SKB

TECHNICAL REPORT

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Plan 93
Costs for management of the radioactive waste from nuclear power production

Swedish Nuclear Fuel and Waste Management Co

June 1993

SVENSK KÄRNBRÄNSLEHANTERING AB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
BOX 5864 S-102 40 STOCKHOLM
TEL. 08-665 28 00 TELEX 13108 SKB S
TELEFAX 08-661 57 19

PLAN 93
COSTS FOR MANAGEMENT OF THE RADIOACTIVE WASTE FROM NUCLEAR POWER PRODUCTION

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Information on SKB technical reports from 1977-1978 (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) and 1992 (TR 92-46) is available through SKB.

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SUMMARY

The Swedish nuclear power utilities are responsible for adopting such measures as are necessary in order to ensure the safe management and disposal of spent nuclear fuel and radioactive waste from the Swedish nuclear power reactors. In order to fulfil this responsibility, the nuclear power utilities have commissioned SKB, the Swedish Nuclear Fuel and Waste Management Co, to plan, build and operate the necessary facilities and systems.

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

The facilities and systems that exist are:

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

Future facilities under planning are:

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

The cost calculations also include costs for research and development, including the Äspö Hard Rock Laboratory, and for decommissioning and dismantling of the reactor plants etc.

The amounts of waste to be handled are dependent upon the total operating time of the nuclear power plants. In order to illustrate some variations, the calculations given in this report are based on three scenarios: 1) operation of all reactors up to and including the year 2010, 2) operation of all reactors for 25 years, and 3) operation of all reactors for 40 years.

The total future costs of the Swedish waste management system, commencing from 1994, have been calculated to be SEK 48.3 billion in January 1993 prices considering operation of all reactors up to and including the year 2010. These costs will be incurred over a period of about 60 years. SEK 9.2 billion has been spent up to the end of 1993. In case of 25 or 40 years of reactor operation the total future costs will be SEK 45.9 or 55.5 billion respectively.

This cost calculation is presented annually to SKI, the Swedish Nuclear Power Inspectorate, which uses it as a basis to propose a fee on the nuclear electricity production to cover all future expenses. The fee for 1993 is on average 1.9 öre/kWh (0.019 SEK/kWh).

ABBREVIATIONS

BWR	Boiling water reactor (ABB–ATOM)
CLAB	Central interim storage facility for spent nuclear fuel
EP	Encapsulation plant for spent nuclear fuel and core components
GA	Common facilities
GD	Common parts of a facility
NPP	Nuclear power plant
PWR	Pressurized water reactor (Westinghouse)
RD&D	Research, development and demonstration
SFL	Deep repository for long–lived waste
SFL 2	- for spent nuclear fuel
SFL 3	- for long–lived waste from Studsvik and certain operating waste from CLAB (as from 2012) and EP
SFL 4	- for decommissioning waste from CLAB and EP
SFL 5	- for core components, etc
SFR	Final repository for short–lived radioactive waste
SFR 1	- for operational waste
SFR 3	- for decommissioning waste
SKI	Swedish Nuclear Power Inspectorate
SKB	Swedish Nuclear Fuel and Waste Management Co
SSI	Swedish Radiation Protection Institute

1. PREMISES

1.1 GENERAL

SKB prepares every year, on behalf of the nuclear power utilities, a calculation of the costs for all the measures that are required to manage the spent nuclear fuel from the reactors and the radioactive waste deriving from it and to decommission and dismantle the reactor plants. The calculations are based on a scenario for energy production, waste quantities and required measures that are presented in this report. The cost calculation is submitted to the Nuclear Power Inspectorate (SKI). SKI uses this as a basis for calculating a proposal for the fee for management of the radioactive waste products of nuclear power that is levied on nuclear-generated electricity.

The premises for the cost calculations have been chosen so that the future costs should not be underestimated. Thus, the waste management system presented here is based on the KBS-3 method /ref. 1/, which has been reviewed in connection with the fuelling applications for Forsmark 3 and Oskarshamn 3. KBS-3 has been found to meet high standards of safety and radiation protection. In this report the experiences from the safety analysis work, SKB-91, /ref.2/ have been incorporated. In its RD&D Programme of 1992, SKB has suggested the direction and time schedule of the future activities. This has a direct influence on the cost calculations presented in this report. The earliest possible time schedule, as set out in the Programme, has been used, which will give a conservative fee calculation.

Through continued research and development within the waste management field, it will probably be possible to introduce simplifications in the disposal system. Other technological progress will also contribute to such simplifications. These factors are not considered in the cost calculations.

To obtain a basis for the design of the waste management system, certain assumptions have to be made regarding the conditions of operation for the nuclear power plants. The amount of spent fuel and radioactive waste is dependent on operation time and power output as well as on the factor of energy utilization for each reactor. The main alternative of this report is based on the amount of spent fuel and radioactive waste given by operation of all reactors up to and including the year 2010. Results are also given for 25 and 40 years of operation of all reactors.

The Financing Act only deals with costs that are attributable to management and disposal of spent nuclear fuel and waste deriving from the fuel and to decommissioning and dismantling of the reactor plants. SKB's plan for management of the radioactive waste also includes operational waste from nuclear power plants and waste from non-electricity-generating facilities, mainly in Studsvik, which is estimated to constitute a few percent of the total waste volume.

1.2 ENERGY PRODUCTION AND WASTE QUANTITIES

Electricity generation and fuel consumption are summarized in Table 1.1.

Table 1.1 Electricity production and fuel consumption for the Swedish nuclear power plants.

Reactor and date of commercial operation		Thermal capacity (MW)	Net electrical capacity (MW)	Energy production (TWh)			Uranium consumption (ton U)	
				through 1992	annually from 1993	Total	Discharged through 1992	Total
B1	1975-07-01	1,800	600	67.2	4.1	140	274	610
B2	1977-07-01	1,800	600	62.8	4.1	140	239	570
R1	1976-01-01	2,500	800	74.0	5.5	170	305	700
R2	1975-05-01	2,570	870	77.2	5.6	180	234	630
R3	1981-09-09	2,780	920	60.8	5.9	170	173	590
R4	1983-11-21	2,780	920	58.2	5.9	160	171	580
O1	1972-02-06	1,375	440	56.0	3.0	110	238	510
O2	1974-12-15	1,800	600	69.9	4.1	140	268	600
O3	1985-08-15	3,300	1,160	59.2	7.9	200	157	750
F1	1980-12-10	2,930	970	79.3	6.6	200	251	790
F2	1981-07-07	2,930	970	73.5	6.6	190	235	770
F3	1985-08-22	3,300	1,150	59.0	7.9	200	152	750
BWR total		21,735	7,290	601.0	49.8	1,500	2,122	6,050
PWR total		8,130	2,710	196.2	17.3	510	578	1,800
All		29,865	10,000	797.1	67.2	2,010	2,700	7,850

Energy utilization factor for BWR = 0.78 Burnup for BWR: 38 MWd/kgU
Energy utilization factor for PWR = 0.73 Burnup for PWR: 41 MWd/kgU

Energy production in the Swedish nuclear power plants totalled 62 TWh in 1992, which corresponds to an average energy utilization factor of 71%. Five reactors have been shut down during the second half of the year, which resulted in a low utilization factor. The average energy utilization factor in 1990 was 75% and in 1991 84%. In the calculation of estimated future electric power generation, the energy utilization factors of 78% and 73% are used for BWR and PWR respectively. The real factors of energy utilization are expected to be higher. The factors above are assumed to give ample room for possible disturbing events in the future. The same factors are also used in the planning of future expansion of power production.

The electricity production in the nuclear power plants has been estimated to reach a total of 2 010 TWh by the year 2010. The corresponding fuel consumption is approximately 7 850 tons of uranium, of which 6 050 from BWR and 1 800 from PWR.

Table 1.2 compares electricity generation and fuel consumption for operation until year 2010 (an average operating period of about 30 years) with the cases covering an operation time of 25 or 40 years respectively.

Most of the spent fuel will be stored in CLAB for about 30 years and then encapsulated and emplaced in a final repository. Besides the amount of fuel accounted for in Table 1.1, there will be 23 tons of German Mox-fuel and approximately 20 tons of fuel from the Ågesta and R1 reactors to be handled. The German fuel has been exchanged for 57 tons of Swedish spent fuel, shipped to Cogema at an earlier stage. 140 tons of uranium are planned to be reprocessed by BNFL, from which no waste will be returned. This gives, for operation of all reactors up to and including the year 2010, 7 700 tons of uranium to dispose.

<u>Table 1.2</u> Electricity production and fuel consumption for the three calculated alternatives.

	Calculated case	Total energy production (TWh)	Total uranium consumption (ton U)
I.	Operation up to and included 2010	2,010	7,850
II.	Operation 25 years of all reactors	1,620	6,550
III.	Operation 40 years of all reactors	2,630	9,890

In 1989 SKB transferred the Cogema reprocessing contract to one Japanese and eight German utilities. For covering some transition costs, a sum of MSEK 500 has been included in the cost summary.

In addition to spent fuel, the Swedish nuclear power programme gives rise to low and intermediate-level operational waste from the nuclear power reactors, CLAB and the encapsulation plant. When the plants are dismantled decommissioning waste arises. Estimated waste quantities are summarized in Table 1.3. Table 1.4 shows how the waste quantities vary for the different calculated cases. The waste quantities are described in detail in Appendix 1. The activity content of the different waste types varies widely. The handling and disposal requirements will therefore be dependent on waste type.

Table 1.3 Main types of radioactive waste products to be disposed of

Product	Principle origin	Unit	No. of units	Volume in final repository (m^3)
Spent fuel		canisters	4,500	13,500
α-contaminated waste	Low- and intermediate level from Studsvik	drums and moulds	1,900	1,500
Core components	Reactor internals	moulds	1,400	9,700
Low- and intermediate level waste	Operational waste from NPPs and other nuclear facilities	drums and moulds	56,000	91,200
Decommissioning waste	From decommissioning of NPPs and other nuclear facilities	10-20 m^3 containers	5,500	111,700
Total quantity			69,300	227,600

Table 1.4 Comparison of waste quantities for the calculated alternatives

Product	Operation through 2010 Volume in final repository (m^3)	Operation 25 years Volume in final repository (m^3)	Operation 40 years Volume in final repository (m^3)
Spent fuel	13,500	10,700	18,000
α-contaminated waste	1,500	1,500	1,500
Core components	9,700	9,500	11,300
Low- and inter-mediate level waste	91,200	76,400	114,000
Decommissioning waste	111,700	110,100	112,500
Total quantity	227,600	208,200	257,300

1.3 PRINCIPLES OF THE WASTE MANAGEMENT SYSTEM

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

- Short-lived waste will be disposed of immediately after it is obtained.

- Spent fuel will be stored for about 30 years before it is placed in a final repository. Heat generation in the final repository is thereby limited.

- Other long-lived waste will be disposed of in connection with the final disposal of spent fuel.

For the purpose of cost calculation, it has been assumed that facilities for which sites have not yet been decided will be located inland. The transportation of the waste is assumed to be made by ship to the nearest harbour and after that by rail.

In SKB's RD&D Programme of 1992 /ref. 3/ a step-by-step implementation of the final disposal programme is suggested. The first stage of the final disposal is suggested to include 5-10% of the total amount of spent fuel. Then, before the decision to extend the facility to full scale is taken, an evaluation of the first step shall be made. This report is based on such a strategy.

2. FACILITIES AND SYSTEMS

2.1 GENERAL

To handle and dispose of the radioactive waste products in Sweden, a number of facilities have to be planned, built and operated. A scenario has been established as a basis for the cost calculations. This chapter presents in outline form the facilities, systems and other activities included in this scenario. Their function and design are briefly described. A more detailed description is provided in the appendix portion of this report.

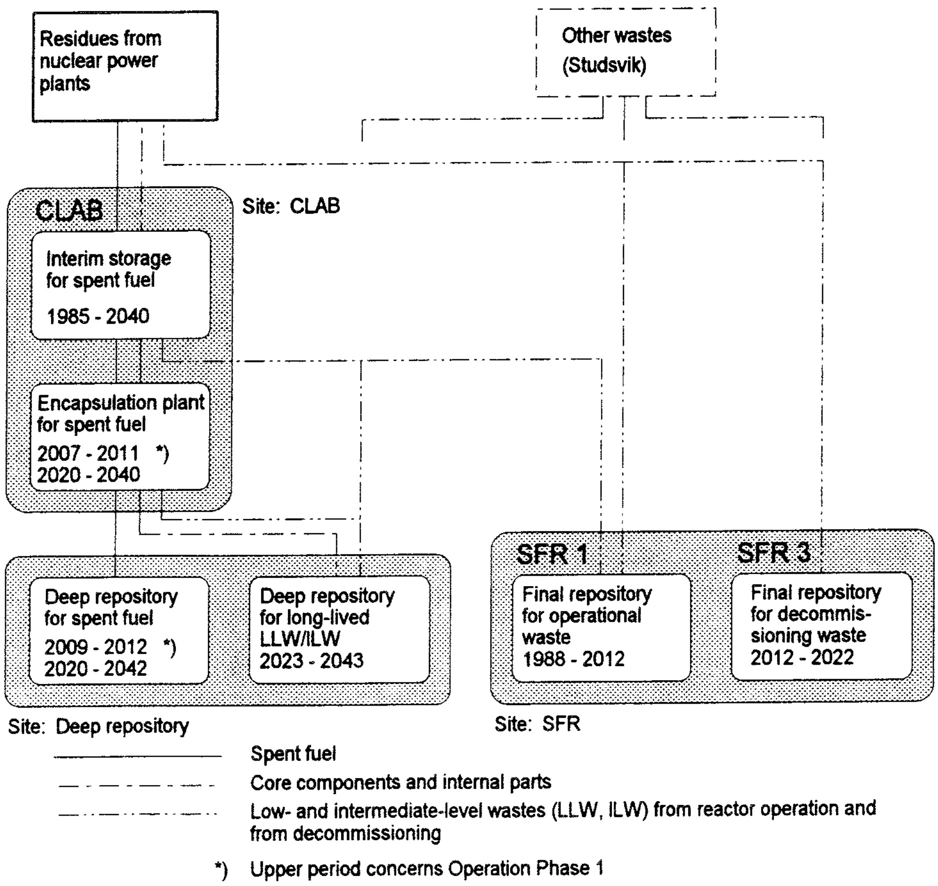


Figure 2.1 Scheme for the handling of radioactive waste products in Sweden

The plans regarding future activities, as presented in the RD&D Programme, highly influence the basis for the cost calculations. This year, the new basis encompasses the following major items:

- The final disposal at the deep repository commences with a first step in which about 400 canisters will be deposited.
- The encapsulation plant is planned to be located at CLAB.
- A new time schedule for the encapsulation plant and the deep repository.
- A new type of reference canister.

The RD&D Programme presented programmes and plans for activities concerning the canister, the encapsulation plant and the deep repository. Based on these plans, synoptic time schedules for the future plants were created as a basis for the cost calculations. The time schedules define the earliest possible investment events, giving conservative cost estimates.

A new reference canister has been chosen. The canister consists of an outer copper container, for the long term corrosion protection, supported by an inner steel container with the purpose of withstanding mechanical loads occurring in the repository. This type of canister is the main alternative in this report. In previous reports the reference alternative has been a lead-filled copper canister. The possibility of using the lead-filled copper canister has been considered when designing the encapsulation plant.

Figure 2.1 shows which facilities are included in the system and how the waste products are planned to be handled. Some of the facilities are in operation, e.g. CLAB, SFR1 and the transportation system, which provide a good basis for the cost calculations. In the case of future facilities, the final design has not yet been chosen. However, as a basis for the cost calculations, a possible waste handling scheme has been described in detail and tentative layout drawings have been prepared.

The timetable for the construction and operation of the facilities that is assumed for the cost calculation in this report is presented in Figure 2.2.

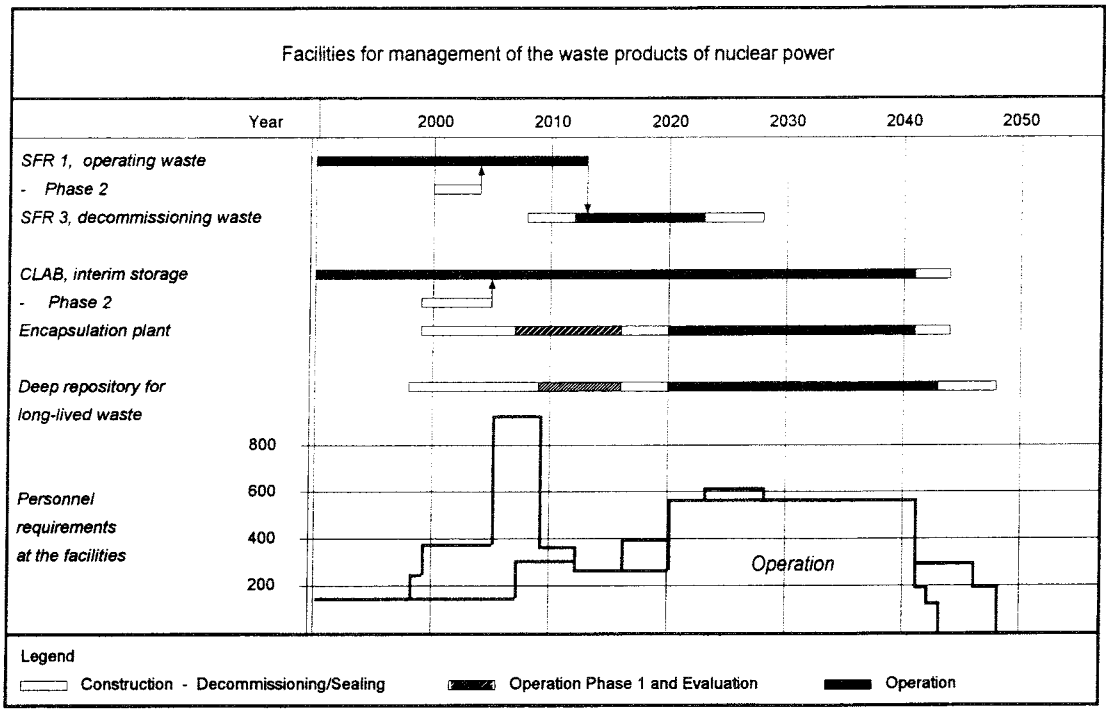


Figure 2.2 Facilities for management of the waste products of nuclear power. Timetable and personnel requirements.

2.2 RESEARCH, DEVELOPMENT AND DEMONSTRATION

The purpose of SKB's research, development and demonstration activities (RD&D) is to gather the necessary information and data to realize a safe final disposal of spent fuel and other long-lived radioactive waste. An updated research and development programme is presented by SKB every third year. The latest programme was presented in 1992 /ref. 3/ and a review report by SKI was presented in March 1993 /ref. 4/.

During the 1990s, the RD&D work concentrates on the efforts that are needed to build an encapsulation plant for spent nuclear fuel and a deep repository for encapsulated spent fuel. Beside the actual design, extensive RD&D work will be needed, mainly directed towards development of a basis for safety assessments.

One important step in the RD&D work is the establishment of an underground hard rock laboratory - the Äspö Hard Rock Laboratory

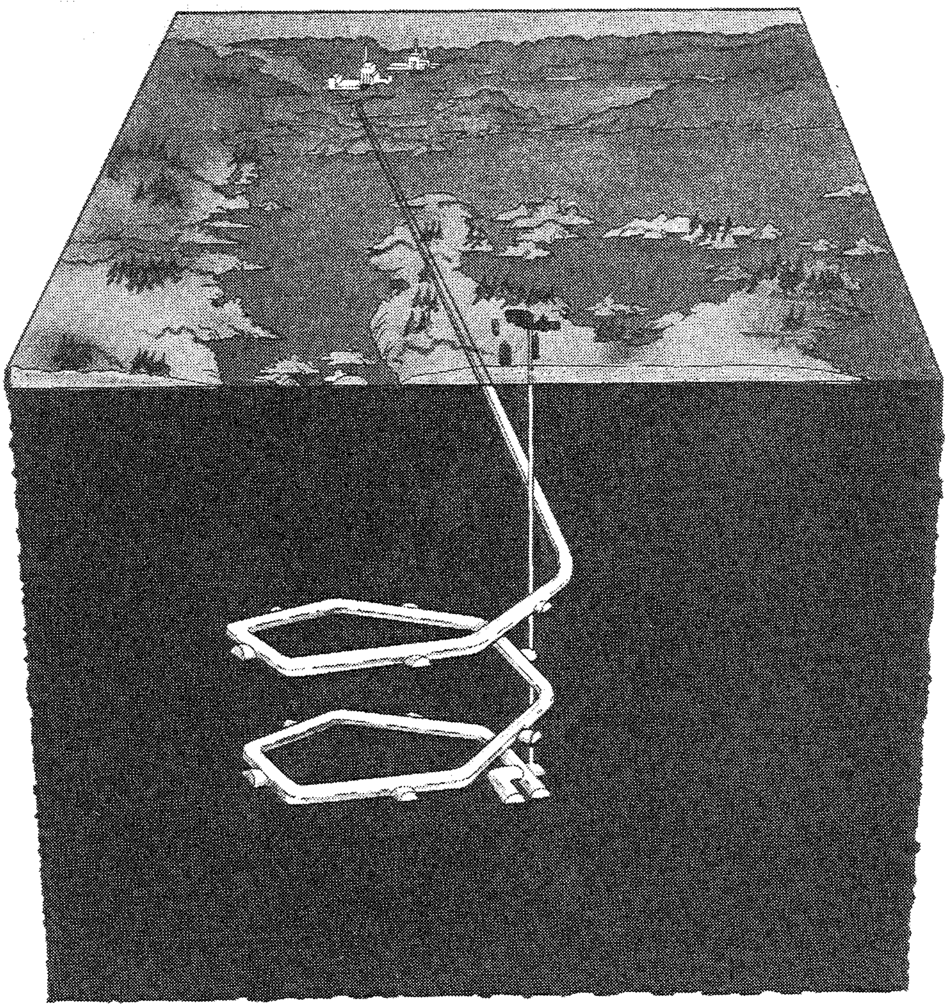


Figure 2.3 The Äspö Hard Rock Laboratory.

- in the Community of Oskarshamn. In April 1990, the Government gave permission for the laboratory to be built, under the Act of Management of Natural Resources. The construction work at the site started in October 1990. The level 460 m below the surface will be reached during 1994. The Äspö Laboratory is essential for the testing, verification and demonstration of investigation methods to be used for the detailed investigations of the candidate sites for the final repository. An explanatory sketch of the laboratory is shown in Figure 2.3. In April 1993 the entrance tunnel had reached about 2,400 m and to a depth of about 300 m below the Äspö island.

Costs for the deep repository are included in RD&D costs up to and including the year 2002. Included are costs for localization, design and detailed field investigations. After the year 2002 all costs concerning the deep repository are accounted for under the heading "Deep Repository".

The costs for the Äspö laboratory and for other research activities have been estimated to about MSEK 100 per year for the period up to and including the year 2015. For the period 2016 through 2040, an additional annual cost of MSEK 250 has been considered for research activities during the operation of the deep repository.

2.3 TRANSPORTATION SYSTEM

The transportation system is based mainly on sea transport. Its main components are one ship, M/S Sigyn, transport containers and equipment for transport at the nuclear power plants and at the other facilities. The system is designed for accommodating all types of radioactive wastes. Reference is made to Appendix 2.

M/S Sigyn has a payload capacity of 1,400 tonnes and is designed as a roll-on/roll-off ship. Loading/unloading by crane is possible as well.

Until the beginning of 1993 about 1,650 tonnes of fuel have been shipped from the nuclear power plants to CLAB and about 11,100 m^3 low and intermediate level waste to SFR.

Containers designed to meet high demands, as regards radiation shielding and to withstand large external loads, are used for the transport. Spent nuclear fuel, core components and core internals are transported in cylindrical casks. One cask can hold about 3 tonnes of fuel.

For the transport of intermediate level waste to SFR, radiation shielding steel containers, called ATB, are used. A common type holds about 20 m^3 of waste, total weight 120 tonnes. For low level waste standard shipping containers will be used. By January 1993, SKB's system included 10 fuel casks, 2 casks for core components and 27 ATB containers.

During loading and unloading, the containers are transported short distances between the vessel and the storage facilities by special terminal vehicles, see Figure 2.4. At present five vehicles are used.

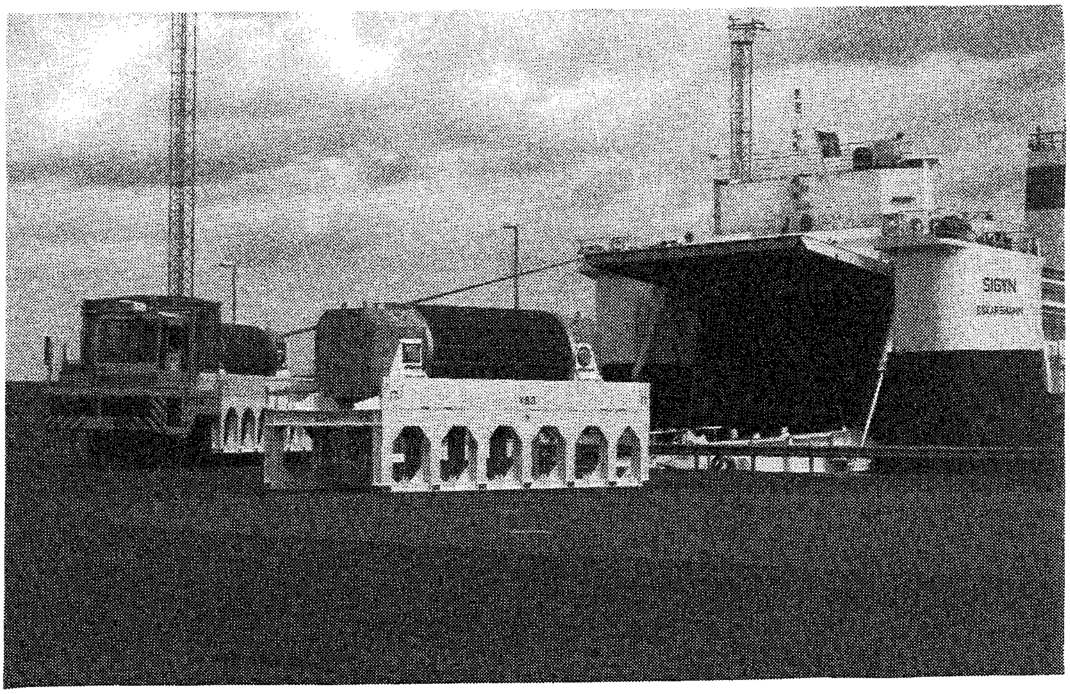


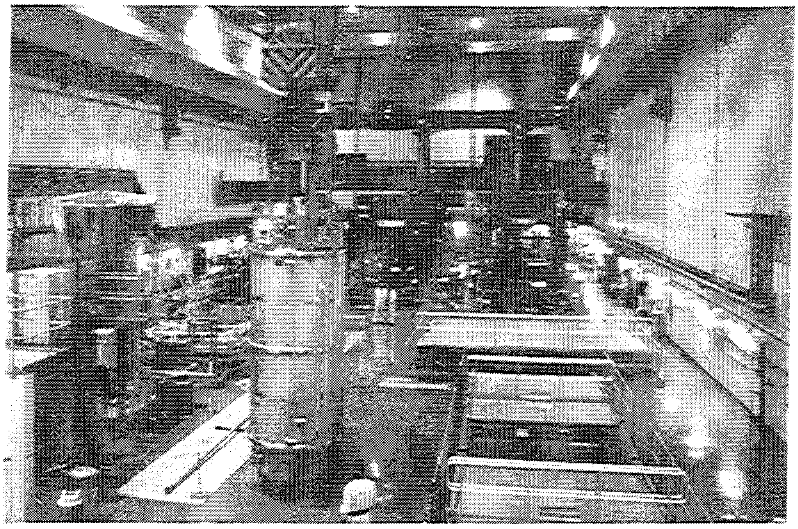
Figure 2.4 Loading of a fuel transport cask onto the M/S Sigyn.

The site of the final repository for long-lived waste is not yet decided. In the cost calculations it has conservatively been assumed that about 750 km of sea transportation will be needed from the encapsulation plant to a harbour, and a further 200 km by rail to the deep repository.

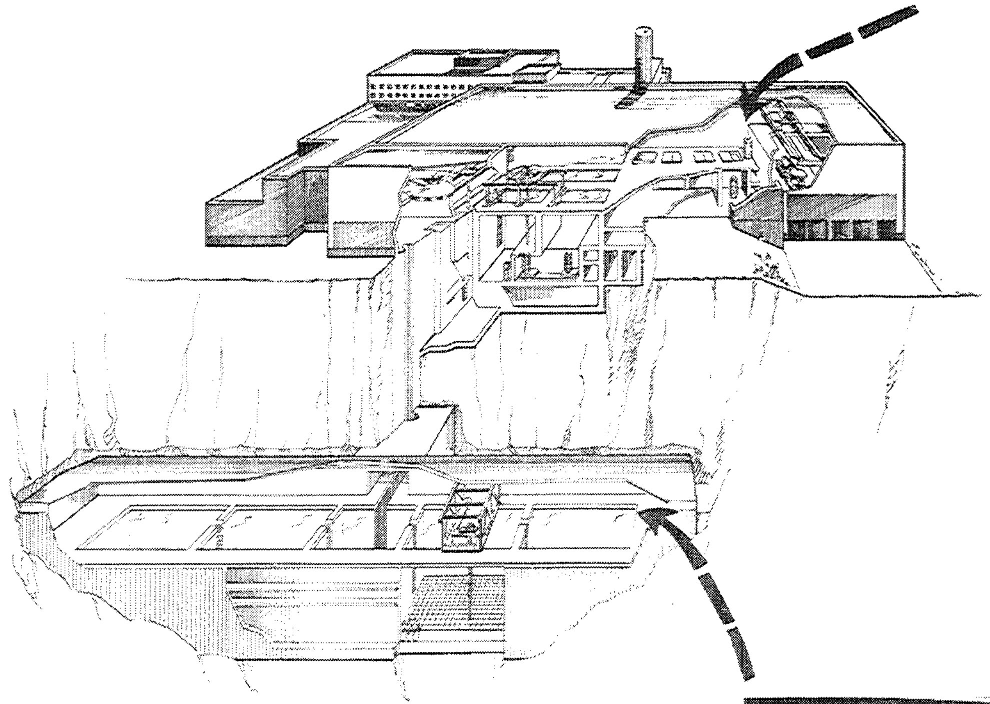
The encapsulated spent fuel will be transported in similar transport casks to those that are used for spent fuel today. Transportation of other long-lived waste and operational waste from CLAB, the encapsulation plant and Studsvik, are planned to be shipped in specially designed transport containers.

