SKB

TECHNICAL REPORT

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PLAN 98
– Costs for management of the radioactive waste from nuclear power production

Swedish Nuclear Fuel and Waste Management Co

June 1998

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PLAN 98

COSTS FOR MANAGEMENT OF THE RADIOACTIVE WASTE FROM NUCLEAR POWER PRODUCTION

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Information on SKB technical reports from1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77), 1984 (TR 85-01), 1985 (TR 85-20), 1986 (TR 86-31), 1987 (TR 87-33), 1988 (TR 88-32), 1989 (TR 89-40), 1990 (TR 90-46), 1991 (TR 91-64), 1992 (TR 92-46), 1993 (TR 93-34), 1994 (TR 94-33), 1995 (TR 95-37) and 1996 (TR 96-25) is available through SKB.

FOREWORD

According to the "Act on the financing of future expenses for spent nuclear fuel etc." (1992:1537), it is the responsibility of the reactor owners to prepare a calculation of the costs for all measures that are needed for the management and disposal of spent nuclear fuel discharged from the reactors and radioactive waste deriving from it and to decommission and dismantle the reactor plants. This cost calculation shall be submitted annually to the Government or the authority designated by the Government. SKB prepares this cost calculation on behalf of the nuclear power utilities.

The present report, which is the seventeenth annual cost accounting, gives an updated compilation of the necessary costs.

Stockholm in June 1998

Swedish Nuclear Fuel and Waste Management Co.

Peter Nygårds

President

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SUMMARY

The companies that own nuclear power plants in Sweden are responsible for adopting such measures as are needed in order to manage and dispose of spent nuclear fuel and radioactive waste from the Swedish nuclear power reactors in a safe manner. The most important measures are to plan, build and operate the facilities and systems that are needed, and to conduct related research and development. The power utilities have commissioned SKB to carry out this work.

This report presents a calculation of the costs for implementing all of these measures. The cost calculations are based on the plan for management and disposal of the radioactive waste products that has been prepared by SKB and is described in the report.

The following facilities and systems are in operation:

- Transportation system for radioactive waste products
- Central interim storage facility for spent nuclear fuel, CLAB
- Final repository for radioactive operational waste, SFR 1

Plans also exist for:

- Encapsulation plant for spent nuclear fuel
- Deep repository for spent fuel and other long-lived waste
- Final repository for decommissioning waste

The cost calculations also include costs for research, development and demonstration, as well as for decommissioning and dismantling the reactor plants etc.

This report is based on the proposed strategy for the activities which is presented in SKB RD&D-Programme 95. This strategy is largely the same as that on which last year's report was based. SKB proposes that deep disposal be implemented in stages, starting with an initial stage in which 400 canisters are deposited. This is followed by an evaluation and a renewed licensing procedure before the facility is expanded to full scale.

At the end of 1995, certain amendments were made in the Financing Act which influence the calculations presented in this report. The most important amendment is that the reactor owners, besides paying a fee or charge on nuclear energy production, must also give guarantees as security for remaining costs. In this way the fee can be based on a probable cost for waste management. This cost includes uncertainties and variations that are normal for this type of project. Cost increases as a consequence of major changes, disruptions etc. can instead be covered via the given guarantees.

As a basis for determining the fee and the need for guarantees, three types of amounts are to be reported:

- **fee-determining amount**, which is supposed to include all costs for managing and disposing of the spent nuclear fuel from 25 years of operation of the reactors, and for decommissioning and dismantling the reactors and carrying out the necessary research and development. If a reactor has been operated for more than 25 years, the costs should include fuel etc. that has been used up to and including the year for which the fee is supposed to apply (i.e. 1999). In this year's cost calculation, this is the case for Oskarshamn I.

- **basic amount**, which is supposed to include corresponding costs for managing and disposing of the fuel which has been used up to and including the year when the calculation is performed (i.e. 1998), plus the costs for decommissioning and dismantling the reactors.

- **contingency allowance** which includes reasonable additional costs depending on unforeseen events.

The basic amount and contingency allowance are to be used to determine the need for guarantees to cover the loss of fees in the event of premature shutdown of the reactors, plus cost increases as a result of future unforeseen events.

The **fee-determining amount** is derived from a base scenario which describes the measures, facilities etc. that are needed to manage and dispose of the spent nuclear fuel and to decommission and dismantle the nuclear power plants. This scenario necessarily contains uncertainties. In order to take these uncertainties into consideration, a calculation method is used where the uncertainties are dealt with by means of a statistical weighing-together of their influence on the costs.

The base scenario thus takes into account uncertainties, variations and disruptions that can be considered normal in a project. Since several variations affect the timetable, the costs have been calculated both in constant prices (January 1998) and as present values with different assumptions regarding real interest rates in the future.

The total future costs are presented as a distribution function, which indicates the probability associated with a future total cost estimate. The figure which is used is the cost which has, according to the calculation, an equal probability of being too great as of being too small.

The total future costs, in January 1998 prices, for the Swedish waste management system from 1999 onward have been calculated to be SEK 45.8 billion. The total costs apply for the waste obtained from 25 years of operation of all Swedish reactors. They will fall due over a total period of approximately 50 years up to the middle of the 21st century, but the greater part will fall due during the next 20 years. Figure 1.1 shows the present value of the costs at different real interest rates.

It is estimated that SEK 12.1 billion in current money terms has been spent through 1998.

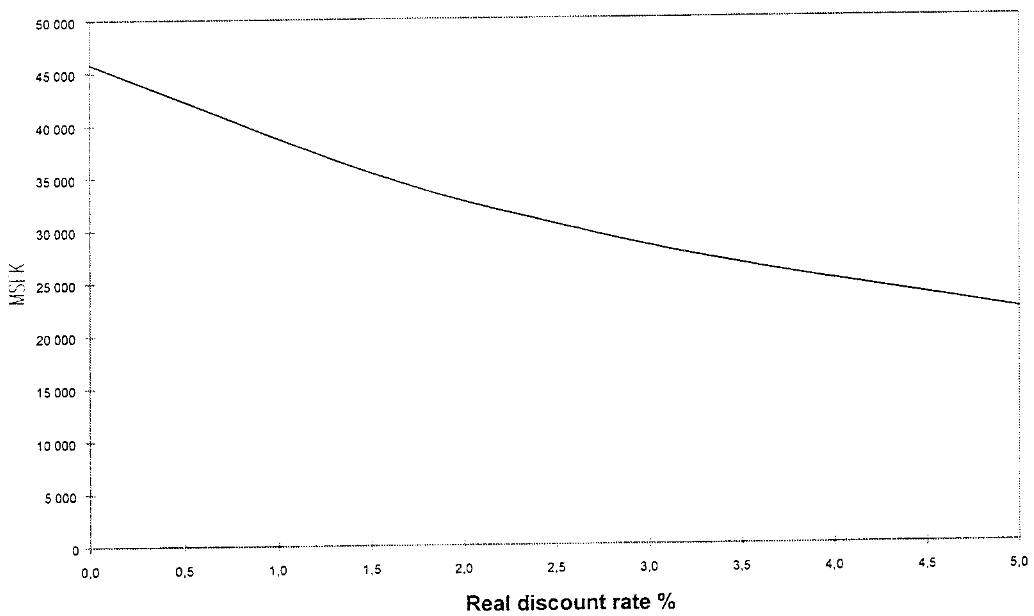


Figure 1.1 Present value (MSEK) of the total future costs from 1999 onward, at different real interest rates. (Price level January 1998)

The **basic amount**, which is the cost for managing and disposing of the waste produced up to and including 1998, is about SEK 1.8 billion lower than the fee-determining amount.

The **contingency allowance,** which is supposed to allow for the risk of unforeseen cost increases, has been calculated using the same statistical method as the fee-determining amount. Greater variations in concept, siting, timetable, cost data and disruptions have been taken into account in calculating the contingency allowance than in the base scenario. The result is obtained in the form of a statistical distribution of the total costs, which indicates the probability associated with a given total cost, i.e. the probability that the calculated cost will prove true.

Aside from the costing calculation discussed above, which is based on waste quantities from operation of the reactors for 25 years, examples are given of the effect of extended operating times. Accordingly, costs based on waste quantities from operation of the reactors for 40 years are also reported.

ABBREVIATIONS

BWR	Boiling water reactor (ABB-Atom)
CLAB	Central interim storage facility for spent nuclear fuel
RD&D	Research, development and demonstration
NPP	Nuclear power plant
PWR	Pressurized water reactor (Westinghouse)
SFR 1	Final repository for radioactive operational waste
SFR 3	Final repository for decommissioning waste
SKB	Swedish Nuclear Fuel and Waste Management Co.
SKI	Swedish Nuclear Power Inspectorate

1. PREMISES

1.1 GENERAL

Every year, on behalf of the nuclear power utilities who own the nuclear power plants, SKB prepares a calculation of the costs for all the measures that are required to manage and dispose of spent nuclear fuel and radioactive waste from the Swedish nuclear power plants. The cost calculation is submitted to the Swedish Nuclear Power Inspectorate (SKI), which recommends to the Government both the fee for management and disposal of the radioactive waste products of nuclear power that is levied on nuclear-generated electricity and the amounts for which the reactor owners have to give guarantees.

At the end of 1995, certain amendments were made in the Financing Act which affect the calculations presented in this report. The most important amendment is that the reactor owners must give guarantees as security for remaining costs. In this way the fee can be based on a probable cost for waste management. This includes uncertainties and variations that are normal for this type of project. Cost increases as a consequence of major changes, disruptions etc. can instead be covered via the given guarantees.

As a basis for determining the fee and the need for guarantees, three types of amounts are to be reported:

fee-determining amount, which is supposed to include all costs for managing and disposing of the spent nuclear fuel from 25 years of operation of the reactors, and for decommissioning and dismantling the reactors and carrying out the necessary research and development. If a reactor has been operated for more than 25 years, the costs should include fuel etc. that has been used up to and including the year for which the fee is supposed to apply (i.e. 1999). In this year's cost calculation, this is the case for Oskarshamn I.

basic amount, which is supposed to include corresponding costs for managing and disposing of the fuel which has been used up to and including the year when the calculation is performed (i.e. 1998), plus the costs for decommissioning and dismantling the reactors.

contingency allowance which includes reasonable additional costs depending on unforeseen events.

The basic amount and contingency allowance are to be used to determine the need for guarantees to cover the loss of fees in the event of premature shutdown of the reactors, plus cost increases as a result of future unforeseen events.

The **fee-determining amount** has been based on a base scenario which describes the measures, facilities etc. that are needed to manage and dispose of the spent nuclear fuel and dismantle the nuclear power plants. The base scenario takes into account normal uncertainties, variations and disturbances for a project.

The base scenario has been based on the KBS-3 method (Ref. 1), which was reviewed in conjunction with the applications for fuelling permits for Forsmark 3 and Oskarshamn 3.

KBS-3 has been found to meet high standards of safety and radiation protection. Account has also been taken of the latest results obtained in SKB's research and development and presented in SKB's most recent programme for research, development and demonstration, RD&D 95 (Ref. 2). The strategy and timetable for the continued activities that are given in RD&D 95 also apply to the base scenario.

In order to include the influence of variations and uncertainties in the cost calculations, a calculation method is employed that deals with the uncertainties with by means of a statistical weighing-together of their influence on the costs. This method is described in greater detail in Chapter 3.

Chapter 2 contains a presentation of the base scenario and the variations and uncertainties that have been weighed in when calculating the fee-determining amount.

The **basic amount**, which gives the total costs for managing and disposing of the waste quantities which arise from reactor operation through 1998 and for dismantling the nuclear power plants, has been calculated based on the costs for the base scenario. Four calculations have been performed, one for each reactor station, assuming a premature shutdown of all units at each station. This means that there is less waste to be managed and disposed of and that the shutdown/dismantling is moved forward in relation to the base scenario.

The **contingency allowance**, which is supposed to allow for the risk of unforeseen cost increases, has been calculated using the same statistical method as the fee-determining amount. Costs for less probable but not unreasonable events that give rise to cost changes are supposed to be included in the calculation of the contingency allowance. Large variations in, for example, concept, siting, timetable, cost data, as well as disruptions of various kinds, are also taken into account. The result is obtained in the form of a statistical distribution of the total costs indicating the probability associated with a given total cost, i.e. the probability that the calculated cost will prove true.

The Financing Act only deals with costs that are attributable to management and disposal of spent nuclear fuel and to decommissioning and dismantling of the reactor plants. SKB's plan for waste management also makes provisions for the operational waste from the nuclear power plants and for other radioactive waste obtained in Sweden, mainly from Studsvik. The latter constitutes only a few percent of the total waste volume.

1.2 CALCULATION ALTERNATIVES

In determining the capacity of the final repository and the transportation system, certain assumptions must be made regarding the operating conditions for the nuclear power units. The quantity of spent fuel and radioactive waste to be managed and disposed of is determined by, among other things, how long and at what power level the reactors are operated, as well as their utilization factors.

According to the Financing Act, the calculations for the fee-determining amount shall be carried out assuming that the reactors are operated for 25 years, but at least up to and including the first year for which the calculations apply, i.e. in this year's calculations through

1999 (the latter condition currently applies for Oskarshamn 1). This represents what is known as the "earning time" for the build-up of the reserve funds. To shed light on how the system is affected by extended operating times, a cost calculation for the case that all reactors are operated for 40 years is also presented in the report.

As a basis for the calculation of the basic amounts, it has been assumed that all reactor units on a site are shut down at the beginning of the calculation period. For this year's report, this means operation through 31 December 1998.

Based on the reactors' operating times, calculations are made of waste quantities and thereby investments and operating times for the facilities in the waste system. Waste quantities for each alternative are presented summarily in the following section, and in greater detail in **Appendix 1**.

