# COSTS FOR THE SWEDISH RADIOACTIVE WASTE MANAGEMENT

Stig Pettersson and Hans Forsström
Svensk Kärnbränslehantering AB
Box 5864
S-102 48 Stockholm, Sweden

## ABSTRACT

The Swedish nuclear power utilities are responsible for adopting necessary measures in order to ensure the safe management and disposal of spent nuclear fuel and radioactive waste from the Swedish NPPs. In order to fulfil this responsibility, the nuclear power utilities have jointly formed SKB, the Swedish Nuclear Fuel and Waste Management Co, with the task to plan, build, and operate the necessary facilities and systems. Every year, since 1982, SKB prepares a cost calculation of all these measures that are required in order to manage the spent nuclear fuel, the low- and intermediate operational level waste and to decommission and dismantle the reactor plants. The cost calculations also include costs for research, development and demonstration, RD&D.

According to the most recent cost calculation the estimated future costs from 1991 to about 2050 are SEK 47.4 billion in January 1991 prices. SEK 8.1 billion has been spent up to the end of 1991 and SEK 9.6 billion are in the fund. The value of the corresponding electrical production up to the year 2010, which is the basis for the cost calculation, is over SEK 700 billion. The fee for 1992 is on average 1.9 öre/kWh (0.019 SEK/kWh). This paper briefly presents the Swedish waste management system, the cost calculation methodology, cost scheduling plus total cost and fee for the nuclear back-end.

## INTRODUCTION

Over the last fifteen years Sweden has developed a system to handle and dispose of all radioactive waste generated in the country. According to Swedish law the owner of a nuclear power plant is responsible for implementing all measures necessary to ensure the safe management and disposal of spent nuclear fuel and radioactive waste from the operation of the nuclear power plants. The responsibility also involves the obligation to pay all costs associated with the back-end of the nuclear fuel cycle and with the decommissioning of the nuclear power plants.

In order to fulfil this responsibility, the nuclear power utilities have jointly formed SKB, the Swedish Nuclear Fuel and Waste Management Co, with the task to plan, build, and operate the necessary facilities and systems. In these facilities also waste from research and development and the use of radioisotopes in medicine and industry is taken care of.

The main facilities in the Swedish system for radioactive waste management are shown in Fig. 1. The strategy adopted is that short-lived waste shall be disposed of as soon as feasible after its generation. To this end a final repository for short-lived radioactive waste has been built and is in operation since 1988. The facility called SFR is built underground in the bedrock close to the Forsmark nuclear power plant.

For the long-lived spent nuclear fuel an interim storage period of about 40 years is foreseen before the fuel is finally disposed of at depth in the Swedish bedrock. A central interim storage facility, CLAB, was taken into operation in 1985. It is located close to the Oskarshamn nuclear power plant. During the 40 year storage period the radioactivity and heat release of the fuel decays with a factor of ten, thus simplifying the final disposal. The site for final disposal has not yet been chosen, but a safe method has been described.

### Cost calculations

To finance the waste management activities a fee is levied on the production of electricity in the nuclear power plants. The fees are paid to the National Board for Spent Nuclear Fuel, SKN, and funded in interest-bearing accounts in the National Bank of Sweden. The level of the fee is determined annually by the Government, after a proposal by SKN.

As a basis for the determination of the fee SKB every year prepares a calculation of the costs for all the measures that are required in order to manage the spent nuclear fuel from the reactors and the radioactive waste deriving from it and to decommission and dismantle the reactor plants. These calculations have been performed since 1982 and are submitted to SKN.

The calculations are based on a scenario for energy production, waste quantities and an approved method for final disposal of the different types of waste. The premises for the cost calculations have been chosen in such a manner that the future costs are not underestimated. Since disposal of the spent fuel and long-lived waste will not commence until some time into the 21st century, continued RD&D activities may reveal new methods, that can affect both system design and costs. This is expected to lead to overall simplifications in the design.