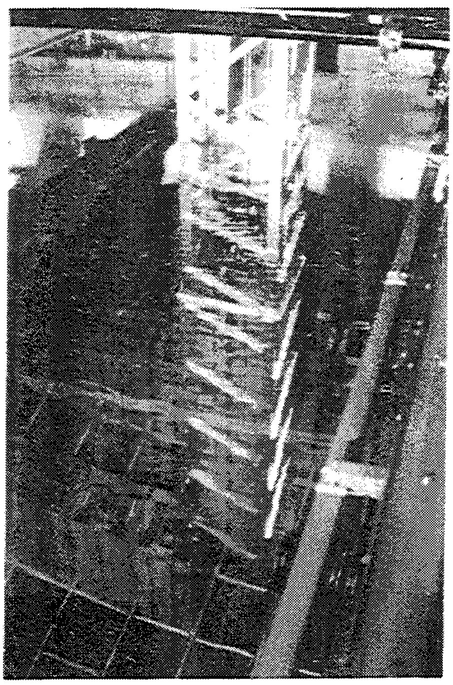
2.4 CENTRAL INTERIM STORAGE FACILITY FOR SPENT NUCLEAR FUEL, CLAB

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



The handling of transport casks in the receiving section





The handling of storage canisters in the storage section

Figure 2.5 CLAB.

At the beginning of 1993, fuel corresponding to 1,650 tonnes of uranium was stored in the facility. Core components and reactor internals, which shall be deposited in the deep repository, are stored in the facility as well.

In the late 1990s, the capacity of the facility will be expanded to hold all fuel from the Swedish nuclear power programme. In this report it is assumed that this will be done by the excavation of a new rock cavern parallel to the existing one.

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 and electrical systems as well as premises for administration and operating staff. Reception of fuel and all handling takes place under water.

The storage pools are located in rock caverns and are made of concrete with stainless steel lining. One pool contains 300 canisters. The spent fuel is mainly being stored in canisters with 25 BWR-elements or 9 PWR-elements. The partitioning walls of the new canisters are made of boron steel to ensure the criticality safety even with the more dense storage. The original canisters contain 16 BWR-elements or 5 PWR-elements. The elements are currently being reloaded from old to new canisters.

The permanent staff during operation are at present about 50 persons. In addition, service personnel are currently being used mainly from OKG's regular operating organization. On average this is equivalent to about 60 full-time employees. During periods when no loading or unloading is taking place, the work force is expected to be reduced.

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

2.5 ENCAPSULATION PLANT FOR SPENT FUEL, EP

In previous reports, the encapsulation plant was assumed to be located at the same site as the deep repository. According to the current SKB RD&D-Programme, the utilization of the deep repository will commence by a start-up phase and the CLAB site will be extended by the construction of the encapsulation plant. In the present

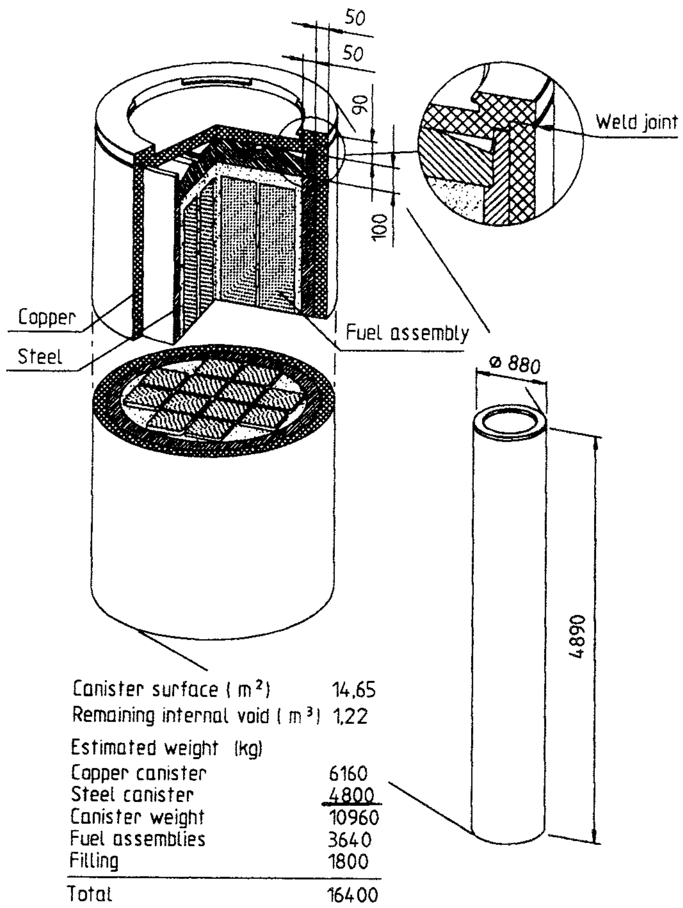


Figure 2.6 Copper canister with an inner steel container

conceptual design phase, the encapsulation plant has been placed adjacent to the existing CLAB–facility. Alternative locations within the CLAB site will however be studied.

A new reference canister has been chosen. It is a copper canister with an inner steel container. The canister can hold maximum 12 BWR–elements or 4 PWR–elements. The final number of elements in the canister depends on the residual heat effect at the time of disposal.

As an alternative, the spent fuel can be encapsulated in copper canisters filled with lead according to the method described in KBS–3 /ref. 1/. This type of canister is considered as an alternative to the reference canister made of copper and steel. The difference in cost between the two alternatives is covered by special risk allowances.

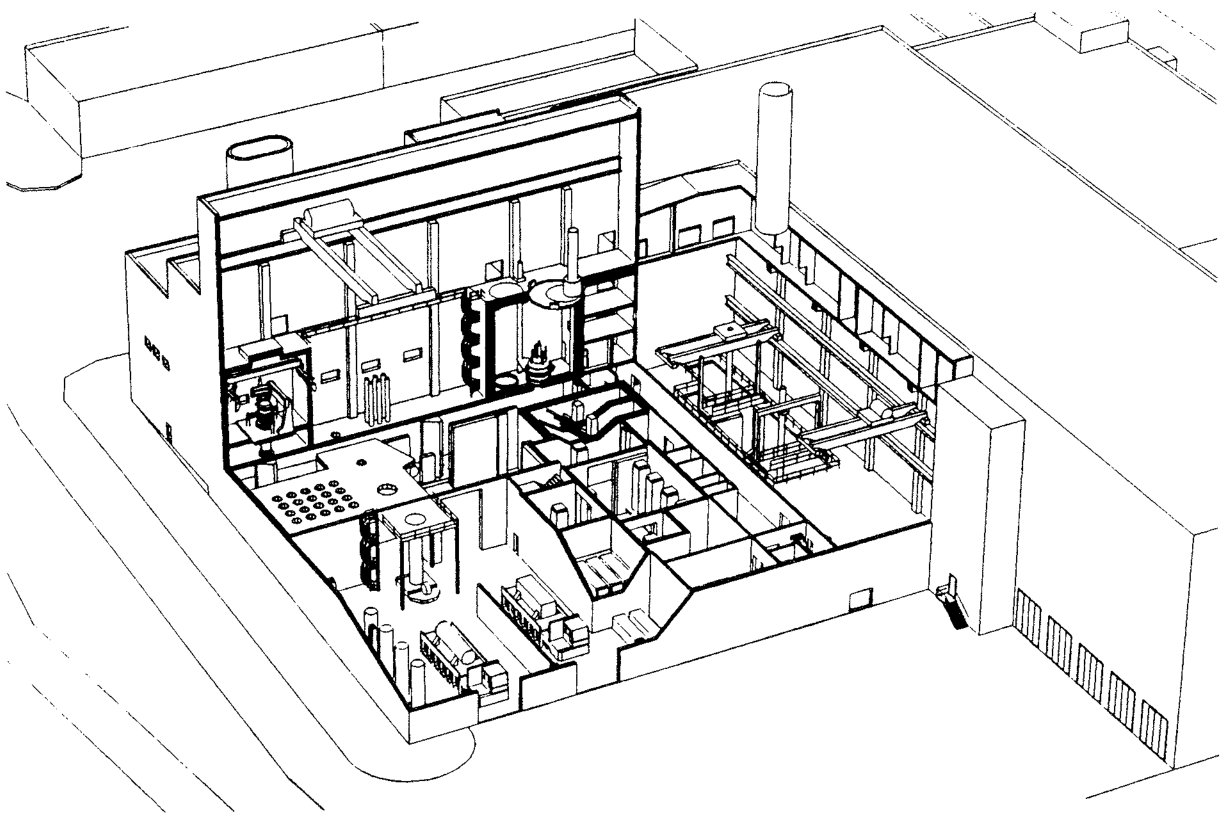


Figure 2.7 Encapsulation station for spent fuel.

The facility consists of the following main sections:

- Encapsulation section for filling and sealing of canisters and for quality verification.
- Section for handling and embedment in concrete moulds of core components and reactor internals.
- Dispatch section for canisters and concrete moulds. Transportation will be done by means of radiation shielded casks.
- Section for auxiliary systems with cooling and purification systems as well as electrical and control equipment.
- Personnel and office premises.

The facility is designed for an average annual capacity of 210 fuel canisters (one canister per day for 10 months). The effective capacity is however conservatively set at 200 canisters per year, taking into consideration transport interruptions that may occur during the winter season. The facility is mainly operated on a one-shift basis. The cost calculations take into account the co-operation possibilities with respect to the existing CLAB organization, which arise when the encapsulation plant is located adjacent to CLAB.

In total, approximately 4,500 canisters will be processed in the encapsulation plant. In this report it is assumed that 400 canisters will be processed during the period 2007 - 2011 and the remaining canisters during the period 2020 - 2040. The facility will thereafter be dismantled.

2.6 DEEP REPOSITORY FOR LONG-LIVED WASTE

Common Facilities

The deep repository for long-lived waste is in this report assumed to be situated inland in northern Sweden. The choice has been made to give a certain conservatism in the cost calculations. The transports are assumed to be made by ship to an existing harbour and from there by rail to the final repository. The cost estimates assume that the harbour will be provided with a new roll-on/roll-off quay area, a widened and deepened access channel, harbour aprons, and stores for sand and bentonite. Further it is assumed that 50 kilometres of railway to the deep repository has to be built and rolling stock acquired, i.e. locomotives and specially designed wagons.

The design of the deep repository is in line with the phased disposal of spent fuel. In the first stage 400 canisters will be disposed. In this report the design is based on a separate part of the repository for these canisters.

The most important change affecting the Common Facilities is that the encapsulation plant has been replaced by a receiving facility for transport casks with canisters and other wastes. The latter wastes will arrive only during the second stage of disposal.

The Common Facilities will include several buildings and service functions. The extent will depend on local circumstances and on the final solutions to certain functions, for example the transport down to the repository area which can be arranged by shaft or ramp.

In this report it is assumed that the industrial area consists of the following facilities:

- Entrance building with offices and workshops
- Information building with canteen
- Personnel building including separate locker rooms for different staff categories
- Stores and garages
- Operation building for the reception of waste, housing elevators down to the repository area
- Ventilation building
- Stores for sand and bentonite
- Facility for the high-pressure compaction of bentonite
- Service building for water supply, sewerage, heating etc.

The total operating staff at the site of the deep repository is estimated to about 250 persons.

There are four different final repository areas at the SFL:

SFL 2	for spent fuel
SFL 3	for low- and intermediate-level operational waste from CLAB (after 2012) and the encapsulation plant and long-lived waste from Studsvik
SFL 4	for decommissioning waste from the CLAB and encapsulation plant
SFL 5	for core components and reactor internals

A previously planned unit, SFL 1, for vitrified waste from reprocessing has been omitted.

Deep Repository for Spent Fuel

The final repository for spent fuel, SFL 2, is planned to be located at a depth of about 500 m below the ground surface. It can be reached via an elevator shaft or, alternatively, via a ramp, Both alternatives are illustrated in this report. The most expensive alternative is used in the cost summaries.

The location of the central area and the repository areas will depend on specific site conditions. Deposition will be carried out in three separate areas, one area for the first 400 canisters during stage one, and two areas for the remaining canisters.

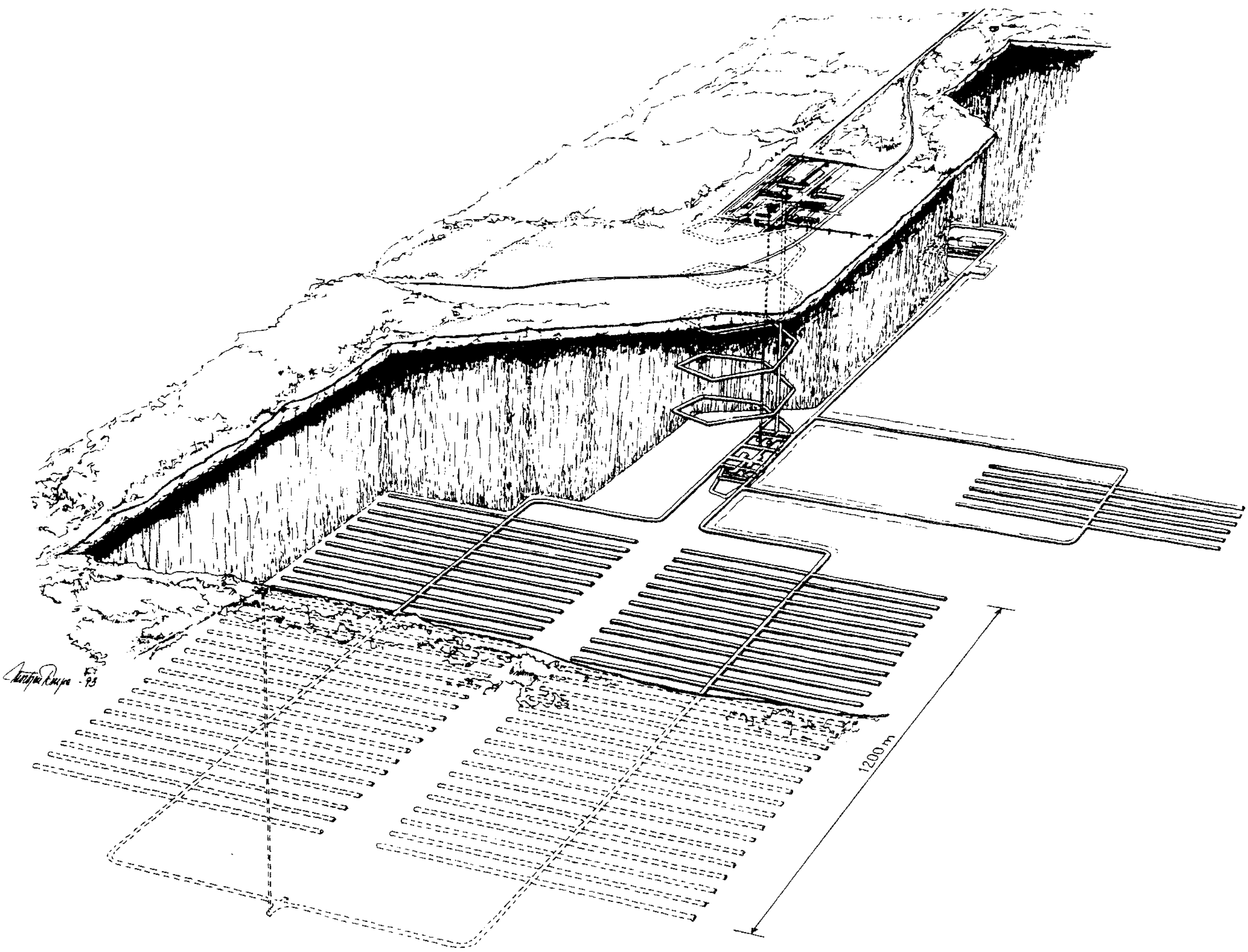


Figure 2.8 Deep repository – overview

The central area has been designed in accordance with new assumptions regarding transportation of canisters and long–lived waste, which will be taken down to the repository area in their transport casks and unloaded there.

The copper canisters are placed in vertical holes, drilled in the bottom of the deposition tunnels and surrounded by a layer of compacted bentonite, 35 cm thick. The distance between holes is 6.0 m and between tunnels 40 m. The spacing of the canisters is determined by thermal restrictions. The temperature in the bentonite shall not exceed 80° C. The total number of deposition holes is about 4,500. Costs for an extra 10% tunnelling are included assuming that deposition is not feasible in certain areas.Figure 2.8 shows an overview of the industrial area and the repository areas.

The copper canister is transported down to the repository level, where it is picked up by a specially designed transport vehicle and driven to the entrance of a deposition tunnel. The canister will then be transferred from its horizontal position in the transport cask to an electrically driven deposition vehicle on rails for further handling inside the deposition tunnel.

The deposition of the canister is preceded by the emplacement of a bentonite block at the bottom of the hole and above that a set of cylinder shaped bentonite blocks. This is done by special purpose equipment. When the deposition vehicle has reached its position above the deposition hole the canister is raised and lowered into the hole. After emplacement additional blocks are stacked on top of the canister.

The deposition tunnels are backfilled with a mixture consisting of 15% bentonite and 85% sand.

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

The emplacement of copper canisters will proceed during the period 2009–2012 in a first stage. An evaluation will take place before further expansion. The remaining canisters are assumed to be deposited during the period 2020 – 2040. The repository will thereafter be sealed and all service tunnels, vaults and shafts will be backfilled.

Deep Repository for Low– and Intermediate–Level Wastes

All low– and intermediate–level operational waste to be deposited after year 2012, when SFR 1 has been closed, is placed in SFL 3. No consideration has to be taken to the temperature since the heat emission is negligible. The storage chambers, which are located at a depth of about 500 m, are reached through the central area of SFL 2. SFL 3–5 are connected to the central area by a tunnel approximately 1 km long. The tunnel between SFL 2 and SFL 3–5 will be sealed in the same way as the deposition tunnels, i.e. with a mixture of sand and bentonite.

SFL 3 consists of a 70 m long rock cavern. The width of the cavern is 18 m and the height about 21 m. The long–lived waste from Studsvik and the operational waste from CLAB (after year 2012) and the encapsulation plant is deposited in SFL 3. The waste, which is placed in concrete moulds (1.2x1.2x1.2 m) or 200 l barrels, is stacked in concrete cells, 2.5 m square and about 10 m in height. The remaining empty space in the cells is filled with concrete. All handling is remotely controlled. The space between the concrete cells and the rock is filled with a sand–bentonite mixture.

SFL 4 occupies the tunnel system that has to be built for SFL 3 and SFL 5. Low–level decommissioning waste from CLAB and the encapsulation plant, transport casks, etc, which are finally deposited at a late stage, will be placed in SFL 4 shortly before the facility is sealed.

SFL 5 consists of three caverns, each about 130 m long, 6 m wide and 10.5 m high. The concrete moulds for core components etc. are stacked in the caverns and embedded in concrete. The moulds are handled by a remotely operated overhead crane and placed in concrete troughs each holding 50 moulds. When a trough is full, it will be sealed with prefabricated concrete planks.

2.7 FINAL REPOSITORY FOR RADIOACTIVE WASTE, SFR

A final repository for operational waste, SFR 1, is in operation since 1988 at 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 tunnels lead 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 2, which was intended for core components etc., is assumed in this report not to be built, being replaced by SFL 5.

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

SFR 1

When completed, SFR 1 will consist of five to six 160 m long rock vaults and two 70 m high cylindrical rock caverns containing concrete silos, see Figure 2.9. 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, of which about 37,000 m^3 in silos.

The concrete silo stands on a bed of sand and bentonite. The silo is divided into vertical shafts, where the waste is deposited and surrounded with concrete grout. The space between the silo and the rock is filled with bentonite. The space above the silo will be filled with a sand–bentonite mixture when the silo is full.

The part of the intermediate–level waste placed in rock vaults, will be surrounded by concrete grout. The low–level waste will not be embedded in concrete.

The handling of the intermediate level waste is remotely controlled, while the low active waste is handled by a forklift truck.

A crew of about 20 persons operates the facility. To this number should be added some services that are obtained from the nearby nuclear power plant.

Up to the beginning of 1993, 11,100 m^3 of waste have been deposited in SFR. The facility is expected to be sealed in the early 2010s.

SFR 3

The decommissioning waste from the nuclear power stations and Studsvik will be deposited in SFR 3. 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 containers that 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.

SFR 3 will be in operation during the period when the nuclear power plants are dismantled. The number of operation personnel will be similar to SFR 1.

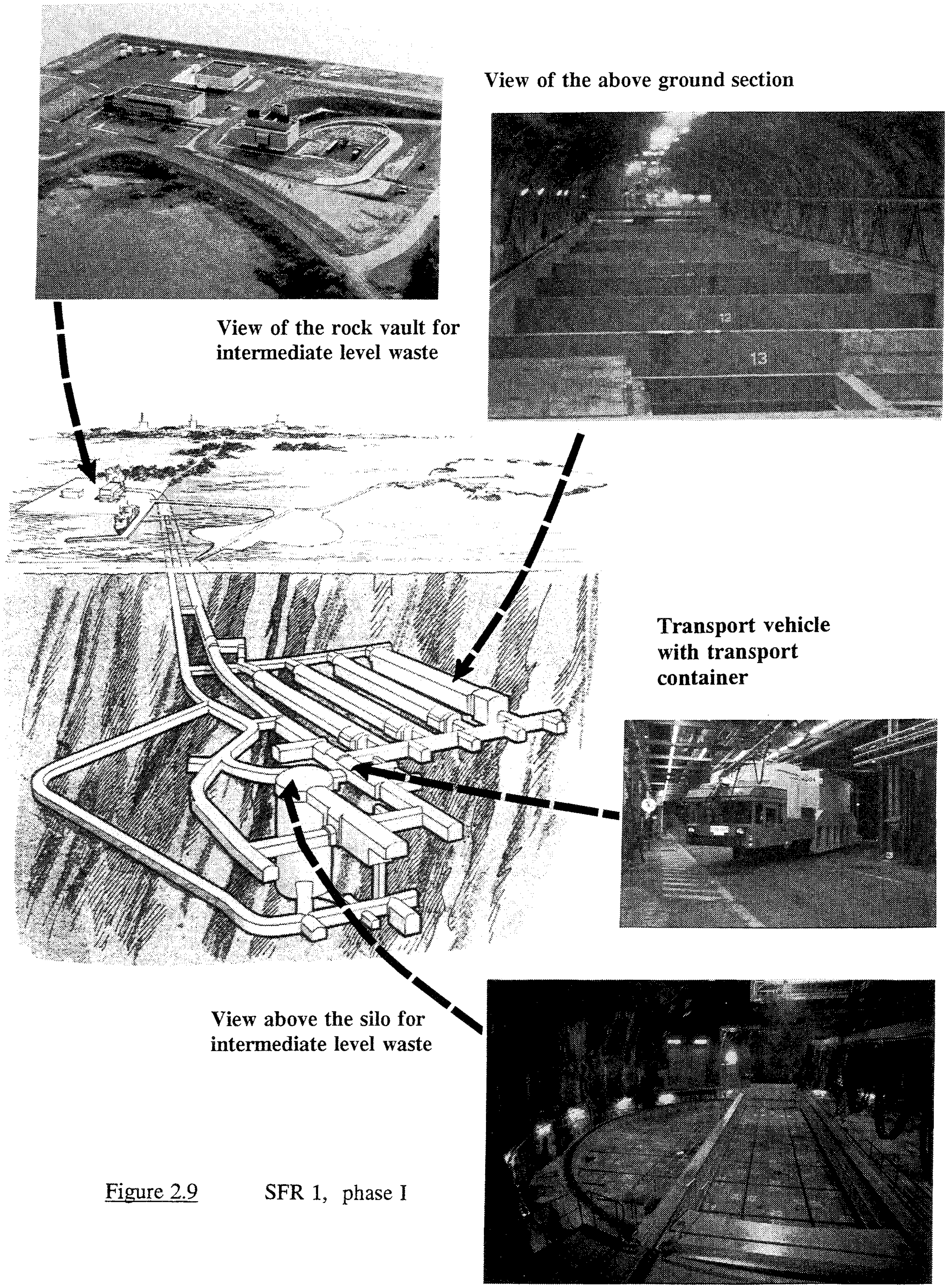


Figure 2.9 SFR 1, phase I

2.8 DECOMMISSIONING OF NUCLEAR POWER PLANTS

The measures required for management of the radioactive waste products of nuclear power also include decommissioning of the facilities after they have been taken out of operation /ref. 4/.

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

With regard to resource utilization and the reception capacity in CLAB and in SFR, it is suitable 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.

During the period from when the unit is taken out of operation until dismantling, removal of fuel, decontamination and preparations for dismantling (shutdown operation) take place. During this period, the personnel can be gradually 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 low– and intermediate–level waste. 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 in SFL 5. Other radioactive decommissioning waste will be transported directly to SFR 3 and deposited there. A large quantity of the decommissioning waste can be declassified, some of it after decontamination.

3. CALCULATION ALTERNATIVES

3.1 GENERAL

To establish a basis for design of the final repositories and the transport system certain assumptions have to be made regarding the operation time of the various nuclear power plants. The main alternative with respect to costs that is accounted for in this report is, as in previous reports, based on the amounts of waste that are produced if all nuclear plants are operated up to and including the year 2010. This results in an average operating time of 30 years. To illustrate the sensitivity with respect to the operating times, calculations are also made and described in this report for the cases of 25 and 40 years of operation of all nuclear power reactors.

Based on the operating time, the amount of waste is estimated which in turn gives the need of investments and operating schedules for the overall waste management system. The waste quantities for the three alternatives studied are listed in Appendix 1.

3.2 CHANGES IN THE WASTE MANAGEMENT SYSTEM FOR DIFFERENT OPERATING TIMES

The description of the Waste Management System, as given in previous chapters, is based on the amount of waste and the time schedules given if all nuclear power plants are in operation up to and including the year 2010. The waste system will not significantly change if the operation time of the reactors changes. However, the amount of spent fuel and low- and intermediate-level waste is related to the operation times of the reactors, a fact that, among other things, will affect the time schedule of the waste management system.

In this report it is assumed that the encapsulation, and the deposition, will start at the same time for all of the calculated alternatives. The capacity of the encapsulation plant and the deep repository will also be the same, i.e. 200 canisters per year. Consequently the operation time of the transport system, CLAB, the encapsulation plant and the deep repository will be determined by the number of canisters in the actual alternative. Figure 3.1 shows a time schedule including all three alternatives. The corresponding number of canisters was estimated at 4,500, 3,600 and 6,100 respectively.

The storage capacity needed in CLAB is also affected by the amount of spent fuel. SFR 1 is assumed to be in operation as long as the reactors are. The volumes of the waste bound for SFR 3 are not affected but the operation time follows the time of decommissioning of the nuclear power plants.

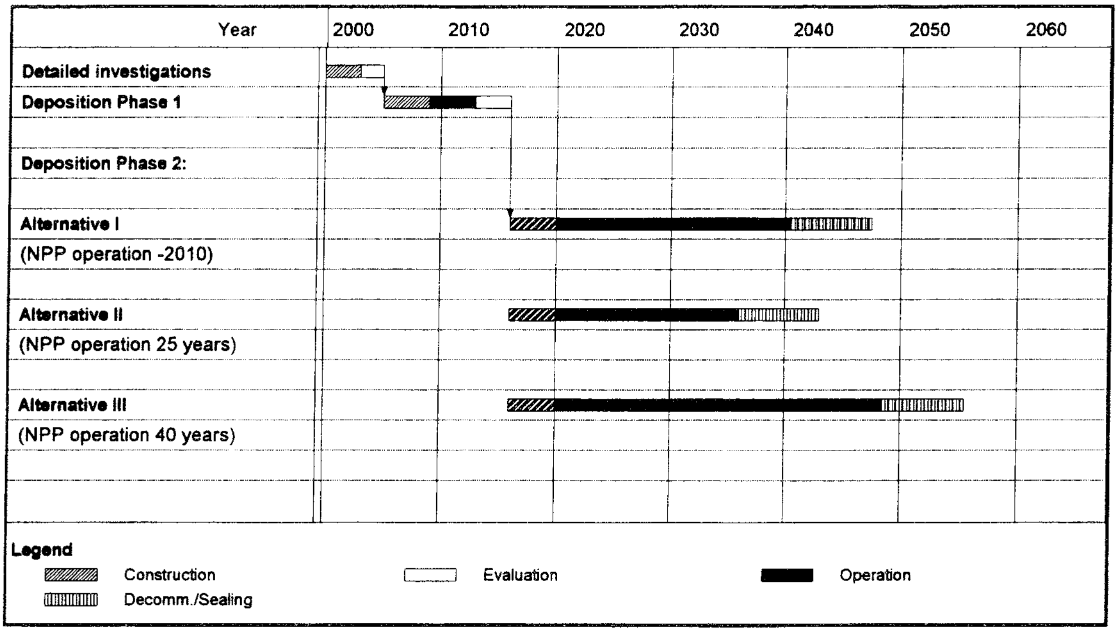


Figure 3.1 Time schedule for deposition for different alternatives

4. COSTS

4.1 GENERAL

All costs for the management and disposal of the radioactive waste products described in Section 1.2 are reported in this chapter. The cost calculations have been based on the scenario and the facilities, systems, etc., that are described in Chapter 2.