It is assumed in this report that the starting time for encapsulation and deposition, as well as the other calculation premises, are the same for the different alternatives. This means that the operating time for the transportation system, CLAB, the encapsulation plant and the deep repository is determined by the total number of canisters to be deposited in each alternative.

The size of the storage capacity in CLAB is also affected by the quantity of fuel in the different alternatives. It is assumed that SFR 1 is operated as long as the reactors are in operation. Regarding SFR 3, the waste volumes and operating time are not affected by different alternatives; operation is merely shifted in time depending on when the reactors are dismantled.

1.3 ENERGY PRODUCTION AND WASTE QUANTITIES

Energy production in the Swedish nuclear power plants in 1997 totalled 67 TWh, which corresponds to an average energy utilization factor of 77%. The energy utilization factor in 1996 was 81%, and in 1995 it was 77%. In calculating expected future energy production, a utilization factor of 80% is used for both BWRs and PWRs. This utilization factor corresponds to the best estimate of the power utilities and agrees with the figures they report to the Energy Commission. It also takes into account expected future renovations and possible disruptions in operation.

Within the base scenario, fuel burnup for future electricity production at BWRs is varied[1] between 38 and 55 MWd/kgU. The corresponding figure for PWRs is between 41 and 60 MWd/kgU.

With operation of all reactors for 25 years, but at least through 1999, a total fuel consumption of between 6,100 and 6,500 tonnes uranium (tU) is obtained for the base scenario, depending on the assumed future burnup. Total electricity production for the base scenario has been calculated to be about 1,650 TWh. Electricity production and fuel consumption per reactor

[1] It should be emphasized that the specification, numerical or otherwise, that is done for variations mentioned in the report is attributable to an estimated probability of outcome, usually 1:10. In the statistical processing included in the calculation process, the outcome will therefore to some extent fall short of or exceed the minimum and maximum values given here.

unit are shown in Table 1.1. This table applies at a future utilization factor of 80% for all reactors and a future average burnup of 42 MWd/kgU for BWRs and 44 MWd/kgU for PWRs.

Table 1.1 Electricity production (net) and fuel consumption for operation of all nuclear power plants for 25 years (Oskarshamn 1 through 1999)

Reactor and date of commercial operation		Thermal capacity MW	Net capacity MW	Energy production TWh			Fuel consumption tU	
				Through 1997	Annually from 1998	Total	Discharged through 1997	Total
B1	1 July 1975	1,800	600	86.5	4.2	97	341	460
B2	1 July 1977	1,800	600	80.9	4.2	100	296	430
R1	1 Jan. 1976	2,500	830	97.7	5.8	115	308	490
R2	1 May 1975	2,570	870	104.1	6.1	118	313	430
R3	9 Sept. 1981	2,780	920	92.6	6.5	149	262	500
R4	21 Nov. 1983	2,780	920	89.7	6.5	160	262	540
O1	6 Feb. 1972	1,375	440	61.2	3.1	67	258	380
O2	15 Dec. 1974	1,800	600	89.3	4.2	98	328	450
O3	15 Aug. 1985	3,300	1,160	102.4	8.1	205	281	720
F1	10 Dec. 1980	2,930	970	113.7	6.8	168	375	660
F2	7 July 1981	2,930	970	109.8	6.8	168	342	650
F3	22 Aug. 1985	3,300	1,160	103.5	8.1	206	291	710
BWRs total		21,735	7,330	845	51.4	1,224	2,821	4,950
PWRs total		8,130	2,710	286	19.0	427	837	1,470
All NPPs total		29,865	10,040	1,131	70.4	1,651	3,658	6,420

The utilization factor is not varied in the base scenario, since such a variation would affect both waste quantities and electricity production, i.e. both the cost and the revenue side. A separate calculation where the future utilization factor has been assumed to be 70% is therefore presented in Chapter 4.4.

Most of the spent fuel will be temporarily stored in CLAB and then emplaced in a deep repository. Besides the fuel accounted for in Table 1.1, there will be about 20 tonnes of fuel from Ågesta and 23 tonnes of German MOX fuel. The latter fuel replaces 57 tonnes of Swedish fuel previously shipped to Cogema. In 1989, SKB transferred the right to reprocessing at Cogema to eight German companies. 140 tonnes of fuel has also been sent to BNFL for reprocessing, from which no waste will be returned. This gives – assuming future operating conditions as shown in Table 1.1, i.e. 25 years of operation but at least through 1999 – a quantity of about 6,300 tonnes of uranium to be disposed of.

With 40 years of operation, the quantity of fuel to be disposed of increases to about 9,300 tonnes of uranium and the total electricity production to 2,700 TWh.

Besides spent fuel, the Swedish nuclear power programme gives rise to low- and intermediate-level operational waste (LLW and ILW) from the nuclear power reactors, CLAB and the encapsulation plant. When the plants are decommissioned and dismantled, decommissioning waste arises. Estimated waste quantities are summarized in Table 1.2 assuming all reactors are operated for 25 years, but at least through 1999. The waste quantities are reported in detail in Appendix 1. The activity content in the different waste types varies widely. The handling and disposal requirements will therefore be dependent on waste type.

Table 1.2 Main types of radioactive waste products to be disposed of

Product	Principal origin	Unit	No. of units	Volume in final repository m^3
Spent fuel		canisters	3,100	12,800
Alpha-contaminated waste	LLW and ILW from Studsvik	drums and moulds	2,800	1,700
Core components	Reactor internals	moulds	1,400	9,500
LLW and ILW	Operational waste from NPPs and treatment plants	drums and moulds	48,000	76,400
Decommissioning waste	From decommissioning of NPPs and treatment plants	mainly 20 m^3 ISO containers	8,200	155,300
Total quantity, approx.			63,500	255,700

1.4 PRINCIPLES OF THE WASTE MANAGEMENT SYSTEM

As a basis for the timetable for and the design of the Swedish waste management system, it has been assumed in this report that:

- Short-lived waste will be disposed of in SFR immediately after it is obtained.
- Spent fuel will be stored in CLAB before being emplaced in a deep repository. Heat generation in the deep repository will be limited in this way. The interim storage period in the base scenario is about 35 years. The influence of variations with about 30 and 45 years of interim storage is also being studied.
- Other long-lived waste will be disposed of in connection with the deep repository for spent fuel.
- It is assumed that dismantlement of the NPPs will begin as soon as possible after shutdown.

It is assumed in the base scenario that the encapsulation plant will be located at CLAB and the deep repository for spent fuel and other long-lived waste will be located in northern Sweden, in the interior or on the coast. It is assumed that the waste will be transported by ship to the nearest harbour, and from there to the repository (if necessary) by rail.

In SKB's most recently submitted programme for research, development and demonstration, FUD 95, SKB proposes, as in RD&D 92, that deep disposal be carried out in stages, beginning with an initial stage when 400 canisters are deposited. This will be followed be an evaluation and renewed licensing before a decision is taken to expand the facility to full scale. The base scenario is based on the strategy proposed in RD&D 95. In connection with the calculation of the contingency allowance, the influence of retrieving the fuel after the initial stage and disposing of it on another site will also be studied.

2. FACILITIES AND SYSTEMS IN THE BASE SCENARIO

2.1 GENERAL

The waste management system on which the calculation of the fee-determining amount has been based is referred to as the base scenario. It takes into account normal uncertainties, variations and disruptions in a project. In the calculation of the fee-determining amount, the influence of the variations on the costs is weighed together statistically. The base scenario is based on the alternative where the reactors are operated for 25 years, or at least through 1999.

This chapter provides a general description of the facilities, systems and measures included in the base scenario. Their function and design are described briefly and the variations that have been studied and have influenced the design, personnel requirements and other cost items are dealt with briefly. Several of the variations within the base scenario affect several facilities within the waste management system. Their influence on each facility is also described below. A more detailed description of the variations can be found in Chapter 3.

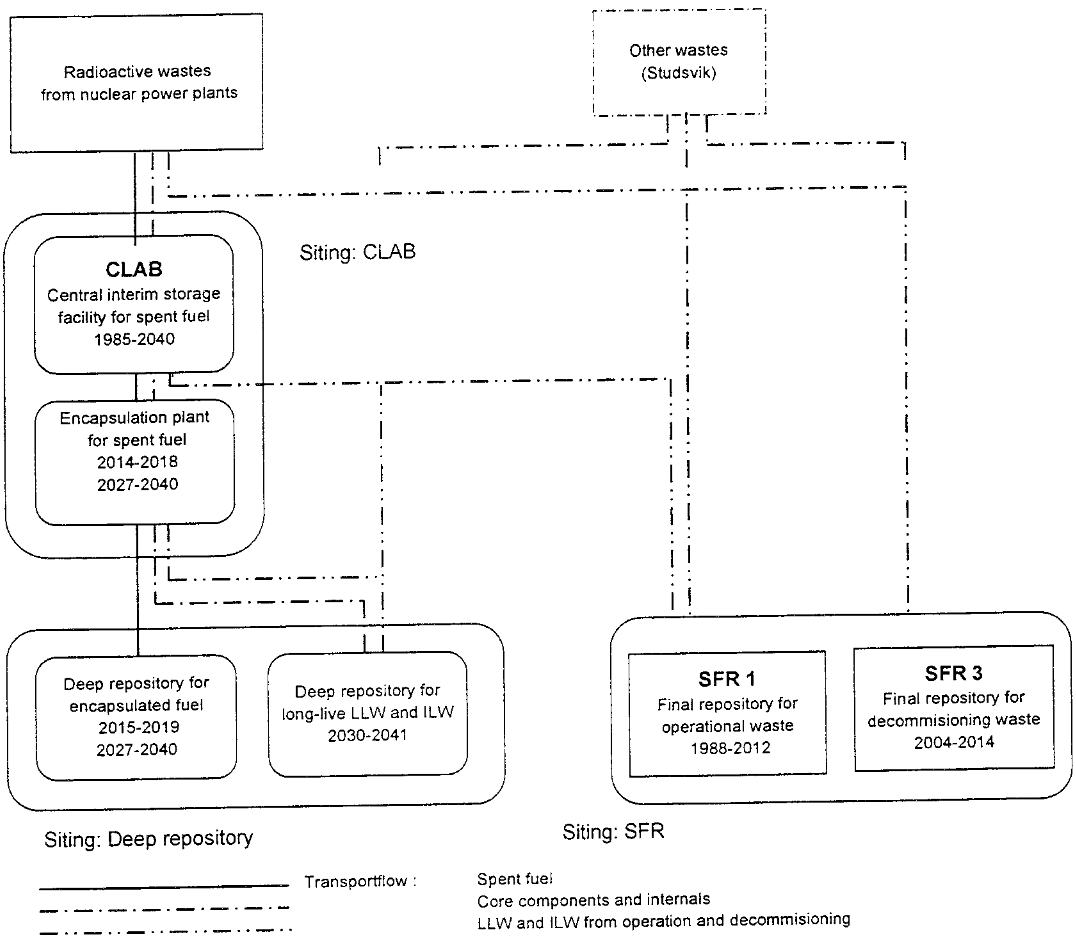


Figure 2.1 Scheme for the management of the waste products from nuclear power in Sweden (operating times apply for the base scenario without disruptions)

RD&D 95 presented programmes and plans for activities relating to the canister, the encapsulation plant and the deep repository. Based on these plans, synoptic timetables for the future facilities have been drawn up as a basis for the cost calculations. According to these timetables, the encapsulation plant and deep repository will be built so that deposition of encapsulated fuel can begin in the year 2010 at the earliest. The actual starting time is dependent on how long the work of siting the deep repository takes. Variations in the starting time between 2010 and 2025 are taken into account in the base scenario, with 2015 as a reference.

Figure 2.1 shows which facilities are included in the base scenario and how waste management is planned to be done, as well as the operating times for the selected reference case (i.e. without allowance for variations). Some of the facilities are in operation, providing a good basis for the cost calculations. The final design of the other facilities has not yet been chosen. However, as a basis for the cost calculations, a possible waste management scheme has been described and layout drawings and personnel plans have been prepared. The variations take into account uncertainties regarding design, staffing, cost data, etc.

2.2 RESEARCH, DEVELOPMENT AND DEMONSTRATION

The purpose of SKB's research, development and demonstration work (RD&D) is to gather the necessary information, knowledge and data to realize the final disposal of spent nuclear fuel and other long-lived radioactive waste. A programme for this work is presented by SKB every third year. The latest programme was presented in September 1995 (Ref. 2) and a review report from SKI was presented in May 1996 (Ref. 3). A new account will be presented in September 1998.

During the 1990s, the RD&D work has been focused on the measures that are needed to build an encapsulation plant for spent nuclear fuel and a deep repository for encapsulated fuel. In addition to the actual design work and safety assessments, relatively extensive supportive R&D will be needed, with an emphasis on development of methods and background material for safety assessments.

An important component of the RD&D activities is the Äspö Hard Rock Laboratory. The Äspö HRL is being used to test, verify and demonstrate the investigation methods which will later be used for detailed studies of candidate sites for the deep repository and to study and verify the function of various components in the final repository system. It will also be used to develop and test technology for deposition. A schematic drawing of the laboratory is shown in Figure 2.2.