## PREMISES

In order to obtain a basis for the design of storage and the transport system, certain assumptions have to be made regarding the conditions of operation for the 12 NPPs. In the cost calculations it is assumed that the nuclear power plants will be in operation until 2010. The total electricity production in the nuclear power plants is estimated to reach a total of 2 000 TWh. In 1991 the production was 73 TWh. The corresponding fuel consumption will be approximately 7 920 tons of spent nuclear fuel (as tons of uranium), of which 6 100 from BWR and 1 820 from PWR.

Most of the spent fuel will be stored in CLAB for about 40 years and then encapsulated and emplaced in a final deep geological repository. Only 140 tons of uranium are planned to be reprocessed at BNFL, from which no waste will be returned. Earlier reprocessing contracts with Cogema has

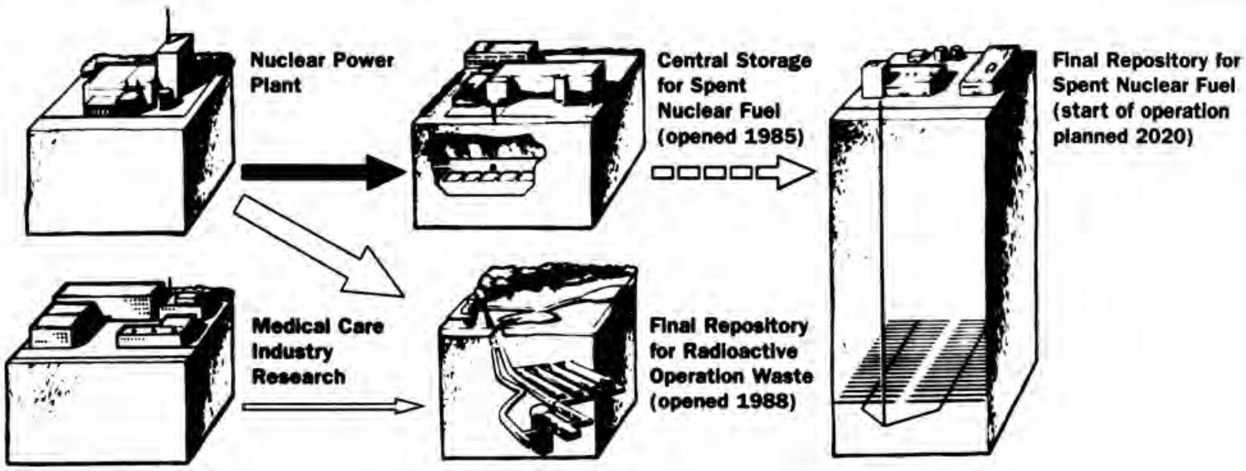


Fig. 1. The Swedish system for radioactive waste management.

been transferred to other foreign companies. In the cost calculations certain costs for these contracts are included.

Apart from spent nuclear fuel also other types of waste are generated. In Table I the main types of radioactive waste products are given.

## FACILITIES AND SYSTEMS

### General

In order to handle and dispose of the radioactive waste products in Sweden, a number of facilities are needed as described earlier. A scenario has been established as a basis for the cost calculations. The function and design of facilities, systems and other activities included in this scenario are briefly described in the following sections.

### Transportation System

As all the existing Swedish nuclear facilities are located on the cost a transportation system mainly based on sea transports have been developed. Its principal components are a special purpose ship, M/S Sigyn, transport containers and transport equipment at the nuclear power plants and other facilities. The system is designed for accommodating all types of radioactive waste. M/S Sigyn has a payload capacity of 1 400 tons and is designed as a roll-on/roll-off ship. Loading/unloading by crane is possible as well. In January 1992, SKB's system included 10 fuel casks, 2 casks for core components and 27 shielded waste containers for LILW. Costs for reinvestment in new ships and transport casks for spent fuel, etc are foreseen in the future costs.

### Final Repository for Radioactive Waste, SFR

All the short-lived low and intermediate level waste will be disposed of in SFR at Forsmark. A first part, SFR1, intended for operating waste is in operation since 1988. The facility is situated underneath the Baltic Sea with a rock cover of about 60 m. From the harbor at Forsmark, two 1 km long tunnels lead out to the repository area. A final repository for decommissioning waste from the nuclear power plants, SFR 3, is planned in connection with SFR 1.