In the accounting system, costs incurred up to and including 1993 are distinguished from future costs. The future costs are estimated at January 1993 prices. Previously incurred costs are quoted in current prices.

In this report, as opposed to previous reports, cost calculations for all future facilities and systems have been carried out on the basis of the RD&D-Programme of 1992. A new layout for the encapsulation plant has been worked out. Also the layout for the deep repository has been updated. The features of the industrial area will to some extent depend on whether a ramp or a shaft will be the main access to the repository area. Costs have been calculated for both alternatives. Cost tables below account for the ramp alternative which is the most expensive under given premises.

Revised waste quantities and operating times have been considered. Costs for the transport system, and for CLAB and SFR have been reviewed in the light of operation experience from recent years.

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 are broken down into the following items: investment, reinvestment, operation, 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 deep repository, where the deposition tunnels will be excavated continuously during the deposition phase, the costs for this work have, however, been assigned to the investment costs.

Costs that do not fall under the Financing Act are also reported (operational waste from the nuclear power plants, spent fuel from Ågesta and waste from Studsvik).

4.2 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.

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 prices, experience gained in construction of the nuclear power plants, CLAB and the SFR have been drawn on.

All details are not included on the drawings. Non–quantity stipulated costs can be estimated with good accuracy based on experience from other similar work.

The final item included in the base costs are 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 based on 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 by the risks of additional work and the engineering level of the facility. On an average, for the whole system, it is about 27%.

In addition to the ordinary contingency allowances an extra allowance is added to the reported costs in order to cover uncertainties in the overall system design and other uncertainties of a general nature. Examples of uncertainties in this category are: The design of the canister; The localization and design of future facilities; The time schedules. This kind of allowance makes up 15-20 % of the costs for future facilities. It is included in the costs reported below.

Included in the proposed strategy for disposal of canisters during two phases is an evaluation period and a new licensing following the first phase. This could lead to a decision on a take back of the deposited canisters and the selection of an alternative location. In such a case the deposition programme will be delayed. Additional cost inflicted by such an event is covered by the extra allowance.

4.3 REPORTING OF FUTURE COSTS

The costs reported in this section are given at the price level of January 1993. The costs are distributed in time, which permits discounting with different values for the real interest rate.

Costs are reported for three alternatives. The main alternative is, as in previous reports, operation of all nuclear power plants up to and including the year 2010. This report has been supplemented with the alternatives considering operation of all nuclear power plants during 25 and 40 years respectively.

Costs shown below are based on the type of copper canister that has an inner steel container. Calculations based on the lead-filled canister have also been performed. The lead-filled canister gives higher investment costs for the encapsulation plant but lower operating costs because of lower canister costs. The costs of a possible return to the lead-filled copper canister, covered by allowances, are included in the total costs.

Operation of all reactors up to and including the year 2010

Table 4.1 shows the future costs for waste management. The costs are distributed by object and category of cost. The total future costs from 1994 amount to SEK 48.3 billion.

The table separates costs under the Financing Act, i.e. the total cost less costs for low- and intermediate-level operational waste and waste from Studsvik and Ågesta. The future costs under the Financing Act from 1994 amount to SEK 46.8 billion.

Table 4.2 shows the future costs broken down by object and distributed over time.

Table 4.1 Future costs (MSEK) from 1994, including contingency allowance for unforeseen items. Operation of all reactors up to and including the year 2010. (January 1993 prices).

Object	Cost category	Total future costs	Total future costs per object	Total cost under Financing Act [1]
SKB, Adm, RD&D	-	3,844	3,844	3,844
Transports	Reinvestment	856		
	Operation	953	*) 1,808	1,582
Decommissioning NPP	Shutdown operation	1,394		
	Dismantling	10,830	12,224	12,224
CLAB	Investment	617		
	Reinvestment	922		
	Operation	3,339		
	Decommissioning	345	*) 5,223	5,197
Encapsulation Plant	Investment	2,104		
	Reinvestment	87		
	Operation	5,740		
	Decommissioning	157	*) 8,090	8,049
Deep Repository – Common Facilities	Investment	4,224		
	Reinvestment	287		
	Operation	1,658		
	Decommissioning	326	*) 6,495	6,415
Deep Repository – Fuel	Investment	2,818		
	Reinvestment	44		
	Operation	962		
	Sealing	3,193		
	Decommissioning	60	*) 7,078	7,043
Deep Repository – Other Waste	Investment	490		
	Operation	155		
	Decom. + sealing	290	*) 936	834
SFR – Common Facilities	Investment	41		
	Decom. + sealing	3	*) 44	1
SFR 1	Investment	303		
	Reinvestment	9		
	Operation	478		
	Decom. + sealing	97	*) 886	26
SFR 3	Investment	446		
	Operation	208		
	Decom. + sealing	58	*) 712	686
Reprocessing [2]	–	928	928	928
Total			48,268	46,829

* Also includes costs outside the Financing Act. Total over all concerned objects:
Waste from Studsvik, Ågesta etc MSEK 321
Other low- and intermediate- level waste MSEK 1,118

1) Future costs less costs for Studsvik waste etc and other low- and intermediate-level waste

2) Costs of reprocessing including costs at BNFL and for transition of contracts with COGEMA

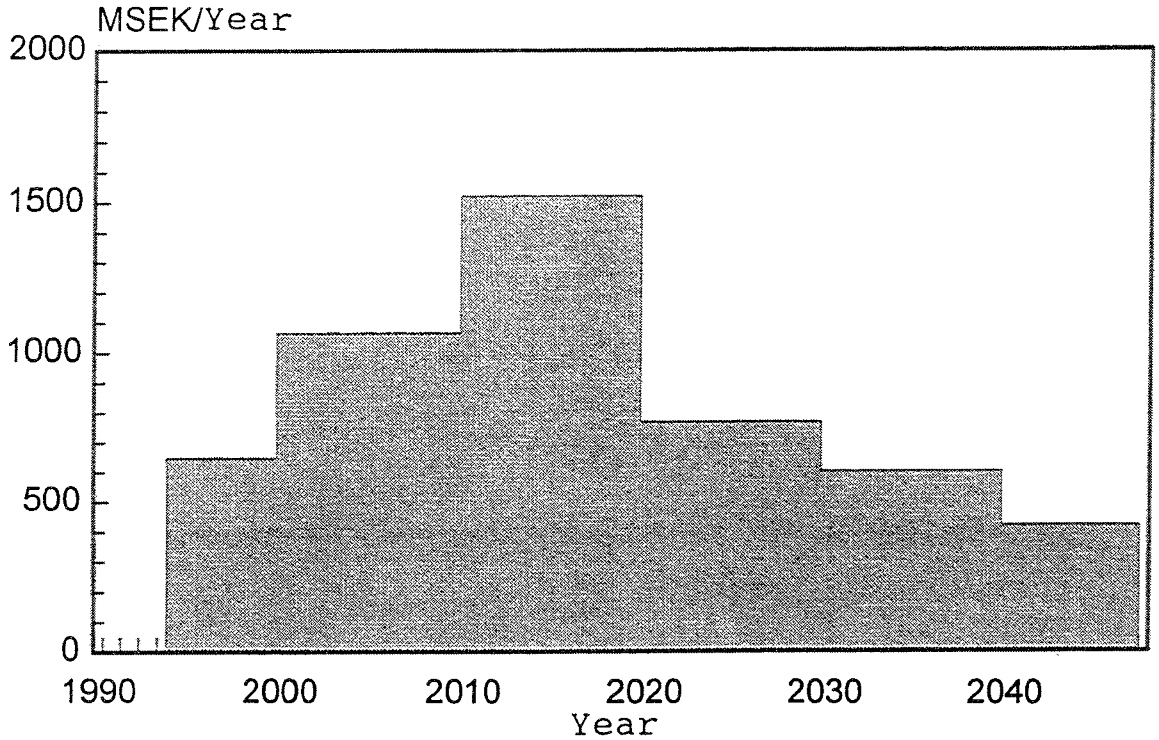


Figure 4.1 Annual future costs. Operation of all reactors up to and including the year 2010. (January 1993 prices)

Table 4.2 Future costs (MSEK) per object under the Financing Act distributed over time. Operation of all reactors up to and including the year 2010. (January 1993 prices)

Year	SKB Adm, RD&D	Transp	Decom. NPP	CLAB	EP	Deep reposi-tory	SFR 1 & 3	Reproc.	Total costs	Accumu-lated costs
1994–99	1,462	105		797	531	264	15	714	3,888	3,888
2000–09	1,575	352		1,438	1,904	4,960	214	214	10,657	14,545
2010–19	587	502	11,139	890	652	1,103	356		15,229	29,774
2020–29	100	353	1,085	933	2,301	2,780	128		7,680	37,454
2030–39	100	186		714	2,323	2,702			6,025	43,479
2040–49	20	84		425	338	2,483			3,350	46,829
Total from 1994	3,844	1,582	12,224	5,197	8,049	14,292	713	928	46,829	

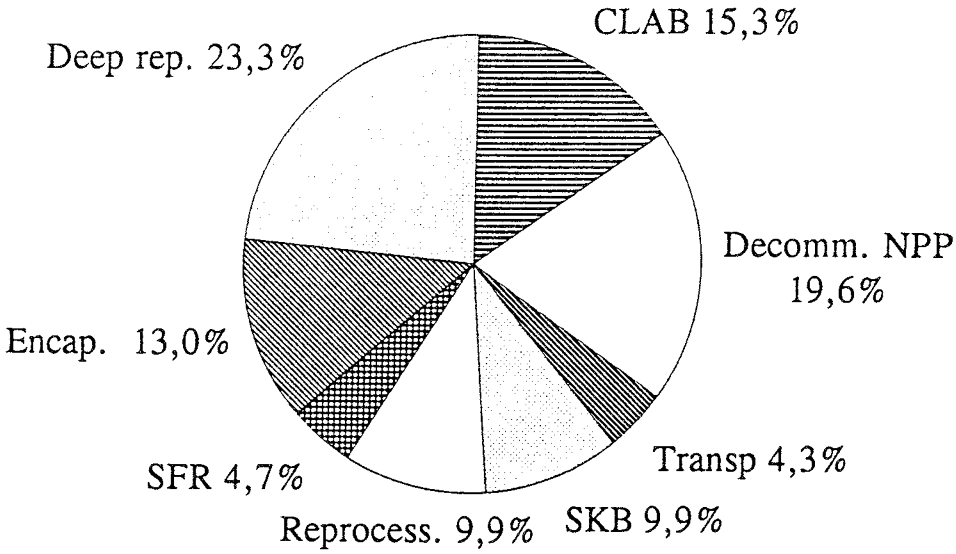


Figure 4.2 Distribution of the total cost for the alternative operation of all reactors up to and including the year 2010.

Distribution of the total costs over different facilities are shown in Figure 4.2. Incurred costs, see Section 4.4, are indexed to price level January 1993.

25 years of operation of all reactors

The total future costs from 1994 amount to SEK 45.9 billion. Table 4.4 shows the future costs distributed by object and category for waste management. Total costs and costs under the Financing Act are separated.

The future costs under the Financing Act from 1994 amount to SEK 44.6 billion. Table 4.3 shows the future costs under the Financing Act broken down by object and distributed over time.

Table 4.3 Future costs (MSEK) per object under the Financing Act distributed over time. 25 years of operation of all reactors. (January 1993 prices)

Year	SKB Adm, RD&D	Transp	Decom. NPP	CLAB	EP	Deep repository	SFR 1 & 3	Reproc.	Total costs	Accumulated costs
1994-99	1,462	105	50	792	531	262	5	714	3,921	3,921
2000-09	1,575	352	1,099	1,274	1,905	4,940	220	214	11,579	15,500
2010-19	587	501	10,875	848	652	1,077	356		14,896	30,396
2020-29	100	353	1,082	852	2,302	2,836	128		7,653	38,049
2030-39	100	186		535	1,596	3,050			5,467	43,516
2040-49	20	2		320		723			1,065	44,581
Total from 1994	3,844	1,499	13,106	4,621	6,986	12,888	709	928	44,581	

Table 4.4 Future costs (MSEK) from 1994, including contingency allowance for unforeseen items. 25 years of operation of all reactors. (January 1993 prices).

Object	Cost category	Total future costs	Total future costs per object	Total cost under Financing Act [1]
SKB, Adm, RD&D	-	3,844	3,844	3,844
Transports	Reinvestment	856		
	Operation	870	*) 1,726	1,499
Decommissioning NPP	Shutdown operation	2,298		
	Dismantling	10,808	13,106	13,106
CLAB	Investment	472		
	Reinvestment	738		
	Operation	3,099		
	Decommissioning	336	*) 4,644	4,621
Encapsulation Plant	Investment	2,104		
	Reinvestment	72		
	Operation	4,687		
	Decommissioning	157	*) 7,021	6,986
Deep Repository - Common Facilities	Investment	4,224		
	Reinvestment	174		
	Operation	1,393		
	Decommissioning	326	*) 6,117	6,030
Deep Repository - Fuel	Investment	2,436		
	Reinvestment	32		
	Operation	799		
	Sealing	2,771		
	Decommissioning	55	*) 6,093	6,063
Deep Repository - Other Waste	Investment	490		
	Operation	123		
	Decom. + sealing	290	*) 903	795
SFR - Common Facilities	Investment	41		
	Decom. + sealing	3	*) 44	1
SFR 1	Investment	155		
	Reinvestment	9		
	Operation	476		
	Decom. + sealing	96	*) 735	22
SFR 3	Investment	446		
	Operation	208		
	Decom. + sealing	58	*) 712	686
Reprocessing [2]	-	928	928	928
Total			45,873	44,581

* Also includes costs outside the Financing Act. Total over all concerned objects:
Waste from Studsvik, Ågesta etc MSEK 322
Other low- and intermediate- level waste MSEK 970

1) Future costs less costs for Studsvik waste etc and other low- and intermediate-level waste

2) Costs of reprocessing including costs at BNFL and for transition of contracts with COGEMA

40 years of operation of all reactors

The total future costs from 1994 amount to SEK 55.5 billion. Table 4.6 shows the future costs distributed by object and category for waste management. Total costs and costs under the Financing Act are separated.

The future costs under the Financing Act from 1994 amount to SEK 53.5. Table 4.5 shows the future costs under the Financing Act broken down by object and distributed over time.

Table 4.5 Future costs (MSEK) per object under the Financing Act distributed over time. 40 years of operation of all reactors. (January 1993 prices)

Year	SKB Adm, RD&D	Transp	Decom. NPP	CLAB	EP	Deep reposi-tory	SFR 1 & 3	Reproc.	Total costs	Accumu-lated costs
1994–99	1,462	105		820	531	267	10	714	3,909	3,909
2000–09	1,575	352		1,490	1,904	4,988	18	214	10,541	14,450
2010–19	587	515	466	962	652	1,228	7		4,417	18,867
2020–29	100	378	4,265	936	2,290	2,921	481		11,371	30,238
2030–39	100	239	8,375	1,173	2,353	2,822	211		15,273	45,511
2040–49	20	186		664	2,049	2,528	3		5,450	50,961
2050–59		43		275	57	2,170			2,545	53,506
Total from 1994	3,844	1,818	13,106	6,320	9,836	16,924	730	928	53,506	

Table 4.6 Future costs (MSEK) from 1994, including contingency allowance for unforeseen items. 40 years of operation of all reactors. (January 1993 prices).

Object	Cost category	Total future costs	Total future costs per object	Total cost under Financing Act [1]
SKB, Adm, RD&D	-	3,844	3,844	3,844
Transports	Reinvestment	952		
	Operation	1,099	*) 2,052	1,818
Decommissioning NPP	Shutdown operation	2,298		
	Dismantling	10,808	13,106	13,106
CLAB	Investment	725		
	Reinvestment	1500		
	Operation	3,775		
	Decommissioning	351	*) 6,352	6,320
Encapsulation Plant	Investment	2,104		
	Reinvestment	160		
	Operation	7,463		
	Decommissioning	157	*) 9,885	9,836
Deep Repository – Common Facilities	Investment	4,224		
	Reinvestment	469		
	Operation	2,132		
	Decommissioning	326	*) 7,151	7,067
Deep Repository – Fuel	Investment	3,535		
	Reinvestment	90		
	Operation	1,241		
	Sealing	3,984		
	Decommissioning	70	*) 8,920	8,875
Deep Repository – Other Waste	Investment	577		
	Operation	210		
	Decom. + sealing	309	*) 1,096	982
SFR – Common Facilities	Investment	41		
	Decom. + sealing	3	*) 44	1
SFR 1	Investment	485		
	Reinvestment	18		
	Operation	851		
	Decom. + sealing	96	*) 1,449	43
SFR 3	Investment	446		
	Operation	208		
	Decom. + sealing	58	*) 712	686
Reprocessing [2]	-	928	928	928
Total			55,539	53,506

* Also includes costs outside the Financing Act. Total over all concerned objects:
Waste from Studsvik, Ågesta etc MSEK 363
Other low- and intermediate- level waste MSEK 1,670

1) Future costs less costs for Studsvik waste etc and other low- and intermediate-level waste

2) Costs of reprocessing including costs at BNFL and for transition of contracts with COGEMA

Comparison between the calculation alternatives

Table 4.7 compares the future costs under the Financing Act for the three calculation alternatives. The costs are distributed by object.

Table 4.7 Comparison between future costs (MSEK) under the Financing Act for the three calculation alternatives. (January 1993 prices)

	Operation through 2010	25 years of operation	40 years of operation
SKB - Adm, RD&D	3,844	3,844	3,844
Transports	1,582	1,499	1,818
Decommissioning NPP	12,224	13,106	13,106
CLAB	5,197	4,621	6,320
EP	8,049	6,986	9,836
Deep Repository - Common Facilities	6,415	6,030	7,067
Deep Repository - Fuel	7,043	6,063	8,875
Deep Repository - Other waste	834	795	982
SFR 1 & 3	713	709	730
Reprocessing	928	928	928
Total costs	46,829	44,581	53,506

4.4 PREVIOUSLY INCURRED COSTS

Table 4.8 reports costs incurred through 1992, in current prices excluding interest, and 1993 budgeted costs.

Table 4.8 Incurred and estimated costs through 1993. (MSEK current prices)

Object	Cost category	Cost incurred through 1992	Estimated costs 1993
SKB (RD&D, Info, Adm)	–	1,558	288
Transports	Investment	254	–
	Operation	257	19
CLAB	Investment	1,747	–
	Operation	744	101
SFR 1	Investment	751	–
	Operation	131	33
Reprocessing	–	3,276	–
Encapsulation plant	–	–	20
Total		8,718	461

4.5 MARGINAL COSTS

The costs of the facilities per unit are presented in Table 4.9, both as average cost and as marginal cost. The marginal costs have been calculated by an estimate of the variable cost portion for each facility section. The capacity of the encapsulation plant has been kept constant, so that a change in fuel quantity leads to a change in operating time.

The marginal costs given in the table are roughly estimated and only apply within a limited interval (approx. 10%) of the quantities given in column three.

Table 4.9 Marginal costs for certain parts of the system. (January 1993 prices)

Object	Cost (MSEK)	Quantity	Unit (parameter)	Cost/unit (kSEK)	Marg. cost (kSEK/unit)	Remarks
TOTAL FACILITIES ETC. FOR MANAGEMENT OF FUEL						
Facilities for management of fuel incl. core components and RD&D	36,800	7,700	ton fuel	4,780	2,010	
DIFFERENT PARTS OF THE SYSTEM						
Transports						Includes costs for all transports of the waste
Total	2,677	15,690	transport unit	171		Ship-transported fuel and waste. The transport unit is a cask or a cintainer
Spent fuel	1,612	7,700	ton fuel	209	54	Incl. core components and LI-waste from CLAB
Operational waste from NPP	327	50,700	m^3 LI-waste	6.5	0.5	By ship from NPP to SFR1
Decommissioning waste from NPP	656	68,000	m^3 LI-waste	9.6	0.6	By ship from NPP to SFR3 and reactor internals from CLAB to deep repository
Studsvik waste	82	19,300	m^3 LI-waste	4.2	0.4	Various wastes
Interim storage facility and encapsulation plant						
CLAB	9,639	7,700	ton fuel	1,252	410	Incl. core components and reactor internals
Encapsulation plant	8,088	7,700	ton fuel	1,050	708	Incl. concreting of core components etc.
Final disposal						
Deep repository - Total	14,507	7,700 4,500	ton fuel canister	1,884 3,224	959 1,642	
Deep repository - fuel	12,656	7,700 4,500	ton fuel canister	1,644 2,812	859 1,470	Incl. part of Common Facilities
Deep repository - other waste	1,851	15,110	m^3 LI-vaste (not decomm.)	123	51	Incl. part of Common facilities
SFR 1	2,270	87,200	m^3 LI-waste	26	9	Incl. Common Facilities (SFR)
SFR 3	712	103,800	m^3 decomm. waste	6.9	4.4	

4.6 WASTE MANAGEMENT FEE

According to Swedish law, the costs for the back-end of the nuclear fuel cycle and for the decommissioning of the reactors shall be borne by the owners of the reactors. To make sure that funds shall be available a fee is levied on the production of electricity in nuclear power plants. The level of the fee is determined annually by the Government. The decision of the Government is based on a proposal by SKI, which has been calculated using the results of the annual cost calculations presented by SKB in this report and its predecessors.

In making the proposal, SKI has to consider all relevant factors, such as total costs, expected operation time of the reactors and interest on the money collected in funds. Separate fees are proposed for each reactor owner. For 1993 the fee has been 1.9 öre/kWh (SEK 0.019/kWh) on average.

The fees are paid into funds at the National Bank of Sweden. The funds are controlled and administered by SKI.

REFERENCES

1. Final Storage of Spent Nuclear Fuel - KBS-3
   Parts I-IV
   Svensk Kärnbränsleförsörjning AB
   May 1983

2. SKB 91
   Final disposal of spent nuclear fuel
   Importance of the bedrock for safety
   April 1992

3. SKB RD&D Programme 1992
   September 1992

4. SKI R&D-Programme 89
   Review by the Swedish Nuclear Power Inspectorate
   Dnr 93/89, March 1990

5. Project on alternative Systems Study (PASS)
   Final Report
   Svensk Kärnbränslehantering AB
   October 1992.

6. Technology and costs for decommissioning a Swedish nuclear power plant, Technical Report 86-16
   Svensk Kärnbränslehantering AB
   May 1986

7. SKB PLAN 92
   Cost for management of the radioactive waste from nuclear power production
   Svensk Kärnbränslehantering AB
   June 1992.

APPENDICES

1 Spent fuel and radioactive waste in Sweden assuming

- operation of all plants through 2010
- 25 years of operation of all plants
- 40 years of operation of all plants

2 Transportation system

3 Central interim storage facility for spent nuclear fuel, CLAB

4 Encapsulation plant for spent fuel, EP

5 Deep repository for long-lived waste, SFL

6 Final repository for radioactive waste, SFR

7 Decommissioning of the nuclear power plants

SPENT FUEL AND RADIACTIVE WASTE IN SWEDEN ASSUMING OPERATION OF ALL PLANTS THROUGH 2010

Waste category	Dimensions of waste units in m, d = diameter (Dimensions before encapsulation for final disposal)	No. of packages	No. of transport units (casks/ containers)	Volume in final repository (m^3)	Final destination
Spent BWR fuel	0.14*0.14 *4.383	33,000	3,260	(included in next row)	
Spent PWR fuel	0.21*0.21*4.103	3,900	1,220	13,500	SFL 2
Other spent fuel	Various	641	56	(included in row above)	
Core components in storage containers	1.2*1.2*4.8	680	680	(included in next row)	
Reactor internals in storage containers	1.2*1.2*4.8	720	720	9,700	SFL 5
Operating waste from CLAB to silo	1.2*1.2*1.2	1,150 2,000	100 500	2,000 3,450	SFR 1 SFL 3
Operating waste from CLAB to rock vault	1.2*1.2*1.2	290	20	500	SFR 1
Waste from Studsvik to silo *)	d=0.6 L=0.9 1.2*1.2*1.2 d=0.6 L=0.9 1.2*1.2*1.2	3,750 690 1,200 660	50 60 75 165	1,200 1,200 400 1,100	SFR 1 SFR 1 SFL 3 SFL 3
Waste from Studsvik to rock vault *)	d=0.6 L=0.9 1.2*1.2*1.2 ISO-cont.	8,750 690 200	150 60 200	2,800 1,200 7,600	SFR 1 SFR 1 SFR 1
Operating waste from encapsulation plant to silo	1.2*1.2*1.2	300	75	500	SFL 3
Operating waste from nuclear power plants to silo	d=0.6 L=0.9 1.2*1.2*1.2	3,375 8,650	50 720	1,100 15,000	SFR 1 SFR 1
Operating waste from nuclear power plants to rock vault	d=0.6 L=0.9 1.2*1.2*1.2 ISO-cont. 3.3*1.3*2.15	18,200 5,770 750 1,100	350 480 750 370	5,900 10,000 28,500 10,200	SFR 1 SFR 1 SFR 1 SFR 1
Decommissioning waste from nuclear power plants to rock cavern	ISO-cont. etc.	4,800	4,800	100,000	SFR 3
Decommissioning waste from Studsvik to rock cavern	ISO-cont.	100	100	3,800	SFR 3
Decommissioning waste from CLAB and encapsulation plant to rock cavern	2.4*2.4*2.4	530	530	7,300	SFL 4
Transport containers		42	42	600	SFL 4
Total approximately		102,000	15,600	227,600	

*) Incl. total about 3.500 m3 of waste within NPP sphere of responsibility

SPENT FUEL AND RADIACTIVE WASTE IN SWEDEN ASSUMING 25 YEARS OF OPERATION OF ALL PLANTS

Waste category	Dimensions of waste units in m, d = diameter (Dimensions before encapsulation for final disposal)	No. of packages	No. of transport units (casks/ containers)	Volume in final repository (m^3)	Final destination
Spent BWR fuel	0.14*0.14 *4.383	27,500	2,620	(included in next row)	
Spent PWR fuel	0.21*0.21*4.103	3,200	940	10,700	SFL 2
Other spent fuel	Various	641	56	(included in row above)	
Core components in storage containers	1.2*1.2*4.8	650	650	(included in next row)	
Reactor internals in storage containers	1.2*1.2*4.8	720	720	9,500	SFL 5
Operating waste from CLAB to silo	1.2*1.2*1.2	930	80	1,600	SFR 1
		1,700	425	2,900	SFL 3
Operating waste from CLAB to rock vault	1.2*1.2*1.2	230	20	400	SFR 1
Waste from Studsvik to silo *)	d=0.6 L=0.9	3,750	50	1,200	SFR 1
	1.2*1.2*1.2	690	60	1,200	SFR 1
	d=0.6 L=0.9	1,200	75	400	SFL 3
	1.2*1.2*1.2	660	165	1,100	SFL 3
Waste from Studsvik to rock vault *)	d=0.6 L=0.9	8,750	150	2,800	SFR 1
	1.2*1.2*1.2	690	60	1,200	SFR 1
	ISO-cont.	200	200	7,600	SFR 1
Operating waste from encapsulation plant to silo	1.2*1.2*1.2	240	60	400	SFL 3
Operating waste from nuclear power plants to silo	d=0.6 L=0.9	2,730	40	900	SFR 1
	1.2*1.2*1.2	6,990	580	12,100	SFR 1
Operating waste from nuclear power plants to rock vault	d=0.6 L=0.9	14,710	280	4,800	SFR 1
	1.2*1.2*1.2	4,660	390	8,100	SFR 1
	ISO-cont.	610	610	23,000	SFR 1
	3.3*1.3*2.15	890	300	8,200	SFR 1
Decommissioning waste from nuclear power plants to rock cavern	ISO-cont. etc.	4,800	4,800	100,000	SFR 3
Decommissioning waste from Studsvik to rock cavern	ISO-cont.	100	100	3,800	SFR 3
Decommissioning waste from CLAB and encapsulation plant to rock cavern	2.4*2.4*2.4	410	410	5,700	SFL 4
Transport containers		42	42	600	SFL 4
Total approximately		88,000	13,900	208,200	

*) Incl. total about 3.500 m3 of waste within NPP sphere of responsibility

SPENT FUEL AND RADIACTIVE WASTE IN SWEDEN ASSUMING 40 YEARS OF OPERATION OF ALL PLANTS

Waste category	Dimensions of waste units in m, d = diameter (Dimensions before encapsulation for final disposal)	No. of packages	No. of transport units (casks/ containers)	Volume in final repository (m³)	Final destination
Spent BWR fuel	0.14*0.14 *4.383	41,600	4,200	(included in next row)	
Spent PWR fuel	0.21*0.21*4.103	5,000	1,560	18,000	SFL 2
Other spent fuel	Various	641	56	(included in row above)	
Core components in storage containers	1.2*1.2*4.8	910	910	(included in next row)	
Reactor internals in storage containers	1.2*1.2*4.8	720	720	11,300	SFL 5
Operating waste from CLAB to silo	1.2*1.2*1.2	1,510 2,140	130 535	2,600 3,690	SFR 1 SFL 3
Operating waste from CLAB to rock vault	1.2*1.2*1.2	380	30	660	SFR 1
Waste from Studsvik to silo *)	d=0.6 L=0.9 1.2*1.2*1.2 d=0.6 L=0.9 1.2*1.2*1.2	3,750 690 1,200 660	50 60 75 165	1,200 1,200 400 1,100	SFR 1 SFR 1 SFL 3 SFL 3
Waste from Studsvik to rock vault *)	d=0.6 L=0.9 1.2*1.2*1.2 ISO-cont.	8,750 690 200	150 60 200	2,800 1,200 7,600	SFR 1 SFR 1 SFR 1
Operating waste from encapsulation plant to silo	1.2*1.2*1.2	400	100	690	SFL 3
Operating waste from nuclear power plants to silo	d=0.6 L=0.9 1.2*1.2*1.2	4,420 11,320	60 940	1,400 19,600	SFR 1 SFR 1
Operating waste from nuclear power plants to rock vault	d=0.6 L=0.9 1.2*1.2*1.2 ISO-cont. 3.3*1.3*2.15	23,830 7,550 980 1,440	460 630 980 480	7,720 13,050 37,310 13,280	SFR 1 SFR 1 SFR 1 SFR 1
Decommissioning waste from nuclear power plants to rock cavern	ISO-cont. etc.	4,800	4,800	100,000	SFR 3
Decommissioning waste from Studsvik to rock cavern	ISO-cont.	100	100	3,800	SFR 3
Decommissioning waste from CLAB and encapsulation plant to rock cavern	2.4*2.4*2.4	590	590	8,100	SFL 4
Transport containers		42	42	600	SFL 4
Total approximately		124,000	17,500	257,300	

*) Incl. total about 3.500 m3 of waste within NPP sphere of responsibility

APPENDIX 2

TRANSPORTATION SYSTEM

Handling of the radioactive waste involves a considerable transport undertaking for moving the waste from the sites of production to final repositories. The spent fuel and the core components also have to be transported to the interim storage facility, CLAB, for about 30 years of storage and then encapsulation. All existing nuclear facilities are located on the coast, permitting sea transport. The site of the final repository for the long–lived waste, SFL, has not yet been decided. In the event of an inland siting of this facility, which is the assumption made in this report, the transportation system will be augmented with a rail link between the SFL and a suitably situated harbour. Existing rail lines will be used to as great an extent as possible.