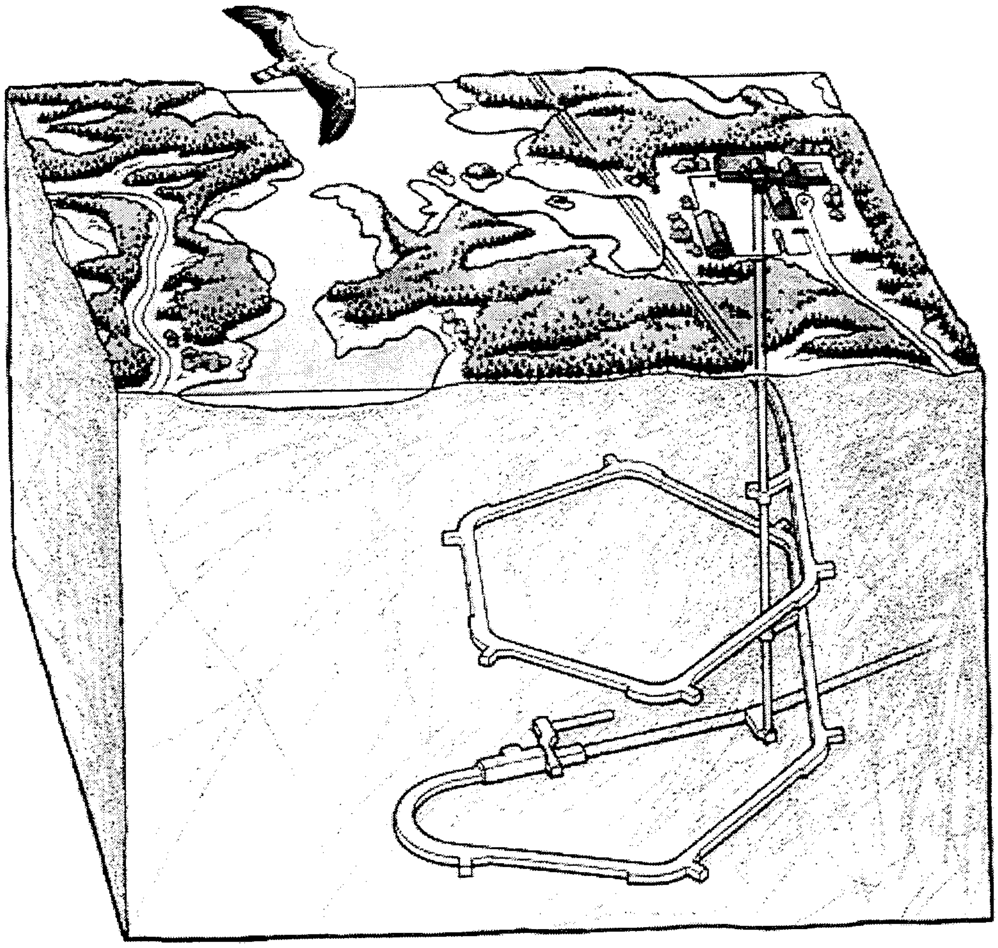


Figure 2.2 Schematic drawing of Äspö HRL

For the purpose of testing and demonstration of the technique for depositing the canisters in the bored holes, a space has been prepared in the Äspö HRL and the detailed engineering of a deposition machine has been commenced. Figure 2.3 shows a shows a drawing of the machine at its current stage of development.

For the purpose of testing and verifying the methods chosen for handling, sealing and inspection of the copper canister, SKB has decided to build a Canister Laboratory in Oskarshamn. The laboratory will be completed in 1998. Trial fabrication of full-sized canisters started in 1996. The laboratory will also be able to be used for training of operators in the various processes and operations included in canister fabrication.

The base scenario assumes that research, development and demonstration, including the activities on Äspö, will be pursued until the second stage of deposition is begun. Besides uncertainties in the scope of the research activities per se, the costs are also affected by other variations that affect the timetable, such as delayed deposition.

Early costs for the deep repository project – i.e. site investigations, design and detailed characterization – are presented in the cost compilation under the heading "Deep repository".

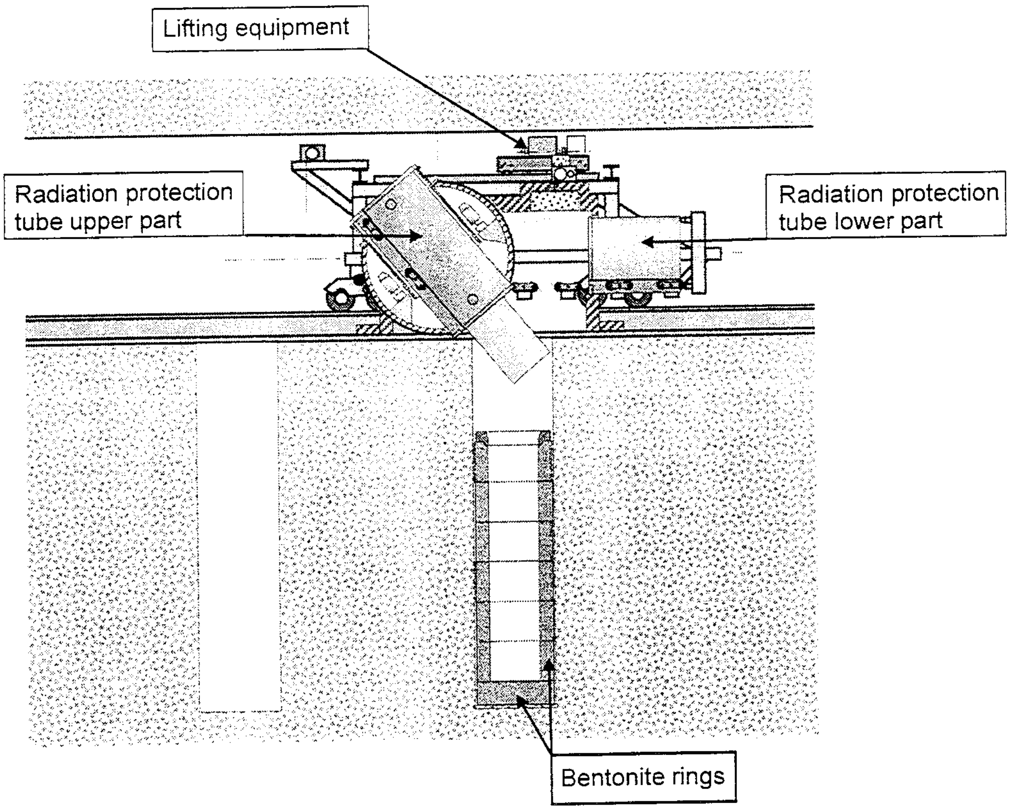


Figure 2.3 Drawing of machine for canister deposition

2.3 TRANSPORTATION SYSTEM

The transportation system is based primarily on sea transport. Its main components are a ship, M/S Sigyn, transport casks/containers and other transport equipment at nuclear power plants and other facilities. The system is designed to accommodate all types of waste.

M/S Sigyn has a payload capacity of 1,400 tonnes and is designed for roll-on roll-off handling. Loading by crane is also possible. Operation and maintenance of the ship is entrusted to Rederiaktiebolaget Gotland.

As of year-end 1997, a total of 2,700 tonnes of fuel had been transported from the NPPs to CLAB, and about 23,000 m^3 tonnes of LLW and ILW to SFR.

Casks and containers designed to meet stringent requirements on radiation shielding and to withstand large external stresses are used for the waste shipments. Spent nuclear fuel, core components and reactor internals are transported in cylindrical transport casks. One cask holds about 3 tonnes of fuel. Radiation-shielding 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 will be used for LLW from operation as well as for most of the decommissioning waste. At present, the system includes 10 fuel casks, 2 casks for core components and 27 radiation-shielding 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 2.4. At present, five vehicles are used.

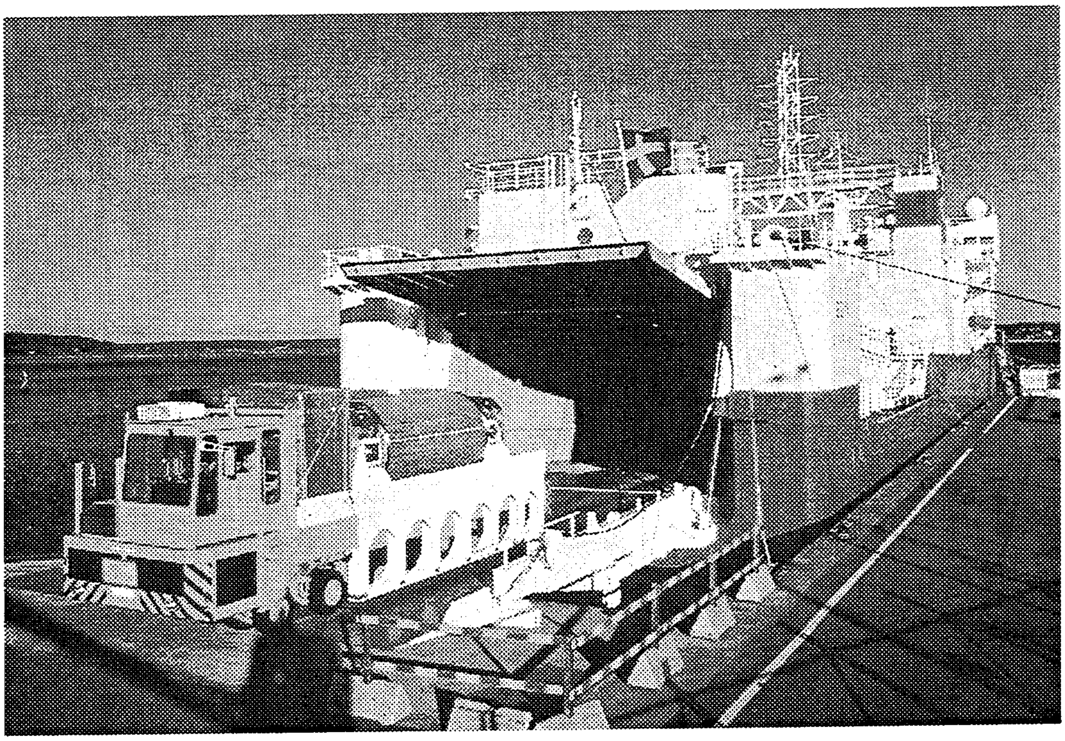


Figure 2.4 Terminal vehicle with fuel transport cask

Since the site of the deep repository for long-lived waste has not yet been decided, it has been assumed in the base scenario that the total distance of sea transport from the encapsulation plant at CLAB to a harbour for possible further transport by rail to the deep repository will be approximately 750 km. 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 and are varied to allow for uncertainties in operating costs and future reinvestment requirements, such as purchase of transport casks/containers, ships etc. The costs of the transportation system are also affected by other variations which change the operating time for the entire waste system, mainly number of canisters and capacity of the encapsulation plant, plus the starting time for encapsulation and deposition.

2.4 CENTRAL INTERIM STORAGE FACILITY FOR SPENT NUCLEAR FUEL, CLAB

The central interim storage facility for spent nuclear fuel, CLAB, is situated adjacent to the Oskarshamn power station. The facility, which started operation in 1985, was originally designed to store some 3,000 tonnes of fuel (uranium weight) in four pools. The introduction of new storage canisters has increased the capacity of these pools to about 5,000 tonnes.

At year-end 1997, the facility contained fuel equivalent to 2,700 tonnes of uranium. Core components and reactor internals are also kept in the facility prior to ultimate disposal in the deep repository.

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

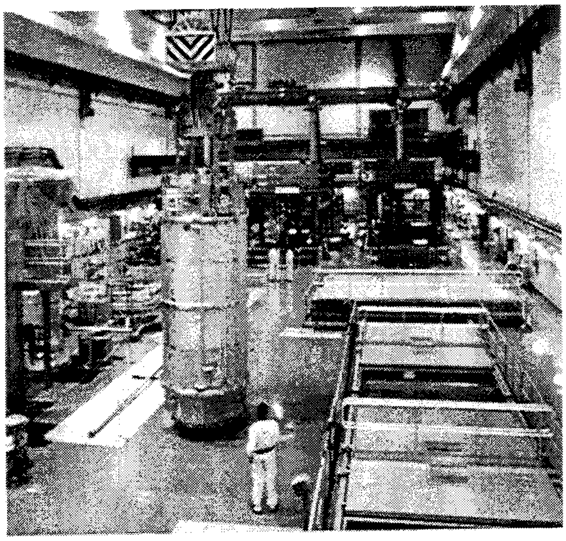
The storage pools are located in a rock cavern and made of concrete with a stainless steel lining. Each pool holds 300 storage canisters. The fuel will mainly be stored in new canisters with either 25 BWR assemblies or 9 PWR assemblies. The new canisters have partitions of boron steel to prevent criticality with the more dense packing of assemblies. The original canisters contain 16 BWR or 5 PWR assemblies. Transfer of assemblies from old to new canisters is currently in progress.

An expansion of the storage capacity so that all fuel from the Swedish programme can be stored in CLAB will commence in 1998 and is expected to be completed in 2004. The expansion of the storage facility will be carried out by building a new rock cavern parallel to the existing one.

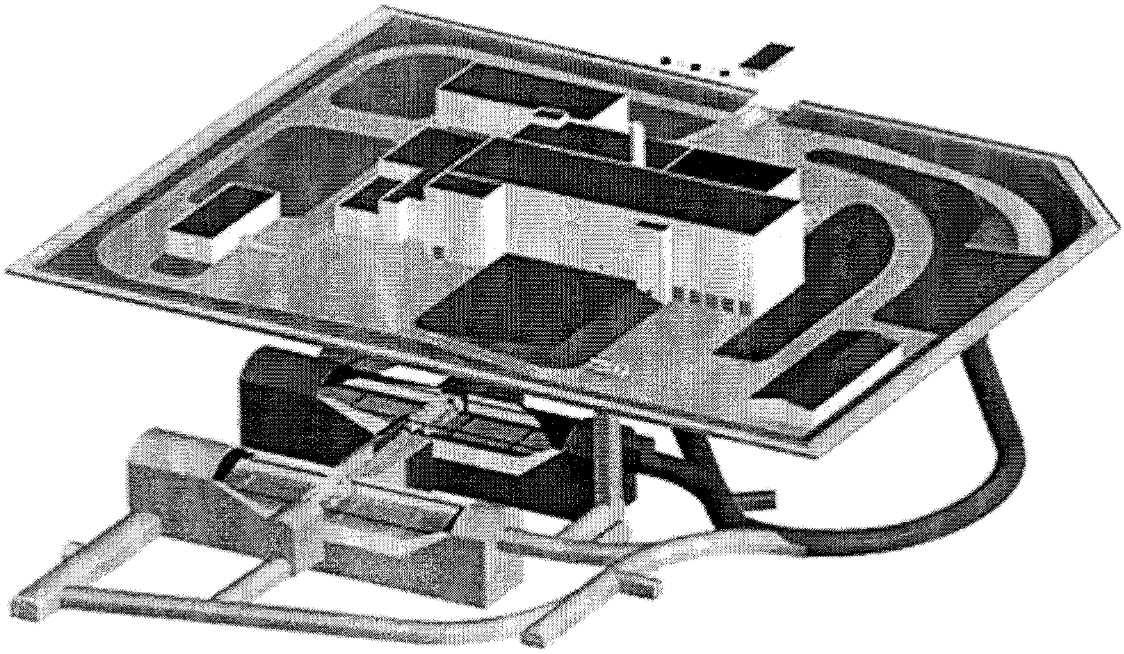
The permanent workforce during operation is currently about 50 persons. In addition there are service personnel, who are mainly taken from OKG's regular base organization. On average, the total personnel complement is equivalent to about 60 full-time employees. During periods when less fuel is being taken in or out of the facility, the workforce can be reduced.

