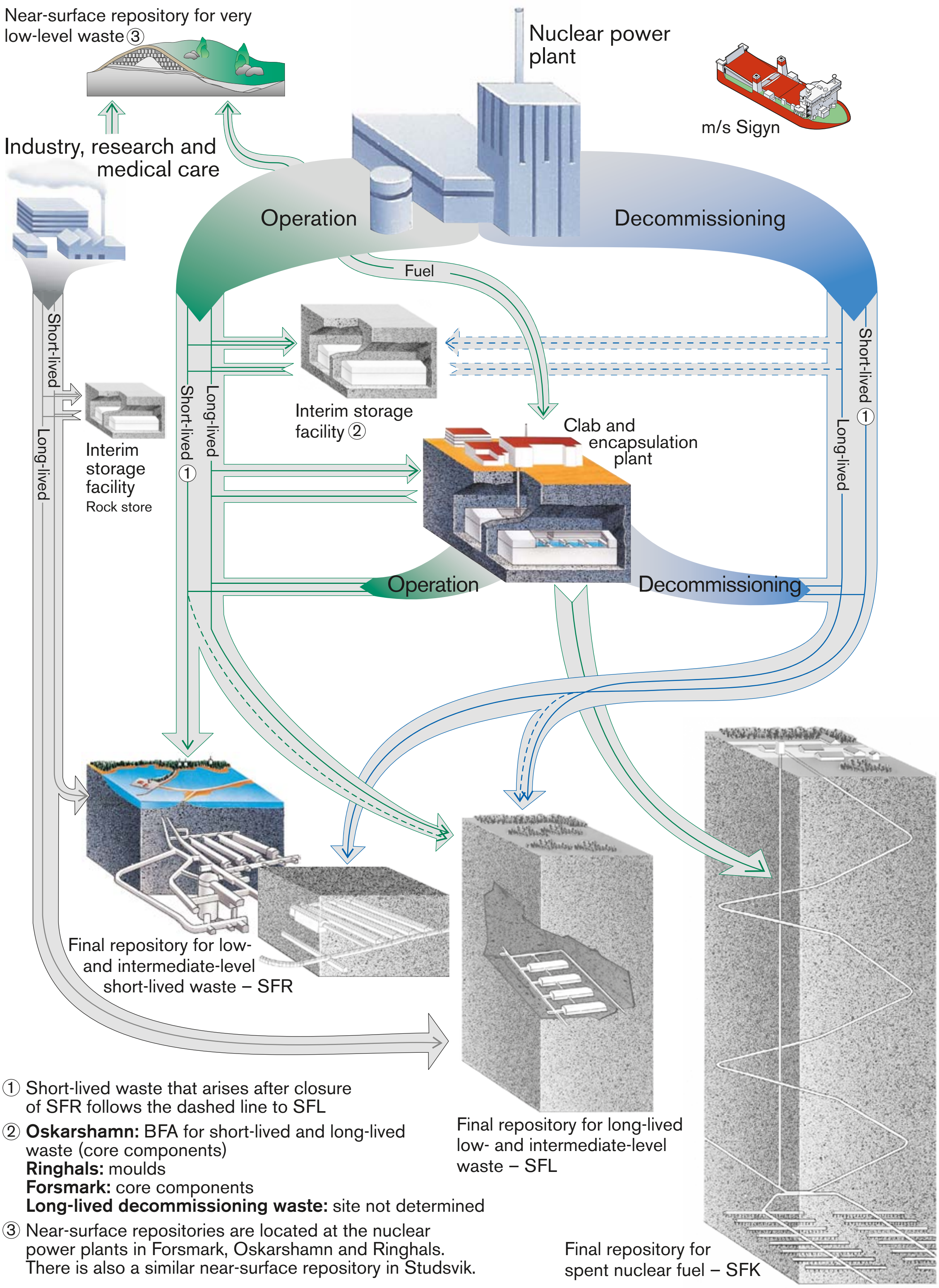


***Figure 2-1.** Overview of the Swedish system for management and disposal of the waste products of nuclear power and other radioactive waste.*

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

2.2 Special premises as a basis for the plan calculation

2.2.1 Operating scenarios for the nuclear power plants and waste quantities

The reference scenario is based on the reactor owners' current plans for future reactor operation. According to these plans, the reactors in 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 on today's situation. Future changes will be incorporated when the decisions have been made and permits obtained.

Table 2-2 shows historical data concerning the total energy production and the average capacity factor up to 2008 (the last months of 2008 are based on 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. The actual weight of the fuel in the form of complete fuel assemblies is much greater.[9]

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

Year	Energy production TWh	Capacity factor %	Comment
1999	70.2	80	Barsebäck 1 was taken out of service on 30 November 1999.
2000	54.8	66	Low energy production due to an unusually high availability of hydropower, which led to some output reductions, but also to extended shutdowns for maintenance work in a couple of cases.
2001	69.2	83	
2002	65.6	84	Oskarshamn 1, which was shut down for renovation, is excluded from the calculation of the capacity factor.
2003	65.5	78	
2004	75.0	92	
2005	69.8	87	Barsebäck 2 was taken out of service on 31 May 2005.
2006	65.0	83	
2007	64.3	82	
2008	64.9	82	

[9] 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 at the nuclear power plants.

Start commercial operation			Thermal capacity/ net capacity MW	Energy production through 2008		Fuel through 2008 t U	Total for reference scenario		
				TWh	mean value from 2009 TWh/y		Operation through	Energy production TWh	Spent fuel t U
F1	(BWR)	10/12 1980	2,928 / 978	193	8.8	720	9/12 2030	385	1,224
F2	(BWR)	7/7 1981	2,928 / 990	190	8.3	702	6/7 2031	376	1,251
F3	(BWR)	22/8 1985	3,300 / 1,170	202	10.6	697	21/8 2035	486	1,402
O1	(BWR)	2/6 1972	1,375 / 473	90	3.5	437	5/2 2032	170	667
O2	(BWR)	15/12 1974	1,800 / 590	135	6.2	535	14/12 2034	296	930
O3	(BWR)	15/8 1985	3,300 / 1,152	196	11.2	675	14/8 2045	607	1,773
R1	(BWR)	1/1 1976	2,540 / 855	159	6.7	630	31/12 2025	273	929
R2	(PWR)	1/5 1975	2,652 / 866	174	7.0	562	30/4 2025	289	890
R3	(PWR)	9/9 1981	2,992 / 985	167	9.2	535	8/9 2031	376	1,043
R4	(PWR)	21/11 1983	2,775 / 935	163	9.0	515	20/11 2033	386	1,016
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			21,771 / 7,408	1,367	55	5,277		2,796	9,055
PWR total			8,419 / 2,786	504	25	1,612		1,051	2,949
All NPPs total			30,190 / 10,194	1,871	80	6,889		3,847	12,004

Waste quantities, in addition to spent fuel (table 2.3) and not including waste placed in at-plant repositories, are shown in the table in Appendix 1. Based on that, Table 2-4 shows the waste volumes that must be accommodated in the different final repositories. The volumes pertain to encapsulated 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 metre 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 2-4. Encapsulated spent nuclear fuel and radioactive waste to be disposed of.

Product	Main origin	Volume in final repository m^3
Spent fuel (6,000 canisters)		25,100
Alpha-contaminated waste	Low- and intermediate-level waste from Studsvik	1,800
Core components	Reactor internals	9,700
Low- and intermediate-level operational waste	Operational waste from NPPs, treatment plants and Studsvik	57,400
Low- and intermediate-level decommissioning waste	From decommissioning of NPPs, treatment plants and Studsvik	163,700
Total quantity ca.		258,000

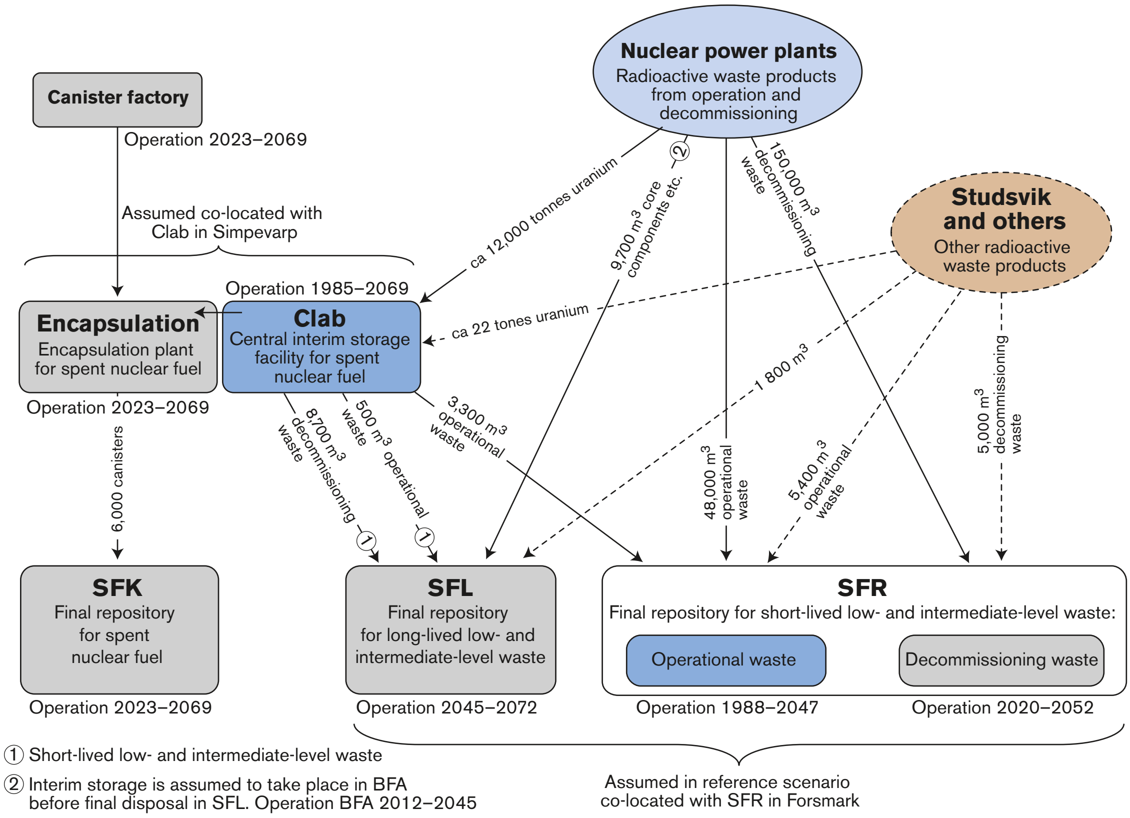


Figure 2-2. *Block diagram with transport flows showing management of the residual from nuclear power and other radioactive waste as a basis for the reference scenario.*

2.2.2 Overall timetable for execution

RD&D Programme 2007 with plan of action presented the programme and plans for the Nuclear Fuel Programme and the LILW Programme. This material has since been supplemented with particulars in SKB's latest activity plan. Based on this, rough timetables have been prepared for all future facilities. These timetables show, for example, that the encapsulation plant and the final repository will be built so that deposition of encapsulated fuel can begin in 2023. This will be done during an initial period with a smaller number of canisters per year, gradually increasing to reach the regular capacity of 150 canisters per year after five years. 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 final repository for the short-lived decommissioning waste will begin operation in 2020. Deposition will continue until the last reactor has been decommissioned. The facility for the long-lived low- and intermediate-level waste (SFL) is planned to receive waste starting in 2045 and remain open until all short-lived decommissioning waste from Clab and the encapsulation plant has been deposited.