The transportation system includes transport containers and casks, ship and terminal equipment.

Transport containers holding a number of waste units are used to protect the transport workers and the public against radiation and the load against damage during transport.

The transport cask for spent fuel consists of a cylinder made of thick steel and provided with a neutron–shielding layer and cooling fins on the surface. The ends are protected by shock–absorbers. See Figure A2.1. The cask is designed to resist extreme stresses in accordance with the IAEA's regulations for type B packages. The casks currently being used, TN17/MK2, hold 17 BWR assemblies or 7 PWR assemblies and have a total weight of about 80 tonnes, of which the uranium weight constitutes about 3 tonnes. Similar casks will be used for transport of the encapsulated fuel from the encapsulation plant at CLAB to the deep repository. During transport, the cask is carried on a transport frame, functionally adapted to the terminal vehicle and the ship's cargo hold.

Intermediate–level waste is transported in radiation–shielding containers, called ATB containers. A common type holds about 20 m^3, equivalent to 12 waste concrete moulds with a surface dose rate of up to 60 mSv/h. There are also larger containers with thinner walls for waste packages with a lower surface dose rate.

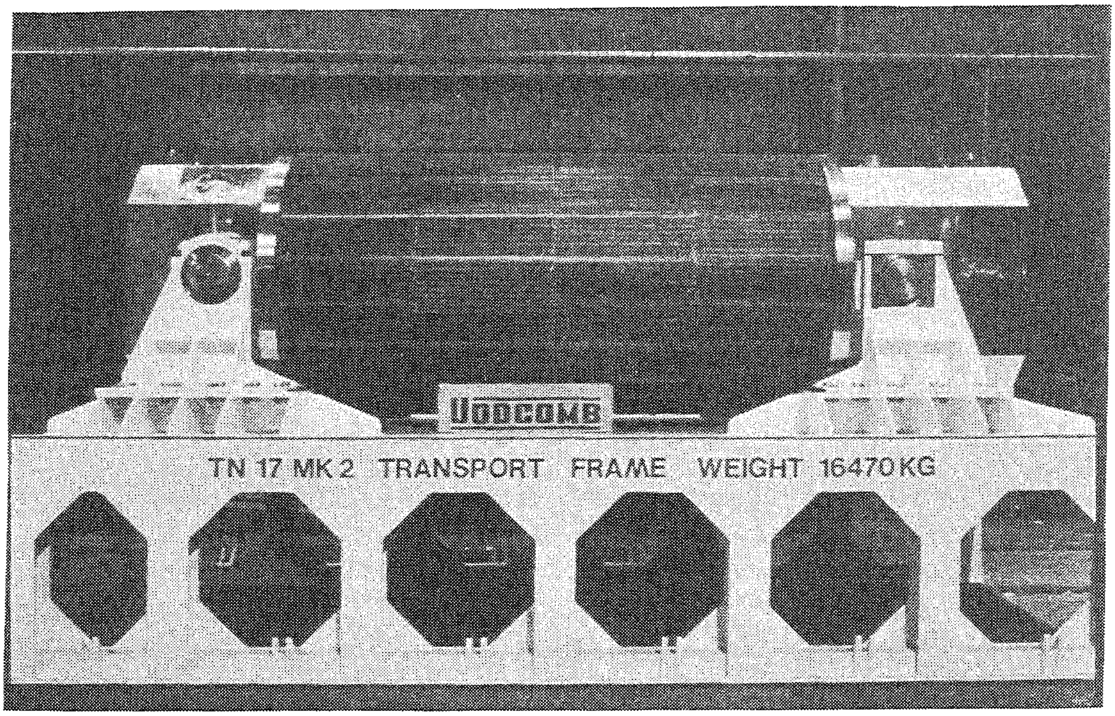


Figure A2.1 Model of TN17/Mk 2 transport cask for spent nuclear fuel.

The transport frame of the container has a design similar to that of the frame for the spent fuel cask, permitting uniform handling, see Figure A2.2. The total weight is max 120 tonnes, of which the waste accounts for about 50 tonnes. Low–level waste from reactor operation and decommissioning is transported in standard ISO containers, which are deposited in the final repository.

Figure A2.2 also illustrates the terminal vehicles. The vehicle consists of a 7–axle unit with separate drive on each wheel pair. The bed can be raised and lowered hydraulically, which is utilized to pick up and off–load the cargo. The vehicle's ground speed is low, less than 5 km/h, and it is therefore only used for short hauls.

The sea transports are carried out primarily by a specially–built ship, M/S Sigyn, see Figure A2.3. The ship is a combined roll–on/ roll–off and lift–on/lift–off vessel, which means that the cargo can either be driven in over the ramp or lifted down through the cargo hatches into the cargo hold. The ship has a deadweight tonnage of 2 000 tonnes and an overall length of about 90 m. Payload capacity is 1 400 tonnes. The transport casks are placed in fixed positions in the hold and the transport frames are bolted to the vessel. Corner and side fittings welded to the deck prevent shifting of the cargo.

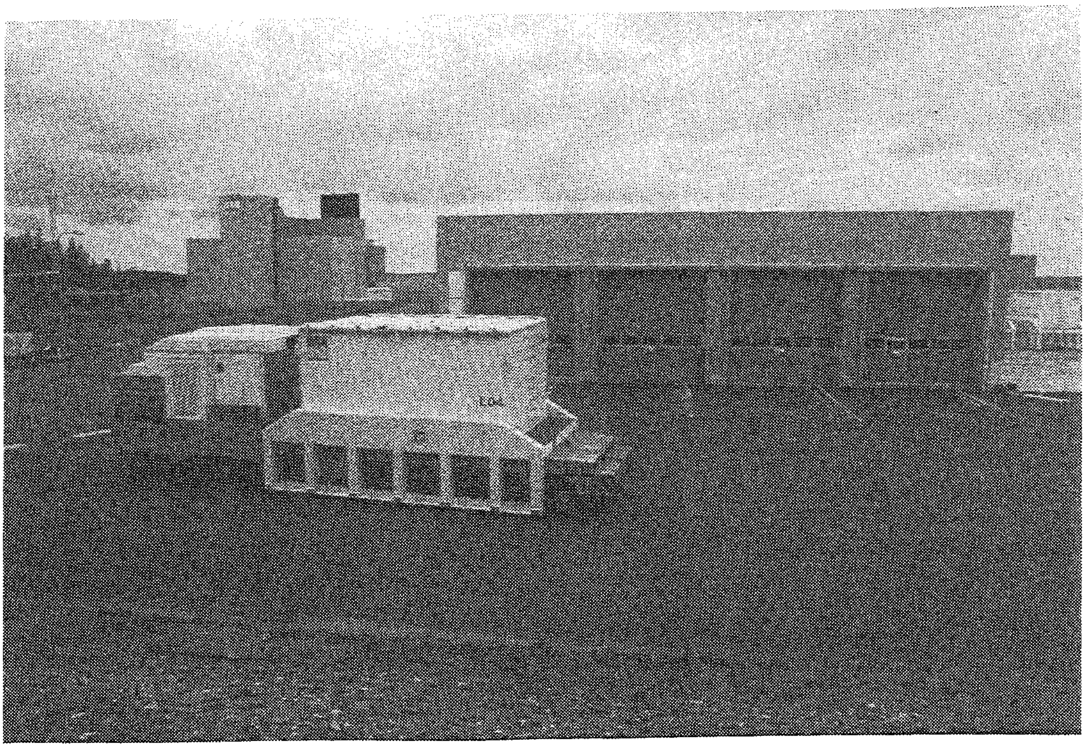


Figure A2.2 Terminal vehicle at SFR with radiation–shielded transport container for intermediate–level waste.

The ship is equipped with extensive safety systems for radiation and fire protection and, in the event of an accident, systems to facilitate search and salvage.

The transportation system, which has been in service since 1983, has transported 57 tonnes of fuel to France and 1,650 tonnes to CLAB up to January 1993. Approximately 11,000 m^3 low and intermediate level waste from reactor operation has been transported to SFR.

The transport system will be in operation until the last of the decommissioning waste from CLAB has been transported to the deep repository. This is assumed to occur about year 2040. Owing to the length of the operating period, about 60 years, it is assumed that the ship will have to be replaced twice.

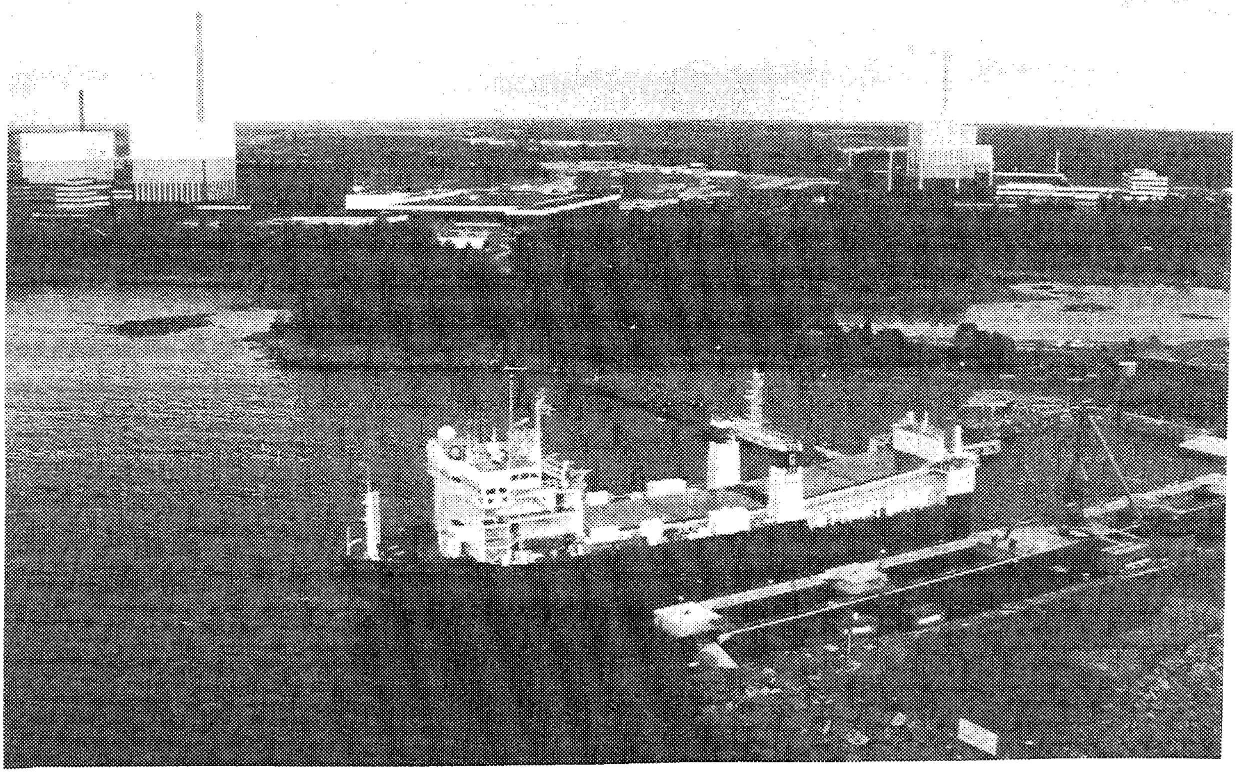


Figure A2.3 M/S Sigyn at the Oskarshamn harbour.

APPENDIX 3

CENTRAL INTERIM STORAGE FACILITY FOR SPENT NUCLEAR FUEL, CLAB

DESIGN

CLAB, situated at the Oskarshamn nuclear power station, is an interim storage facility for spent nuclear fuel. The purpose of the facility is to provide efficient means of storing all spent fuel discharged from the Swedish nuclear power plants pending encapsulation and final disposal.

In addition to the spent fuel, certain replacement items (core components) and decommissioning products that have been activated during reactor operation will be stored in CLAB pending future final disposal.

CLAB consists of an above-ground complex and an underground complex housing the storage pools, see Figure A3.1.

The facility is being built in two phases. Phase 1 was taken into operation in 1985 and encompasses the above-ground complex plus a rock cavern with storage pools originally designed for approximately 3 000 tonnes of uranium. By the introduction of a new type of storage canister, the capacity has increased to approximately 5 000 tonnes from 1992.

In phase 2, the storage section will be expanded to full capacity. This will take place in the late 1990s. In this report, it is assumed that phase 2 will be implemented by construction of a rock cavern parallel to the existing one. For the alternative considering reactor operation up to and including the year 2010, the cost calculations are based on an expansion by three storage pools for spent fuel and one pool for core components and decommissioning products. The latter products are stored in the same way as the fuel but in two layers.

The above-ground complex consists of several interconnected buildings, see Figure A3.1. In terms of function, the buildings can be divided into a reception building, an auxiliary systems building and an electrical building. The reception building mainly houses the equipment required to unload and load the transport casks in connection with reception and dispatch of fuel and core components.

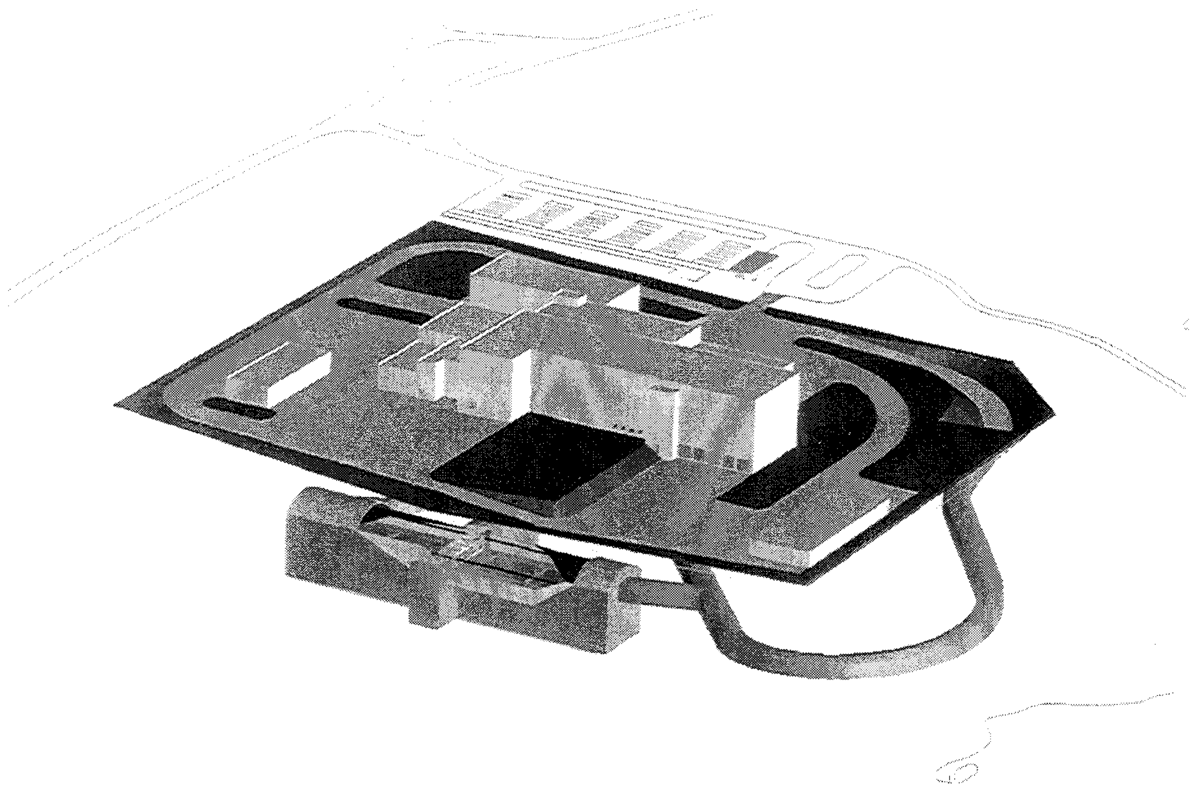


Figure A3.1 CLAB Phase 1

All handling of fuel in the reception building, as in the rest of the facility, is done in water–filled pools, which provide good cooling and effective radiation protection for the personnel. The pool block in the reception building contains seven pools, four of which are used for the two unloading lines and the others for temporary storage and for certain other requirements, for example in connection with the receipt of non–standard transport (other than TN17) casks and in connection with service.

Connected directly to the reception building is a building that houses auxiliary systems for cooling and water purification, waste handling, ventilation etc. The electrical building houses the operations centre as well as all equipment for power supply, control and monitoring of the facility. Separate passages lead to these buildings from a free–standing office and personnel building.

The storage section consists of rock caverns whose roofs are located about 30 m below the surface. They are reinforced with rock bolts and lined partly with concrete. The rock cavern in the first phase is 120 m long, 21 m wide and 27 m high. It contains four storage pools, each with 300 storage positions for the transportable storage modules (canisters) plus a smaller central pool connected to an elevator shaft via a transport channel. The pools are made of reinforced concrete and lined with stainless steel.

The second building phase will comprise a rock chamber parallel to the existing one. The basic design will be the same. One pool will be reserved for core components, see Figure A3.2.

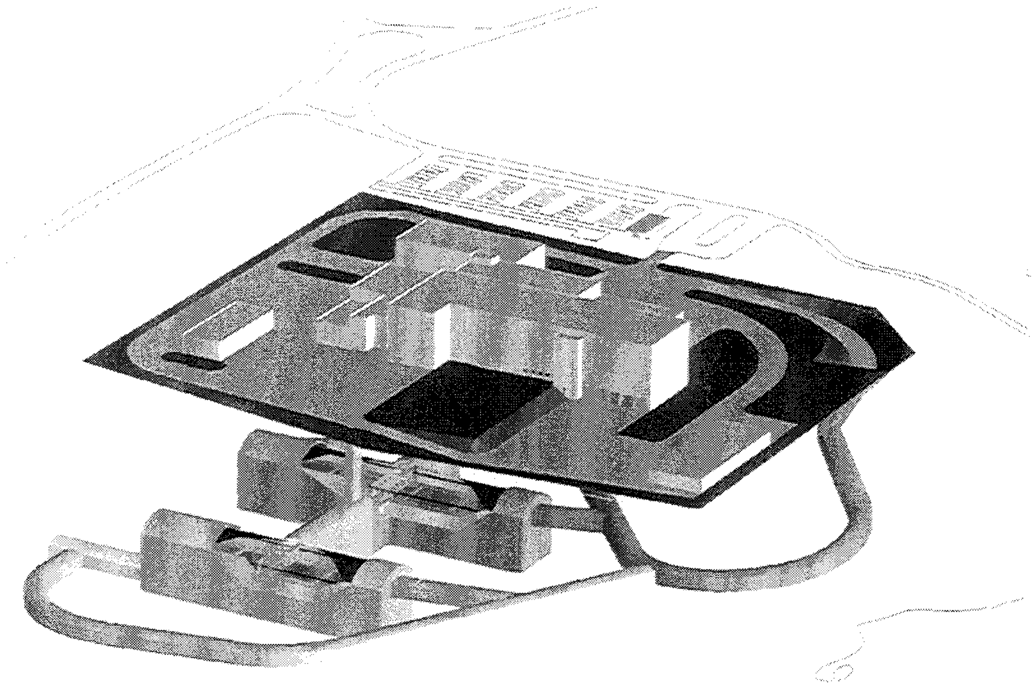


Figure A3.2 CLAB Storage Caverns, Phases 1 and 2

OPERATION

When a fuel transport arrives at CLAB, the transport vehicle with the cask is driven into the air lock underneath the reception hall floor. The cask is inspected, and after removal of the shock absorbers it is coupled to one of the main overhead cranes by means of a lifting frame. The cask is raised upright and lifted through the hatch in the roof of the air lock for transfer to one of the cooling cells.

The cask is provided with a protective skirt in order to protect the cooling fins against mechanical damage and contamination during the subsequent reception work. The annular space between the cask and the skirt is filled with water, which is circulated via hoses connected to a separate skirt cooling circuit in the cooling system, see Figure A3.3.

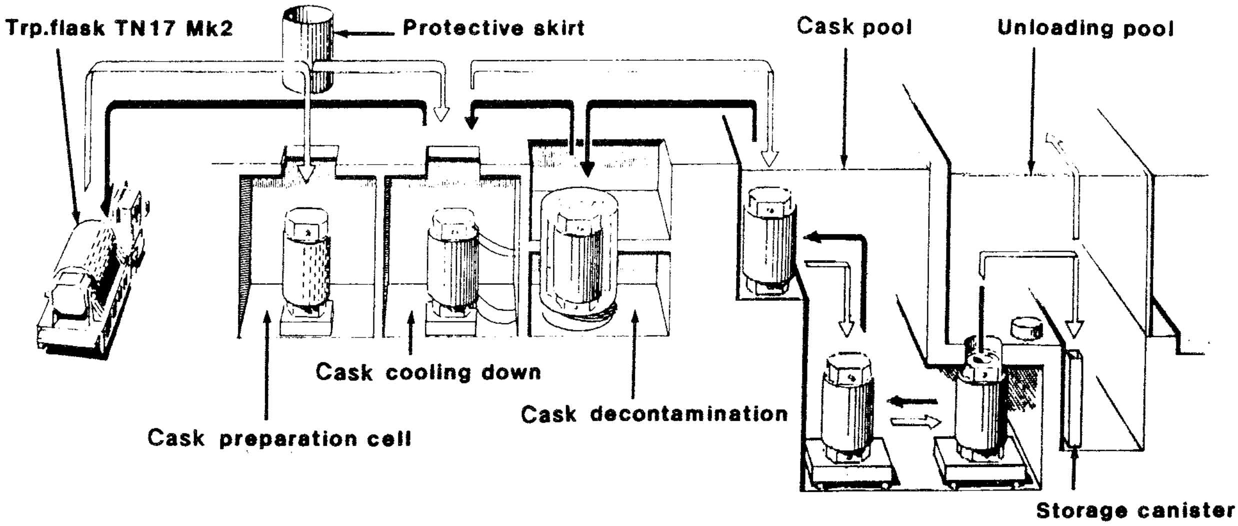


Figure A3.3 Handling of fuel casks and unloading at CLAB

The top and bottom orifices in the cask are fitted with special tools by means of which the sealing plugs can be unscrewed. The tools are fitted with hoses which are also connected to the cooling system. Through the circuit that is established, the cask can be filled with water and cooled to a low temperature. The circulating water also flushes out the cask, thereby reducing the quantity of loose active particles in the cask. The particles are collected on a filter in the cooling system, which is back–flushed as needed to a replaceable filter cartridge.

The outer cover on the cask and the circular flange that locks the cask cover are removed. Adapters for connecting the cask to the unloading pool are fitted to the top of the cask and to the cask cover.

The cask is now ready for transport to the cask pool, where it is lowered and placed on a transport wagon that runs on rails in the bottom of the pool. The wagon takes the cask into a channel that leads in under the unloading pool. In the roof of the channel is a connection device that is lowered down onto the cask. The purpose of the connection device is to keep the uncontaminated water in the cask pool separated from the water in the unloading pool.

The cask is opened by a pole crane, which lifts up the cask cover and the sealing plug in the connection device as a single unit. The pole crane travels on an overhead track that rests on columns along the pool.

The pole crane is provided with a grab for the fuel assemblies, which are then lifted up out of the cask, one by one, and transferred to the fuel canister.

From here on, the canister constitutes a transport unit for the continued handling.

Several types of canisters are used in the facility to cover the various storage needs. A canister for BWR fuel holds 16 fuel assemblies, while a PWR canister holds five. From 1992 new canisters are introduced that are able to take 25 BWR fuel assemblies or 9 PWR fuel assemblies, see Figure A3.4.

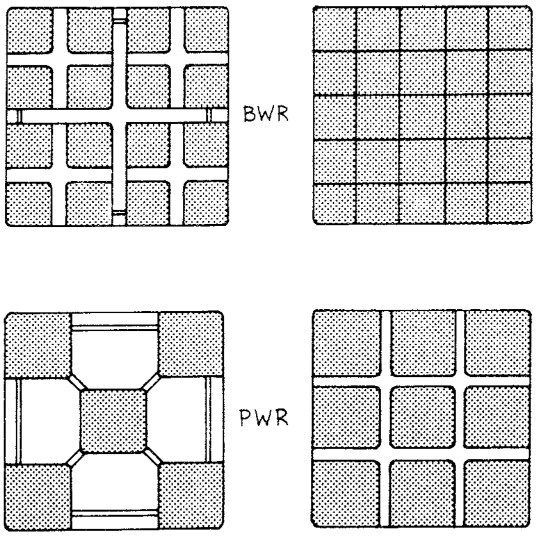


Figure A3.4 Design of the old and new canisters at CLAB.

Another pole crane whose working range covers all pools in the reception section is used to transport canisters from the unloading pool to the fuel elevator. The canisters are taken in the elevator down to the storage section.

In the storage section, the canister is transferred from the elevator to its storage position by an overhead handling crane. The empty casks are transported back to the same cooling cell where they were previously cooled. The water in the cask is drained, and after the removed cask components are reinserted, a final inspection is carried out of the integrity of the casks before they are removed from the facility.

The permanent personnel force during operation is about 50 persons. In addition, service personnel are currently being utilized mainly from OKG's regular operating organization. On average, they are equivalent to about 60 full-time employees. During periods when no loading-in or loading-out is taking place, the work force can be reduced.

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

APPENDIX 4

ENCAPSULATION PLANT FOR SPENT FUEL, EP

In the encapsulation plant, Figure A4.1, the spent fuel coming from CLAB will be received and encapsulated in canisters for the purpose of final disposal. The plant layout is designed for an encapsulation flow of one canister per day, equivalent to 210 canisters a year. The total operating time over the life-time of the plant is, however, somewhat conservatively calculated considering an average annual flow of only 200 canisters. This reduction is intended to cover possible disturbances such as transport interruptions during the winter season. The plant is operated on a one shift basis. The total number of copper canisters will amount to about 4 500.