After all fuel and other waste has been removed from CLAB, the above-ground parts will be dismantled along with those parts of the storage pools that have become active. Radioactive waste will be sent to the deep repository.

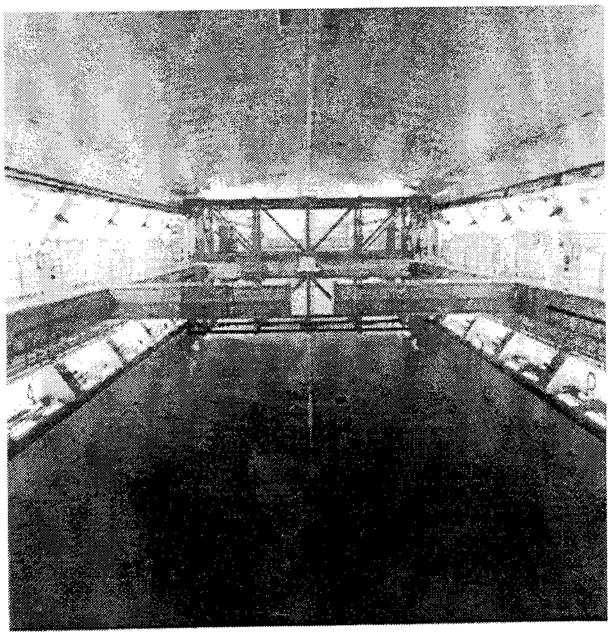
The costs for CLAB are based on experience to date and are varied to allow for uncertainties in operating costs, mainly personnel requirements. CLAB is also influenced by other variations which change the operating time for the entire waste system, mainly number of canisters and capacity of the encapsulation plant, plus the starting time for encapsulation and deposition.



Handling of transport cask
in the receiving section



CLAB with two
rock caverns



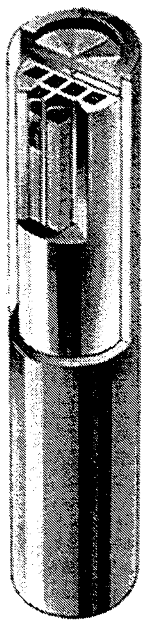
Handling of storage canister
in the storage section

Figure 2.5 CLAB

2.5 ENCAPSULATION PLANT FOR SPENT FUEL

Before the spent fuel is emplaced in a deep repository it must be encapsulated in a durable canister. Encapsulation is planned to take place in a new plant adjacent to CLAB. Other long-lived waste will also be treated in the encapsulation plant. An example of such waste is core components.

It is proposed that the canister be made with a cast steel insert, providing mechanical strength, and an outer shell of copper, providing corrosion protection, see Figure 2.6. The canister holds up to 12 BWR assemblies with boxes or 4 PWR assemblies. The final number of assemblies per canister depends on the fuel's decay heat output at the time of disposal.



Canister surface area (m^2)	17,67
Estimated weight (kg)	
Copper canister	7 600
Insert	13 900
Fuel assemblies	3 600
Total	25 100

Figure 2.6 Copper canister with inner steel container

The encapsulation plant will contain the following functions:

- Encapsulation section for emplacement of fuel in canister, sealing of canister and quality inspection.

- Handling and immobilization in concrete moulds of core components and reactor internals.

- Dispatch section for canisters and concrete moulds. Transport 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 storerooms.

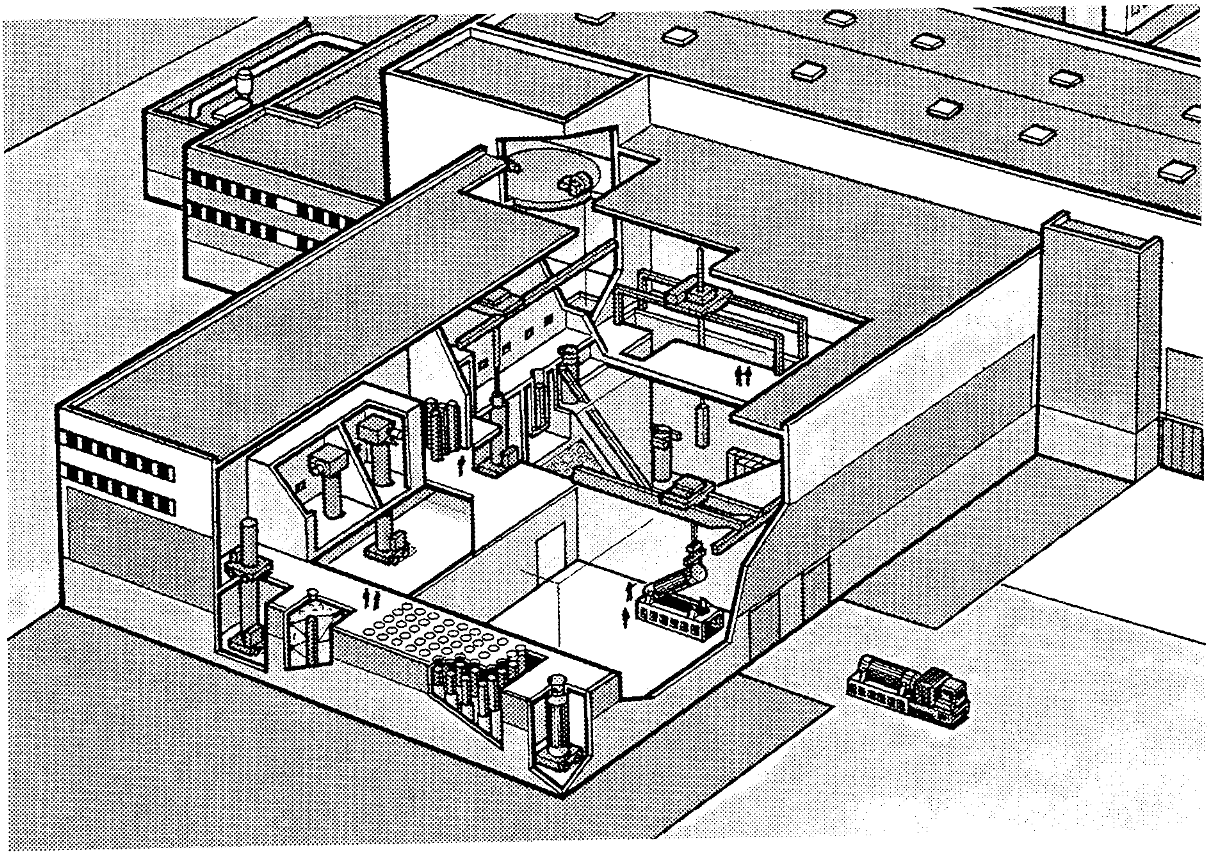


Figure 2.7 Encapsulation plant for spent fuel

The plant is designed for an average annual production capacity of 210 fuel canisters (one canister per work day for 10 months). The total operating time is, however, calculated based on a total production and deposition rate of 200 canisters per year, in order to take into account possible disruptions in the transportation system during the winter. In the cost calculation, the production and deposition rate is varied between 150 and 250 canisters per year, which affects the operating times for the entire waste management system.

The plant will mainly be operated in the daytime. The calculations take into account the coordination advantages that are gained as far as operating personnel are concerned by having the encapsulation plant co-sited with CLAB.

Altogether for the chosen calculation case, i.e. 25 years of operation of all reactors, approximately 3,000 canisters will be fabricated in the encapsulation plant. The number of canisters depends on the quantity of fuel and the degree to which the canisters are filled. These factors are mainly determined by the future burnup of the fuel and the maximum permitted temperature on the canister surface.

During the initial deposition period, it is assumed that 400 canisters will be fabricated for deposition during four years. Fabrication of the remaining canisters will begin 10 years later, i.e. in the reference case 2027, and continue for about 15 years. Then the plant will be dismantled.

Some uncertainties remain before the design of the encapsulation plant and the canister have been finalized. In addition to the variations mentioned above, the base scenario therefore also includes some variations in the cost of building and operating the plant, and in the fabrication cost for empty canisters.

2.6 DEEP REPOSITORY FOR LONG-LIVED WASTE

Off-site facilities and industrial area

The deep repository for long-lived waste is assumed in the base scenario for the cost calculations to be located in northern Sweden, either in the interior or on the coast. It is assumed that waste will be transported by ship to an existing harbour, and from there to the repository (if necessary) by rail. In the cost calculation, the harbour has been provided with a separate quay, a widened and deepened entrance channel, harbour aprons and a storage building for bentonite. If the deep repository is located inland, it is assumed that 20 km of railway has to be laid and rolling stock (locomotives, wagons etc.) purchased. Construction of up to 70 km of railway is included in the variation. All costs for transport from the coast to the deep repository are included in the costs for the deep repository's common facilities.

As described in RD&D 95, the work of siting the deep repository is being pursued in stages with feasibility studies, site investigations and detailed characterization. The costs of feasibility studies and site investigations at two sites are reported under the heading "Siting of deep repository – industrial area". The costs for the detailed characterization, which are assumed to be carried out on one site, are reported under "Investment for deep repository – fuel". The detailed characterization will be carried out in parallel with the construction of the repository's different underground sections.

The deep repository's industrial area will contain a number of buildings and service functions, see Figure 2.8. The extent of the area will be dependent on site-specific conditions and the final design of certain functions, e.g. transport between the ground surface and the repository level, which can take place in a shaft or on a ramp.

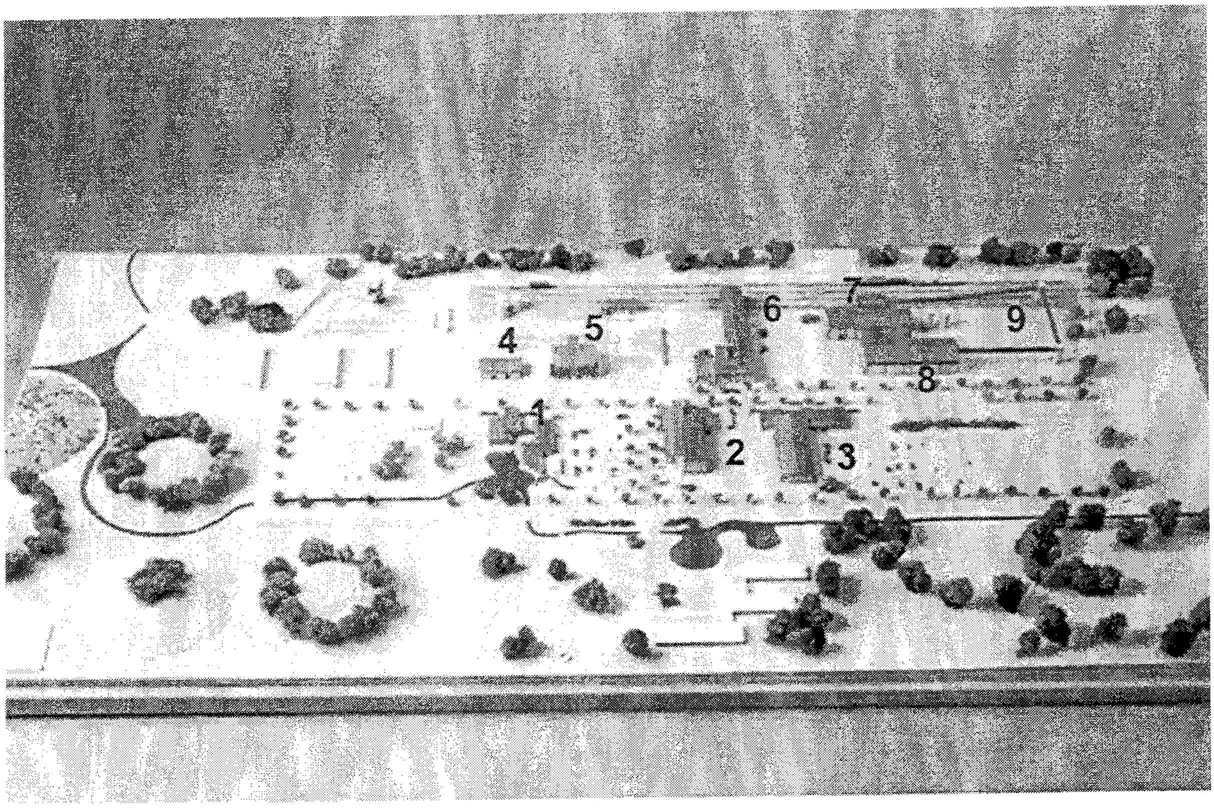


Figure 2.8. Model of the industrial area at the deep repository

In this report it has been assumed that the industrial area contains the following buildings:

1. Information building with canteen

2. Entrance building with offices and workshops

3. Personnel and storage building

4. Service buildings for raw water treatment, sanitary sewerage, heating plant etc.

5. Ventilation building

6. Reception building for transport casks/containers with canisters and other waste

7. Production building for high-pressure compaction of bentonite

8. Store for backfill materials

9. Store for bentonite

During the operating period, some 200 persons will be occupied at the deep repository.