**SFR 1** will consist of five to six 160 m long rock vaults and two 70 m high cylindrical rock caverns containing concrete

**TABLE I**

Waste Types and Quantities

| Product | Principle Origin | Unit | No of Units | Volume in Final repository $m^3$ |
|---|---|---|---|---|
| Spent fuel | Reactors | Canisters | 5 300 | 12 000 |
| $\alpha$-contamin. LILW | Studsvik | Drums/ Moulds | 4 500 | 1 500 |
| Core comp. | Reactor internals | Moulds | 2 400 | 19 700 |
| LILW | Reactor operation | Drums/ Moulds | 57 000 | 95 000 |
| Decom. LILW | Plant decom. | 10-20 $m^3$ Containers | 5 600 | 114 000 |
| Total quantity | | | 75 000 | 243 000 |

silos. The waste containing most of the radioactive substances will be placed in the silos. The first construction stage, which was completed in 1987, comprises four rock vaults and one silo. The second construction stage will be carried out at the end of the 1990s. In all, SFR 1 will hold 90,000 $m^3$ of waste. At the end of 1991 about 8 000 $m^3$ of LILW was disposed in SFR1.

A crew of about 20 persons operates the facility. To this number should be added some services that are obtained from Forsmark NNP's main organization.

**SFR 3** will be used for disposal of decommissioning waste. SFR 3 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 ISO-containers which are emplaced in the rock vaults without being emptied. A total of 104,000 $m^3$ of decommissioning waste will be disposed of in SFR 3.

### Central Interim Storage Facility For Spent Nuclear Fuel, CLAB

The spent nuclear fuel is transported to the central interim storage facility for spent nuclear fuel, CLAB, at Oskarshamn. The storage facility was taken into operation during 1985 and was originally designed to store about 3,000 tons of fuel in four pools. By the introduction of new storage canisters the capacity of the pools will gradually increase to about 5,000 tons. Each pool can hold 300 canisters for 25 BWR- or 9 PWR- assemblies each. In the beginning of 1992, fuel corresponding to 1,450 tons of uranium was stored in the facility.

CLAB consists of an above-ground complex for receiving the fuel and an underground section with the storage pools. The above-ground complex also contains equipment for ventilation, cooling and purification of water, waste handling, electrical systems etc as well as premises for administration and operating staff. The storage pools are located in a rock cavern with roof about 30 m below the surface. The rock cavern in the first store is 120 m long, 21 m wide and 27 m high.

CLAB has a permanent staff of about 50 with some additional 60 general service people from Oskarshamn NPP main organization.

In the late 1990s, the capacity of the facility will be expanded so that all fuel from the Swedish nuclear power program can be stored in CLAB. Core components and reactor internals from decommissioning will also be stored in the facility prior to final disposal.

The expansion is planned by the construction of a new rock cavern parallel to the existing one. The new rock cavern will hold 4 pools for spent fuel and one for core components and reactor internals. These are stored in similar canisters to those for the spent fuel but in two layers.

### Final Repository for Spent Nuclear Fuel

The site for the final repository has not yet been chosen. In the cost calculations it is conservatively assumed that it is located in the inland a certain distance north of CLAB. A combination of sea and rail transport is assumed to reach the site. Before disposal the spent fuel will be encapsulated in a disposal canister. The encapsulation station is assumed to be co-located with the repository.

At the site common service facilities, such as entrance and information building, central administration building for the site organization, workshops, water supply and sewerage, electricity supply, concrete station, canteens, etc. will also be built. The costs for the common facilities also include infrastructure, eg 50 km of new railway, 20 km of roads, harbor modifications, trains, wagons for transport casks, vehicles etc. A plant for compacting the bentonite and a plant for crushing rock material will also be provided on the site.

### Encapsulation Station

The spent fuel is assumed to be encapsulated in copper canisters. The empty spaces in the canisters are filled with lead in order to enable the canister to resist the high water pressures prevailing at the repository level.