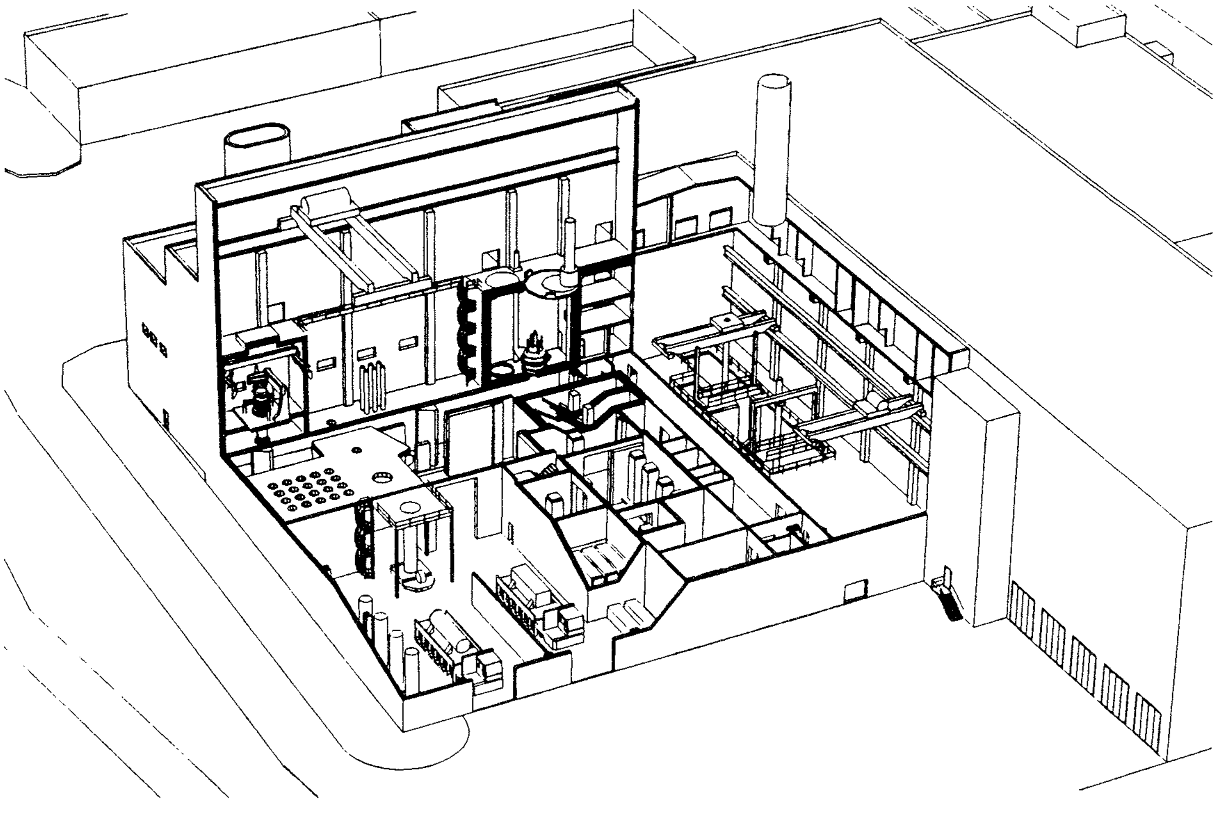


Figure A4.1 The encapsulation plant

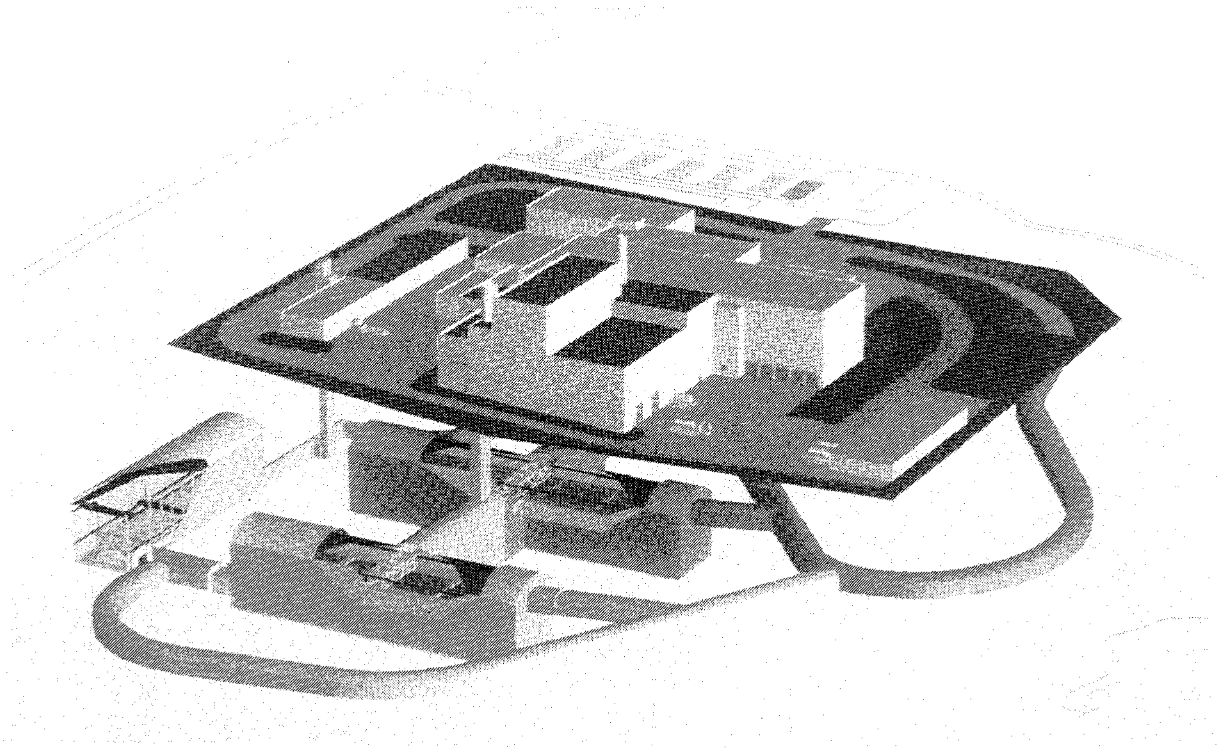


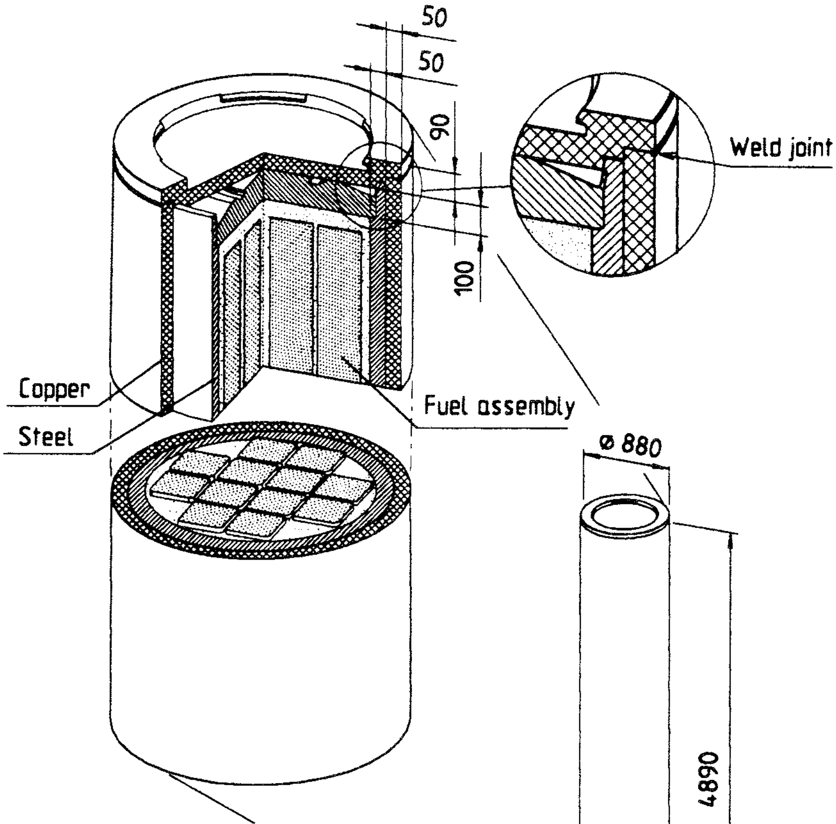
Figure A4.2 CLAB and the encapsulation plant

Figure A4.2 shows the complete CLAB site encompassing CLAB, with its two storage caverns, and the encapsulation plant. A possible rock cavern for storage of about 400 canisters, associated with the encapsulation plant, is also illustrated. See also the site layout, Drawing 4.1.

The SKB RD&D–Programme of 1992 suggests a new reference canister. This canister will be made up of an outer copper canister for corrosion protection and an inner steel canister providing adequate strength to resist the high pressure prevailing at the deposition depth. The copper canister has an outer diameter of 880 mm and a length of about 5 m. Both the copper and the steel walls are 50 mm thick. Details of a copper canister loaded with BWR–elements are shown in Figure A4.3.

The canister can hold a maximum of 12 BWR–elements or 4 PWR–elements. However, the residual heat effect per canister in this study is limited to 1210 W in order not to exceed a temperature of 80 °C in the bentonite. This will limit the number of elements on an average basis to 9 or 10 BWR elements or 3 PWR elements, depending on the burn–up and the decay time of the fuel at disposal.

The encapsulation plant will also receive core components and reactor internals for embedding in concrete moulds, an operation that will take place in a special part of the facility. The concrete mould is illustrated in Figure A4.4.



Canister surface (m^2)	14.65
Remaining internal void (m^3)	1.22
Estimated weight (kg)	
Copper canister	6160
Steel canister	4800
Canister weight	10960
Fuel assemblies	3640
Filling	1800
Total	16400

Figure A4.3 Canister with BWR–elements

The particular layout of the encapsulation plant that has been used as a basis for cost calculations in this report is shown on Drawings 4.2 to 4.8 and in Figure A4.1 above. During the next few years the design will be studied in more detail, whereafter the final layout will be decided. The total building volume is at present estimated at 108 400 m^3. The maximum length of the building is about 80 m and the height about 32 m. In order to meet demands on radiation shielding and ventilation tightness, the building is mainly made of cast–in–place concrete.

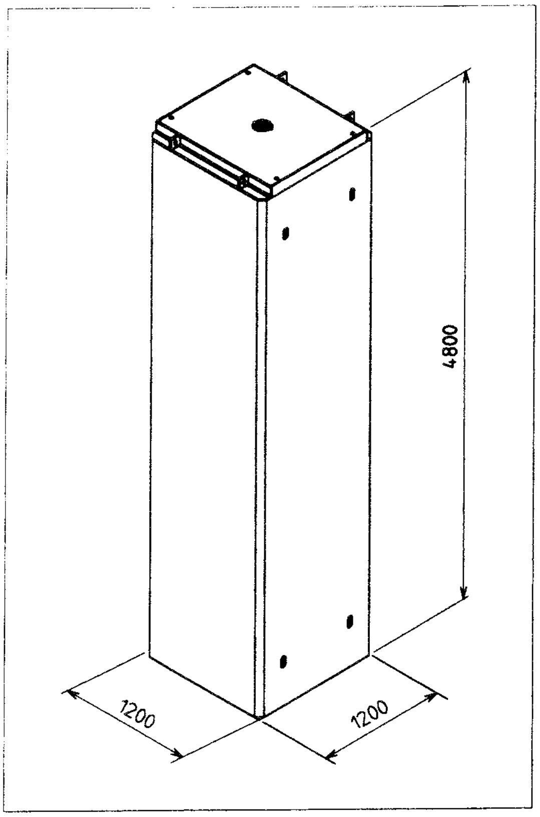


Figure A4.4 Concrete mould with core components.

The encapsulation plant is planned to include the following functions:

- Arrival section for fuel and core components in storage canisters
- Encapsulation section for filling and sealing of canisters and for quality verification
- Section for handling and embedding in concrete of core components and reactor internals
- Dispatch section for canisters and concrete moulds. Transportation will be made in radiation shielding casks
- Auxiliary systems with cooling and purification systems as well as electrical and control equipment
- Personnel and office premises

A key plan of the encapsulation plant, giving the principle layout, is shown in Figure A4.5. Encapsulation of fuel takes place in functional areas 1–5. For the embedment of core components and reactor internals functional areas 1 and 6–8 will be used. In functional area 9, canisters and moulds will be loaded into transport casks before transportation to the deep repository. The transport cask for long moulds with core components (1.2x1.2x4.4 m) will also be used for standard moulds (1.2x1.2x1.2 m) and barrels from Studsvik for transport to the deep repository.

The encapsulation plant will be built in two stages. The first stage will include all systems needed for encapsulation of spent fuel. In the second stage, after an evaluation of the first stage, the encapsulation plant will be completed for handling of core components and reactor internals.

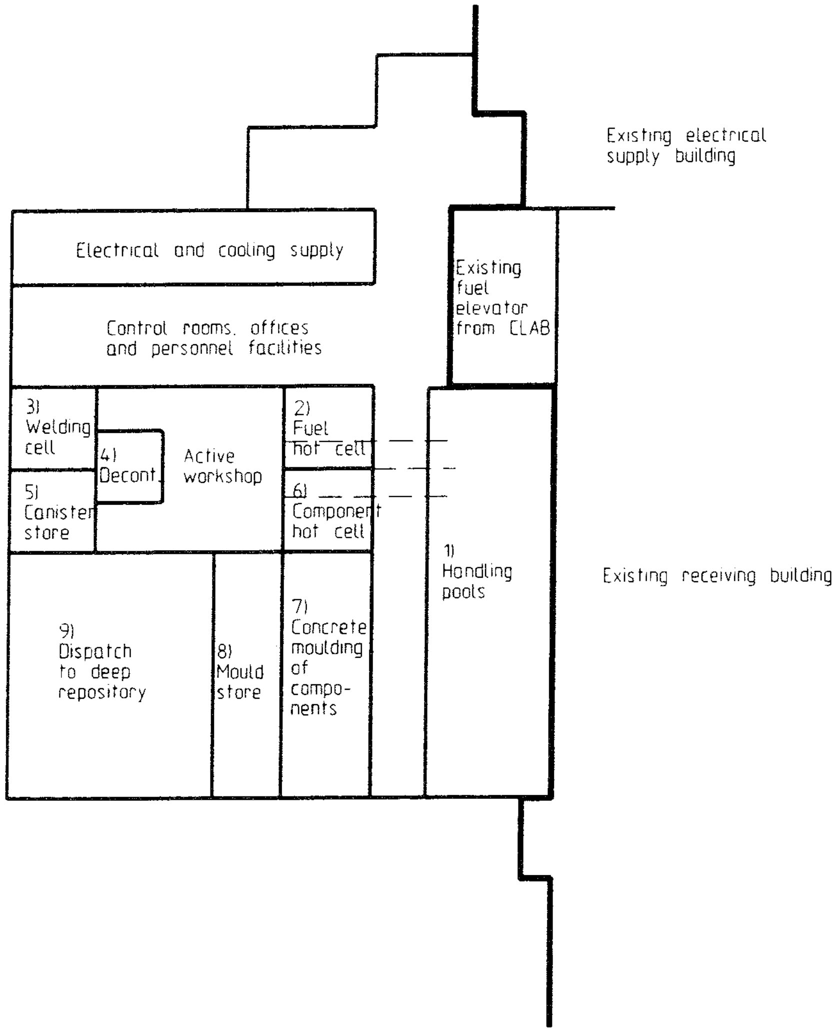


Figure A4.5 Key plan of the encapsulation plant

The following section describes the encapsulation of spent fuel. The position numbers refer to Figure A4.5 above.

Position 1, Pool for fuel handling. The handling pool is connected to the fuel elevator in CLAB. In this pool certain checking activities will be performed and it will also be possible to mix fuel with different residual heat outputs before the storage canister is transferred to the encapsulation area.

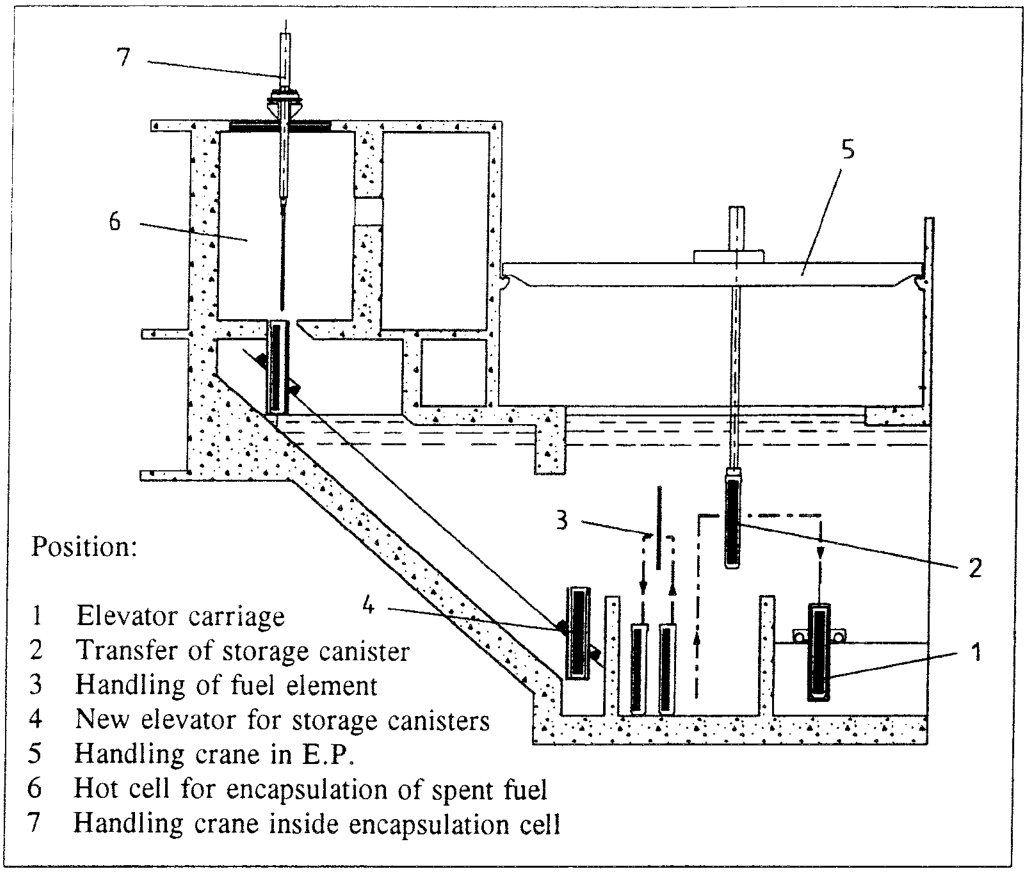


Figure A4.6 Handling pool and connection of a storage canister to the hot cell.

Position 2, Hot cell for fuel encapsulation. The canister is placed in a radiation shield with a built–in lifting device and is moved by an air cushion transport vehicle to the correct position underneath the hot cell. The canister is connected to the cell by the built–in lifting device. Figure A4.7 shows a copper canister placed inside the radiation shield on a transport vehicle.

The encapsulation cell is shown in Figure A4.8. The encapsulation procedure starts by the removal of the steel lid from the canister using a manipulator inside the docking unit. The docking unit is thereafter moved aside and the transfer of fuel from the storage canister to the copper canister is carried out. This is done by means of manipulators controlled from outside the cell.

When the canister has been filled with the predetermined number of fuel elements, a safeguard checking of the fuel in the canister is made. The number of fuel elements that can be placed in a certain canister will be determined by the actual residual heat output of the fuel elements.

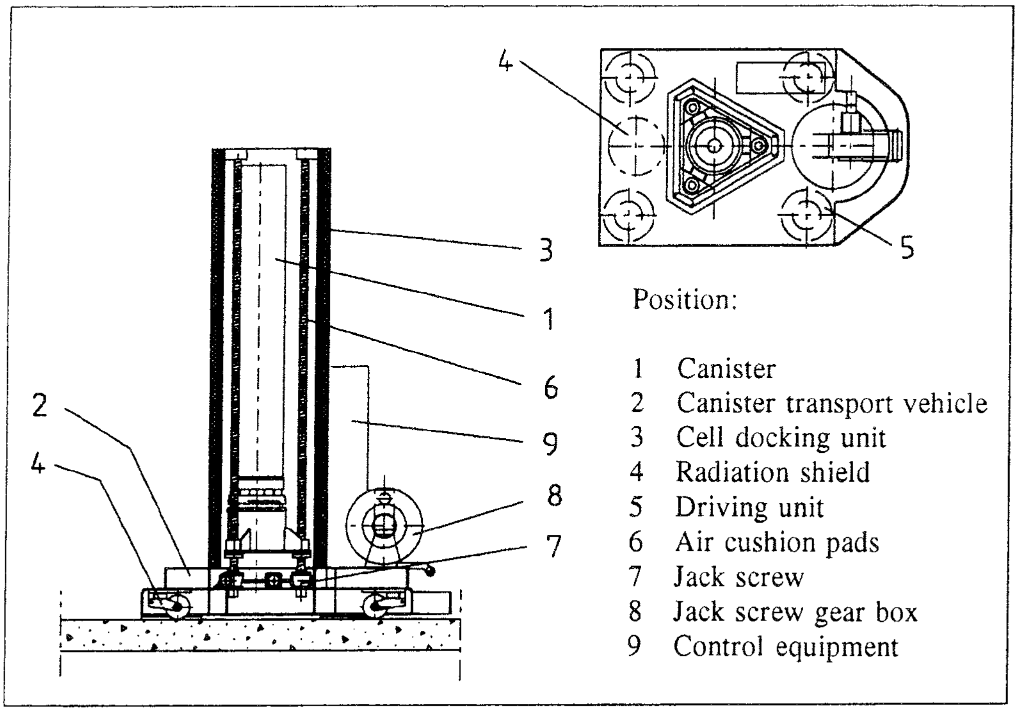


Figure A4.7 Copper canister with its radiation shield

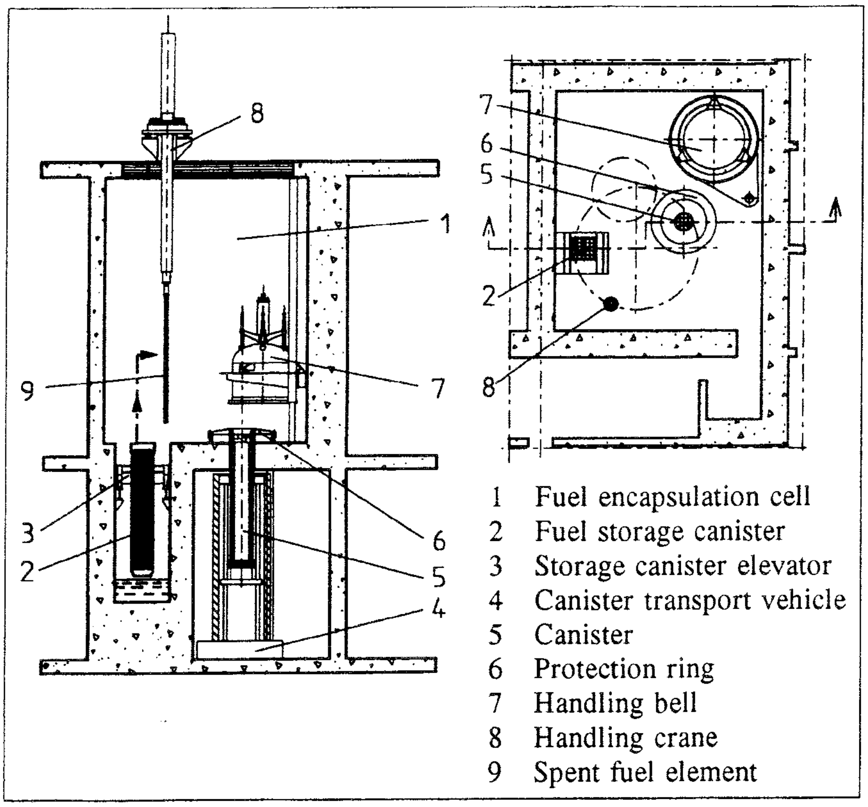


Figure A4.8 Hot cell for encapsulation of spent fuel

The docking unit is thereafter repositioned above the canister and the inside of the canister dried by vacuum. The drying process is possibly completed by filling the canister with boron glass granulate and with inert gas, e.g. helium. The steel lid of the canister can now be sealed, for example by rolling. Thereafter the canister is ready to be transferred to the welding station where the copper lid is welded on. After the canister has been lowered back into its radiation shield it is transported to the welding and machining station.

Position 3, Welding and machining station. This cell is equipped with an electron beam welding equipment plus equipment for inspection of the welded joint, e.g. based on ultrasonics. In case of a defect welding, the work station is equipped with facilities to make it possible to remove the copper lid, if required, and prepare for a new welded joint.

The layout of the welding and machining station is shown in Figure A4.9. The canister is lifted into the welding cell with the lifting device installed inside the radiation shield.

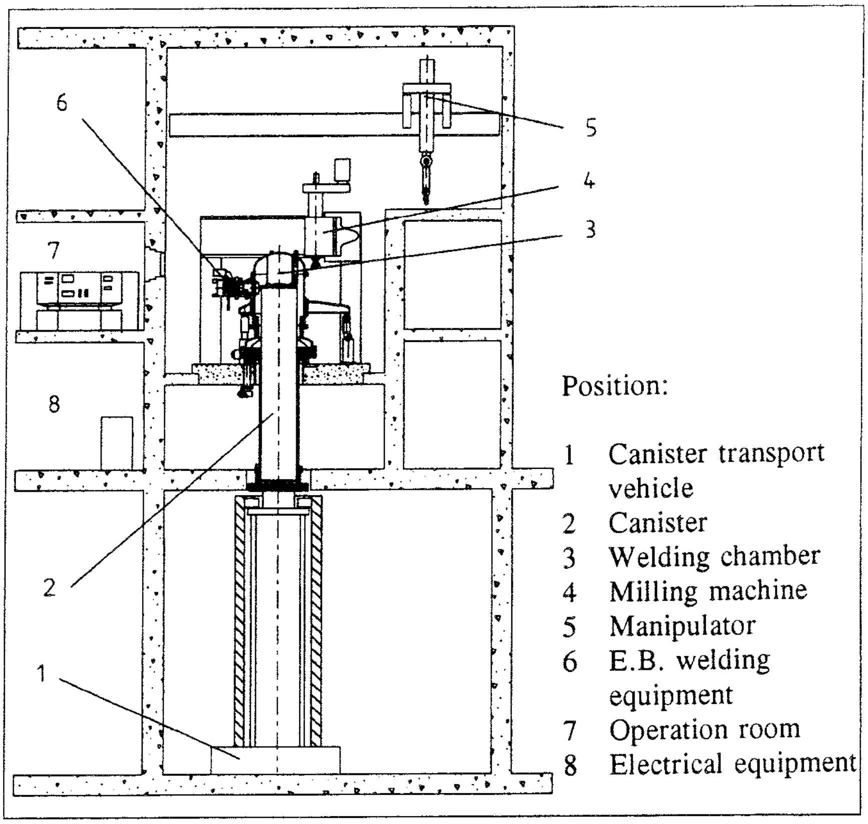
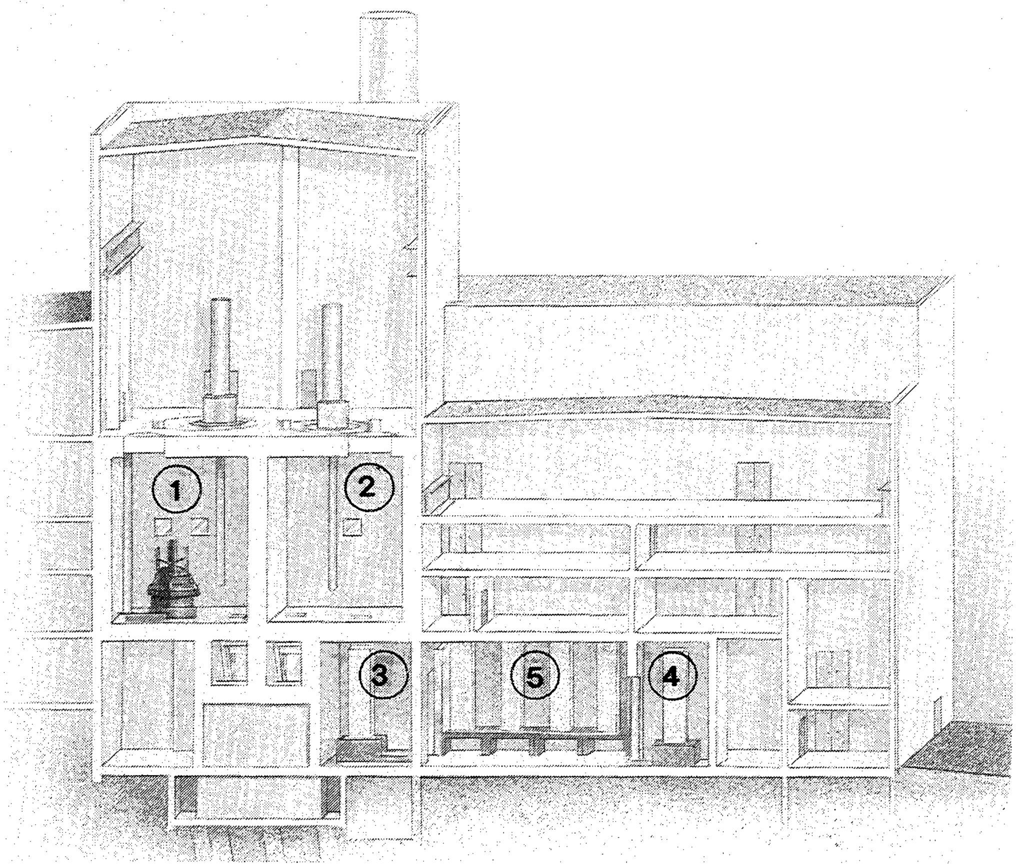


Figure A4.9 Welding and machining cell

After the welding of the lid is finished, an ultrasonic inspection of the welded joint is carried out in order to find any defects. If a weld defect should be detected, normally that area can be rewelded without any additional machining work. It should also be possible, if so required, to remove the entire lid by means of the machining equipment and then reweld with a new lid.

The finished canister is moved from the welding and machining station to the dispatch section. Here the process starts with a contamination check–up and, if necessary, a cleaning of the outside of the canister, **position 4**. Thereafter the canister is placed in an interim storage, **position 5**, or in a transport cask for transport to the deep repository, **position 9**.

Position 6, Core components and reactor internals. The core components and reactor internals will be brought from the storage pools in CLAB in the same way as the spent fuel. The empty concrete mould, with a well trimmed lid and with a docking collar, is connected to the hot cell for core components in the same way as the fuel canister. In this cell preparations have been made for a future connection of copper canisters, in case an increase in the capacity of the plant should be desired.



1. Encapsulation cell for spent fuel
2. Encapsulation cell for spent fuel and core components
3. Position for filling of the mould
4. Position for concrete injection of the mould
5. Position for curing of the concrete

Figure A4.10 Handling and concrete embedment of core components and reactor internals

The concrete mould is filled with core components from the storage canisters. When the mould has been filled, the lid is put on, which is done from inside the hot cell. Thereafter the mould is transferred to the concrete filling position outside the cell. Injection of concrete into the mould starts after the lid of the mould has been bolted on. After curing, a contamination check of the mould surface is carried out and the mould is transferred to the storage area.