The deep repository contains four different repository areas:

- Deep repository for spent fuel
- Deep repository for long-lived LLW and ILW, which will hold
  - operational waste from CLAB (after 2012 when SFR has been closed) and the encapsulation plant, and long-lived LLW and ILW from Studsvik
  - decommissioning waste from CLAB and the encapsulation plant
  - core components and reactor internals

An overview of the deep repository's industrial area and repository sections is shown in Figure 2.9.

Deep repository for spent fuel

The deep repository for spent fuel is planned, according to RD&D 95, to be situated at a depth of about 500 metres below the ground surface. The repository depth is varied in the cost calculation between 400 and 700 metres. The repository areas will be reached via hoist shaft or ramp. Which access system is the most suitable depends on technical factors, but also on local conditions. A combination of shaft and ramp is considered in the calculation.

The layout of the deep repository allows for the fact that the fuel will be deposited (emplaced) in stages. 400 canisters will be deposited in the first stage. It is assumed that a separate repository section is arranged for them in the deep repository.

In the shaft alternative, the deep repository's central area under ground will be located directly below the industrial area, while the ramp alternative allows greater flexibility in positioning. The central area is adapted to the assumed conditions for transport of canisters and long-lived waste in transport casks down to the repository level and to the fact that unloading of transport casks will take place there.

The positioning of the different deposition areas in the deep repository will be dependent on site-specific conditions. There will be at least two self-contained deposition areas, one for each of the two deposition stages.

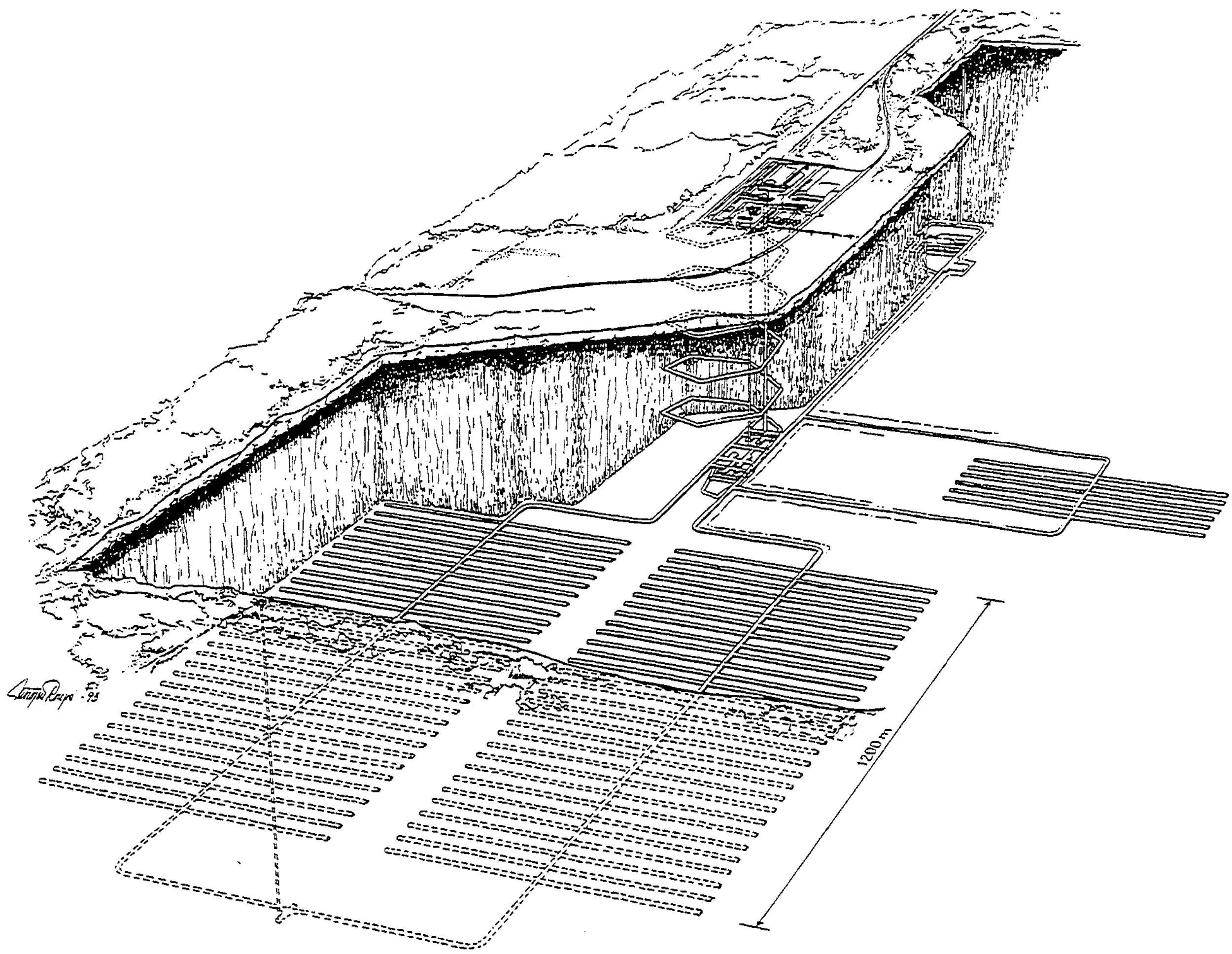


Figure 2.9 Deep repository – overview

The copper canisters with fuel are placed in vertical holes bored in the bottom of the tunnel, where they are surrounded by a 35 cm thick layer of compacted bentonite. The number of deposition holes is about 3,000, of which about 400 are included in stage 1. In order to allow for the existence of certain rock formations in which waste should not be emplaced, costs have been included in the reference case for 10% extra tunnel length. The extra tunnel length is varied to allow for variations in rock conditions.

The distance between the canisters and between the deposition tunnels is determined by the temperature expected to develop around the canister, especially the temperature on the canister surface and in the surrounding bentonite. This is determined by the fuel's decay heat, the thermal properties of the rock and the buffer material, as well as the initial temperature of the rock. The latter is determined to a large extent by the selected siting. All factors are associated with uncertainties and can be treated statistically. In the reference case, the canister spacing has been chosen so that the probable value of the temperature in the bentonite will be 80°C at an initial rock temperature of 10°C (siting in Norrland). This provides good margin to 100°C, even with the variations that can occur. This has given a distance between the deposition holes of 6.0 m and a distance between the deposition tunnels of 40 m. The variations that have been studied and are included in the base scenario lie within the range 70/15 to 90/5°C (bentonite/rock temperature).

The copper canisters are transported from the encapsulation plant at CLAB to the deep repository in special transport casks. The transport casks are brought down to the repository level and transported to the deposition tunnel in question. There the horizontal canister is transferred to the deposition machine. See Figure 2.3 above.

Prior to deposition of the canister, the bottom pad and the rings of bentonite are emplaced in the deposition hole by separate handling equipment.

When the deposition machine is situated above the deposition hole, the canister is raised to a vertical position and lowered into the hole, after which the remaining compacted bentonite rings and bentonite blocks are stacked on top of the canister with the aid of the same handling equipment. The whole sequence is performed behind radiation shielding. The influence of other deposition methods, for example remote-controlled unshielded handling or deposition of the canister together with the bentonite as a package, are studied as a variation.

The deposition tunnels are backfilled with a mixture consisting of 15% bentonite and 85% crushed rock. A bentonite/sand mixture and only crushed rock are used in the variation calculations.

Excavation of new deposition tunnels is carried out simultaneously with deposition of canisters and backfilling of deposition tunnels. The rock excavation activities will be separated from the deposition work.

Deposition of copper canisters is planned to proceed in an initial stage for four years. This will be followed by an evaluation before further excavation. Deposition of the remaining canisters will begin about 10 years later and continue for about 15 years. The deposition tunnels will be closed and sealed as the deposition progresses. After concluded deposition and closure and sealing of the remaining deposition tunnels, transport tunnels and shafts will be backfilled.

Some uncertainties remain before the design of the final repository has been finalized. In addition to the variations mentioned above, the base scenario therefore also includes some variations in the cost of building, operating and closing the facility.

The operating time of the deep repository is also influenced by other variations which affect the timetable for the entire waste management system, for example changed encapsulation capacity and delayed start of encapsulation and deposition.

Deep repository for long-lived low- and intermediate-level waste

The deep repository for long-lived LLW and ILW is assumed to lie at the same level underground as the fuel repository, but about a kilometre away. Temperature effects do not have to be taken into consideration when designing this repository section, since the heat output of the waste is insignificant. The repository is reached via a tunnel starting from the central area for the fuel repository. The tunnel will be sealed in the same manner as the deposition tunnels with a mixture of bentonite and crushed rock.

The repository for low- and intermediate-level operational waste and for waste from Studsvik consists of an approximately 130 m long rock vault. Operational waste from CLAB and the encapsulation plant, plus long-lived LLW and ILW from Studsvik, is deposited in this repository (after 2012 when SFR has been closed). The waste, which consists of moulds (cubes 1.2 m on a side) or of drums (grouped to approximately the size of a mould), is stacked in concrete pits, which are then backfilled with porous concrete. After backfilling, the pits are covered with concrete planks and sealed. All handling is done by remote- controlled overhead crane. Finally, the space between the concrete pits and the rock is filled with crushed rock and the openings of the rock cavern are sealed with concrete plugs. This takes place later in conjunction with sealing and closure of the repository.

The repository for core components and reactor internals has in principle the same design and function as the repository for operational waste described above. The waste here consists of concrete moulds measuring 1.2x1.2x4.8 m.

The repository for decommissioning waste consists of the tunnel system that must be built for the other repositories. Low-level decommissioning waste from CLAB and the encapsulation plant, transport casks etc., which have to be disposed of at a late stage, are emplaced in this repository before closure of the facility.

The repository in its entirety is planned with some expansion reserve.

2.7 FINAL REPOSITORY FOR REACTOR WASTE, SFR

A final repository for operational waste from the nuclear power plants, SFR 1, has been in operation since 1988 at the Forsmark nuclear power station. The facility is situated underneath the Baltic Sea with a rock cover of about 60 m. From the harbour at Forsmark, two 1 km long access tunnels lead out to the repository area. A final repository for the decommissioning waste from the NPPs, SFR 3, is also planned in connection with SFR 1. It is assumed in this report that SFR 2, which was intended for core components etc., will not be realized, but will instead be replaced by a repository connected to the deep repository.

Radioactive waste from CLAB and similar radioactive waste from non-electricity-producing activities, including Studsvik, will also be disposed of in SFR.

SFR 1

SFR 1 consists of four 160 m long rock vaults plus a 70 m tall cylindrical rock cavern containing a concrete silo. The waste containing most of the radioactive substances is placed in the silo. Figure 2.10 shows a drawing of SFR 1 and pictures from the different repository chambers.

In the selected calculation case, 25 years of operation of all reactors, SFR 1 will receive a maximum of 60,000 m^3 of waste. An expansion of SFR 1 is thus not considered for this calculation case.

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 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.

ILW, which is emplaced in rock vaults, is also embedded in concrete. The LLW is not embedded in concrete.

ILW packages are handled in the silo repository and in one of the rock vaults by remote control, while LLW packages in the other rock vaults are handled by forklift truck.

It is assumed in the base scenario that the facility will be sealed and closed in the early 2010s. A workforce of about 15 persons is required during operation. Additional support services are provided by the Forsmark station's regular base organization.

Approximately 22,900 m^3 of waste had been deposited in SFR by year-end 1997.

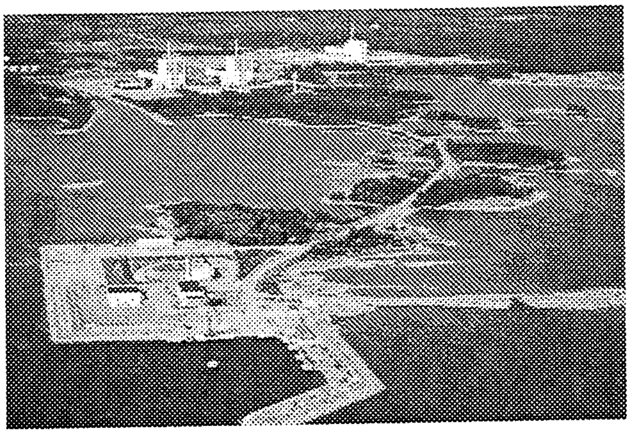
SFR 3

The decommissioning waste from the NPPs and Studsvik will be deposited in SFR 3, which is planned to consist of five rock vaults of a type similar to those in SFR 1. Most of the decommissioning waste can be transported in standard freight containers, which are placed in rock vaults without being emptied. A total of about 140,000 m^3 of decommissioning waste will be disposed of in SFR 3.

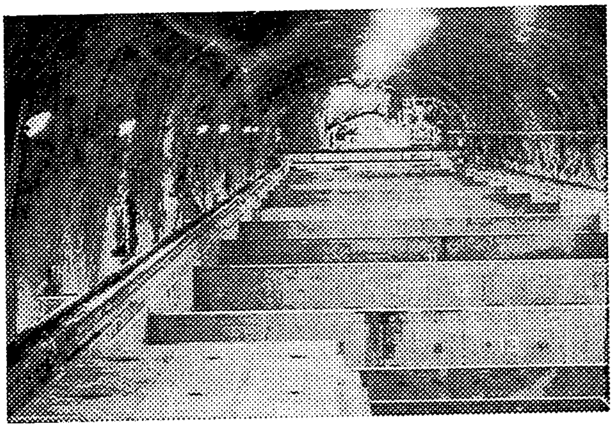
SFR 3 will be in operation while the NPPs are being dismantled and will have a workforce roughly equivalent to that in SFR 1.