Transport casks containing fuel or core components etc. arrive at the encapsulation station by rail. The fuel is unloaded and further handling of the fuel is made dry in a hot cell. Before the fuel is placed in a copper canister the fuel boxes are separated from the fuel.

The lead-filling of the canisters is made in a special oven. The canisters are then moved to positions for cooling, lid welding and checking and further to a buffer storage before transport down in the repository. The encapsulation line is duplicated to permit continuous operation even in the case of disturbances in the operation.

The facility is designed for an average annual capacity of 210 fuel canisters, one canister per day for 10 months. The facility is mainly operated in the daytime. In total, approximately 5300 canisters will be processed during the period 2020 - 2044. The facility will thereafter be dismantled.

### Deep Repository

The final repository for spent fuel, is situated directly below the encapsulation station at a depth of about 500 m. It consists of a series of parallel deposition tunnels with a total length of approx. 40 km. The deposition tunnels are connected by transport tunnels. The deposition tunnels have a cross sections of 14 $m^2$.

The copper canisters are placed in vertical holes, drilled in the bottom of the deposition tunnels, and surrounded by a layer of compacted bentonite. The distance between the holes, 6.2 m, and tunnels, 25 m, have been chosen to keep the temperature in the bentonite below 80°C.

The copper canister is transported down in a radiation-shielding elevator cage from the encapsulation station to the deposition level, where it is picked up by the deposition vehicle and driven out to the deposition location. At the deposition location the canister is put vertically into the deposition hole. Afterwards blocks of highly compacted bentonite are placed around the canister. The deposition tunnels are backfilled with a mixture consisting of 15% bentonite and 85% quartz sand.

The emplacement of copper canisters will proceed during the period 2020-2046. The repository will thereafter be sealed and all service tunnels, vaults, and shafts will be backfilled.

In connection with the repository for spent nuclear fuel also some other waste types will be disposed of, mainly core components, BWR fuel channels and reactor internals, operational waste from CLAB after closure of SFR1, alpha-bearing waste from Studsvik, and decommissioning waste from CLAB and the encapsulation station. Different types of rock caverns will be utilized for these wastes.