The layout of the hot cell for handling of core components and reactor internals is shown in Figure A4.10. When the mould is transferred between work stations it is placed inside a radiation shield and the whole unit is moved with a transport vehicle in the same way as the copper canisters.

APPENDIX 5

DEEP REPOSITORY FOR LONG-LIVED WASTE, SFL

GENERAL

The spent nuclear fuel and other long-lived radioactive waste will be finally disposed of in repositories located in the bedrock at the depth of approximately 500 m below the ground surface. Two types of repositories are planned, intended for different types of waste.

Deep repository for encapsulated fuel:

- SFL 2, for encapsulated spent fuel. The repository consists of tunnels where the waste is deposited in holes drilled in the tunnel floor. SFL 2 will be built in a first stage for 5-10 % of the fuel and then later for the total amount of spent fuel.

Deep repository for other long-lived wastes embedded in concrete:

- SFL 3, for operational waste from CLAB and EP and long-lived intermediate- and low-level waste from CLAB and Studsvik. The repository consists of concrete troughs, with a cell structure, placed in a rock cavern.

- SFL 4, for decommissioning waste, mainly from CLAB and EP. The repository area is the tunnels and other empty spaces which remain after the deposition in SFL 3 and SFL 5 is concluded.

- SFL 5, for core components and reactor internals embedded in concrete moulds. The repository consists of tunnels in which the moulds are stacked and embedded in concrete.

The SKB RD&D Programme from 1992 suggests that the deep repository will be built in two stages. In the first stage 5-10 % of the total amount of spent fuel will be deposited. The outcome of this stage will be evaluated before a descision is taken to expand the facility to full-scale.

Prior to deposition in the repository, the spent fuel will be encapsulated in copper canisters. This will take place in the encapsulation plant, EP, situated at CLAB.

The industrial area on ground level above the repository includes a number of buildings and service functions. The extent of these services will depend on local circumstances and the final design of certain functions, e.g the communication with the repository area, which can be accomplished by means solely of shafts or by a combination of shaft and ramp.

The deep repository for fuel, SFL 2, will be located approximately 500 m below the ground surface. The other repositories, SFL 3–5, will be located at the same level but at a distance of approximately 1 km from SFL 2. These other repositories are reached via the same shafts, or ramp, as SFL 2 and then by a separate tunnel.

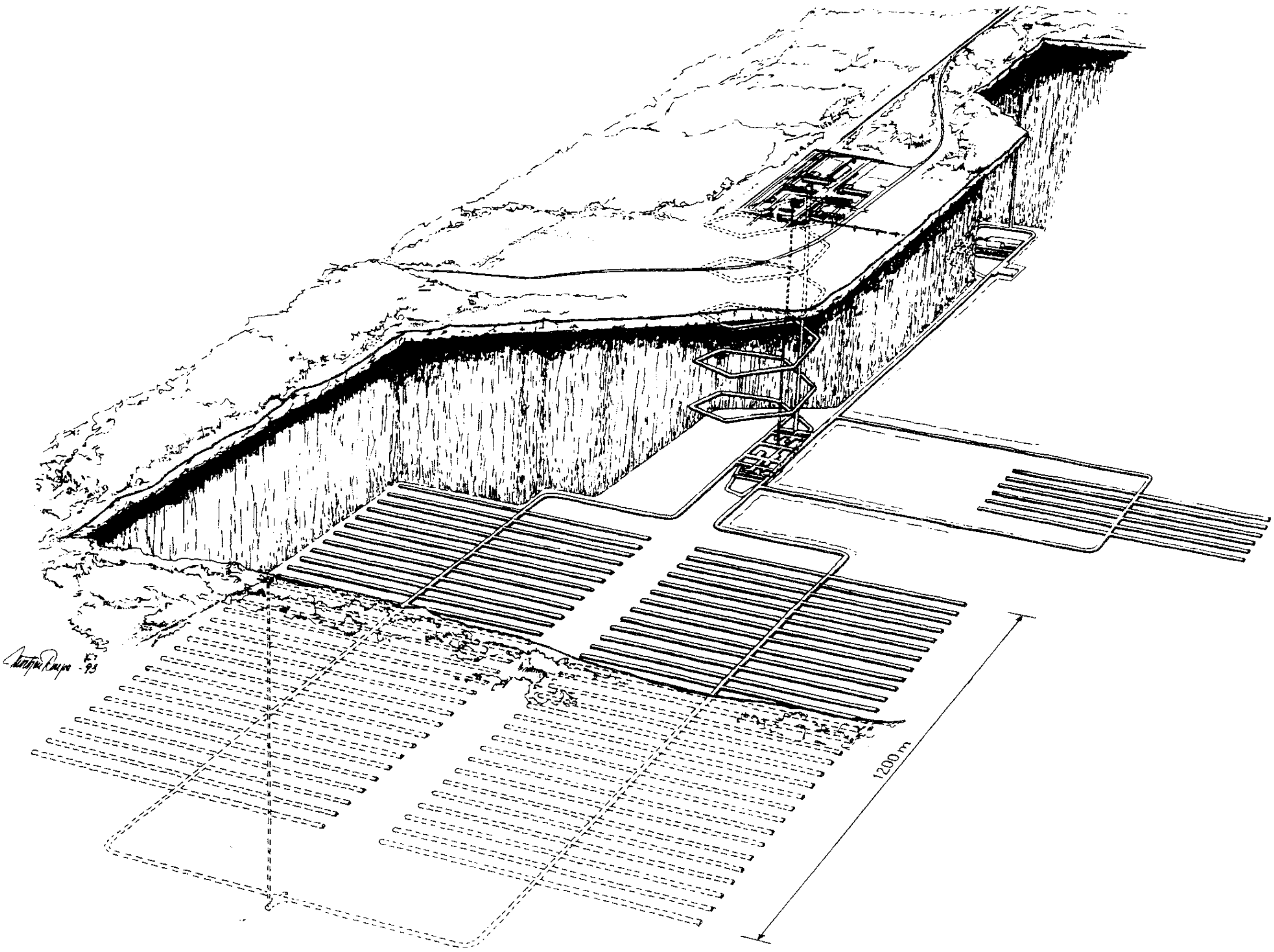


Figure A5.1 Deep repository – an overview.

ABOVE-GROUND FACILITIES

Encapsulated fuel and other waste coming from CLAB, EP and Studsvik is transported by ship to the nearest available harbour that can be considered suitable for this type of transport after certain improvements of the access channel and the harbour facilities. The waste is transported from the harbour in its containers by rail to the deep repository. It is assumed that 50 km of new railway will have to be built. In addition, rolling stock will have to be acquired, i.e. locomotives and specially-designed wagons, for transportation of waste casks or containers and sand and bentonite.

The layout of the industrial area is illustrated by Drawing 5.1 and Figure A5.2 below. In this report it is assumed that the industrial area includes the following facilities:

- Entrance building with offices and workshops
- Information building with canteen
- Personnel building including separate locker rooms for different staff categories
- Stores and garages
- Operation building for the reception of waste, housing elevators down to the repository area.
- Ventilation building
- Stores for sand and bentonite
- Facility for the high-pressure compaction of bentonite
- Service building for water supply, sewerage, heating etc.

Facilities for handling of the backfilling materials and bentonite provide the following functions. Bentonite granulate will be stored indoors (in a silo), along with the sand that, mixed with bentonite, will be used as backfill in tunnels and rock caverns. The storage capacity at the repository for these materials corresponds with the chosen transport capacity. Additional storage facilities at the harbour are foreseen, which should be designed considering ship unloading requirements.

Some of the bentonite is compacted in a high-pressure press and moulded into blocks. These blocks are used for filling the deposition hole around the copper canister or for other purposes, e.g. plugging of tunnels and shafts. The rest of the bentonite is used in the sand/bentonite mixture (85/15) as backfill. The mixing is done above ground. The material is then filled in containers and taken down to repository level by elevator via the central shaft.

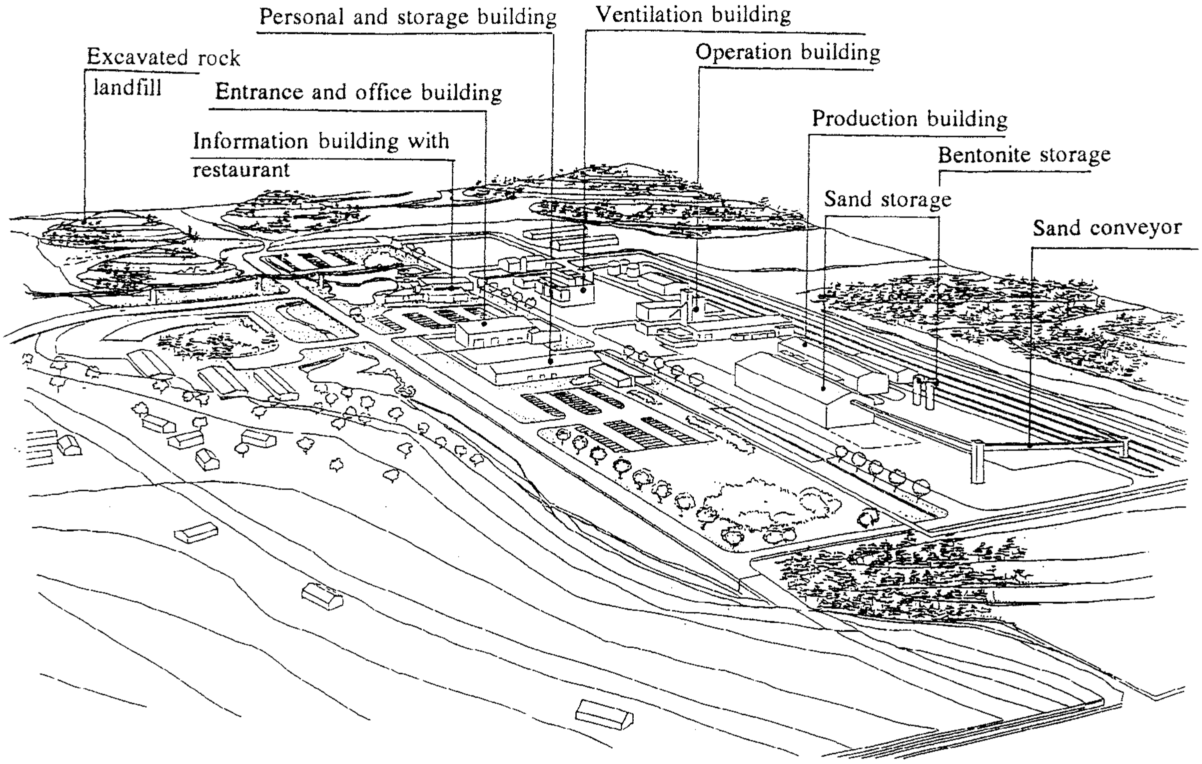


Figure A5.2 Deep repository – industrial area

After completed deposition, all facilities will be dismantled and the site will be restored as close to the original state as possible. Radioactive decommissioning waste from CLAB and EP will be placed in SFL 4. All activities are estimated to be concluded by the year 2047.

DEEP REPOSITORY FOR SPENT FUEL

The repository consists basically of a system of parallel deposition tunnels, each with a length of about 250 m, with a spacing of 40 m and a total length of about 30 km. These tunnels together with appurtenant transport tunnels, service areas and shafts to the ground surface, are occupying a total horizontal area of about 1 km^2. SFL 3–5 are located outside this area as a certain distance between the two types of repositories is required. The total area needed is determined primarily by the heat generation of the deposited fuel. The layout is shown on Drawings 5.1 and 5.2. for the shaft and ramp alternatives respectively. The copper canisters are deposited in vertical holes drilled in the bottom of the deposition tunnels, a total of about 4 400 holes, of which 400 in the first stage.

The deep repository for encapsulated fuel consists of a central area with service facilities and deposition areas. The central area is designed to conform with the new premises regarding transportation of waste containers down to the repository area. The actual locations of the deposition areas will be affected by local conditions but will consist of three separated areas. Compared with previous studies, the repository includes an additional area for deposition of 5–10% of the spent fuel, to be deposited during the first stage.

The repository is divided into two parts to permit a simple physical separation of the deposition work from the excavation work. The deposition tunnels will be excavated as deposition proceeds. It should be pointed out that the division of the repository, as it is shown on the drawings, is only schematic. In practice, the configuration of the repository will be adapted to the joint zones of the rock. In order to determine these zones, extensive exploratory drilling will be carried out.

In the shaft alternative, the central area is connected to the ground surface via three shafts:

- The skip shaft, provided with rock hoisting equipment. The skip shaft is the first shaft to be excavated and, accordingly, a sunk shaft. This shaft will be fully equipped already during the detailed investigation phase.

- The ventilation shaft for inlet air, also in operation during the detailed investigation phase.

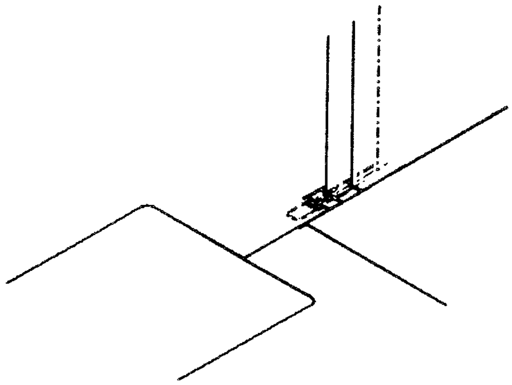
- The central shaft, comprising the main entrance to the repository for both personnel and materials via two elevators. The repository is supplied with water, electricity, etc., via this shaft.

In the ramp alternative, illustrated in Figure A5.3, some of the transports will be carried out via the ramp, e.g. haulage of excavated rock.

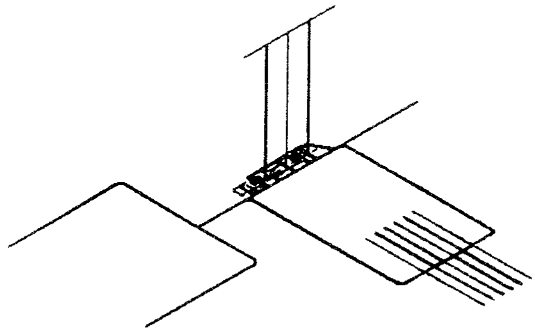
At the far end of the repository there is an outlet air shaft, which in an emergency situation can be used for evacuation of personnel.

The deep repository will be constructed in three stages, see Figure A5.3 which also presents information about excavated rock volumes. Stage 1 concerns the detailed investigation phase. During this stage, geological investigations will be carried out at the repository level. The skip shaft, alternatively ramp, and the ventilation shaft will be excavated and equipped. Stage 2 concerns the establishing of the first deposition area. Stage 3 concerns the remaining deposition areas and the construction of the repository for other waste, SFL 3–5.

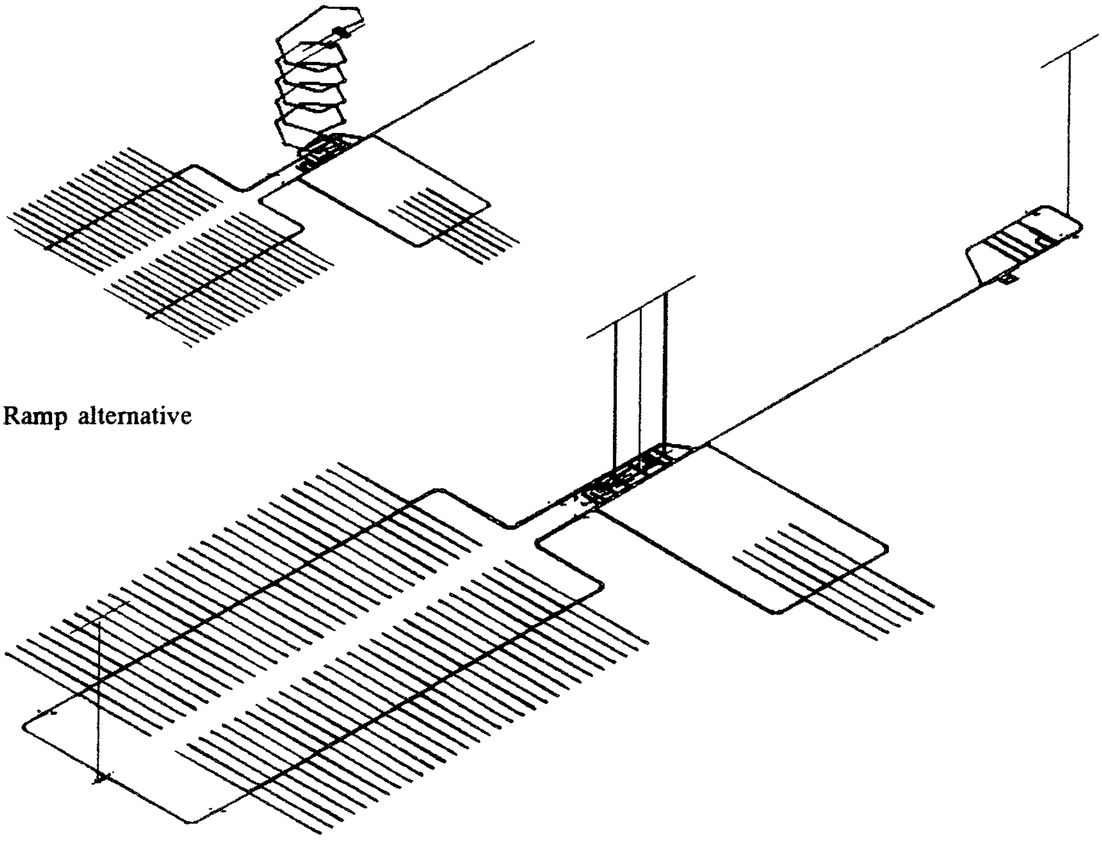
The total excavated rock volume for the ramp alternative (SFL 3–5 not included) is about 950,000 m^3 of which the deposition tunnels account for about 550,000 m^3. The deposition tunnels have a cross–sectional area of about 14.6 m^2. It is assumed



Detailed investigations
Excavated rock volume:
With ramp access - 205 000 m^3
With shaft access - 105 000 m^3



Operation phase 1
Excavated rock volume - 170 000 m^3



Operation phase 2

Figure A5.3 Illustration of the deep repository at different phases that the deposition tunnels are excavated by means of conventional tunnelling technique, with careful blasting that minimizes the cracking of the tunnel periphery. Blasting and excavation take place with a certain lead time as deposition proceeds, and in stages of about 4 km tunnel length, corresponding to approximately 3 years of deposition. After one stage, the activities in the two deposition areas will be shifted.

The transport of the canister from the elevator to the deposition tunnel, handling of bentonite and lowering of the canister in the deposition hole is illustrated in Figure A5.4.

The transport from the elevator to the deposition tunnel is made by an electrically powered vehicle, equipped with a radiation shield in which the canister is placed during transport. The positioning of the canister into the hole is carried out by a rail-bound deposition vehicle. The transfer of the canister between the vehicles is done at the entrance of the deposition tunnel.

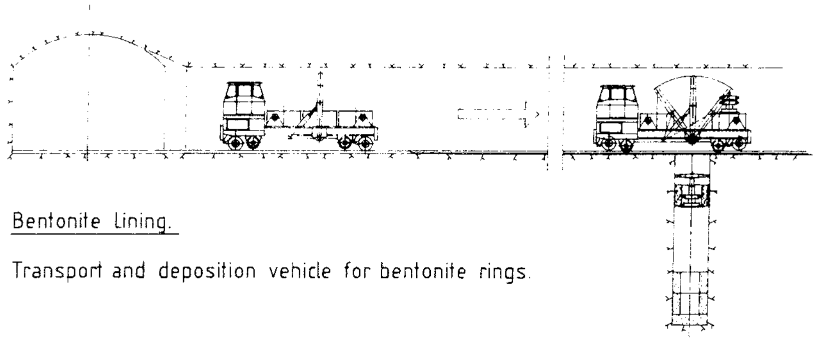
The deposition procedure begins with the placement of all ring-shaped bentonite blocks in the hole. This work is carried out from a rail-bound handling unit. If necessary the blocks are trimmed by using a dummy canister. The uppermost block is provided with a protective steel collar with the purpose of protecting the bentonite edge from damage during the lowering of the canister. The steel collar also holds alignment gauges, used to guide the automatic centring of the canister.

After the canister has been lowered the remaining bentonite buffer is placed in the hole on top of the canister and the tunnel can then be accessed without restriction. Finally, the hole is capped with a watertight seal. The seal is allowed to remain in place until all holes in the tunnel have been completed and backfilling is about to commence.

Figure A5.5 shows a cross-section of deposition tunnel with a canister after the deposition and backfilling has been completed. The deposition hole has a diameter of 1.58 m and depth of 7.9 m. The spacing between holes is 6 m.

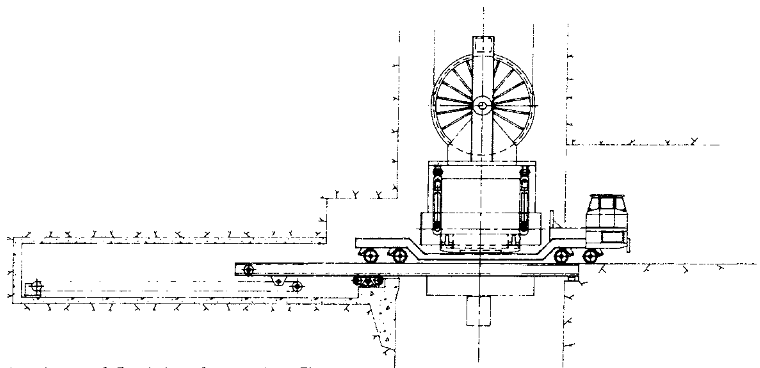
When one or a number of deposition tunnels are completed, the work of sealing them begins. The temporary seals are removed and the tunnels are filled with sand/bentonite. The tunnel entrances are sealed off with a temporary steel wall, which is removed during backfilling of the central tunnel. See Figure A5.6.

After concluded deposition of all canisters, the entire facility is sealed with sand/bentonite. The shafts are provided with plugs of compacted bentonite in certain sections.



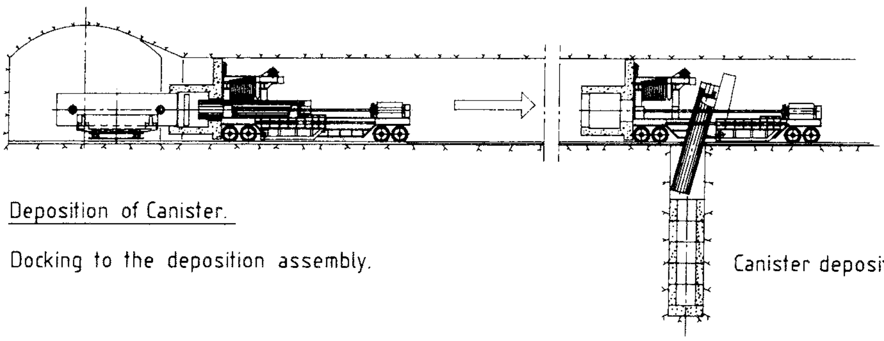
Bentonite Lining.

Transport and deposition vehicle for bentonite rings.



Unloading of Canister from the Elevator.

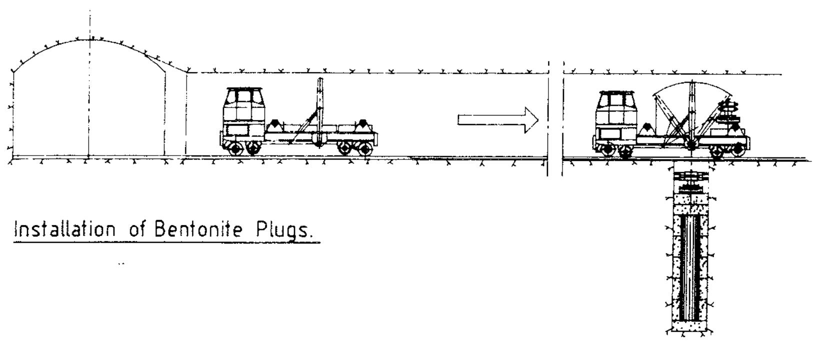
Transfer of canister in transportation shield from elevator to the transportation vehicle.



Deposition of Canister.

Docking to the deposition assembly.

Canister deposition.



Installation of Bentonite Plugs.

Figure A5.4 Transport and disposing of canister

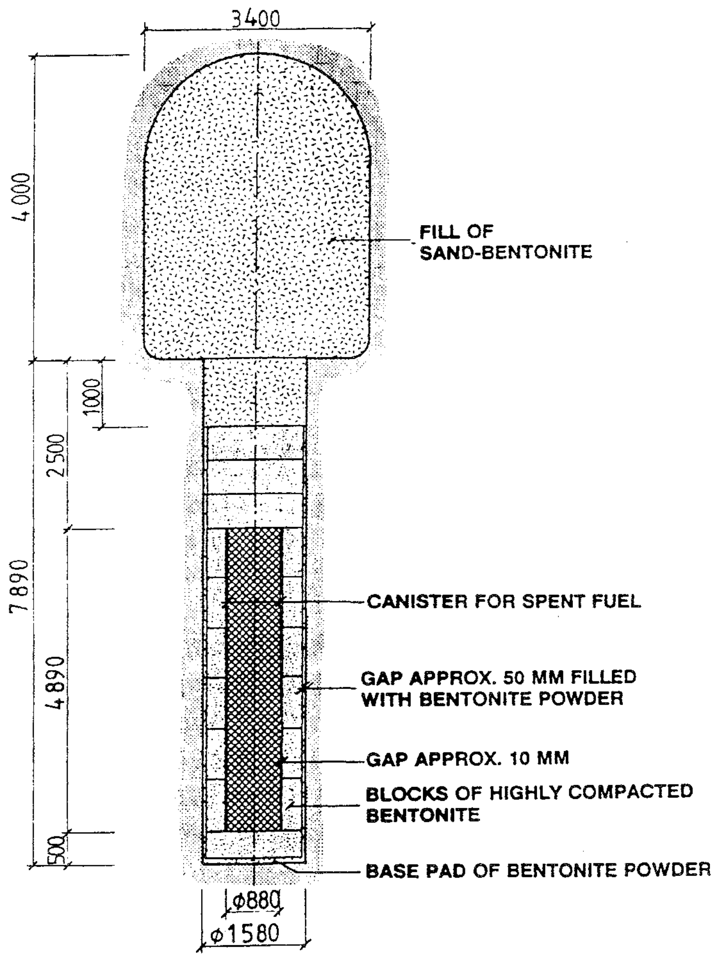


Figure A5.5 Deposition hole with canister and buffer material

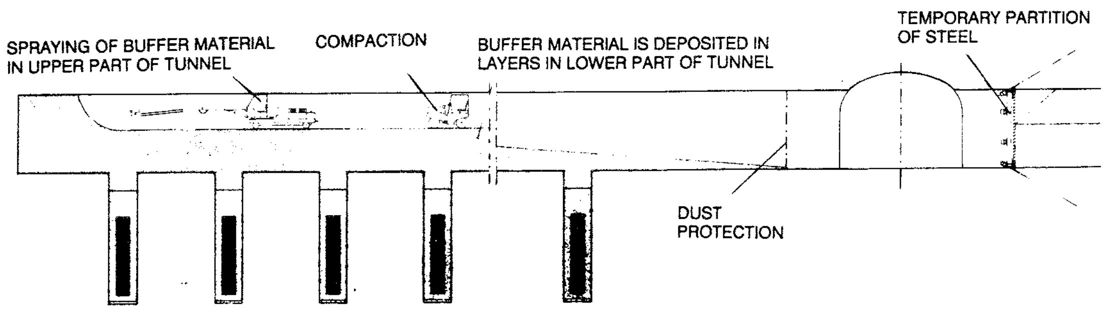


Figure A5.6 Backfilling of deposition tunnel

DEEP REPOSITORY FOR LONG-LIVED LOW- AND INTERMEDIATE-LEVEL WASTE, SFL 3, 4 AND 5

SFL 3, 4 and 5 are located in one repository area and thus equipped with a number of common areas and functions. The repositories are located at a depth of about 500 m in the bedrock. The rock cavern layout is shown on Drawing 5.12. The total excavated rock volume amounts to 110,000 m^3.

Waste is transported down to the repository level by the same elevator as for the canisters. In the receiving area at repository level, the waste is transferred to an electrically powered transport vehicle, which takes it to the unloading station at the storage area. The low-level waste can be handled in a simpler manner with a radiation-shielded forklift truck.

SFL 3

SFL 3 consists of a number of concrete troughs located in a 70 m long rock vault with a width of 18 m and a height of 21 m. Operational waste from CLAB and the encapsulation plant will be deposited in SFL 3 after SFR 1 has been closed. SFL 3 will also receive the long-lived low- and intermediate-level waste from Studsvik.

The positioning and design of the concrete troughs have many similarities with the silo concept in SFR 1. Thus, the trough is surrounded by sand/bentonite or by pure bentonite. It is also divided into square cells, 2.5 by 2.5 m and with height about 10 m, into which the waste is lowered and grouted. Handling is done by remote control with the aid of a deposition machine of an overhead crane type, which runs on the long walls of the trough. After concluded deposition, the troughs are covered with concrete lids and all nearby service areas are filled with concrete. Adjoining tunnels are plugged and the cavities are filled with sand/bentonite.

SFL 4

SFL 4 is intended to receive active decommissioning waste from mainly CLAB and the encapsulation plant as well as empty transport casks. Consequently, it will be in operation when all other waste has been deposited. The repository consists of the tunnel system remaining after deposition in SFL 3 and SFL 5 has been concluded and the repositories sealed.