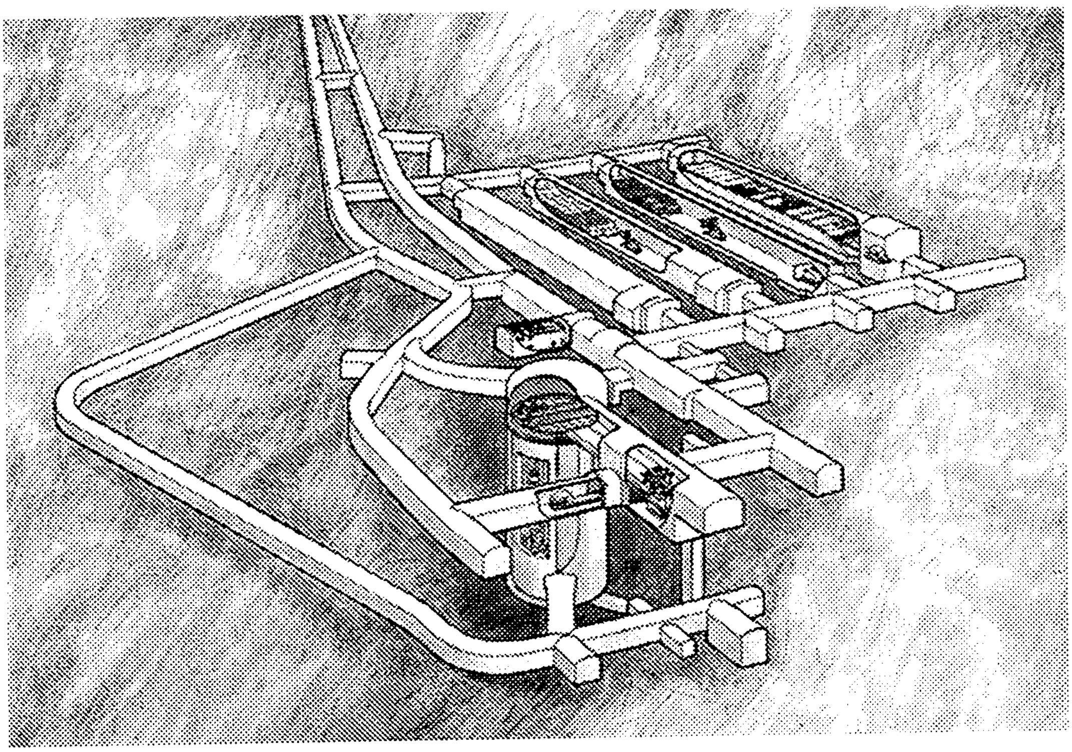
SFR 1 and SFR 3 are only subject to minor variations in costs for operation, sealing and decommissioning. SFR 3 is also varied with respect to waste volumes from decommissioning.

View of the above-ground complex



Rock vault for intermediate-level waste





View over top of silo

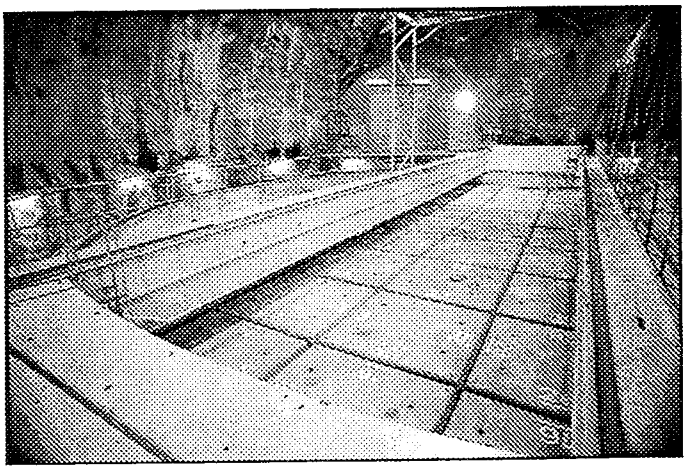


Figure 2.10 SFR 1

2.8 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 operation (Ref. 4).

The timetable for decommissioning of the NPPs is influenced by a number of different factors. Dismantling can be carried out safely a short time after shutdown, but there may be certain technical advantages with deferred dismantling. Here it is assumed that the plants are dismantled early, however.

With regard to resource utilization and the receiving capacity of CLAB and SFR, it is desirable to stagger the start of dismantling of different units. Here the time between the start of dismantling of units at the same station is assumed to be two years.

The period between when the unit is taken out of operation and the start of dismantlement is occupied by removal of fuel, decontamination and preparations for dismantlement. This operating period is called shutdown operation. During this period the workforce can gradually be reduced. The actual dismantling work is expected to take five years per unit and employ an average of a couple of hundred persons.

The radioactive waste from decommissioning is all LLW and ILW. However, the activity level varies considerably between different parts. The waste with the highest activity, the reactor internals, is assumed to be stored in CLAB for about 20–30 years before being emplaced in the deep repository for long-lived LLW and ILW. Other radioactive decommissioning waste will be transported directly to SFR 3 and deposited there. A large quantity of the decommissioning waste can be released for unrestricted use, when necessary after decontamination.

To take into account uncertainties in the cost for shutdown operation and direct dismantling costs, these are varied by up to 50% in the cost calculation, which corresponds to a changed personnel requirement during shutdown operation and major complications during the actual dismantlement. Experience from comparisons with international studies has hereby been drawn on.

3. CALCULATION METHOD

3.1 OVERVIEW

For calculation of the fee-determining amount, a statistical calculation method is employed which takes into account the variations and uncertainties that naturally enter into an appraisal of the cost of a project, particularly at an early stage. The method is based on a calculation principle termed “Progressive convergence calculation” (Ref. 5), which was developed specially as a tool for handling uncertainties of this type in a project.

The method employs established statistical principles. Each cost item or variation is regarded as a variable which can assume different values with varying degrees of probability. A suitable function that defines this probability distribution (distribution function) is chosen for each cost item and variation.

The total cost is then obtained by adding up all the cost items according to the rules that apply to addition of stochastic variables. The outcome is obtained as the result of a large number of calculation cycles, where each cycle arrives at a calculated total cost for a certain outcome of the component cost items and variations. The result is then presented as a distribution function indicating the probability associated with a given total cost, i.e. the probability that the calculated cost will prove true. A probability of 50%, for example, means that there is an equal likelihood that the value will be too large as that it will be too small. The probability level chosen for presentation of the results is dependent on the purpose of the calculation. The 50% level is used for the fee-determining amount that is supposed to reflect a probable cost outcome.

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

The application of the method in the present calculation is illustrated schematically in Figure 3.1 below. The numbers in the following description refer to the figure.

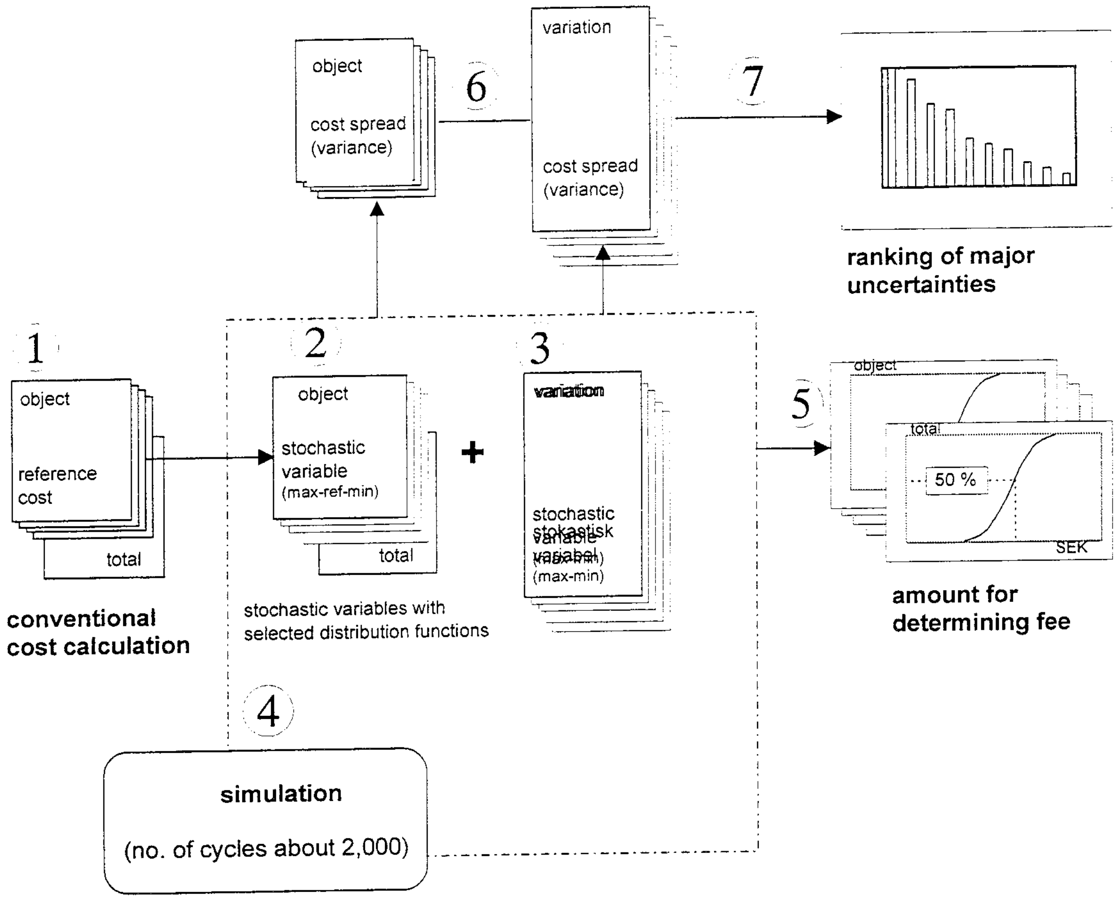


Figure 3.1 Schematic description of the calculation steps (numbered references in text)

The input values in the calculation are obtained from so-called "reference costs" for each calculation object and for the total **(1)**. The reference costs are calculated by means of a traditional deterministic calculation, but without allowances for variations and uncertainties. The subdivision into calculation objects corresponds in principle to the different cost categories for each different facility, i.e. investment, operation, closure etc.

The next step is to determine what variations and uncertainties are to be included in the cost calculation. They may be of the type that affect calculation objects in several parts of the waste system **(3)**, e.g. changed timetable or changed number of canisters, or they may only affect single calculation objects **(2)**, e.g. uncertainty in workforce or canister cost. Each variation is defined in terms of scope and an assessment is made of which calculation objects are affected by the variation. In specifying the scope, a range of values is given which has a given probability of encompassing the actual value, normally about 80%. The variations are described in greater detail in section 3.3.

Subsequently, the cost influence of the variations chosen to be included in the base scenario on different calculation objects is evaluated. Since both the calculation objects and the variations have been defined not only with their respective reference costs but also with a range of values (lowest to highest cost related to a given probability that they will prove true), 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 nature of the variation as closely as possible. Thus, special properties of the variation are taken into account, such as a pronounced skewed distribution of the outcome or an either-or value.

Finally, a statistical summation of the costs is done by calculating the total cost for a statistically selected outcome of the component cost items and variations. This calculation is repeated in a sufficient number of cycles (about 2,000) to ensure that the final result has stabilized and is sufficiently accurate.

The result gives, for each object as well as for the system as a whole, a mean value of the cost and the standard deviation of the cost, which together define a distribution function **(5)** from which the cost can be obtained for the chosen probability (degree of confidence). 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 is dependent upon the real interest rate that is used. The calculations are therefore carried out in the form of a number of present-value calculations with differing assumptions regarding the real interest rate used for discounting (i.e. the discount rate).

The relatively lengthy process described above is done for the alternative with operation of the reactors for 25 years. If the reactor has reached an age of 25 years, it is operated through 1999. The costs for the two alternatives – operation for 40 years and operation through 1998 – are obtained by means of relatively simple marginal cost calculations based on the 25-year calculation. The calculation of the influence of the varying utilization factor has also been done in this way. Calculation of the cost of operation through 1998 yields figures for the basic amount.

The amount used as a basis for determining the contingency allowance is calculated in the same manner as the fee-determining amount, but major system and timetable-related variations are also included here.

3.2 CALCULATION OF REFERENCE COST

The reference cost is calculated by means of a traditional costing calculation, based on functional descriptions of each facility, resulting in layout drawings, equipment lists, personnel forecasts etc. This material is very detailed for facilities and systems already in operation, while the degree of detail is lower for future facilities.

For each cost item a base cost is calculated, 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, e.g. for concrete casting, rock blasting and operating personnel. Experience gained in the construction of the nuclear power plants, 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.

3.3 VARIATIONS IN THE BASE SCENARIO

The method for handling uncertainties in the calculation is based on a systematic identification and evaluation of events which can significantly affect the cost outcome. The events, which may be either project-internal (facility design, quantities etc.) or external (government actions, economic factors) in turn give rise to variations in the reference concept which may be of a technical, economic or administrative nature. These variations are quantified with a "lowest" and a "highest" outcome, related to a given probability that they will prove true.

Certain variations can be said to be normal within construction and civil engineering. They are accommodated within the base scenario and thus do not change the overall concept or timetable strategy. All variations within the base scenario are included in the calculation of the fee-determining amount.

Other variations which influence the overall concept or timetable strategy, or are otherwise deemed to be less likely, are included only in the amount used for determining the contingency allowance (which also includes the variations within the base scenario). These are described in Chapter 5.