In section 2.7 Costs, a general timetable is shown of the flow of payments and the individual facilities.

2.2.3 Siting of future facilities

SKB has submitted an application for a permit to build the encapsulation plant integrated with Clab. As regards other future facilities, SKB has not yet made a final decision on the question of siting. But in order to carry out the cost calculation, certain assumptions must be made. The uncertainty in these assumptions is dealt with later in the risk analysis that is done to arrive at the amounts called for in the Financing Act.

The following siting assumptions have been made as a basis for the plan calculation:

Final repository for spent nuclear fuel

The final repository for spent nuclear fuel is assumed to be located in Forsmark. This is mainly so that the calculation can include the costs of sea transport of canisters with spent nuclear fuel.

Final repository for short-lived low- and intermediate-level waste

The final repository for short-lived low- and intermediate-level waste from decommissioning of the nuclear power plants is assumed to be located in Forsmark as an extension of the existing SFR. This is further based on a planning premise that applied back when SFR was built.

Final repository for long-lived low- and intermediate-level waste from operation or decommissioning

Long-lived low- and intermediate-level waste may not be deposited together with short-lived low- and intermediate-level waste in SFR. The repository must be located at greater depth and ensure a longer period of isolation. The repository will be built relatively far in the future, and there are no definite plans for its location. The premise for the plan calculation 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.

Canister factory

The canister factory is not a nuclear facility and will be regarded as a normal industrial siting where different alternatives are evaluated with regard to economics, safety and environmental impact. It is assumed in the plan calculation that the factory is located near the encapsulation plant.

2.2.4 Decommissioning of nuclear power plants

The measures required for managing and disposing of the radioactive waste products from nuclear power also include decommissioning of the facilities after they have been taken out of service.

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 fuel has been transported to Clab, is linked to the construction of facilities for management of the decommissioning waste and the processing of permit and licence applications. Decommissioning will begin with Barsebäck 1 and 2, which are expected to start being dismantled when the final repository for short-lived decommissioning waste (an extension of the current SFR) is put into operation in 2020.

With regard to resource utilization and the receiving capacity of interim stores and final repositories, it is desirable to stagger the start of dismantling of different reactor plants. In the reference scenario, a minimum of one year is assumed between the start of dismantling of reactors at the same station. 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[10] 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 period with shutdown operation, which varies in length depending on the decommissioning timetable, the workforce will be reduced to a very low level. The actual dismantling work is expected to take seven years per unit and employ an average of a couple of hundred persons. The principle is illustrated by Figure 2-3.

---

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

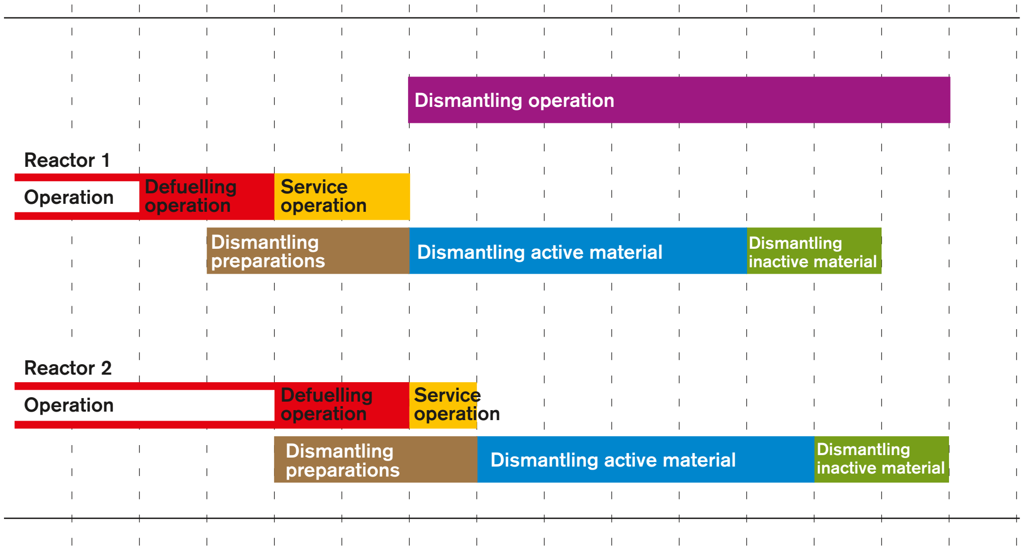


Figure 2-3. *Principles showing the decommissioning and dismantling phase for a pair of interconnected reactor plants.*

The radioactive waste from decommissioning is all LLW and ILW. However, the activity level varies considerably between different parts. It is assumed that the waste with the highest activity, the reactor internals, will be interim-stored before being emplaced in the deep repository for long-lived LILW (see section 2.4.4). Some waste with very low activity will be deposited on the site. Other short-lived decommissioning waste will be transported directly to the final repository for decommissioning waste, SFR, and deposited there (see section 2.4.2). A large quantity of the decommissioning waste can be released for unrestricted use, either directly or after decontamination, and thereby be handled according to the rules that apply to demolition waste from industry in general.

How far dismantling should be carried out for facility parts that are radiologically free-released and exempted from the requirements of the Nuclear Activities Act varies between the nuclear power plants, depending on their plans for the future use of the site.

2.3 Description of facilities in the Nuclear 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 implement the final disposal of spent nuclear fuel and other long-lived radioactive waste. A programme for this work is presented by SKB every three years. The most recent programme, RD&D Programme 2007, with SKB's plan of action, was submitted to the Government in September 2007.

RD&D, as a separate cost unit, has mainly been focused on management of spent nuclear fuel and will continue to be so in the future. However, an increasingly large portion is being devoted to the LILW Programme, above all with regard to the long-lived waste, and to method studies and follow-up of experience from decommissioning of reactor plants. Since most of the activities are included in the Nuclear Fuel Programme, all RD&D is described here.

The long-term safety of a final repository for spent nuclear fuel is evaluated by means of safety assessments. The safety assessment uses scientific methodology and obtains knowledge concerning long-term changes from research. The most important safety assessment projects during the periods up to 2006 and 2010 are safety assessments for the applications for permits to build an encapsulation plant and a final repository. An important milestone was the presentation in 2006 of a safety assessment, SR-Can, showing the methodology that will be used.

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 isolate the spent nuclear fuel.

The RD&D work is aimed at the measures needed to carry out construction of an encapsulation plant for spent nuclear fuel and a final repository for encapsulated nuclear fuel.

An important component in the RD&D work is the Äspö Hard Rock Laboratory (HRL). It 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 investigations of the selected final repository, as well as to study and verify the function of different components in the final repository system. It is also used to develop and test technology for deposition of buffer and canisters. An illustration of the HRL is shown in Figure 2-4.

The various tests of technology and methods being conducted in the Äspö HRL involve 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 in the final repository.

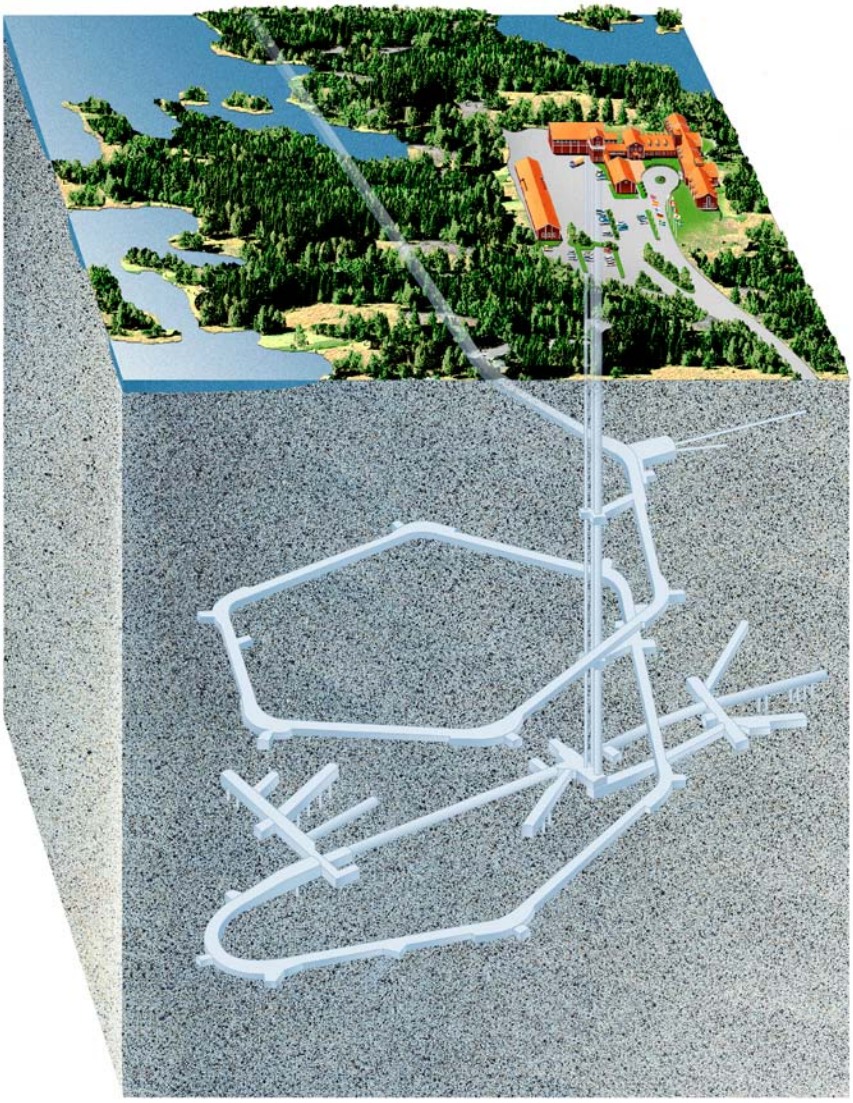


***Figure 2-4.** Äspö HRL.*

Figure 2-5. *Newly developed deposition machine for handling of canisters in the final 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. In the future, the laboratory will also be able to be used for training of operators for 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 manufacturers in Sweden and abroad.

In the reference scenario it is assumed that research, development and demonstration will continue on Äspö until routine operation is commenced. A small group of scientists who conduct research and development in the geosciences will then be transferred to the final repository's operating organization. Development and training will be pursued at the Canister Laboratory until the encapsulation plant is put into operation.

Early costs for the final repository project – site investigations, design and detailed characterization – are presented in the cost compilation under the heading "Final repository for spent nuclear fuel".