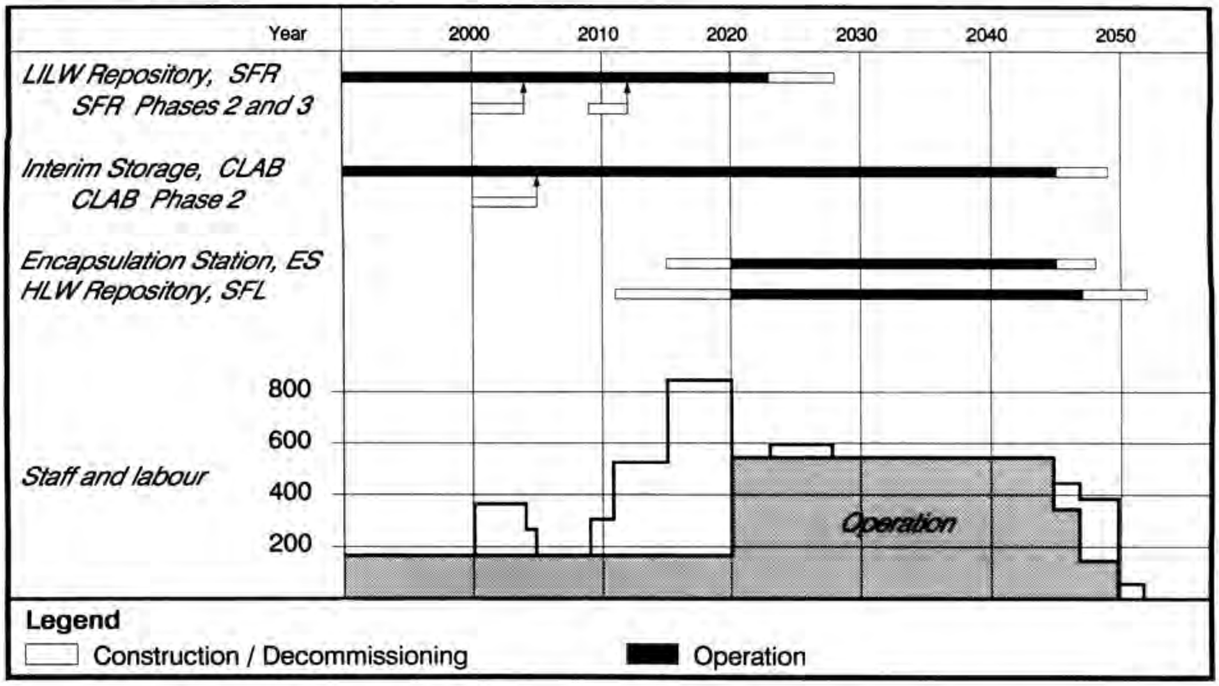


Fig. 2. Facilities for management of the waste products and their time schedules and personnel requirements.

**Decommissioning of Nuclear Power Plants**

The measures required for management of the radioactive waste products of nuclear power also include decommissioning the reactors and fuel cycle facilities after they have been taken out of operation.

Before dismantling of the reactor is begun, the fuel is removed and decontamination and preparations for dismantling (shutdown operation) take place. During this period, the personnel force can be gradually reduced. The actual work of dismantling then starts. It is expected to take five years per unit and to employ an average of a couple of hundred persons.

The radioactive waste from decommissioning is all of low and intermediate level. 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 a period of about 30-40 years before being disposed of. Other radioactive decommissioning waste will be transported directly to SFR 3 and deposited there. A large quantity of the decommissioning waste is assumed to be declassified, some of it after decontamination.

**Research, Development, and Demonstration, RD&D**

In order to gather the necessary information and data to realize a safe final disposal of spent fuel and other long-lived radioactive waste, SKB is conducting a comprehensive research, development and demonstration program. The aim of the RD&D work during the 1990s will be to establish an adequate basis for a specific Siting Application to be submitted not later than 2003. By that time the system should be optimized and it should be possible to describe it in relation to a specific site.

During the 1990s, the RD&D work will be shifted from R&D towards development and demonstration. The selection of a principal system design is planned to take place in the mid 1990s. Candidates for the location of the final repository will be selected and detailed investigations of two of the candidates will start in good time so that a completion of the Siting Application can be possible in 2003.

All RD&D costs up to the year 2010 are separately accounted for. Costs after 2010, at which time the construction work for the final repository starts, are included in the purchaser's planning and design costs, which is part of the investment costs per facility.

## TIME SCHEDULES

The time schedules for the construction and operation of the facilities, etc are of great importance in the cost calculation. Some of the facilities are already in operation, which provides a good basis for the cost calculations. In the case of other facilities, the final design has not yet been chosen. However, as a basis for the cost calculations, a possible waste handling scheme has been established in detail and layout drawings have been prepared. The overall time schedule and the personnel requirements are shown on Fig. 2.

## COSTS

**General**

Cost calculations have been carried out for all facilities and systems. Experience from the construction and operation of CLAB, SFR and the transportation system has thereby been incorporated. In the accounting system, costs incurred up to and including 1991 are distinguished from future costs. The future costs are estimated at January 1991 prices. Previously incurred costs are quoted in current prices.

The costs are reported in detail in a computerized cost scheduling system called BECOST, which permits present value calculations and variation analyses as well as distribution of the costs among different nuclear power plants etc.

The costs for different facilities reported here are broken down into the following items: investment, reinvestment, operation, and decommissioning and sealing. Normally, only those costs that arise before a facility or part of a facility is taken into operation are attributed to investment costs. In the repository for spent nuclear fuel, however, where the deposition tunnels will be excavated continuously during the deposition phase, the costs for this work have been assigned to the investment costs.

**Calculation Method**

The cost calculations are based on functional descriptions for each facility, which result in layout drawings, equipment lists, personnel forecasts etc. For facilities and systems that are in operation, this background material is very detailed, while the degree of detail is lower for future facilities.