Two types of variations are distinguished. The first type is those that affect several objects, so-called external variations. These include timetable and capacity changes. The second type is those that only affect a single calculation object, known as object-specific variations. The latter include e.g. uncertainties in the design of an individual facility or in an estimated workforce, as well as cost uncertainties per se. Following is an overview of the variations for the base scenario, divided into the following groups:

- operating conditions for the NPPs
- management and disposal concept
- technology
- siting

- timetable dependencies
- other calculation premises
- object-specific variations

Variations included in the calculation of the fee-determining amount

Operating conditions for NPPs

- The future burnup is varied between 38 and 55 MWd/tU for BWRs and between 41 and 60 MWd/tU for PWRs. This affects the decay heat and the number of canisters and thereby the operating time for the waste management system.

Technology

- The probable temperature on the canister surface in the deep repository is varied between 70 and 90°C. This affects the permissible decay heat and thereby the spacing between the canisters in the deep repository.
- The deviation of the canister from the nominal decay heat. An elevation of the canister heat by 10% is posited, which influences the canister spacing in the deep repository.
- The thermal parameters for bentonite and rock are varied with respect to the thermal conductivity of the bentonite and the rock and the initial temperature of the rock. This affects the spacing between the canisters in the deep repository.
- The capacity of the encapsulation plant is varied between 150 and 250 canisters per year. This primarily affects the operating time for the waste system, but also the canister spacing in the deep repository, since the age of the fuel at deposition is affected and thereby the decay heat.
- The depth of the deep repository is varied between 400 and 700 m. The length of the deposition tunnels is changed to allow for different rock conditions and the complexity of the access system is increased. This affects the costs of building and sealing the deep repository.
- The deposition method is varied, e.g. by assuming deposition of the canister as a package with the bentonite.
- Materials and method for sealing the deep repository are varied between crushed rock alone and a sand/bentonite mixture. This affects the closure/sealing costs for several repository sections.

Siting

- The siting of the deep repository is varied between a coastal location, without any need for long overland transport, and an inland location, requiring construction of up to 70 km of railway.

Timetable dependencies

- Changes in the starting time for encapsulation and deposition (moved up 5 years and postponed 10 years). This affects virtually all cost items. The time for research, as well as the operating time of CLAB and the transportation system, are changed. The start of operation of other facilities is changed.

Other calculation premises

- Technological progress is taken into account by means of an optimistic and a pessimistic variation. Affects all future facilities.

- The general economic situation when the major construction contracts are procured is taken into account by means of a variation of the construction costs.

- Realism in the cost estimates is taken into account by means of an optimistic and a pessimistic variation.

Object-specific variations

Object-specific variations consist of specified or more general increases in the reference cost for each object (36 objects). Typical increases relate to e.g. changes in building volume or operating organization, or varying requirements on execution (for example in connection with deposition).

Two of these variations can be specially mentioned:

- Canister cost is varied by ± 30%.

- Cost of decommissioning of NPPs is varied, mainly with respect to personnel requirement and method development, altogether about -20% / +40%.

4. COST ACCOUNTING

4.1 GENERAL

An account of all costs for management and disposal of the radioactive waste products described in Chapter 1.3 is given in this chapter. The cost calculations have been based on SKB's plan for facilities, systems etc. as described in Chapter 2.

Costs incurred through 1998 and future costs are distinguished in the account. The future costs are calculated in January 1998 prices. Previously incurred costs are given in current money terms.

With respect to the above-ground facilities at the deep repository, a distinction is made in the report between off-site facilities – which refers to roads, railway, harbour, housing, etc. – and the industrial area, i.e. the fenced-in worksite immediately surrounding the deep repository. The cost for the industrial area also includes costs for the siting work.

The costs are presented in detail in a computerized compilation program. The program permits present value calculations and variation analyses, as well as distribution of the costs among different NPPs etc.

The costs for different facilities are reported here in the following items: investment, operation and reinvestment, plus decommissioning and sealing. The investment costs normally only include those costs which arise before a facility or facility section is put into operation. In the deep repository, however, where construction of the deposition tunnels will take place progressively during the deposition phase, the costs for this work have also been included in the investment costs.

Costs which do not fall under the Financing Act are also presented in the report (operational waste from the NPPs, Ågesta fuel and waste from Studsvik).

4.2 FEE-DETERMINING AMOUNT – BASE SCENARIO

The fee-determining amount has been calculated for the case where all reactors are operated for 25 years or at least through 1999. The calculations have been carried out with a statistical weighing-together described in Chapter 3. The result of the calculations is obtained in the form of a distribution function which gives the probability associated with the total cost, i.e. the probability that the calculated cost will prove true. For the fee-determining amount, which is supposed to be the probable cost, the value is used which has an equal likelihood of being too great as of being too small.

Table 4.1 shows the future costs for the waste management system according to the base scenario. The costs are broken down by object and cost category. The total future costs through 1999 amount to SEK 45.8 billion.

The table separates costs covered by the Financing Act, i.e. the total cost less costs for LLW and ILW, and waste from Studsvik and Ågesta. The future costs under the Financing Act from 1999 amount to SEK 44.7 billion.

Figure 4.1 shows the future costs according to the Financing Act distributed over time. The costs will be incurred over a period of about 50 years, the greater part during the next 20 years.

A breakdown of the total costs, both incurred and future, for the different facility sections is shown in Figure 4.2

Table 4.1 Future costs (MSEK) from 1999 onward. Operation of all reactors for 25 years, but at least through 1999. January 1998 prices.

Object	Cost category	Total future costs	Sum of future costs per object	Future costs under Financing Act [1)]
SKB - adm. + R&D	-	3,600	3,600	3,600
Transport	reinvestment operation	910 790	1,700*	1,500
Decom. NPPs	shutdown operation dismantling	2,300 10,800	13,100	13,100
CLAB	investment reinvestment operation decommissioning	680 840 3,600 520	5,600*	5,570
Encapsulation plant	investment operation + reinvestment decommissioning	2,100 4,500 170	6,800*	6,770
Deep repository - off-site facilities	investment operation + reinvestment	1,100 80	1,200*	1,190
Deep repository - industrial area	siting investment operation + reinvestment decommissioning	1,600 1,700 1,900 210	5,400*	5,370
Deep repository - fuel	investment operation + reinvestment decom. + sealing	3,700 740 2,100	6,500*	6,470
Deep repository - other	investment operation decom. + sealing	390 50 100	540*	350
SFR 1	operation + reinvestment decom. + sealing	480 110	590*	20
SFR 3	investment operation + reinvestment decom. + sealing	440 230 60	730*	710
Total		45,800	45,800	44,700

* Also includes costs outside of the Financing Act

1) Future costs less costs for Studsvik waste etc. and other LLW and ILW

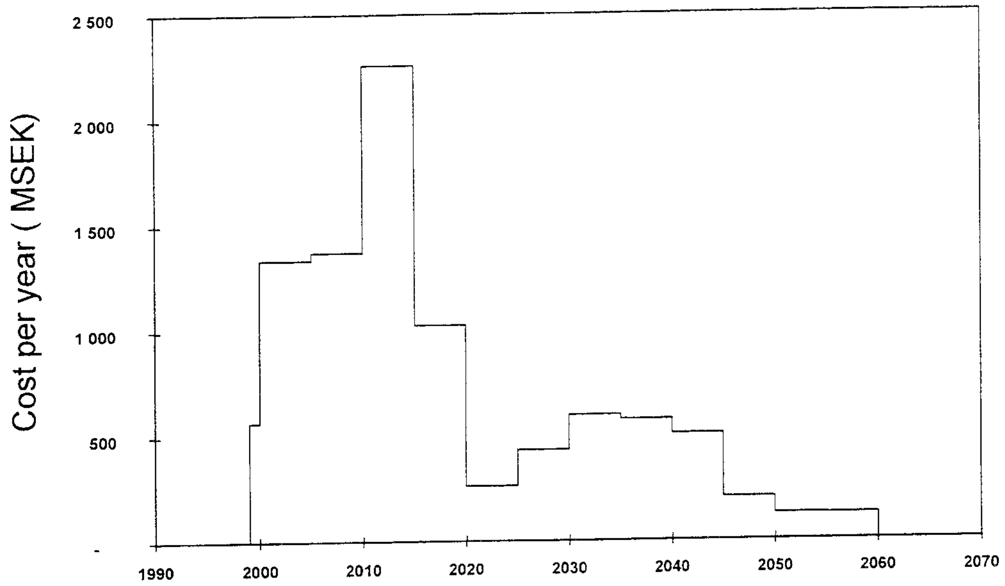


Figure 4.1 Future costs according to the Financing Act distributed over time, MSEK per year.[2] Operation of all reactors for 25 years, but at least through 1999. January 1998 prices.

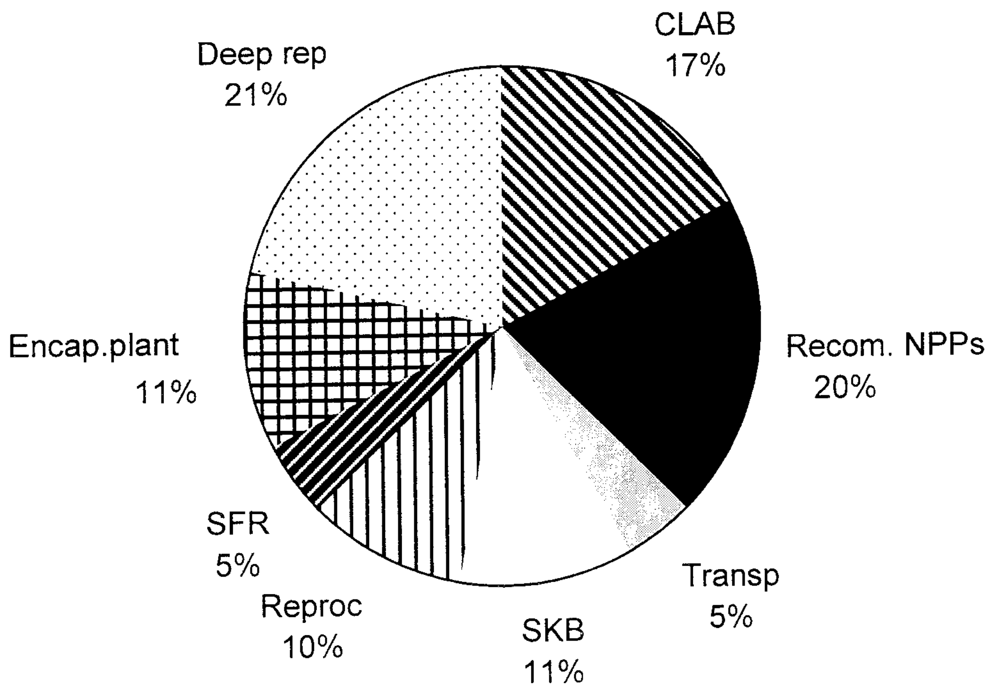


Figure 4.2 Breakdown of the total cost (incurred and future) for operation of all reactors for 25 years, but at least through 1999. January 1998 prices.

Since several variations affect the timetable for the waste system, the present values of the costs have also been calculated with different assumptions concerning the real interest rate. To

[2] The distribution over time takes into account the timetable variations that are included in the cost calculation so that present-value calculations for different real interest rates (0–5%) give correct results.

show the importance of the real interest rate, the total future costs under the Financing Act as a function of the real interest rate chosen for the purposes of the cost calculation are shown in Figure 4.3.

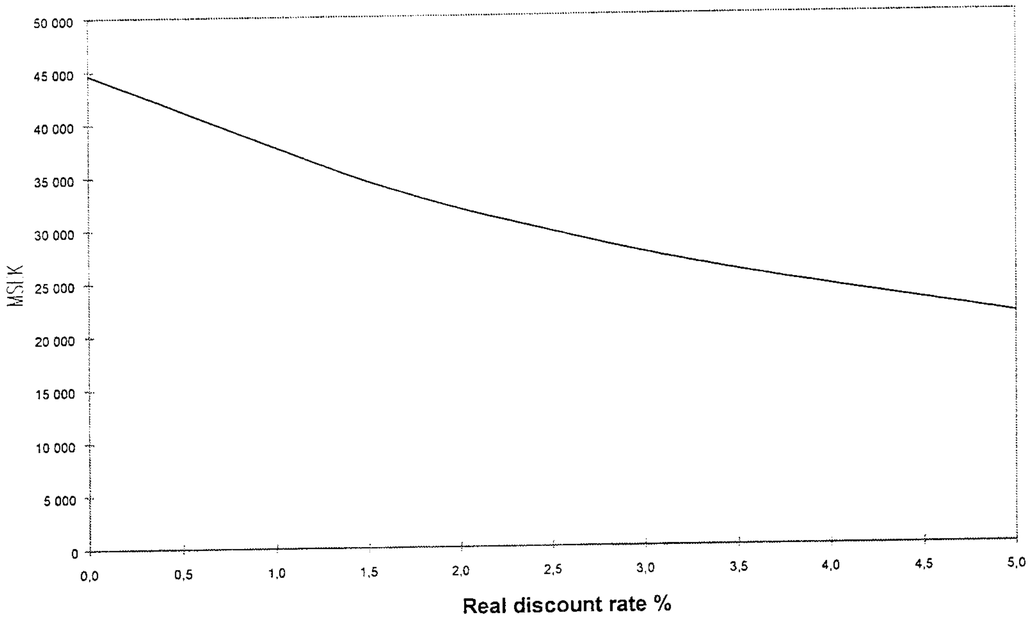


Figure 4.3 Total future costs under the Financing Act as a function of the real interest rate. Operation of all reactors for 25 years, but at least through 1999. January 1998 prices.

4.3 DETERMINATION OF BASE AMOUNT

As a basis for determining what guarantees are needed to cover the loss of fees in the event of a premature shutdown, a basic amount has been calculated separately for each power company for the case that all reactors on a site are shut down on 31 Dec. 1998. In the event of an early shutdown, the quantity of spent fuel decreases and thereby the costs for disposing of it. At the same time, the average time between shutdown and start of dismantlement increases, which increases the costs of shutdown operation. Taken together, this means that the cost decrease is small in relation to the fee-determining amount, totalling about SEK 1.8 billion.