2.3.2 Clab – Central interim storage facility for spent nuclear fuel

Clab is situated adjacent to the Oskarshamn Nuclear Power Plant. Operations started in 1985. The facility was originally designed to store some 3,000 tonnes of fuel (uranium weight) in four pools. The introduction of new storage canisters 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 2008, fuel equivalent to 4,900 tonnes of uranium spent weight (about 5,130 tonnes of uranium initial weight) is expected to remain in the facility. Core components and reactor internals are also kept in the facility prior to ultimate disposal in the final repository for long-lived LILW.

CLAB consists of an above-ground or surface part for receiving fuel and a below-ground or underground part with the 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.

The permanent workforce during operation is currently about 80 persons. SKB operates the facility with its own personnel.

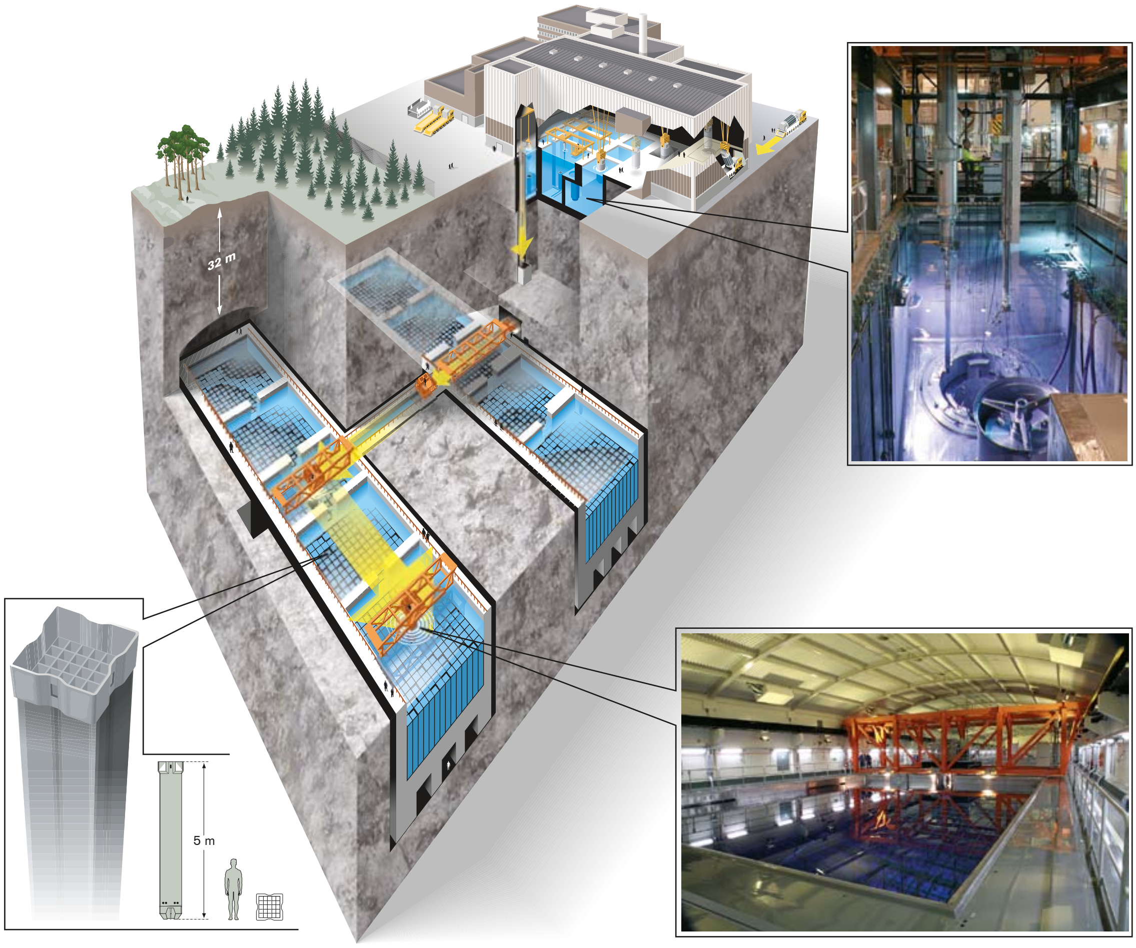


Figure 2-6. *Clab.*

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 sent to the final repository for long-lived low- and intermediate-level waste, SFL.

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

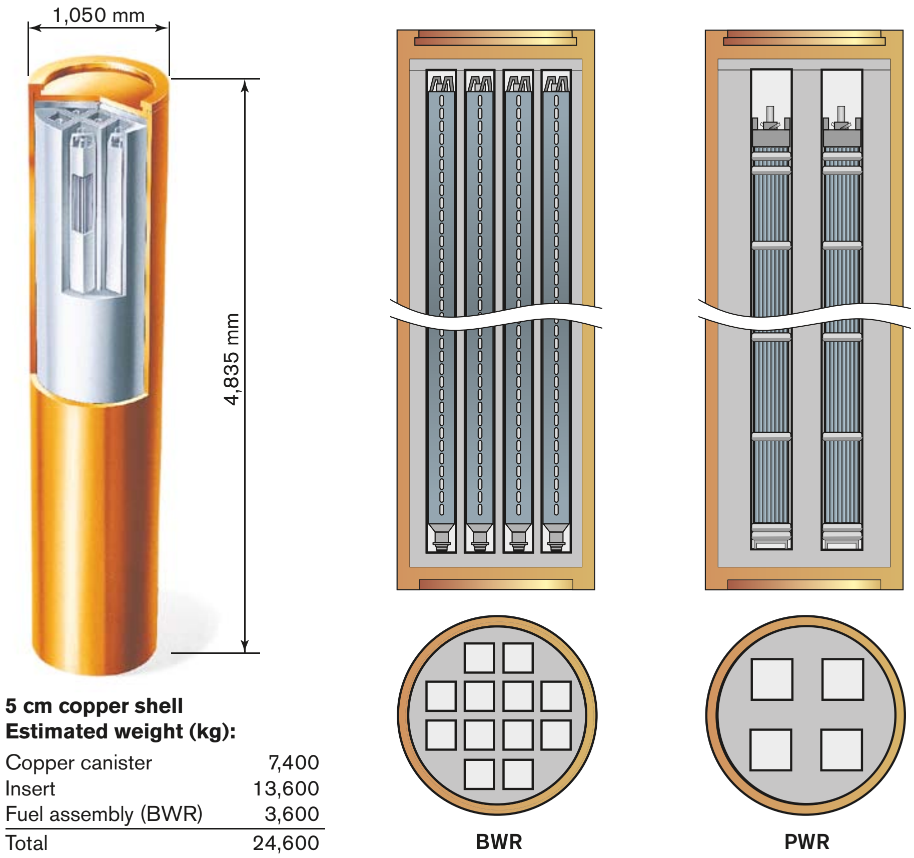
2.3.3 Encapsulation of spent nuclear fuel

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 mm 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.



5 cm copper shell
Estimated weight (kg):

Copper canister	7,400
Insert	13,600
Fuel assembly (BWR)	3,600
Total	24,600

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

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.

The canister factory is planned to be 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 with outer casings, called boxes, 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 a single facility under the name Clink.

The encapsulation plant will contain the following functions:

- Arrival section with quality inspection of delivered canister parts.
- Encapsulation section for emplacement of fuel in canister, sealing of canister and quality inspection.
- 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 fuel 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 150 canisters per year, decreasing to 100 towards the end.

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 fuel will begin in 2023 with a trial operation involving 20 canisters. Routine operation will begin the following year.

After completed encapsulation, the plant will be decommissioned and radioactive decommissioning waste will be transported to the final repository for long-lived low- and intermediate-level waste, SFL.

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

2.3.4 Final repository for spent nuclear fuel

Siting and site investigations

The work with siting of the final repository began in 1992 and has largely followed the plan described in RD&D Programme 92. The work has been carried out stepwise with feasibility studies followed by site investigations, and is now being concluded by site selection.

After eight feasibility studies had been carried out, the Government decided on 1 November 2001, based on SKB's supplement to RD&D 98 (RD&D-K), to give SKB the go-ahead to commence site investigations. Once the municipal councils in Oskarshamn and Östhammar had decided to let SKB conduct site investigations under certain conditions, they were commenced in 2002.

The purpose of the site investigations has been to gather detailed background material on the rock for the safety assessments and design studies that will serve as a basis for licensing applications for the final repository. Such an application for a permit to build the final repository is expected to be ready for submission in the summer of 2010. During the licensing process, some monitoring will continue on the selected site, for example of groundwater levels, while investigation activities on the rejected site will be discontinued.

The site investigations are currently being wound up. The cost calculations that cover the time from 2010 include costs for the first year only. These costs are presented in Table 2-5 as a separate cost item.

Facility design

The site of the final repository for spent nuclear fuel is assumed in the reference scenario to be located southeast of the Forsmark nuclear power plant, Figure 2-9. The facility consists of an above-ground or surface part and an underground part.

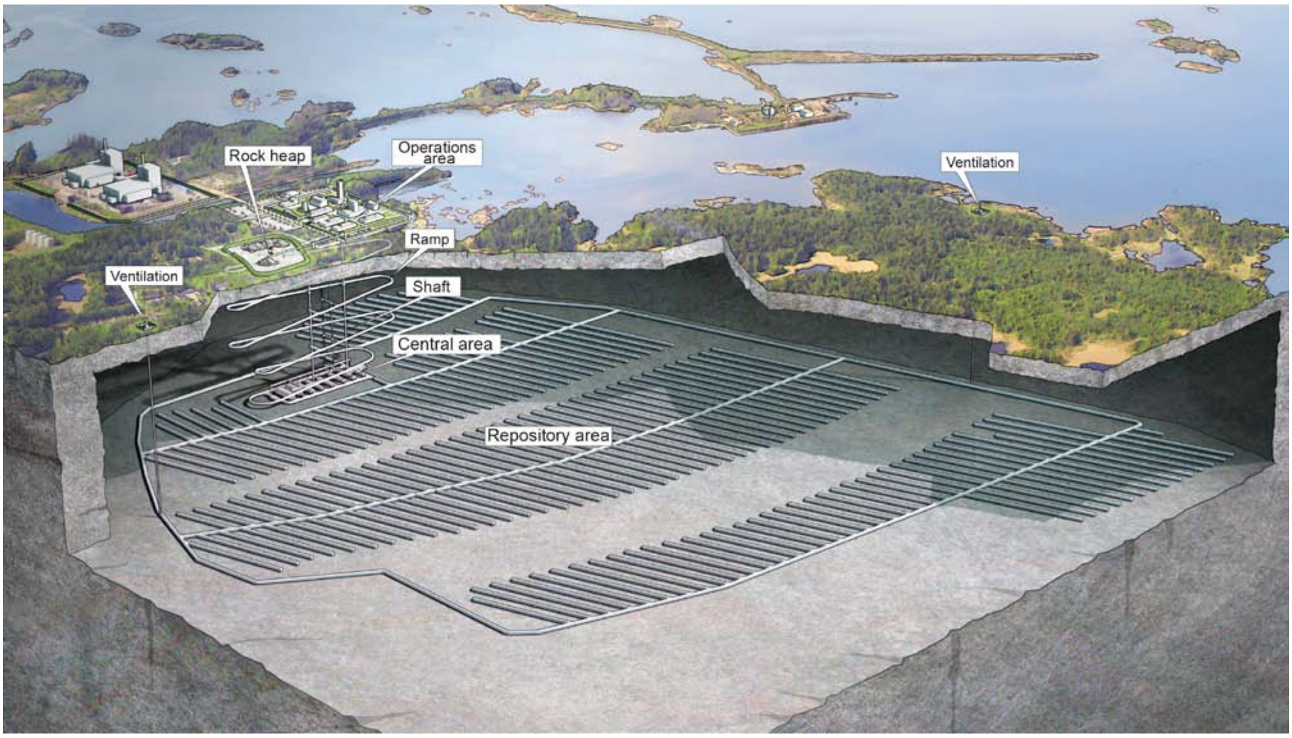


Figure 2-9. *The main parts of the final repository for spent nuclear fuel in Forsmark.*

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 metres below the ground surface. In order to avoid conductive structures and limit rock stresses, a repository depth of 475 metres has been selected in Forsmark.