The waste, which arrives in small steel containers or moulds, is placed in the tunnels or other empty spaces which thereafter are backfilled, possibly with crushed rock material. Finally, the shaft is backfilled, and a number of plugs of backfilled with a mixture of sand/bentonite.

SFL 5

SFL 5 consists of three tunnels, each about 130 m long and with a cross section of 63 m^2. The waste is handled by a remotely operated travelling crane. The concrete moulds containing core components and reactor internals have dimensions 1.2 x 1.2 x 4.8 m. The moulds are stacked in concrete troughs, each holding 50 moulds, in a lying position across the tunnel. Each tunnel holds 10 troughs and the total number of moulds is about 1,400. After each trough has been filled, it is covered by concrete planks.

APPENDIX 6

FINAL REPOSITORY FOR RADIOACTIVE WASTE, SFR

FINAL REPOSITORY FOR OPERATIONAL WASTE, SFR 1

A final repository for short-lived low- and intermediate-level waste located at the Forsmark nuclear power station has been in operation since 1988. The waste derives primarily from reactor operation, but also from non-electricity-producing activities. In the latter case, the waste comes mainly from Studsvik. In all, SFR 1 will hold about 90 000 m^3 of waste, of which about 37 000 m^3 in silos. The layout of the repository, SFR1 phase I, is illustrated schematically in Figure A6.1.

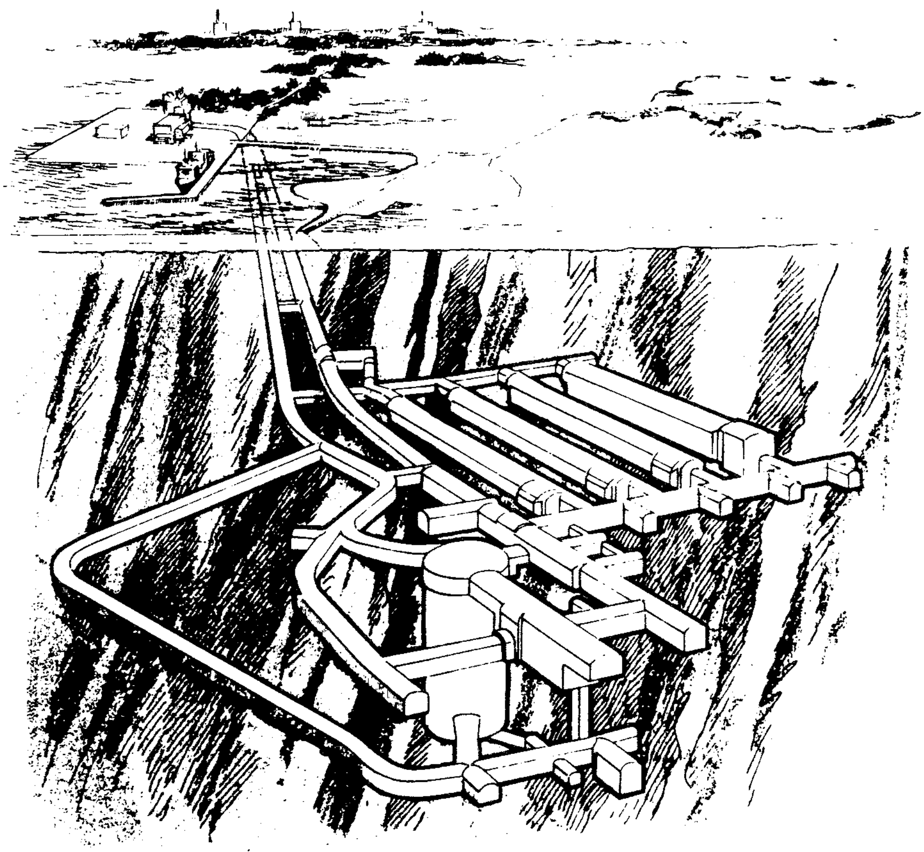


Figure A6.1 SFR 1, phase I.

The site plan of the repository is shown on Drawing 6.1. Two tunnels lead from the power station harbour out under the Baltic Sea to the rock cavern repository, which is built with a rock cover of at least 60 m. The water depth at the site is 5–6 m.

The surface facilities comprise three buildings: an office and workshop building(1), a terminal building(2) for storage of transport units, and a ventilation building(3), see Figure A6.2.

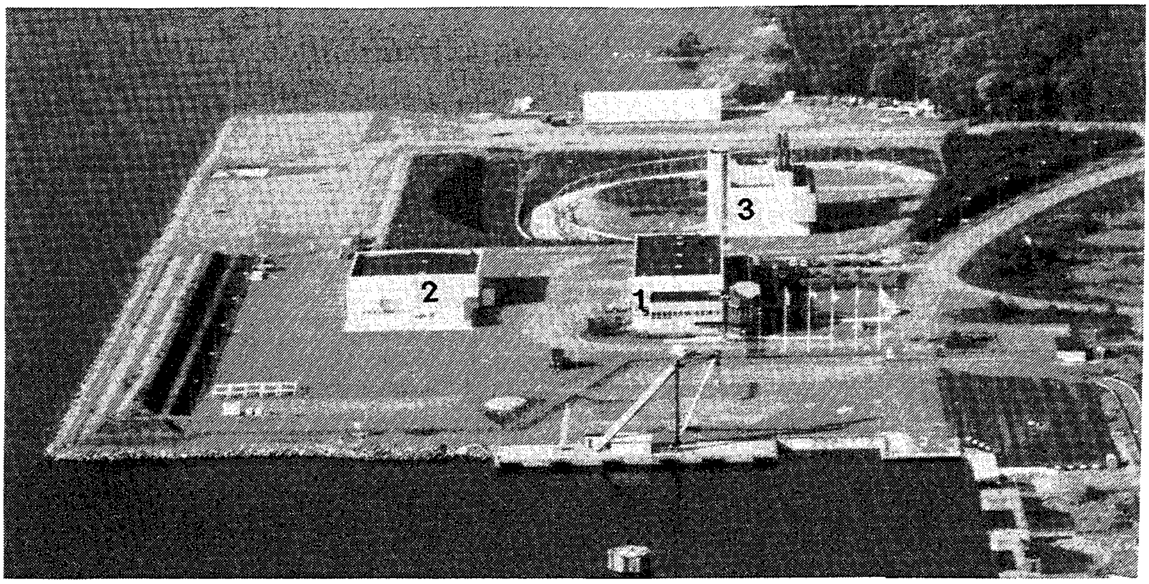


Figure A6.2 Surface facilities at SFR1

SFR 1 is being built in two phases. See Drawing 6.2. The first phase, currently in operation, consists of one cylindrical rock cavern containing a concrete silo plus four 160 m long rock vaults.The concrete silo contains intermediate-level waste. Three of the rock vaults contain low-level waste, handled by a radiation-shielded truck. The fourth rock vault contains intermediate-level waste and handling is remote controlled. The second building phase comprises one additional silo and one or two rock vaults. The total volume of rock excavated for the two building phases will amount to about 600 000 m^3.

The rock chamber for the silo is 70 m high and has a diameter of 30 m. A free-standing concrete silo is being built inside the rock cavern. The silo stands on a 1.5 m thick bed of compacted sand/ bentonite. The space between the silo wall and the rock wall, about 1 m, is filled with bentonite granulate.

Internally, the concrete silo is divided into cells of square cross section, 2.6 x 2.6 m. This cellular division provides a stiffening of the silo wall and facilitates emplacement and grouting of the waste packages.

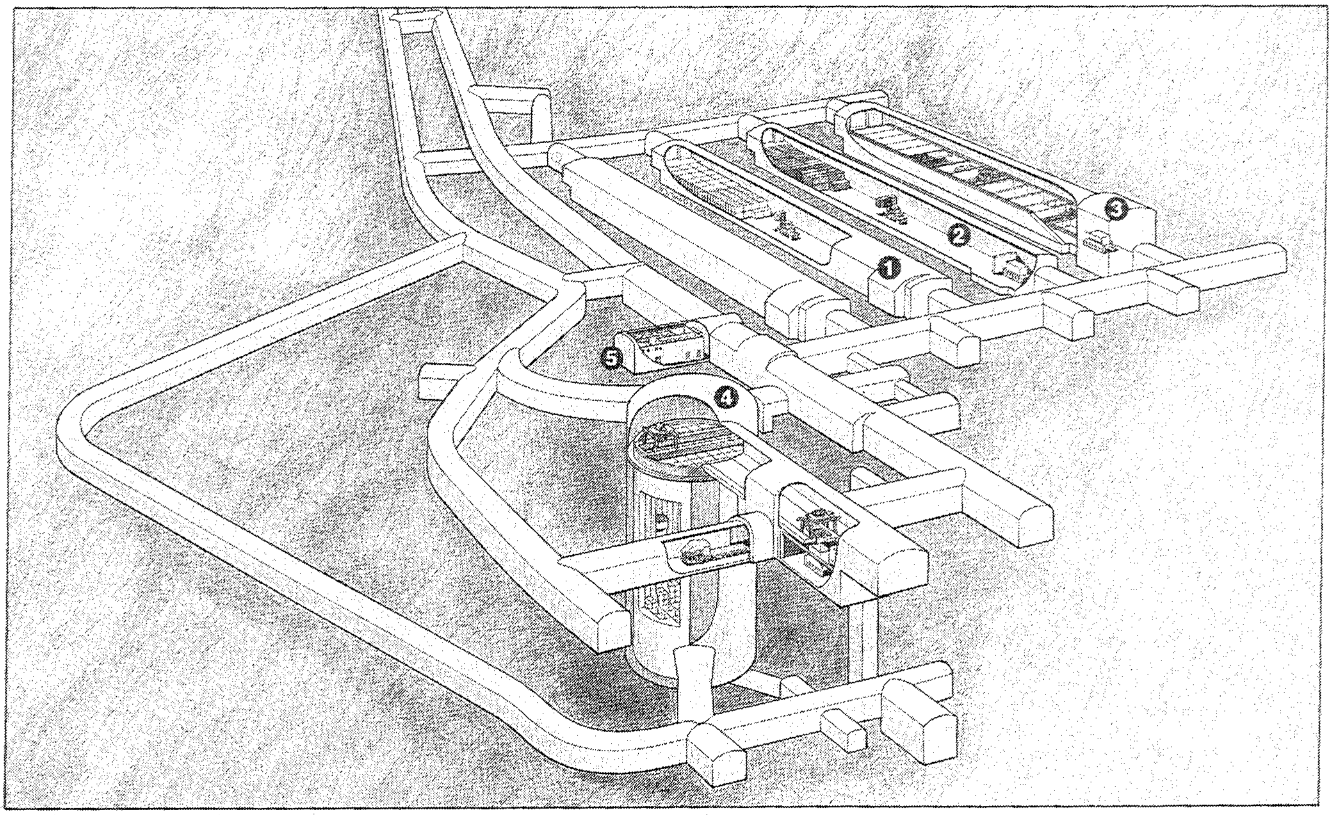
The procedure for depositing waste in the silo is schematically illustrated in Figure A6.3. The transport container with the waste packages is brought down into the repository by an electric-powered terminal vehicle and placed in a receiving room. Above the room runs a tunnel that is connected to the upper part of the silo and contains a rail-bound remote controlled polar crane. The deposition vehicle picks up the waste packages, one at a time, out of the transport container, drives out onto the polar crane over the silos, drives to the correct position and lowers the package into one of the cells. When three layers of waste have been emplaced in the cell, they are grouted with a low-viscosity cement mortar. After completion of deposition, a concrete lid is poured over the silo and all remaining cavities are filled with sand/bentonite and backfill materials.

The principle arrangement of the caverns and the handling of the waste is schematically illustrated in Figure A6.3.

The intermediate-level waste emplaced in the rock caverns is also grouted, while the low-level waste is not.

The repository also includes surface facilities situated in the area around the tunnel entrances. See Drawing 6.3. The total building volume is about 30 000 m^3. The buildings include a ventilation building (for the rock chambers), an office and workshop building and a terminal building where the transport units are temporarily stored prior to transport down to the repository.

SFR 1 is scheduled to be sealed in the mid 2010s. The operating organization will amount to 20 men.



1. Rock vault for intermediate-level waste in concrete tanks. The tanks are handled by forklift truck.
2. Rock vault for low-level waste in freight containers. The containers are handled by forklift truck.
3. Rock vault with pits for intermediate-level waste in metal drums or moulds. The waste is handled by remote-controlled overhead crane.
4. Silo for intermediate-level waste in metal drums or moulds. The waste is handled by a special remote-controlled handling machine.
5. Operating building with operations centre and personnel quarters.

Figure A6.3 SFR1, silo and caverns for low– and intermediate–level waste

FINAL REPOSITORY FOR DECOMMISSIONING WASTE, SFR 3

SFR 3 is intended for decommissioning waste from the nuclear power plants and Studsvik. The total waste quantity may amount to about 100 000 m^3. The site of SFR 3 has not yet been determined, but it is assumed at present that SFR 3 will constitute an expansion of SFR 1. SFR 3 will be in operation at the same time as the nuclear power plants are being decommissioned. Activities at SFR 1 will then have ceased and SFR 3 can be run by the same personnel as SFR 1. The operating and service buildings constructed for SFR 1 can also be utilized.

SFR 3 will consist of four rock caverns of a similar type as in SFR 1. See FigureA6.4 and Drawing 6.5. The decommissioning waste will primarily be transported to the repository packed in standard ISO containers that are deposited with their contents. ATB containers are used for waste that requires radiation shielding during transport and are emptied by means of a remote-controlled overhead crane.

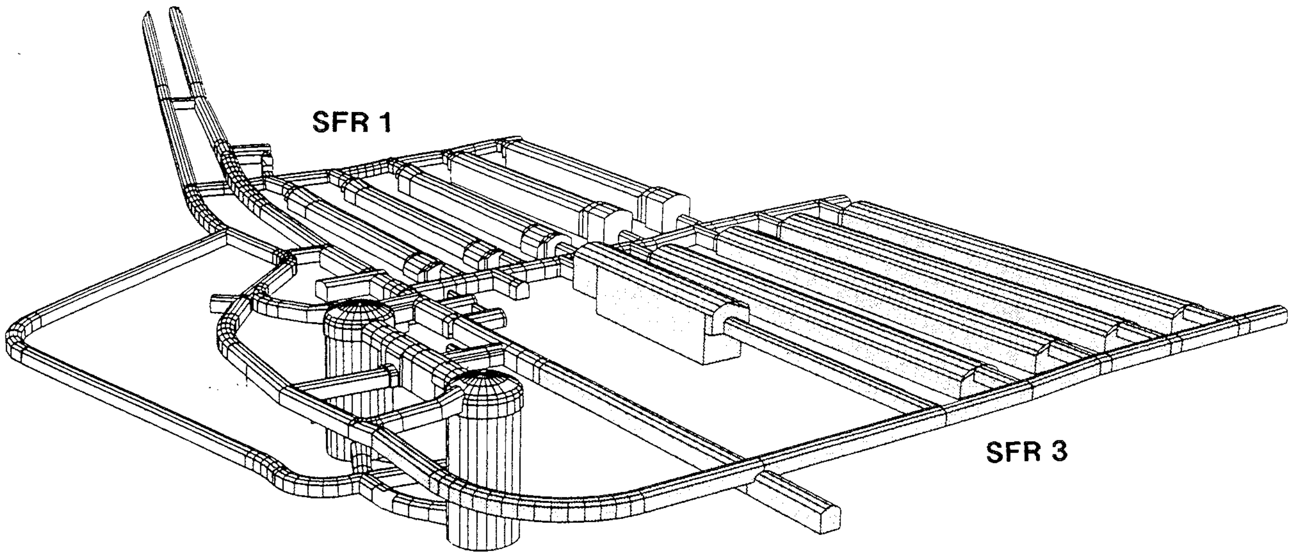


Figure A6.4 SFR1, phase I and II plus SFR3

APPENDIX 7

DECOMMISSIONING OF THE NUCLEAR POWER PLANTS (Summary from Ref. 6)

When a nuclear power plant is retired from service, parts of it are radioactive and must be dismantled and disposed of in a safe manner. The procedures and costs involved in decommissioning nuclear power plants are described in the study.

The study shows that, from the viewpoint of radiological safety, a nuclear power plant can be dismantled immediately after it has been shut down and the fuel has been removed, which is estimated to take about one year. Most of the equipment that will be used in decommissioning is already available and is used routinely in maintenance and rebuilding work at the nuclear power plants. Special equipment need only be developed for dismantling of the reactor vessel and for demolishing heavy concrete structures. Examples of existing equipment that can, after minor modifications, be used for this are given in the study.

The dismantling of a nuclear power plant can be accomplished in about five years, with an average labour force of about 200 men. The maximum labour force required for Ringhals 1 has been estimated at about 500 men during the first years, when active systems are being dismantled on a number of fronts in the plant. During the last years when the buildings are being demolished, approximately 50 men are required.

In order to limit the labour requirement and the dose burden to the personnel, the material is taken out in as large pieces as possible. This means, for example, that pipes are cut into lengths of 2–5 m and packed directly in refuse containers, and that certain items of equipment are taken out and transported intact.

The study has focused on immediate dismantling. By waiting ten years or so, certain advantages can be gained due to the fact that the radioactivity in the plant declines. In the case of immediate dismantling, the same effect can be achieved by system decontamination. A number of other factors also influence the choice of time of dismantling, for example availability of personnel, need for the site and the availability of a final repository. Non–technical factors will also be of importance. The choice of time of dismantling can therefore vary for different plants.

Cost figures below are taken from Technical Report 86–16 /ref. 6/ and adjusted to the 1993 price level by using the price index.

The cost of decommissioning a boiling water reactor (BWR) of the size of Ringhals 1 has been estimated to be about MSEK 860 at January 1993 prices, and for a pressurized water reactor (PWR, Ringhals 2) about MSEK 730. The costs for the other Swedish nuclear power plants lie in the range of MSEK 660 to 1,210. These are the direct costs for the decommissioning work, to which must be added the costs of transportation and disposal of the decommissioning waste, about 100 000 m^3. These costs have been estimated at about MSEK 1,000 for the 12 Swedish reactors.

Additional costs are incurred for the shutdown period from the time the nuclear power plant is finally taken out of operation until the dismantling work is begun. During this period, the fuel is transported away and some decontamination is carried out. The costs for the shutdown period are largely dependent upon how long the shutdown period will last.

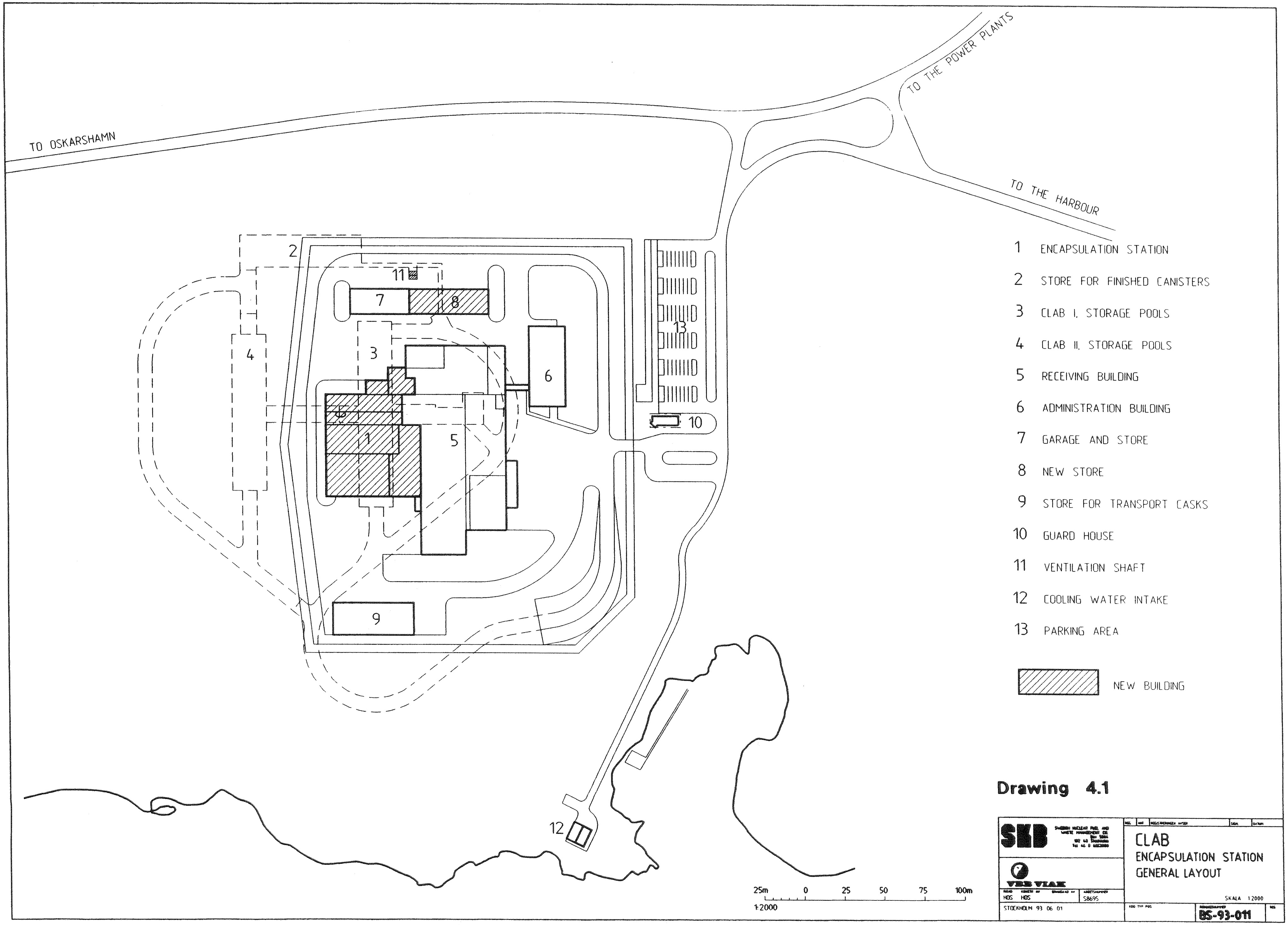
There are considerable quantities of spare parts, materials and equipment on the reactor sites that can be sold when the plants are closed down. The total value of these materials for all nuclear power plants is estimated to be MSEK 1,420. To this must be added the value of the land and the infrastructure.

The table below presents the costs of immediate dismantling of the Swedish nuclear power plants.

Table S–1: Costs (MSEK) for decommissioning of the Swedish nuclear power plants.
January 1993 price level

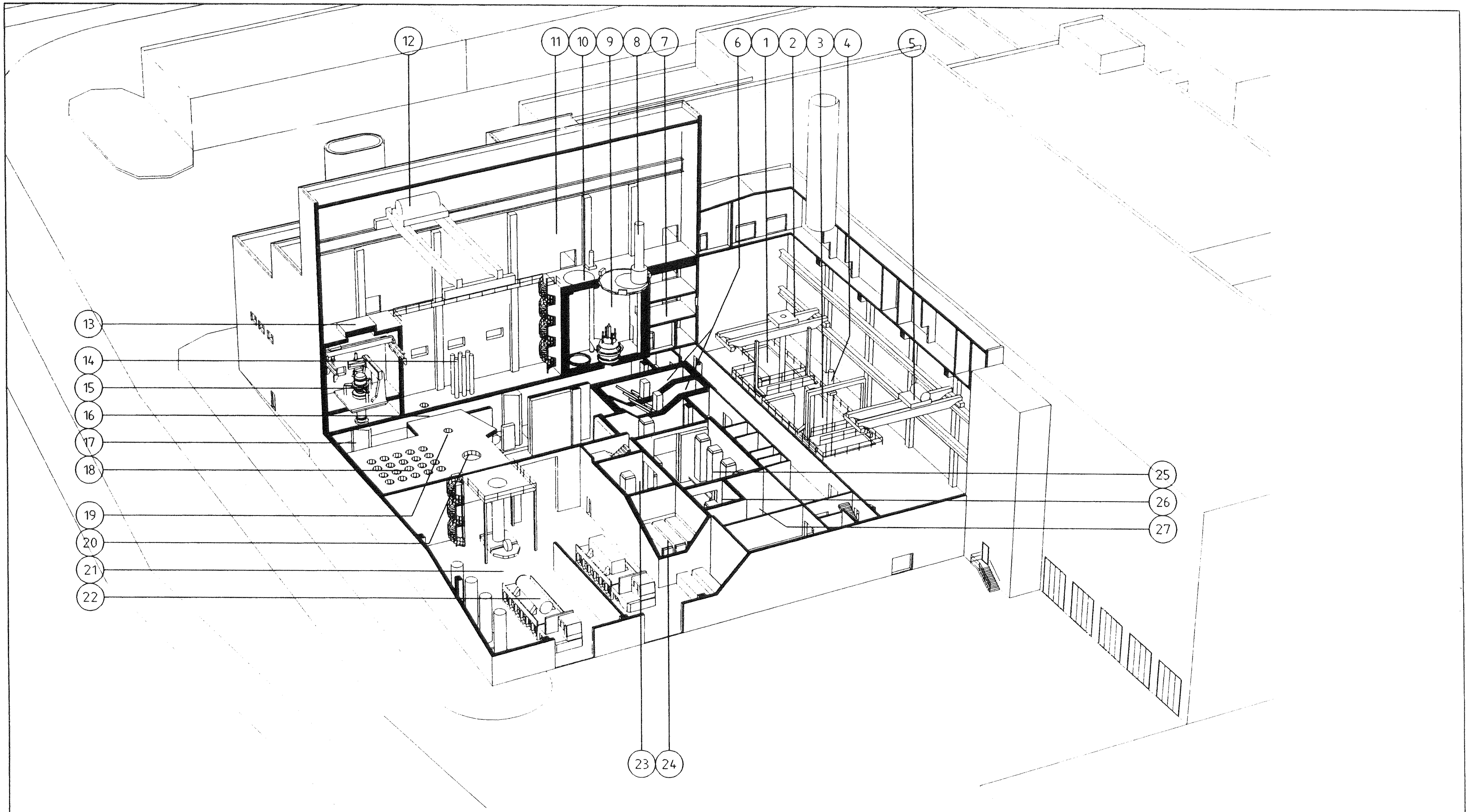
	Barsebäck 1–2	Ringhals 1–4	Oskarshamn 1–3	Forsmark 1–3
Shutdown operation[1)]	190	540	330	330
Decommissioning	1,540	3,110	2,640	3,540
Transport and final disposal of waste	150	315	250	285
Total	1,880	3,965	3,220	4,155
Residual value	-240	-480	-350	-350

1) An extra contingency adjustment of 10% has been added to these costs in the systems cost calculations.