If dismantlement in its entirety is done earlier than in the base scenario, however, the calculated present value of the cost increases as the real interest rate rises.

4.4 VARIATIONS IN OPERATING CONDITIONS

To shed light on the influence of different operating conditions on waste quantities and thereby costs, two calculation cases are presented here: operation of all reactors for 40 years and a change of the utilization factors to 70% with 25 years of operation of all reactors. The variations have been calculated as marginal costs in relation to the base scenario.

40 years of operation of all reactors

With 40 years of operation of all reactors, a total fuel consumption of about 9,500 tU is obtained, 7,200 tonnes of which comes from BWRs and 2,300 tonnes from PWRs. In this case, the total energy production would be about 2,700 TWh.

Future costs per object are shown in Table 4.2. The total future costs from 1999 amount to SEK 52.1 billion. A cost comparison is also made in the table with 25 years of operation of all reactors.

Table 4.2 Total future costs (MSEK) from 1999 onward. Operation of all reactors for 40 years. January 1998 prices. Comparison with 25 years of operation.

Object	25 years of operation	40 years of operation
SKB - adm. + R&D	3,600	3,600
Transport	1,700	2,000
Decommissioning of NPPs	13,100	13,100
CLAB	5,600	6,600
Encapsulation plant	6,800	9,100
Deep repository – off-site facilities	1,200	1,200
Deep repository – industrial area	5,400	5,900
Deep repository – fuel	6,500	7,900
Deep repository – other waste	540	670
SFR 1	590	1,400
SFR 3	730	730
Total	45,800	52100

70% utilization factor

With operation for 25 years, a change in the future utilization factor from 80% to 70% leads to a decrease in energy production by about 70 TWh and a decrease in total fuel consumption by about 200 tU.

The total future costs from 1999 onward with a utilization factor of 70% and 25 years of operation amount to SEK 45.5 billion.

4.5 PREVIOUSLY INCURRED COSTS

Table 4.3 shows costs incurred through 1997 in current money terms, excluding interest, and the costs budgeted for 1998.

Table 4.3 Incurred and estimated costs through 1998
MSEK, current money terms

Object	Cost category	Costs incurred through 1997	Estimated costs 1998	Total through 1998
SKB (RD&D, info, adm.)	–	2,498	302	2,800
Canister development	–	59	55	114
Transport	Investment	260	13	273
	Operation	348	21	369
CLAB	Investment	1,818	64	1,882
	Operation	1,184	84	1,268
SFR 1	Investment	743	5	748
	Operation	267	30	297
Reprocessing	–	3,276	540	3,816
Encapsulation plant	Investment	112	40	152
Deep repository	Investment	275	93	368
Total		10,840	1,250	12,090

5. DETERMINATION OF CONTINGENCY ALLOWANCE

The contingency allowance should be used as a basis for determining the need for guarantees as security for additional costs resulting from unforeseen events. The same calculation method has been employed for calculating the amount used in determining the contingency allowance as for the fee-determining amount (see Chapter 3). However, the variations that have been applied are much greater in scope and pertain to the deep repository concept, siting, timetable, cost data and different types of disruptions. The special variations included in the calculation of the contingency allowance are discussed below. The variations included in calculation of the fee-determining amount are also discussed (see Chapter 3.3).

Special variations included in the calculation of the contingency allowance

Operating conditions for NPPs

- Fuel damages of considerable scope in a reactor, making it necessary for a large part of a reactor core to be disposed of in a special manner. This affects the operation of the encapsulation plant

Management and disposal concept

- Other final disposal concept for fuel than KBS-3. Deposition in very deep boreholes, but with about 20 year delay. Affects encapsulation and deep repository, plus timetable for other activities.

- Variation of final repository concept for other long-lived waste, with more qualified encapsulation prior to deposition.

- SFR 1 needs to be expanded with a second stage due to increased waste quantities.

Technology

- Canister type and size are varied. Both larger and smaller canisters are studied. Affects the encapsulation plant, the number of canisters and deposition holes, and the operating time for the entire waste management system.

- The capacity of the encapsulation plant is assumed to be less than expected, which is compensated for by extra shift personnel. Greatly increased capacity is also studied as an alternative.

Siting

- The encapsulation plant is co-sited with the deep repository, which affects the costs for the repository as well as the transport costs.

- The deep repository is sited in connection with the encapsulation plant at CLAB.

- The deep repository for other long-lived waste is sited separately from other facilities.

Timetable dependencies

- The overall timetable strategy is changed so that stage 2 directly follows stage 1, or alternatively so that the start of deposition is postponed with completion around 2050. In the latter case, the pace of encapsulation increases to 400 canisters per year. This affects the timetable and the operating time for all facilities, as well as the decay heat and thereby the distances between deposition holes and tunnels in the deep repository.

- Prolonged operating disruption (interruption for 5 years) in the encapsulation plant, which also affects the deep repository.

- Retrieval of canisters after Stage 1 and deposition of all fuel on a new site after a renewed siting process. Affects the timetable for all facilities, and necessitates the construction of an interim store for retrieved canisters.

- Supervision of the deep repository is required for about 70 years after deposition, after which it is sealed and closed.

- Dismantling of the NPPs is postponed by up to 25 years.

Other calculation premises

- Large changes in currency exchange rates.

- Sabotage and similar.

- Changed regulatory requirements.

The result of the of the cost calculation is obtained in the form of a probability distribution for the total costs, which indicates the probability associated with a given cost, i.e. the probability that the calculated cost will prove true (degree of confidence).

In determining the need for guarantees, it is desirable to choose a cost level that has a high probability associated with it. If 80% probability is used, the total amount used to determine the contingency allowance is an undiscounted SEK 60 billion.

The contingency allowance is highly dependent on the chosen discount rate. Figure 5.1 shows how the present value of the amount used to determine the contingency allowance and the fee-determining amount vary as a function of the assumed future real interest rate.

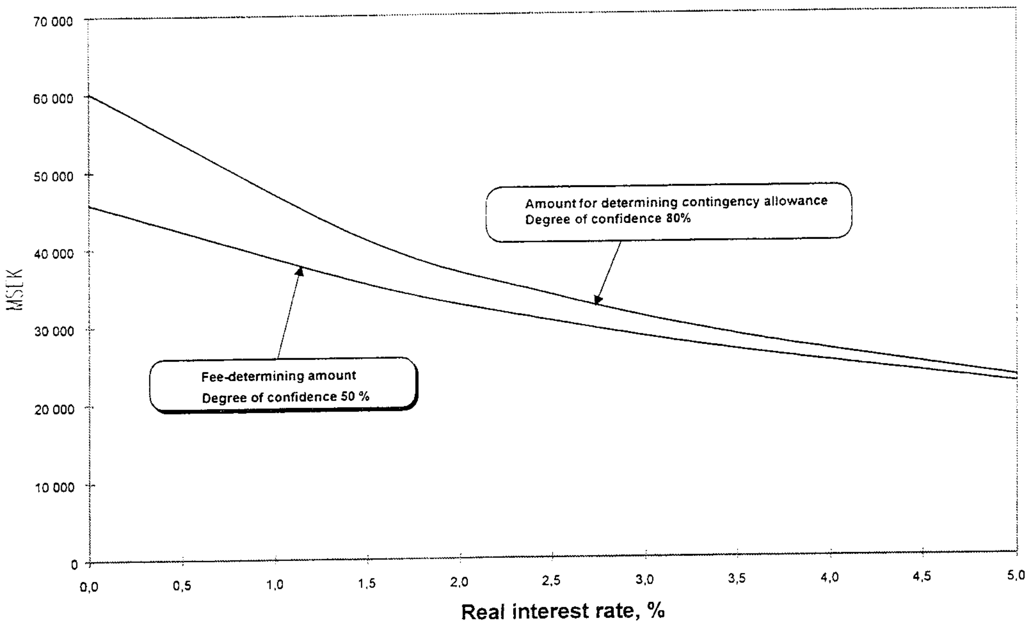


Figure 5.1 Amount used to determine the contingency allowance (MSEK) as a function of the real interest rate. Operation of all reactors for 25 years, but at least through 1999. January 1998 prices.

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Spent fuel and radioactive waste arising in Sweden from 25 years of operation of the NPPs, but at least through 1999

Waste category	Dimensions of waste units before encapsulation for final disposal (d = diam.) [m]	Number of packages	Number of transport units (casks/ containers)	Volume in final repository [m^3]	Final repository
Spent BWR fuel	0.14 x 0.14 x 4.383	26,800	2,230		
				12,800	Deep repository, fuel
Spent PWR fuel	0.21 x 0.21 x 4.103	3,100	790		
Other spent fuel (MOX, Ågesta, Studsvik)	Various	641	35		
Core components	1.2 x 1.2 x 4.8	600	600		
				9,500	Deep repository, core components
Reactor internals	1.2 x 1.2 x 4.8	770	770		
Operational waste from CLAB to silo	1.2 x 1.2 x 1.2	900	80	1,600	SFR 1
		1,700	425	2,900	Deep repository, other long-lived waste
Operational waste from CLAB to rock vault	1.2 x 1.2 x 1.2	230	20	400	SFR 1
Waste from Studsvik to silo [1)]	d=0.6 L=0.9	3,750	50	1,200	SFR 1
	1.2 x 1.2 x 1.2	690	60	1,200	SFR 1
	d=0 L=0.9	2,250	140	700	Deep repository, other
	1.2 x 1.2 x 1.2	550	140	1,000	long-lived waste
Waste from Studsvik to rock vault [1)]	3=0.6 L=0.9	8,750	150	2,800	SFR 1
	1.2 x 1.2 x 1.2	690	60	1,200	SFR 1
	ISO container	200	200	7,600	SFR 1
Operational waste from encapsulation plant to silo	1.2 x 1.2 x 1.2	250	60	400	Deep repository, other long-lived waste
Operational waste from NPPs to silo	d=0.6 L=0.9	2,730	40	900	SFR 1
	1.2 x 1.2 x 1.2	6,990	580	12,100	SFR 1
Operational waste from NPPs to rock vault	d=0.6 L=0.9	14,710	280	4,800	SFR 1
	1.2 x 1.2 x 1.2	4,660	390	8,100	SFR 1
	ISO container	610	610	23,000	SFR 1
	3.3 x 1.3 x 2.15	890	300	8,200	SFR 1
Decommissioning waste from NPPs to rock cavern	ISO container etc.	6,000	6,000	144,000	SFR 3
Decommissioning waste from Studsvik to rock cavern	ISO container	100	100	3,800	SFR 3
Decommissioning waste from CLAB and encapsulation plant to rock cavern	2.4 x 2.4 x 2.4	140	140	2,000	Deep repository,
	Storage canisters	1,900	210	5,300	decommissioning waste
Transport casks/containers		37	37	200	Deep repository, decommissioning waste
Total, approx.		91,000	14,500	256,000	

1) Incl. about 3,500 m^3 of waste within the NPPs' sphere of responsibility

Spent fuel and radioactive waste arising in Sweden from 40 years of operation of the NPPs

Waste category	Dimensions of waste units before encapsulation for final disposal (d = diam.) [m]	Number of packages	Number of transport units (casks/ containers)	Volume in final repository [m^3]	Final repository
Spent BWR fuel	0.14 x 0.14 x 4.383	39,500	3,290		
				18,900	Deep repository, fuel
Spent PWR fuel	0.21 x 0.21 x 4.103	4,900	1,230		
Other spent fuel (MOX, Ågesta, Studsvik)	Various	641	35		
Core components	1.2 x 1.2 x 4.8	850	850		
				11,200	Deep repository, core components
Reactor internals	1.2 x 1.2 x 4.8	770	770		
Operational waste from CLAB to silo	1.2 x 1.2 x 1.2	1,500	130	2,600	SFR 1
		2,400	600	4,100	Deep repository, other long-lived waste
Operational waste from CLAB to rock vault	1.2 x 1.2 x 1.2	380	30	660	SFR 1
Waste from Studsvik to silo [1)]	d=0.6 L=0.9	3,750	50	1,200	SFR 1
	1.2 x 1.2 x 1.2	690	60	1,200	SFR 1
	d=0.6 L=0.9	2,250	140	700	Deep repository, other
	1.2 x 1.2 x 1.2	550	140	1,000	long-lived waste
Waste from Studsvik to rock vault [1)]	d =0.6 L=0.9	8,750	150	2,800	SFR 1
	1.2 x 1.2 x 1.2	690	60	1,200	SFR 1
	ISO container	200	200	7,600	SFR 1
Operational waste from encapsulation plant to silo	1.2 x 1.2 x 1.2	400	100	680	Deep repository, other long-lived waste
Operational waste from NPPs to silo	d=0.6 L=0.9	4,420	60	1,400	SFR 1
	1.2 x 1.2 x 1.2	11,320	940	19,600	SFR 1
Operational waste from NPPs to rock vault	d=0.6 L=0.9	23,830	460	7,720	SFR 1
	1.2 x 1.2 x 1.2	7,550	630	13,050	SFR 1
	ISO container	980	980	37,310	SFR 1
	3.3 x 1.3 x 2.15	1,440	480	13,280	SFR 1
Decommissioning waste from NPPs to rock cavern	ISO container etc.	6,000	6,000	144,000	SFR 3
Decommissioning waste from Studsvik to rock cavern	ISO container	100	100	3,800	SFR 3
Decommissioning waste from CLAB and encapsulation plant to rock cavern	2.4 x 2.4 x 2.4	180	180	2,400	Deep repository,
	Storage canisters	2,600	290	7,300	decommissioning waste
Transport casks/containers		37	37	200	Deep repository, decommissioning waste
Total, approx.		127,000	18,000	304,000	

1) Incl. about 3,500 m^3 of waste within the NPPs' sphere of responsibility

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