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 spacing between the canisters is thereby determined by the fuel's decay heat, the thermal properties of the rock and the bentonite, and the initial temperature of the rock. The latter is determined to a large extent by the selected siting. A canister spacing of 6.0 m and a tunnel spacing of 40 m have been chosen in the reference scenario. The depicted extent also includes 13% spare capacity for loss of deposition holes. The repository area is situated in a tectonic lens with advantageous rock properties.

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[11] in parallel with the blasting of the ramp. During the operating period, the skip shaft will be utilized for transport of rubble and backfill material, and the ramp mainly for hauling transport casks with canisters.

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 for operations below ground. 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 storerooms, 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 to meet requirements on entrance and exit control. The inner operations area also contains a terminal building that serves as a reception and transloading station for canisters with spent nuclear fuel that arrive in canister transport casks (KTBs). In the reference scenario, these casks are transported from the encapsulation plant by m/s Sigyn to the harbour in Forsmark at SFR. SKB's terminal vehicles transport them further to the final repository's terminal building. The transport casks are stored in the terminal building before being transported down to the underground part for emptying.

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 a conveyor 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 repository.

---

[11] A sunk shaft is a shaft that is driven from the ground surface down to the intended depth. This is in contrast to raise driving, which is done from the bottom upward by drill-and-blast or by boring up a predrilled small-diameter hole. The latter method is cheaper and is used for other shafts in the facility.

Figure 2-10. *Final repository for spent nuclear fuel in Forsmark – surface part.*

In addition to the aforementioned surface parts there is a storeroom for bentonite and backfill material situated at the receiving harbour in Hargshamn, about 30 kilometres south of Forsmark. Transloading and storage of material for production of buffer and backfill occurs there prior to transport to the production plant, which is located in the outer operations area.

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 the trial operation phase. The principal operating activities are rock excavation, deposition and production/transport of buffer and backfill. These activities entail that the canisters are deposited at the same time as new deposition tunnels are blasted out and buffer and backfill are produced.

Both deposition and rock excavation can be commenced immediately when trial operation begins, since a number of deposition tunnels with associated transport and trunk tunnels have been prepared during the construction of the facility. The trunk tunnels are the transport and handling tunnels that interconnect the deposition tunnels. 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 225 persons will be employed at the final repository.

Rock excavation

By “rock excavation” 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 excavation 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 excavation in a deposition tunnel is 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 sealing of the deposition tunnel, see Figure 2-11.

Backfilling of the deposition tunnel is started 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 deposition tunnel. Concrete plugs have no long-term function after the entire final repository has been backfilled.

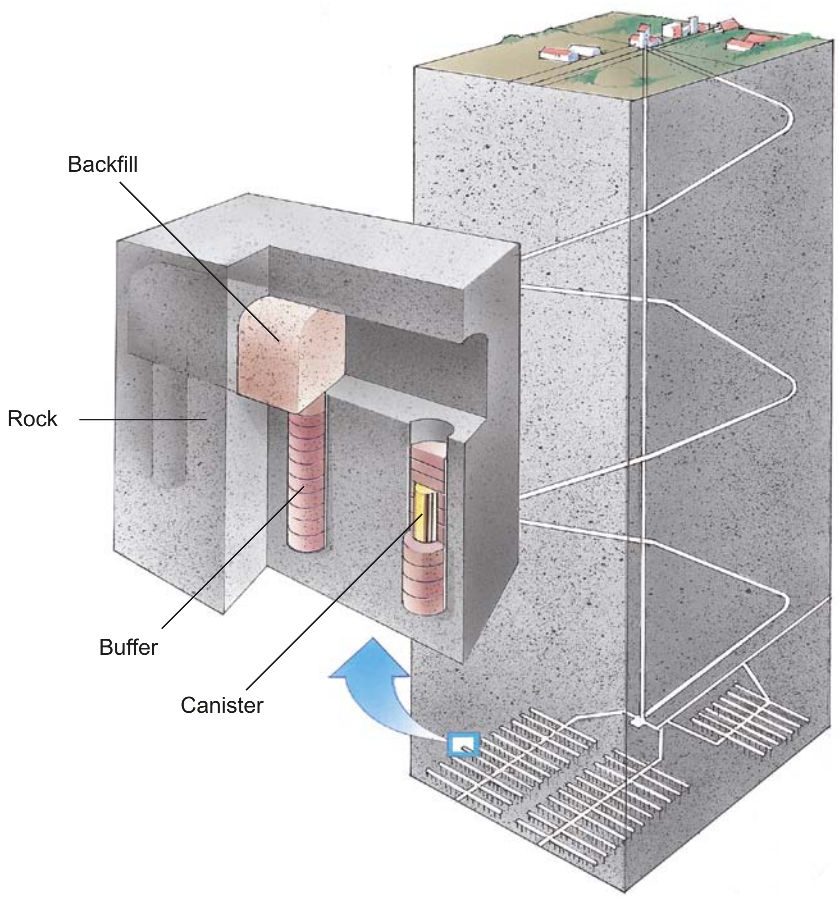


Figure 2-11. *KBS-3 with vertical deposition.*

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.

The backfill replaces the excavated rock in the deposition tunnels. It consists of compacted blocks of clay that are stacked in the tunnels and pellets of the same material to fill the gap between the block and the 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 blocks for buffer and backfill are transported to the inner operations area via the entrance building to the skip building. Transport down to the central area takes place by skip, and then by vehicle out to the point of use in the deposition tunnels.

2.4 Description of facilities in the programme for low- and intermediate-level waste (LILW)

2.4.1 Final repository in SFR for short-lived radioactive operational 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 one kilometre long access tunnels 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.

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 and pictures from different repository disposal chambers.

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 50,000 m^3 of operational waste. The capacity of the present-day SFR is about 63,000 m^3. The need for an extension with storage space in SFR for this type of waste is currently being investigated, but is not included in the present estimate.

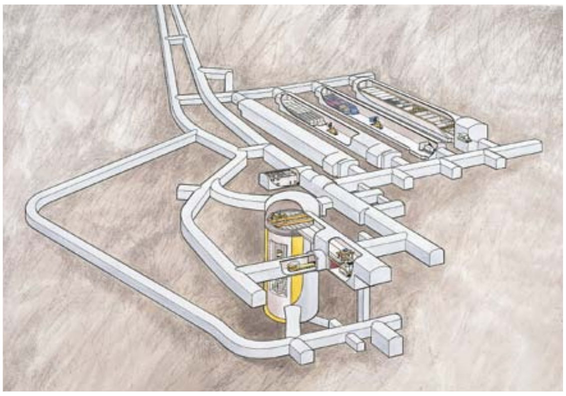
The concrete silo stands on a bed of sand and bentonite. Internally it is divided into vertical shafts, where the waste is deposited and embedded in porous concrete. The space between the silo and the rock has been filled with bentonite. When the silo is full, the space above the silo will be filled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

Certain waste categories are embedded in cement after they have been deposited in the rock vaults. It is also possible to pour more concrete around the waste when the facility is being closed.

Handling of intermediate-level waste packages in the silo repository and in one of the rock vaults takes place by remote control, while low-level packages in the other rock vaults are handled by forklift truck.

An operations group consisting of seven persons from the Forsmark Nuclear Power Plant is in charge of operation and maintenance at the Forsmark plant. In addition, support services are provided by the Forsmark plant's regular base organization. External contractors are also engaged for parts of the maintenance work. Altogether, operation and maintenance of SFR requires about 15 full-time equivalents per year. SKB plans to take over operation in 2009.

View of the surface part of SFR
(Forsmarks NPP is in the background)



SFR under ground

Rock vault for intermediate-level waste

View over top of silo

Figure 2-12. *SFR.*

It is assumed in the reference scenario that the final repository for decommissioning waste and the final repository for long-lived low- and intermediate-level waste will be built at SFR. It is nevertheless assumed that the staffing requirement on the site can be kept to the same level as today, so that in the future it will be more of a question of distributing a virtually constant operating cost between the different repositories. This means that costs for the management and disposal of operational waste in SFR, in contrast to decommissioning waste or long-lived waste, are not included in the basic cost (see Chapter 3) and are thus financed outside of the Nuclear Waste Fund.

Based on the planning assumptions in the reference scenario, it is assumed that the present-day facility, along with the extension described in the next section, will be closed and decommissioned together with the final repository the long-lived low- and intermediate-level waste.

Approximately 32,900 m^3 of waste are expected to have been deposited in SFR by year-end 2008.

2.4.2 Final repository in SFR for short-lived radioactive waste from decommissioning

The short-lived decommissioning waste from the NPPs and from Studsvik and Ågesta is planned to be deposited in SFR after SFR has been extended for this purpose. The extension will consist of rock vaults of a type similar to those in the present-day SFR. Most of the decommissioning waste can be transported in standard freight containers, which are placed in these rock vaults without being emptied. A total of about 155,000 m^3 of decommissioning waste will be stored there. According to the plans, the extended SFR will be optimally utilized with respect to the waste categories, which means that the same rock caverns will be able to be utilized for deposition of both operational waste and decommissioning waste.

Core components and reactor internals from decommissioning of the NPPs are planned to be deposited in the final repository for long-lived LILW, see section 2.4.4.