**TABLE II**

The Swedish Waste Management Bill

| Facility | Costs up to 1992 | Future costs in MSEK |
|---|---|---|
| SKB-Adm. | | |
| SKB-RD&D | 1 166 | 3 841 |
| SKB-INFO | | |
| Transport | 510 | 1 515 |
| CLAB | 2 391 | 6 345 |
| SFR1 | 980 | 935 |
| SFR3 | --- | 607 |
| Rep for SF | | |
| Common Fac | --- | 5 345 |
| Encaps stat | --- | 8 041 |
| Deep repos | --- | 8 750 |
| NPP- Decom. | --- | 11 152 |
| Reprocessing | 3 065 | 874 |
| TOTAL | 8 112 | 47 406 |

The costs of the future facilities are calculated in several steps. For each cost item, a base cost is calculated, after which a contingency allowance for unforeseen costs is added. the base costs include:

- quantity-calculated costs
- non-quantity-calculated costs
- secondary costs

Quantity-calculated costs are costs that can be calculated directly with the aid of the design specifications and with knowledge of unit prices, e.g. for concrete casting, rock blasting and operating personnel. In estimating both quantities and unit price, experience gained in construction of the nuclear power plants, CLAB and the SFR has been drawn on.

All details are not included on the drawings. These non-quantity stipulated costs can be estimated with good accuracy on the basis of experience from other similar work.

The final item included in the base costs is secondary costs. These include costs for administration, engineering, purchasing and inspection as well as costs for temporary buildings, machines, housing, offices and the like. The amounts allowed for these costs are also relatively well known, and have been calculated on the basis of the assumed service requirements during the construction phase.

A contingency allowance is added to the calculated base costs for unforeseen items. The size of the contingency allowance is determined object-by-object on the basis of the risks of additional work and the engineering level of the facility. On an average it is about 25%.

The calculated costs for the management of all radioactive waste from the Swedish nuclear program is shown in Table II. Incurred costs are given as running costs without interest. The future costs are given in the price level January 1991. The total future costs from 1992 amount to SEK 47,4 billion. Up to 1992 SEK 8.1 have been spent. The total is thus about SEK 55 billion as shown in Table II.

The costs are spread out over a time period of more than 60 years. In the cost system the costs are distributed in time, which permits discounting with different values for the real interest rate.

## WASTE MANAGEMENT FEE

Based on the calculations presented by SKB, as described in this report, SKN, the National Board for Spent Nuclear Fuel prepares a proposal for the fee for the next year. The fee is then decided upon by the Government.

In making the proposal, SKN has to consider all relevant factors, such as total costs, expected operation time of the reactors and projected future interest on the money collected in funds. Separate fees are proposed for each reactor owner, taking into account the differences in the operation of the separate reactors.

For 1992 the fee is 1.9 öre/kWh (SEK 0.019/kWh) on an average. It ranges between 1.7 and 2.2 öre/kWh. The fees are paid into funds at the National Bank of Sweden and the funds are controlled and administered by SKN. The total content of the funds is at present about SEK 10 billion. Annually about 1.3 billion is added to the funds as fees and about 1 billion as interest, while about 0.3 billion is used to cover the present costs.

Since 1985 the fee have been unchanged. The main reason for that is an increased electrical output from NPPs, increased utilization factor, less amount of spent fuel due to higher burn-up, more efficient operation of the waste facilities plus some simplifications in the back-end system. However, up to now no optimization of the system has been carried out which could result in additional savings.

## CONCLUSIONS

Calculations of the costs to safely manage and dispose of the radioactive waste from the Swedish nuclear power systems have been performed since many years in Sweden. The experience gained in this exercise is very useful for the optimization of the system.

In parallel with the technical development and implementation of the waste management system, development has also proceeded on the administrative and regulatory system. We thus today have a comprehensive legislation clearly regulating the responsibilities of the utilities. Through the build-up of Government-controlled funds the financing of the future waste management activities are secured. The good function of this system can be seen from the fact that the waste management fee has been kept constant for the last seven years.

## REFERENCES

1. "PLAN-90. Costs for management of the radioactive waste from nuclear power production"SKB Technical Report 90-33, Swedish Nuclear Fuel and Waste Management Co, Stockholm (June 1990).