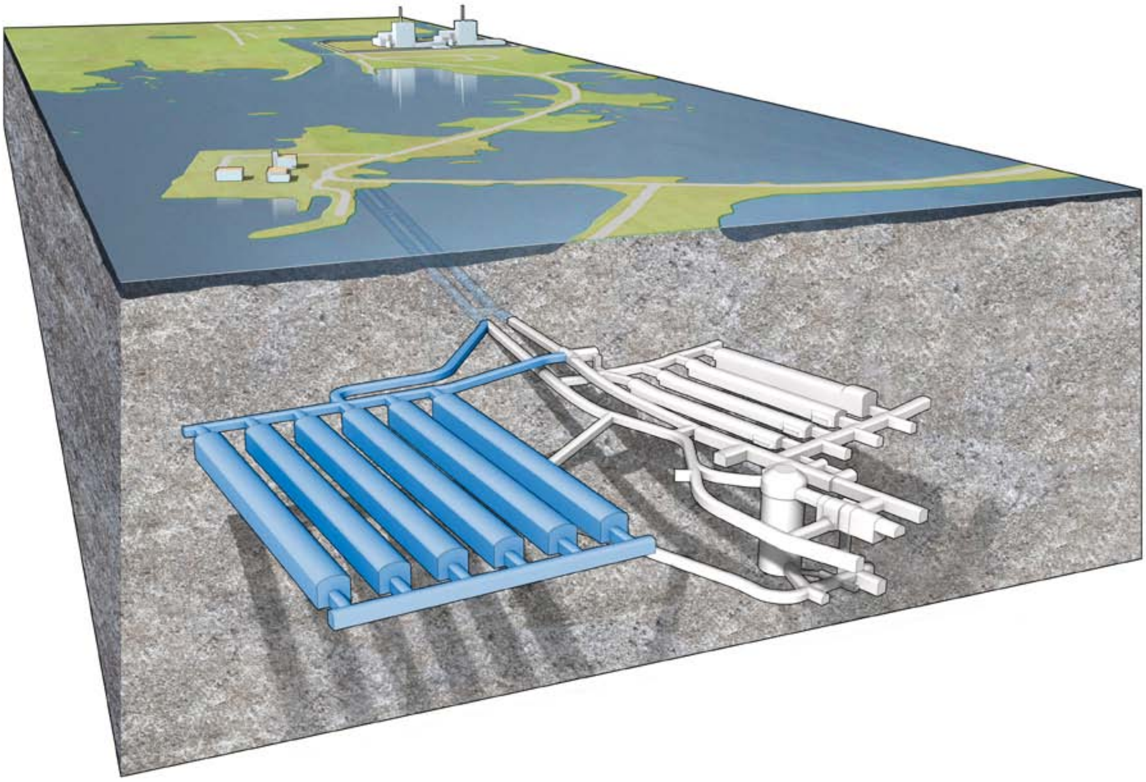


Figure 2-13. SFR with planned extension.

What is said about the existing SFR in the preceding section applies to the workforce during operation.

When decommissioning waste will be deposited is determined by the timetable for decommissioning of the reactor plants.

2.4.3 Facilities at the nuclear power plants for interim storage or deposition of low- and intermediate-level waste

The at-plant facilities that exist today at our nuclear power plant sites for management of 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 dealt with in this report.

Those that are operated with a special licence are currently:

- A near-surface final repository for very low-level operational waste 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.

The part of BFA that is utilized jointly by the different NPPs is included in the cost calculation under the object BFA. The operating licence for BFA is held by OKG Aktiebolag. SKB has a right of use to 38% of the total storage capacity in BFA by agreement. SKB expects to be able to receive core components in BFA from all NPPs in Sweden no earlier than at the beginning of 2012 (at least until the planned extension of SFR has been completed). In view of the timetable for the start of operation of interim storage in BFA and Forsmarks Kraftgrupp AB's plans for replacement of reactor internals, Forsmarks Kraftgrupp AB will build their own interim store for long-lived waste (core components) which they will use until the waste can be transported to BFA. For the time being, disposal of control rods and equipment containing fissionable material is not included in these plans. This material will continue to be stored in Clab.

Other facilities, those that only serve the NPP on the site, are not included in the reference cost, except that the decommissioning of those facilities is included in the total cost for decommissioning of the NPP in question.

BFA consists of a tunnel system blasted out of the rock with about 20 metres of rock cover. The facility is interconnected by an approximately 160 metre long main tunnel with storage chambers excavated on either side. On one side there are six tunnels, about 45 metres long and spaced at a distance of about 25 metres. Two of them have been fitted out for storage of scrap and other waste as well as concrete tanks. On the other side, parallel to the main tunnel, is the mould store, which is connected to the main tunnel by two short transport tunnels.

2.4.4 Final repository for long-lived low- and intermediate-level waste, SFL

The final repository for long-lived LILW, called SFL, is mainly intended to contain core components and reactor internals, plus long-lived LILW from Studsvik[12]. In the reference scenario, the short-lived decommissioning waste from Clab and the encapsulation plant is also deposited in this repository, since it is assumed that SFR will be closed when it is time for these facilities to be dismantled.

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. SKB plans to locate the repository 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, which are then backfilled with porous concrete. After backfilling, the shafts are covered with concrete planks and sealed. All handling is done by remote-controlled overhead crane. Finally, 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. This takes place later in conjunction with sealing and closure of the repository.

The waste consists primarily of cubical concrete moulds with sides of 1.2 metres and of the types of containers that have been developed for dry interim storage of core components and reactor internals. In the calculation of the waste volume in the final repository in the reference scenario, a unit mould with sides measuring 1.2/1.2/4.8 metres is used, as previously.

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.

The transportation system for sea transport is composed of the following main components: the ship m/s Sigyn, transport casks and containers, and terminal vehicles. The system is designed to be used for spent nuclear fuel and all types of nuclear waste.

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

[12] 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* it is assumed that this occurs in an at-plant rock cavern at the Oskarshamn NPP (BFA).

By year-end 2008, a total of about 4,900 tonnes of fuel spent weight (ca. 5,130 tonnes initial weight), is expected to have been transported from the nuclear power plants to Clab and about 32,900 m^3 of low- and intermediate-level 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, two for core components, and 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 vehicles are used.

Transport of canisters with spent nuclear fuel from the encapsulation plant at Clab to the final repository is assumed in the reference scenario to take place by sea to the harbour in Forsmark (see section 2.2.3 with regard to siting of the final repository). The final repository is assumed to be located near the harbour, and transport to the operations area at the final repository can take place directly by terminal vehicle.

The encapsulated fuel will be carried in transport casks of a type similar to those used for the fuel today. Other LLW and operational waste from CLAB, the encapsulation plant and Studsvik is planned to be transported in specially designed transport containers.

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.

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 calculations. Instead, all types of uncertainties are treated separately in the risk 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.

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 in the drawings. These non-quantity-specified costs can be estimated with good accuracy based on experience from other similar projects.

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.

Finally, an allowance is added to take into account future real price increases within different sectors of the programme. These increases are mainly dependent on factors in society as a whole over which SKB as the project manager has little or no control. There are referred to as external economic factors (EEFs) and include the trend in payroll costs (including the productivity trend), the cost 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.

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* and *decommissioning and backfilling* (backfilling of rock caverns). 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 costs in Table 2-5 are a best cost estimate based on current data for the reference scenario. No adjustments have been made for real price increases according to external economic factors, EEFs. Furthermore, there is no allowance for unforeseen factors and risk. Allowances for EEFs and unforeseen factors and risk are dealt with in Chapter 3 where only the scenario based on 40 years of operation of the reactors is presented.

Table 2-5. Future costs for the reference scenario up to and including 2010, January 2008 price level.

		Cost per cost category, SEK M	Cost per facility, SEK M
SKB's central functions and RD&D		9,180	9,180
Transportation system	investment	1,510	3,560
	operation and maintenance	2,050	
Clab	investment	1,410	7,040
	operation and maintenance	5,010	
	decommissioning	620	
Encapsulation plant	investment	2,550	13,190
	operation and maintenance	10,450	
	decommissioning	190	
Final repository for spent nuclear fuel, SFK			
– Off-site facilities	investment and operation	560	560
– Site investigations		100	100
– Operations areas above ground	investment	3,250	8,760
	operation and maintenance	5,370	
	decommissioning	140	
– Facilities below ground	investment	8,290	14,550
	operation and maintenance	1,970	
	decommissioning and backfilling	4,290	
Final repository for long-lived low- and intermediate-level waste, SFL	investment	490	1,500
	operation and maintenance	660	
	decommissioning and backfilling	350	
At-plant near-surface repositories for very low-level waste	operation and maintenance	50	50
Final repository for low- and intermediate-level operational waste, SFR	investment	140	910
	operation and maintenance	770	
	decommissioning and backfilling		
Interim storage facility for low- and intermediate-level operational and decommissioning waste – BFA and others	investment	50	130
	operation and decommissioning	80	
Final repository for short-lived low- and intermediate-level decommissioning waste, SFR	investment	1,030	2,750
	operation and maintenance	1,490	
	decommissioning and backfilling	230	
Decommissioning of reactor plants	operation at shutdown nuclear power units	2,480	15,860
	decommissioning	13,380	
Total reference cost (excluding EEFs and allowance for unforeseen factors and risk)			78,140

The reference cost amounts to a total of SEK 78.1 billion. Of this total, SEK 62.2 billion falls within SKB's responsibilities and are thereby common costs for the licensees, known as joint costs. The remainder comprises costs 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 final repository for spent nuclear fuel, and on the other the decommissioning of the nuclear power plants.

2.7.2 Incurred and budgeted costs

Table 2-6 shows, in current money terms, incurred costs through 2007, the forecast cost outcome for 2008 and budgeted costs for 2009. (The reference cost reported in section 2.7.1 includes the costs from 2010.)

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 2008 price level, whereby incurred costs have been adjusted upwards with the consumer price index, CPI.

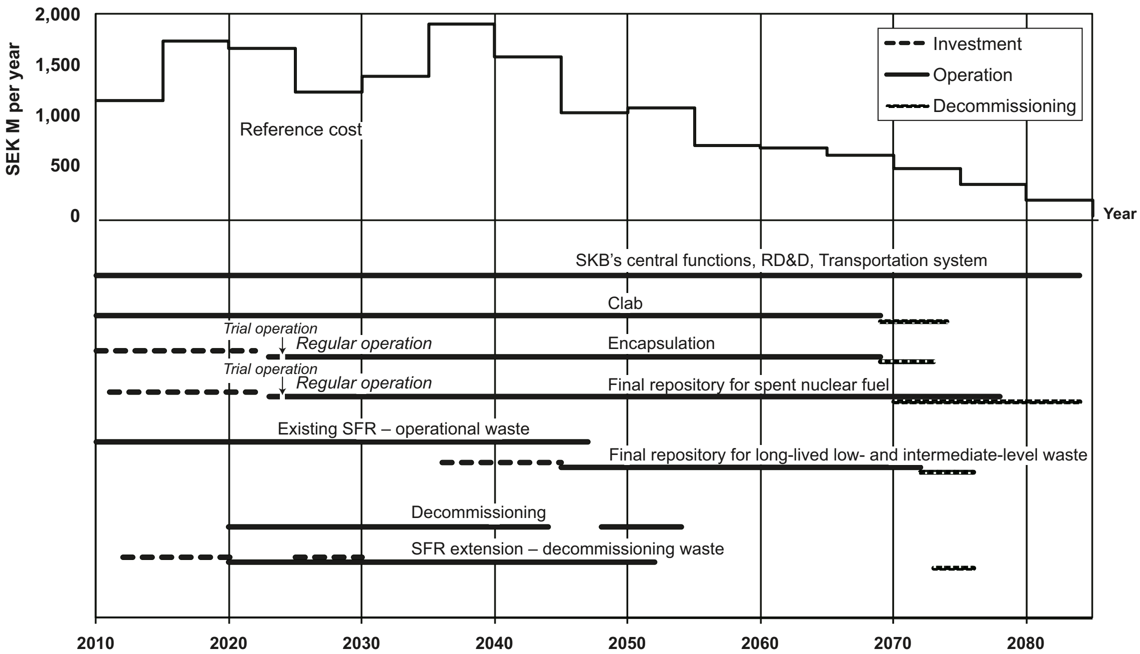


Figure 2-15. *Distribution in time of the future costs for the reference scenario and rough timetables for the facilities.*

Table 2-6. Incurred costs through 2007, the forecast cost outcome for 2008 and budgeted costs for 2009, current money terms.

	Incurred through 2007 SEK M	Outcome 2008 (forecast) SEK M	Budget 2009 SEK M	Total through 2009 SEK M
SKB's central functions	1,810	262	282	2,354
RD&D	5,041	327	370	5,738
Transportation system				
– investment/reinvestment	213	6	7	226
– operation	688	35	34	757
Clab				
– investment/reinvestment	3,479	73	119	3,671
– operation	1,616	110	136	1,862
Encapsulation plant				
– investment	289	21	30	340
Final repository for spent nuclear fuel (siting, site investigations and design)	2,519	307	256	3,082
SFR and other within LILW programme				
– investment/reinvestment	949	67	102	1,118
– operation	624	44	75	743
Total	17,228	1,252	1,411	19,891

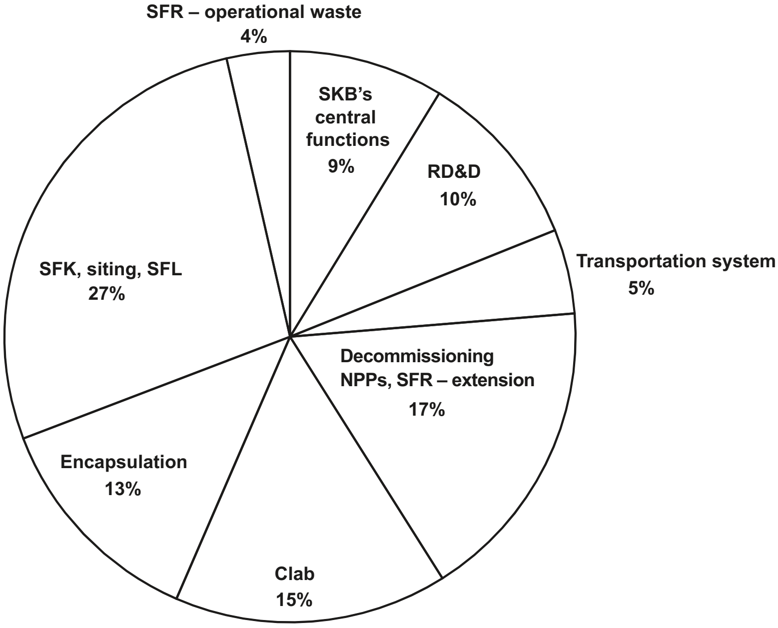


Figure 2-16. *Distribution of the total cost (incurred and future) for the reference scenario entailing operation of reactors in Forsmark and Ringhals for 50 years and in Oskarshamn for 60 years. January 2008 price level.*

3 Costs according to the Financing Act

3.1 Operating scenarios for the reactors and energy production and waste quantities

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 Financing Act and Ordinance. All of these calculations are, however, 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 fuel data that follow from these. The reference scenario follows the current plans in place for the nuclear power production companies, but for the cost calculations under the Financing Act the regulatory framework prescribes what operating times are to apply. Two operating scenarios are above all of interest and will be described here. A third, which is not presented, concerns the basis for distributing the costs among the licensees.

The one operating scenario is meant for the basis for calculation of the fee. According to the regulatory framework, the calculation of the fees should be based on the assumption that each of the reactors in operation today will be operated for 40 years. However, for those reactors that have been in operation for 34 years or more a remaining operating time of 6 more years should be assumed unless there are reasons to assume an earlier shutdown. This 'minimum rule' entails that all reactors will be operated at least up to and including 2015.

The other operating scenario, which serves as a basis for calculating the financing amount, calls for a reconciliation at the start of the first fee year included in the calculation, which in our case means 31 December 2009. By reconciliation is meant that an inventory is made of the quantity of spent fuel at the stipulated date, including the fuel present in the reactor cores. The costs are then calculated for this quantity. Costs for decommissioning of the nuclear power plants are also included in all calculations. This calculation alternative is treated with in principle the same level of detail as the preceding one as regards the influence of the fuel quantity on costs and timetables, but more approximately for the low- and intermediate-level waste.

Operating data and fuel quantities for both scenarios are presented in Table 3-1, while Table 3-2 only applies to the scenario with 40 years of operation. 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 (3.5.2). Only the total amount is given for the reconciliation at 31 December 2009 (3.5.3).

3.2 Changes in the system compared with the reference scenario

The consequence for the system of the changes in fuel and waste quantities outlined in the preceding section is primarily dependent on the total operating time for the facilities in the Nuclear Fuel Programme. The rate of deposition of the canisters with spent fuel 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 on the canister surface within the specified limit.

Other changes, although of less cost-related importance, are associated with the fact that facilities 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.

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 2008		Fuel through 2008 t U	Total for basic cost		
				TWh	mean value from 2009 TWh/y		Operation through	Energy production TWh	Spent fuel t U
F1	(BWR)	10/12 1980	2,928 / 978	193	8.8	685	9/12 2020	296	995
F2	(BWR)	7/7 1981	2,928 / 990	190	8.3	677	6/7 2021	301	1,011
F3	(BWR)	22/8 1985	3,300 / 1,170	202	10.6	643	21/8 2025	378	1,137
O1	(BWR)	6/2 1972	1,375 / 473	90	3.5	412	31/12 2015	114	497
O2	(BWR)	15/12 1974	1,800 / 590	135	6.2	501	31/12 2015	174	625
O3	(BWR)	15/8 1985	3,300 / 1,152	196	11.2	622	14/8 2025	383	1,175
R1	(BWR)	1/1 1976	2,540 / 855	159	6.7	583	31/12 2015	206	742
R2	(PWR)	1/5 1975	2,652 / 866	174	7.0	532	31/12 2015	221	703
R3	(PWR)	9/9 1981	2,992 / 985	167	9.2	475	8/9 2021	279	819
R4	(PWR)	21/11 1983	2,775 / 935	163	9.0	479	21/11 2023	294	814
B1	(BWR)	1/7 1975	1,800 / 600	93	0.0	425	30/11 1999	93	425
B2	(BWR)	1/7 1977	1,800 / 600	108	0.0	455	31/5 2005	108	455
BWR total			21,771 / 7,408	1,367	55	5,004		2,054	7,061
PWR total			8,419 / 2,786	504	25	1,486		793	2,336
All NPPs total			30,190 / 10,194	1,871	80	6,490		2,847	9,397

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

Product	Main origin	Volume in final repository m³	
Spent fuel (4,522 canisters)		18,900	(25,100)[1)]
Alpha-contaminated waste	Low- and intermediate-level waste from Studsvik	1,800	(1,800)
Core components	Reactor internals	9,700	(9,700)
Low- and intermediate-level waste	Operational waste from NPPs, treatment plants and Studsvik	47,300	(57,400)
Decommissioning waste	From decommissioning of NPPs, treatment plants and Studsvik	163,700	(163,700)
Total quantity ca.		241,000	(258,000)

[1)] Cf. reference scenario in Chapter 2.

The most important changes in summary are:

- The number of canisters with spent nuclear fuel declines from the 6,000 included in the reference scenario. For the scenario behind the remaining basic cost the number of canisters is 4,522, and for the financing amount 3,367. The total operating time decreases by 15 and 23 years, respectively. The shortening of the timetable also affects other facilities, mainly the final repository for long-lived low- and intermediate-level waste, 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 waste 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 (Studsvik and others) should be included in terms of costs. This waste is financed from other sources than via the licensees' fund shares.

3.3 Calculation methodology

3.3.1 The successive principle – a probabilistic calculation method

A so-called probabilistic 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", or simply "successive calculation," which has been developed specially as a tool for management of uncertainties of this type.

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 risk analyses.

According to the originator of the method, Professor Steen Lichtenberg, 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 of this group.

The total cost is 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 every amount that can be read from it is linked to a given probability. In our case, this link is expressed as the "probability that a given amount will not be exceeded". This is designated the "confidence level for an amount" in the model. 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. So far, from when 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%. (The probabilities that the amount will be greater or lesser are equal.) 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. This proposed level is 80%, see 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.

3.3.2 Brief description of the applied methodology

Certain aspects of this relatively unique calculation project warrant a departure from the theoretical formulas normally used for adding stochastic variables. Instead an iterative method called Monte Carlo simulation is used. The method provides a high degree of flexibility that is very well suited to the following special problems to be dealt with in this particular case:

- 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 on the assumed time for different events to occur.

- 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 (especially unplanned) 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 and backfilling 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 "Ref. 40", see Figure 1-2, which does not include an allowance for unforeseen factors and risk.

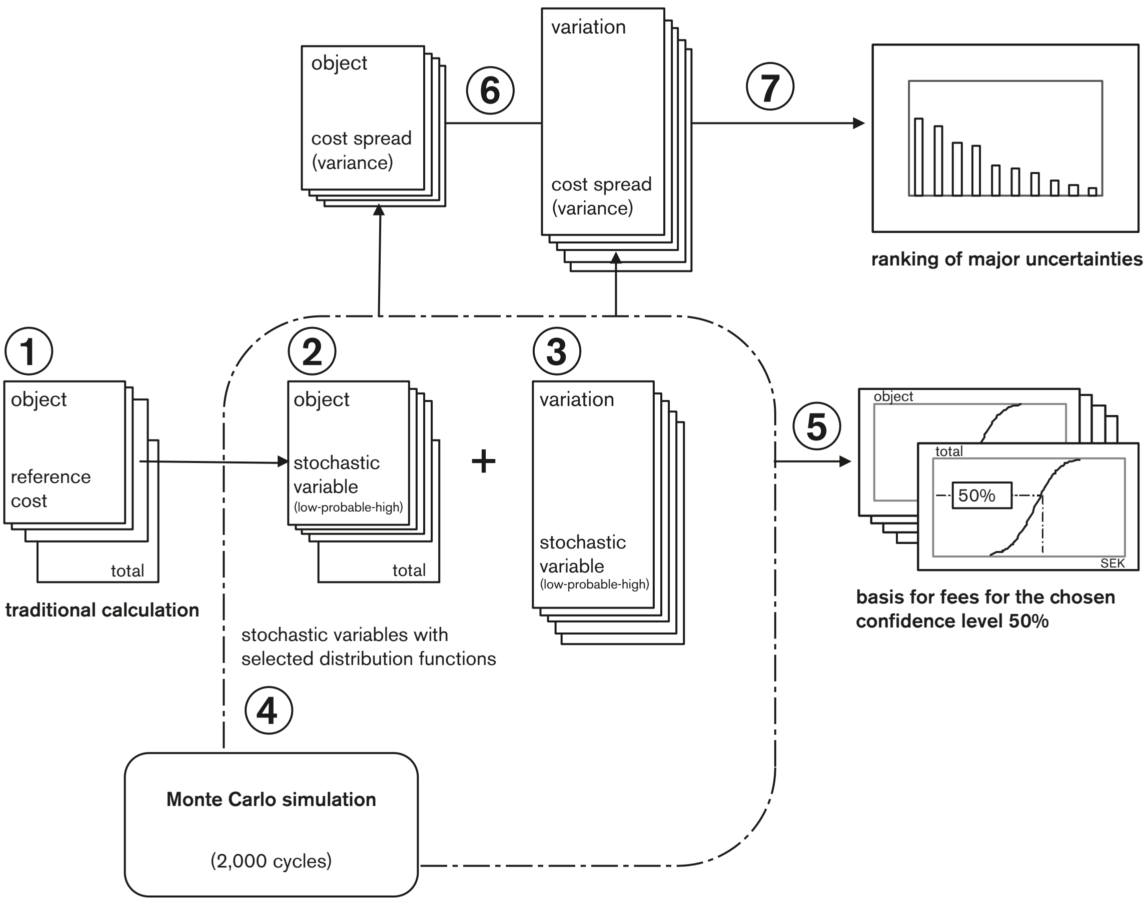


Figure 3-1. Schematic description of calculation steps (numbers refer to description in text).

The next step is to determine what variations and uncertainties are to be included in the cost calculation. They may be of the character 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 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 chosen to be included is evaluated. Since both the calculation objects and the variations have been defined not only with their probable reference costs but also with a range of values (lowest and highest cost related to a given confidence level), 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 constitute properties of the type that 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.[13] 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 variations with a greater system or timetable impact.

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 (low value / probable value / high value). Both of these steps are carried out by the specially composed analysis group. Finally, a statistical summation is made of the uncertainties by means of a 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 no special reasons for choosing another one, the probability 1:10 is used.[14] It should be emphasized that the low and high values are not limit values. The limit values, in other words 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.

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

[14] 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.

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, despite real extra costs, lead to a reduction of the basis for fees and give a low alternative. 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, a sign convention is used here 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 to the reactor operation time stipulated in the Financing Act.
- The calculation considers the real price trend and is set up in today's price level.

Two sets of general conditions with associated variations have 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 normal or even common in civil engineering activities. Variations of this type are included in the calculation from which the remaining basic cost and the basis for the financing amount are obtained.

The second set (category 2) consists of more extreme variations with a low probability of occurring. Variations of this type are included, along with variations in category 1, in the calculation from which the supplementary amount is obtained.

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, politics and public administration in general. This includes the question of how value shifts in society pertaining 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, cyclical dependencies 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 referred to this group. For natural reasons, the greatest uncertainties pertain to the future facilities for both nuclear fuel and low- and intermediate-level waste. A very large group within this area consists of most object-specific variations or uncertainties (see below).
- **Calculation**. This group considers the risks of misjudgements in the actual calculation work. They can consist of both overestimation of the difficulties (pessimistic or conservative judgements) or underestimation (optimistic).

Object-specific variations consist of specified or more general variations in 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. Typical such variations relate, for example, to changes in building volume or operating organization for individual objects, or varying requirements on execution (for example deposition). For certain objects a standard variation is assumed without being able to point at any specific cost factor.

Object-specific variations are usually within the interval –20% to +30%, but may have a much greater spread for certain objects. This applies above all to certain dismantling objects as well as less cost-demanding objects where even small disturbances can have a large relative effect.

One object-specific uncertainty of interest concerns the investment in the repository for long-lived low- and intermediate-level waste. 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%.

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 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, with corresponding cost increases as a result. In the evaluation of uncertainty, a distinction is made between requirements of a nuclear nature 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 an 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 SEK –5 or SEK +30 million per year.

The operating time for the reactors does not normally affect the system, since this is a fixed premise following from the regulatory framework. There is an exception, however: the timetable for decommissioning of the nuclear power plants. The reference timetable ("Ref. 40") is based on the date given by 50 and 60 years of operation of all reactors (except Barsebäck 1 and 2).

An earlier shutdown (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 whole cost of the dismantling process is postponed, resulting in an increased return on the funds set aside to pay for this (at a positive real rate of interest). The low alternative is based on an average operating time of 70 years. The high alternative is based on an average operating time of 30 years, but earliest possible shutdown in 2016.

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 risk analysis. The real price and cost trend is defined in the calculation with trend lines, which are based wherever possible on historical data. The analysis group evaluates possible discrepancies in these trend lines. 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.

Variations in exchange rates only affect products that are purchased directly from abroad and where the effect of the exchange rate variation cannot be assumed to be included in cyclical variations or in the general price level. This applies particularly to purchases of bentonite, copper and special machines.

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 encapsulation plant and the final repository for spent nuclear fuel, 2015–2022, and secondly the period during which most of the nuclear power plants are being dismantled. This will occur starting in the 2030s and lasting 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 for dismantling is –25% to +20%. The reason the dismantling costs are affected in a more favourable direction is that it is assumed that the timetables there can more easily be adapted business cycle fluctuations.

3.4.4 Variations and uncertainties in the group "Execution"

Delays due to a prolonged licensing process are set at three years. However, the delay entails a longer decay period for the fuel, and with a moderate increase in the deposition rate the final date can be retained despite the delay.

The siting of the final repository for nuclear fuel has not yet been decided. For the reasons cited in section 2.2.3, the "probable" value has been based on a siting of the final repository for nuclear fuel to one of the two sites where SKB has conducted site investigations and is now concluding them (at Forsmark and Oskarshamn). This is in part to provide a concrete basis for the calculation. No siting alternative besides these two sites is being studied within the framework of the basic cost.

Based on current knowledge, it is not possible to state with certainty how the sites relate to a low or high alternative. Studies are under way, and it is most likely that siting will prove to have a cost-related significance. A standard cost variation is included in this year's calculation, firstly with a ten percent impact on investments, and secondly taking into consideration the different transport premises on the sites.

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% is assumed in the operation of the encapsulation plant and the final repository in order to cover the extra costs.

Additional variations and uncertainties in the basis for the supplementary amount

General delays in start-up. This uncertainty differs from delays in the licensing process described above in that the cause here is of a more general nature and above all linked to political decisions. A delay of 17 years is assumed, but 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. The material damage is not included since it is compensated for by insurance (the premium is included in 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 final repository for spent nuclear fuel includes a variation where none of the designated areas at Forsmark and Oskarshamn are accepted, so that a new siting process has to be started. The final result is conservatively assumed to be an inland siting in Norrland (in the north of Sweden). The cost effect of the variation is varied with respect to the delay in the programme that arises, with the chosen extreme cases of 7 and 25 years. The probability of this event is set at 1:20.

The siting of the encapsulation plant includes a variation where the facility is located at the site for the final repository for spent nuclear fuel (Forsmark). (When the final repository is sited in Oskarshamn, see above, the encapsulation plant is sited at Clab, as in the reference case.) In this alternative, external canister shipments are eliminated and replaced by fuel transport from Clab to the encapsulation plant. The probability of this event is set at 1:20.

The siting of the final repository for long-lived LILW includes a variation where the repository is sited separately from other final repositories. This is a high alternative with 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 event 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 +30%. The variation is limited to the construction of the final repository's surface and underground parts and the construction of the encapsulation plant.

The learning effect associated with the decommissioning of the twelve reactor plants concerns the actual procedure around the decommissioning of nuclear power plants (the learning effect when it comes to the dismantling method and dismantling work falls under the economic factors above, where they are included in the of the productivity trend). The reference calculation is set up without reference to this learning effect. A low value is assumed entailing that the efficiency in the handling of the process increases by 20% from the time the first reactor is decommissioned to the last.

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 final repository for spent nuclear fuel that are taken into account in the technology area. There are above all four factors that include uncertainties of significance.

Adaptation to local conditions. This refers firstly to the fracture structure of the rock and other properties, and secondly to the geographically caused conditions on the ground surface. This is assumed to influence the design of the underground facility parts firstly because the extent of the repository is affected by the block structure in the rock, and secondly because the accesses, i.e. ramp and shafts, are affected by repository depth and connections to the above-ground facilities. To this must be added uncertainties regarding handling equipment etc., which influence the dimensions of rock caverns and tunnels. An example of a low value is a decrease in the extent of the repository (all tunnel lengths) by 10% and a decrease in the repository depth to 400 metres (probable 475 metres). Similarly, an example of a high value is an increase in the extent of the repository by 20%, an increase in the repository depth to 700 metres, and an extra ramp.

The **thermal conditions** constitute another factor of importance for the final repository. This affects both the fuel, i.e. its decay heat, and the properties in the buffer and the surrounding rock. These conditions affect the spacing between the canisters, which is adjusted so that temperature limits are not exceeded. The risk of high temperatures can 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 extended deposition process. This latter method is used as a variable in the model with a variation of the total operating time by three years in either direction.

The third factor concerns the conditions surrounding **backfilling of deposition tunnels** and other rock caverns. The low and high alternatives are not expressed in concrete alternatives to the method and the materials assumed in the probable case, since this is not possible without extensive studies. The uncertainty is instead expressed in 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 ongoing development work has yielded promising results. In this year's calculation the probability is set at 40%.

Of less importance, but nevertheless a variation that is taken into account in the analysis, is **the method for rock excavation**. The reference scenario is based on drill-and-blast, with high demands on exposed surfaces and limitation of disturbances in the form of fracturing that propagates 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 value assumed in the calculations is 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 the 150 canisters per year in the reference scenario 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 final 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 not necessarily. 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 rock excavation by 10%.

The variation called **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 excavation, 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 2010) for managing and disposing of spent nuclear fuel and such radioactive waste that is not operational waste. The price level is January 2008. The costs include adjustment for real price changes according to 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 mainly evaluates the total uncertainty. It also agrees with how the Nuclear Waste Fund is divided up. If each object were to be analyzed separately in the calculations, the "statistical" effect of the fact that the probability of negative or positive events occurring simultaneously for most or all of the objects is very low would be lost.

Moreover, an allowance 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 waste 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 (basis for calculation of fees).

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* and *decommissioning and backfilling* (backfilling of rock caverns). 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 75.6 billion. Of this, SEK 65.8 billion is the result of the calculation of reference cost level and SEK 9.8 billion is allowance for unforeseen factors and risk. Of this amount, approximately 75% falls within SKB's responsibilities and is thereby common for the licensees, known as joint costs. The remainder, about 25%, comprises costs for activities where each licensee has his own cost responsibility and does not share the costs with other licensees, known as separable costs.

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 in time by means of an approximate method (this is not done here). The distribution in time is only associated with "Ref. 40", see section 1.3.

Table 3-3. Remaining basic costs from 2010, price level January 2008.

		Cost per cost category, SEK M	Cost per facility, SEK M
SKB's central functions and RD&D		8,840	8,840
Transportation system	investment	940	2,570
	operation and maintenance	1,630	
Clab	investment	940	5,540
	operation and maintenance	3,890	
	decommissioning	710	
Encapsulation plant	investment	2,840	9,740
	operation and maintenance	6,700	
	decommissioning	200	
Final repository for spent nuclear fuel, SFK			
– Off-site facilities	investment and operation	420	420
– Site investigations		100	100
– Operations areas above ground	investment	3,120	7,690
	operation and maintenance	4,430	
	decommissioning	140	
– Facilities below ground	investment	6,790	11,560
	operation and maintenance	1,280	
	decommissioning and backfilling	3,490	
Final repository for long-lived low- and intermediate-level waste, SFL	investment	390	960
	operation and maintenance	210	
	decommissioning and backfilling	360	
At-plant near-surface repositories for very low-level waste	operation and maintenance	0	0
Final repository for low- and intermediate-level operational waste, SFR	investment	0	0
	operation and maintenance	0	
	decommissioning and backfilling		
Interim storage facility for low- and intermediate-level operational and decommissioning waste – BFA and others	investment	0	60
	operation and decommissioning	60	
Final repository for short-lived low- and intermediate-level decommissioning waste, SFR	investment	1,010	2,940
	operation and maintenance	1,700	
	decommissioning and backfilling	230	
Decommissioning of reactor plants	operation at shutdown nuclear power units	2,700	15,440
	decommissioning	12,740	
Total Cost "Ref. 40" (not including allowance for unforeseen factors and risk)			65,860
Allowance for unforeseen factors and risk			9,780
Total remaining basic cost			75,640

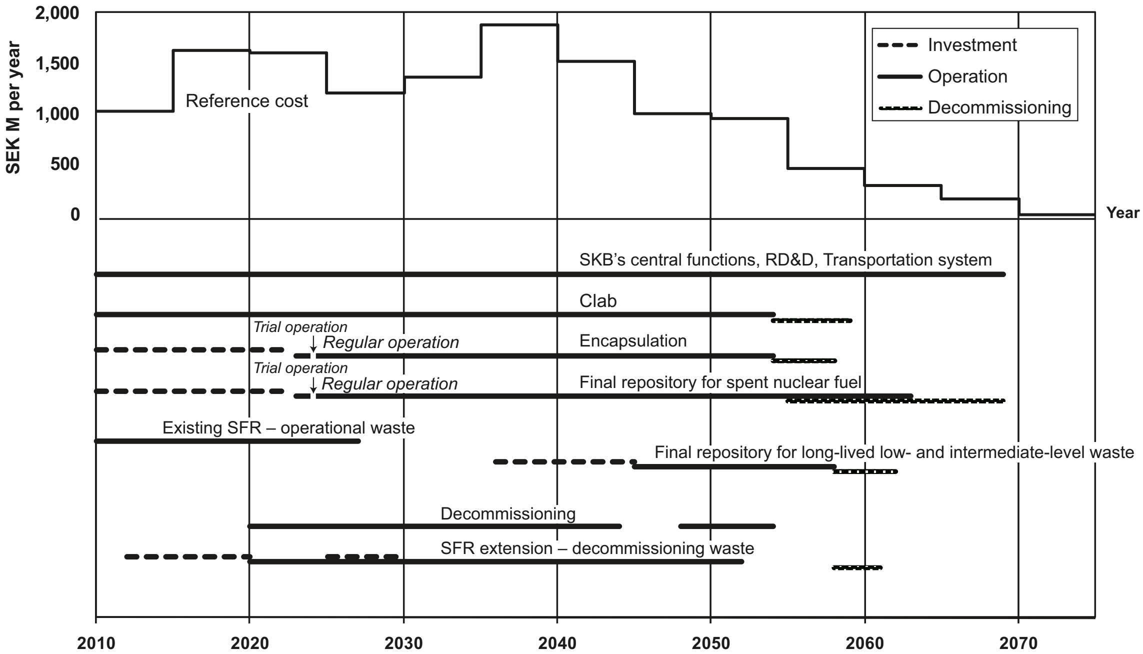


***Figure 3-2.** Remaining basic cost distributed in time and associated timetable for the facilities, price level January 2008 (not including allowance for unforeseen factors and risk).*

Figure 3-2 also shows a simplified timetable for the different facilities ("Ref. 40") 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 final repository for spent nuclear fuel, and on the other the decommissioning of the nuclear power plants. For natural reasons, timetable changes (a type of uncertainty in the risk analysis) that are statistically included in the allowance cannot be illustrated in the chart.

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.

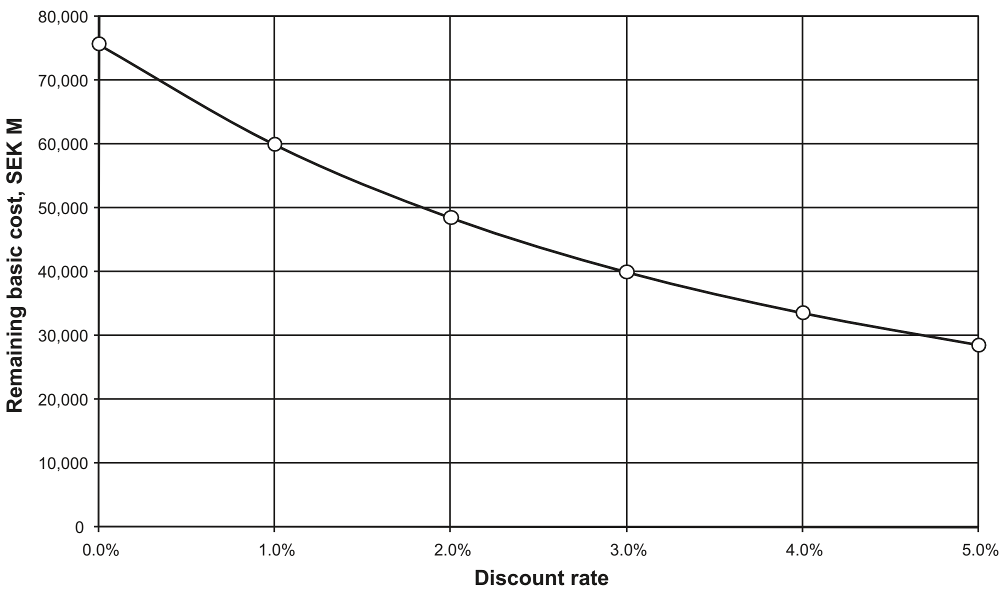


***Figure 3-3.** The present value of the remaining basic cost as a function of the discount rate, price level January 2008.*

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, when it comes to waste products, should only include those that exist at the end of the year before the first fee year to which the calculations apply. In our case, this means the waste products that exist on 31 December 2009 (the first fee year is 2010). This means that the number of canisters decreases from 4,522 to 3,367.

The basis for the financing amount in SKB's case is SEK 68.9 billion, which is SEK 6.6 billion lower than the remaining basic cost. The financing amount is obtained by adding the regulatory authority's 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 risk analysis therefore includes events and uncertainties that are assumed to be of a considerably greater scope than those included in the calculation of the other amounts. See the description 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 risk analysis at a higher confidence level than the 50% assigned to the remaining basic cost. SKB believes that a confidence level of 80% is a level that corresponds well 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 12.4 billion.

References

SKB, 2007. RD&D programme. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste, including social science research. Svensk Kärnbränslehantering AB.

SKB, 2004. RD&D programme. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste, including social science research. Svensk Kärnbränslehantering AB.

SKB, 2001. RD&D programme. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste. Svensk Kärnbränslehantering AB.

SKI, 2002. The Swedish Nuclear Power Inspectorate's Review Statement and Evaluation of the Swedish Nuclear Fuel and Waste Management Co's RD&D Programme 2001. SKI Report 02:33. Swedish Nuclear Power Inspectorate.

SKB, 1998. RD&D-Programme 98. Treatment and final disposal of nuclear waste. Programme for research, development and demonstration of encapsulation and geological disposal. Svensk Kärnbränslehantering AB.

SKB, 2000. Integrated account of method, site selection and programme prior to the site investigation phase. [RD&D-K]. Supplement to SKB RD&D-Programme 98. Svensk Kärnbränslehantering AB.

SKI, 1999. The Swedish Nuclear Power Inspectorate's Evaluation of SKB's RD&D Program 98. SKI Report 99:30, April 1999. Swedish Nuclear Power Inspectorate.

SKB, 2006. Long-term safety for KBS-3 repositories at Forsmark and Laxemar – a first evaluation. Main report of the SR-Can project. SKB TR-06-09, Svensk Kärnbränslehantering AB.

Westinghouse, 2006. Swedish BWR Reference Plant Decommissioning Study.

Hedin Gunnar, Gustavsson Börje, Carlsson Jan, 2004. Teknik och kostnader för rivning av svenska kärnkraftverk. SKB R-04-44, Svensk Kärnbränslehantering AB.

Lichtenberg Steen, 2000. Proactive Management of Uncertainty using the Successive Principle. Polyteknisk Press, Denmark.

Appendix 1

List of spent nuclear fuel and radioactive waste to be disposed of according to the reference scenario with operation of the reactors for 50 and 60 years, respectively, and the regulatory scenario (40 years)

Values in parentheses pertain to design quantities for the *remaining basic cost*, i.e. operation up to and including 40 years of operation, but at least six remaining operating years.

Waste category	Volume in final repository m^3		Final repository
Spent BWR fuel [1)] Spent PWR fuel [2)] Other spent fuel (MOX, Ågesta, Studsvik)	25,100	(18,900)	SFK
Reactor internals and core components	9,700	(9,700)	SFL
Operational waste from Clab and encapsulation plant to silo	2,780	(1,780)	SFR operational waste
Operational waste from Clab to rock vault	460	(320)	SFR operational waste
Operational waste from Clab and encapsulation plant [3)]	540	(540)	SFL
Waste from Studsvik to silo	460	(330)	SFR operational waste
Waste from Studsvik to rock vault	4,920	(3,940)	SFR operational waste
Waste from Studsvik to rock vault	1,800	(1,800)	SFL
Operational waste from NPPs to silo	11,500	(8,560)	SFR operational waste
Operational waste from NPPs to rock vault	36,700	(31,800)	SFR operational waste
Decommissioning waste from NPPs to rock cavern	150,000	(150,000)	SFR decommissioning waste
Decommissioning waste from Studsvik to rock cavern	5,000	(5,000)	SFR decommissioning waste
Decommissioning waste from Clab and encapsulation plant to rock cavern	8,700	(8,700)	SFL
Total approx.	258,000	(241,000)	

[1)] Number of BWR fuel assemblies 52,010 (38,910). Dimension 140×140×4,383 mm.

[2)] Number of PWR fuel assemblies 6,570 (5,030). Dimension 210×210×4,103 mm.

[3)] Operational waste arising after closure of SFR.

ISSN 1404-0344
CM Gruppen AB, Bromma, 2009