TO OSKARSHAMN
TO THE POWER PLANTS
TO THE HARBOUR
1 ENCAPSULATION STATION
2 STORE FOR FINISHED CANISTERS
3 CLAB I, STORAGE POOLS
4 CLAB II, STORAGE POOLS
5 RECEIVING BUILDING
6 ADMINISTRATION BUILDING
7 GARAGE AND STORE
8 NEW STORE
9 STORE FOR TRANSPORT CASKS
10 GUARD HOUSE
11 VENTILATION SHAFT
12 COOLING WATER INTAKE
13 PARKING AREA
NEW BUILDING
25m 0 25 50 75 100m
1:2000
SKB
VBB VIAK
CLAB
ENCAPSULATION STATION
GENERAL LAYOUT
SKALA 1:2000
HOS HOS
S8695
STOCKHOLM 93 06 01
BS-93-011

Drawing 4.1



1 ELEVATOR POOL

2 MANIPULATOR CRANE FOR STORAGE CANISTERS AND FUEL

3 HANDLING POOL

4 BRIDGE CRANE FOR POOL HANDLING

5 SERVICE OVERHEAD CRANE FOR POOL AREA

6 CASSETTE TRANSFER SHAFTS

7 OPERATOR ROOM FOR HANDLING CELLS

8 FUEL HANDLING MANIPULATOR

9 HANDLING CELL FOR SPENT FUEL

10 SERVICE HATCH INTO HANDLING CELL FOR SPENT FUEL

11 SERVICE HALL

12 SERVICE HALL OVERHEAD CRANE

13 SERVICE HATCH INTO WELDING CELL

14 STORAGE AREA FOR EMPTY CANISTERS

15 WELDING EQUIPMENT

16 CANISTER TRANSFER CORRIDOR

17 CANISTER TRANSFER TRUCK

18 FILLED CANISTER STORAGE

19 DECONTAMINATION CELL FOR CANISTERS

20 CANISTER TRANSPORT CASK FILLING

21 DISPATCH HALL

22 TERMINAL VEHICLE WITH CANISTER TRANSPORT CASK

23 EQUIPMENT FOR TILTING OF CONCRETE MOULDS

24 FILLED CONCRETE MOULD STORE

25 MOULD HALL

26 CONCRETE FILLING STATION

27 CONCRETE PREPARATION

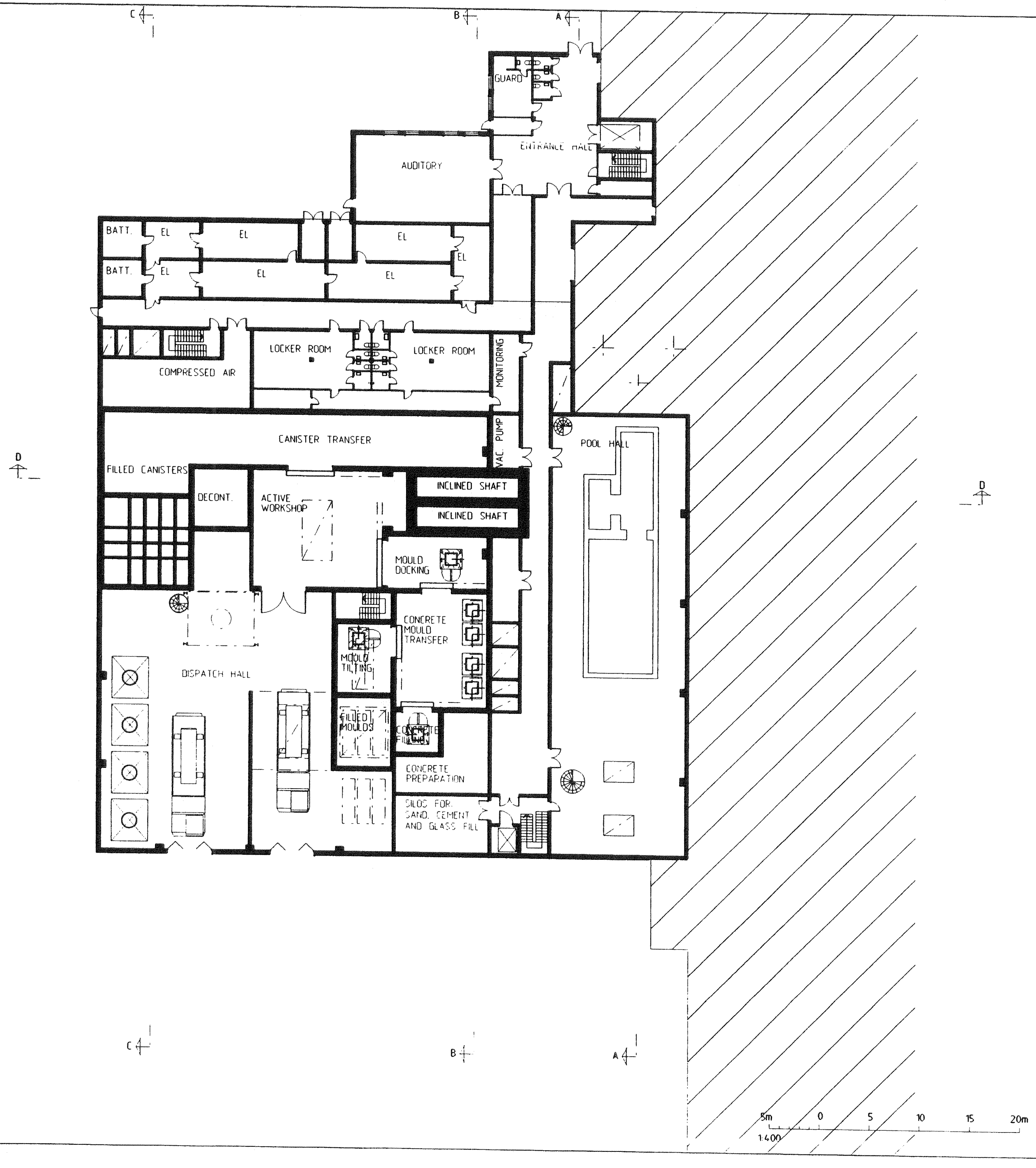
Drawing 4.2

SKB

VBB VIAK

ENCAPSULATION STATION
VIEW OF INTERIOR

BS-93-901



Drawing 4.3

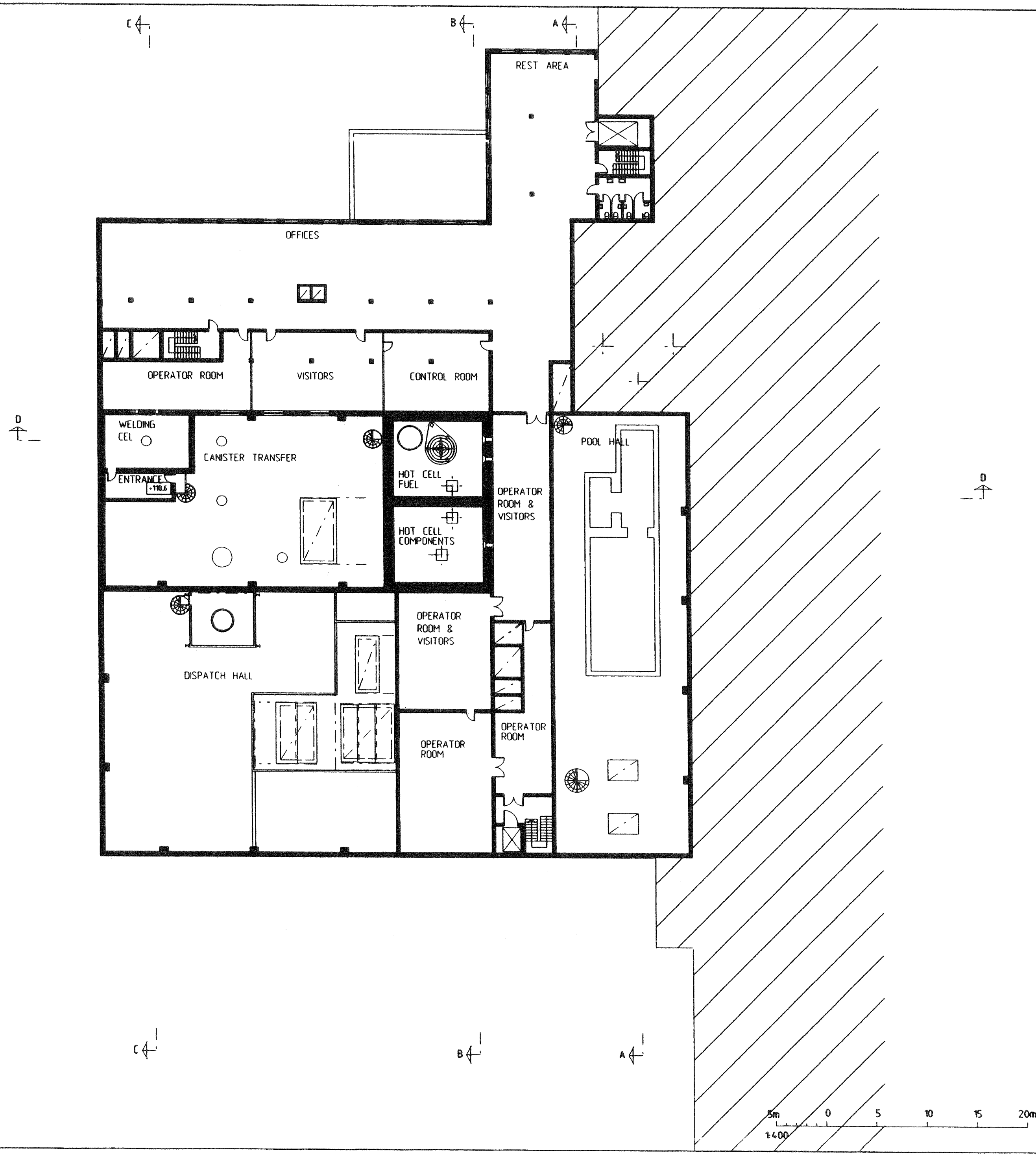
SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

VBB VIAK

ENCAPSULATION STATION
LAYOUT
PLAN +112,0

SCALE 1:400

BS-93-103

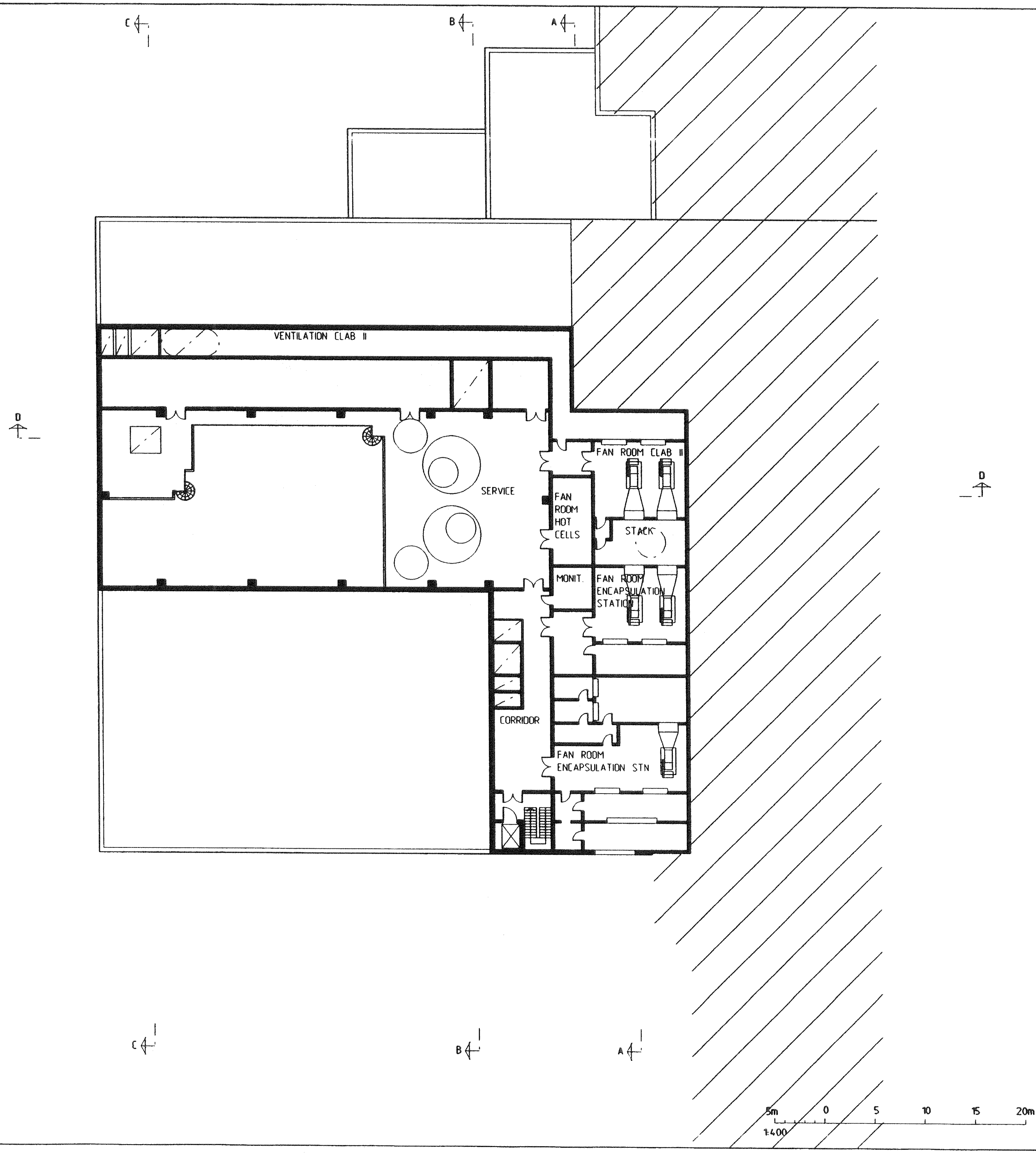


Drawing 4.4

SKB
VBB VIAK

ENCAPSULATION STATION
LAYOUT
PLAN +119,5

HOS HOS S8695
STOCKHOLM 93 06 01
SCALE 1:400
BS-93-105



Drawing 4.5

SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

VBB VIAK

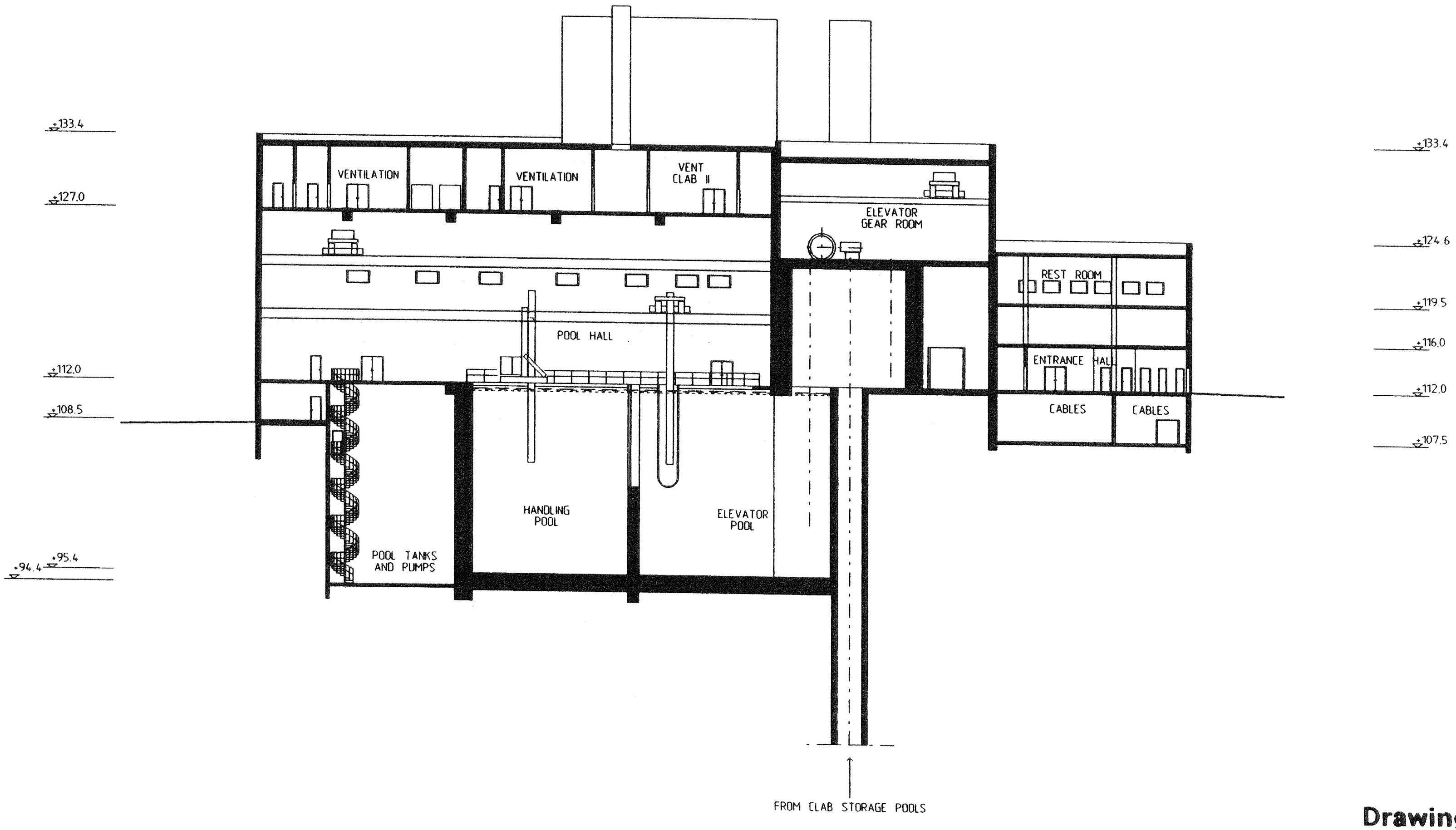
ENCAPSULATION STATION
LAYOUT
PLAN +127,0

HOS HOS S8695

SCALE 1:400

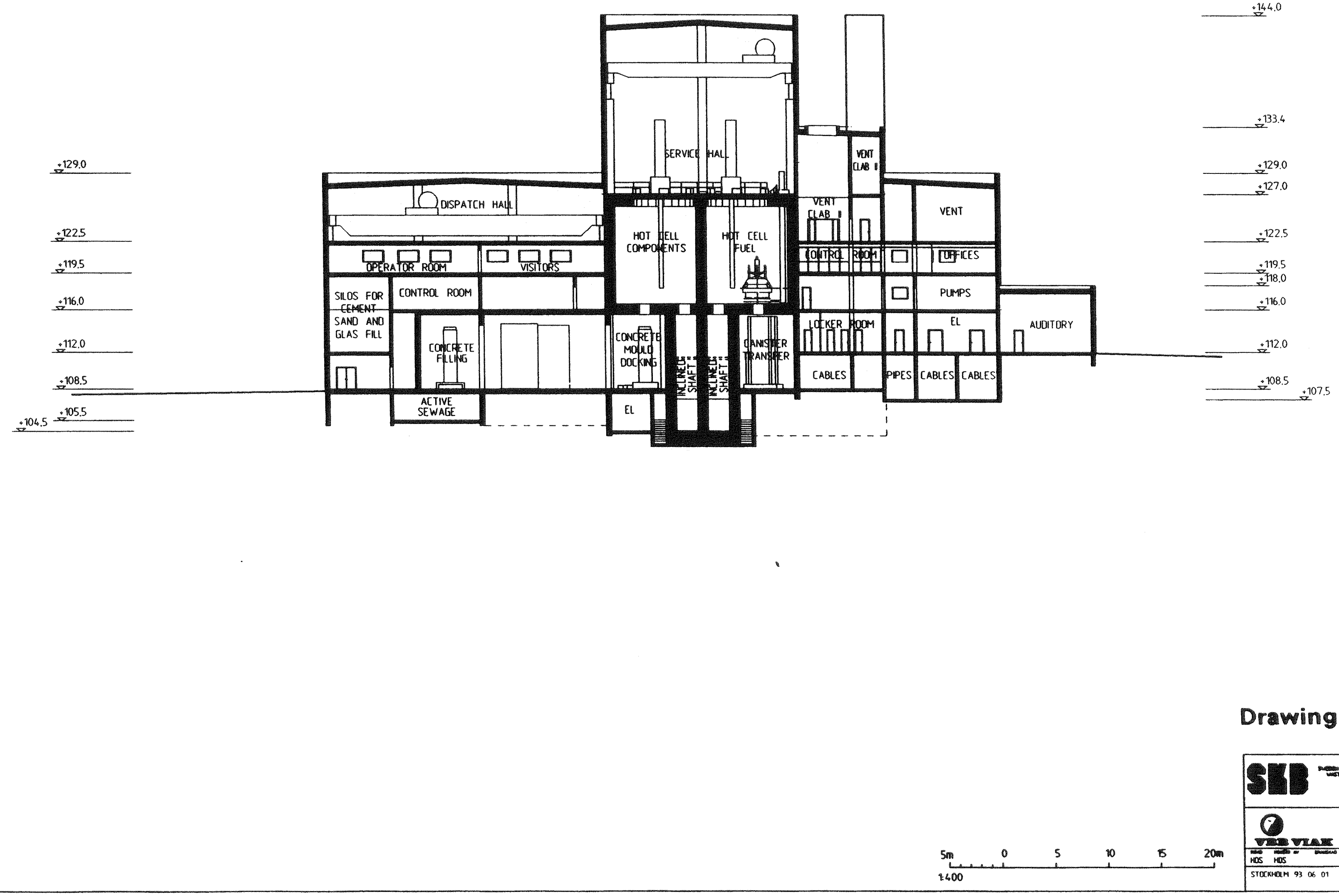
STOCKHOLM 93 04 0?

BS-93-107



Drawing 4.6

SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO.	ENCAPSULATION STATION SECTION A
VBB VIAK	
HOS HOS 58695	SKALA 1:400
STOCKHOLM 93 06 01	BS-93-111



Drawing 4.7

SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

VBB VIAK

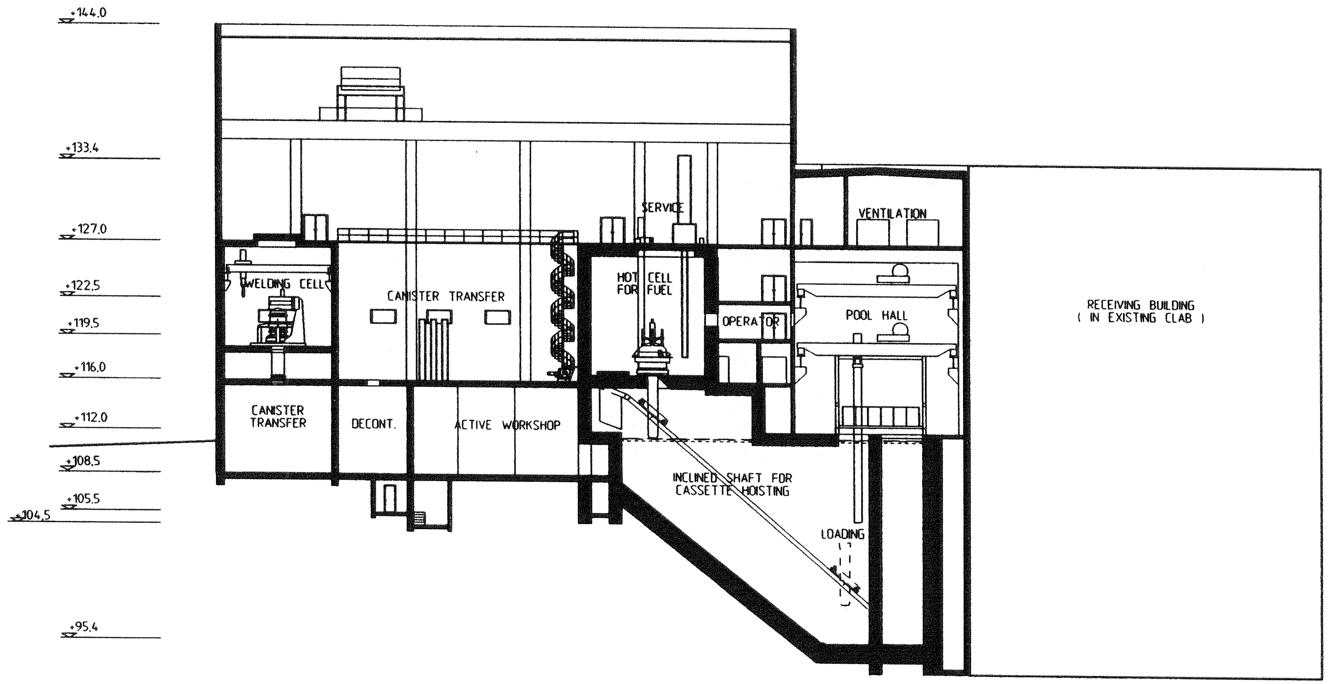
HDS HDS S8695

STOCKHOLM 93 06 01

ENCAPSULATION STATION
SECTION B

SKALA 1:400

BS-93-112



Drawing 4.8

5m 0 5 10 15 20m

1:400

SKB

VBB VIAK

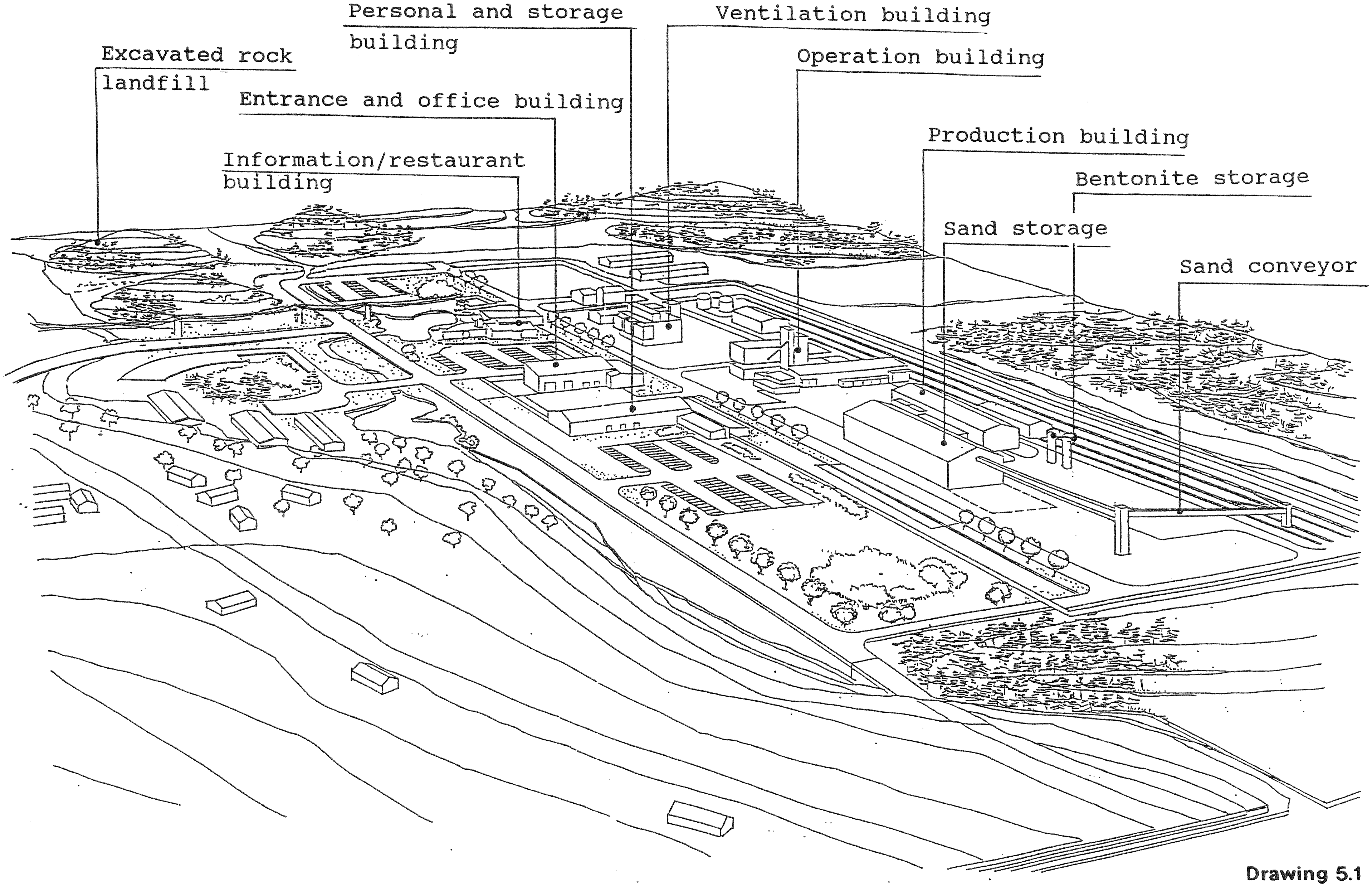
HOS HOS S8695

STOCKHOLM 93 06 01

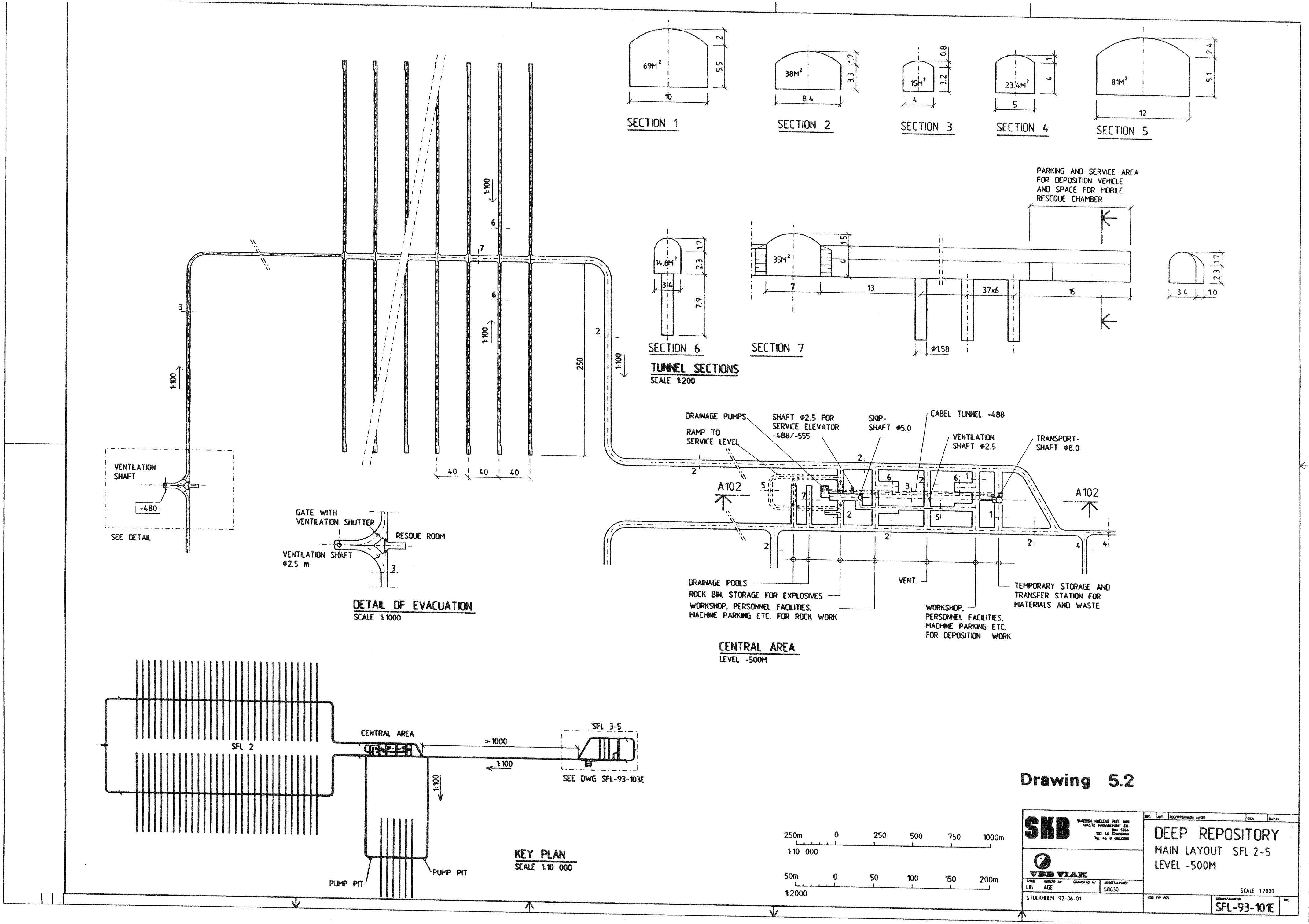
ENCAPSULATION STATION
SECTION D

SKALA 1:400

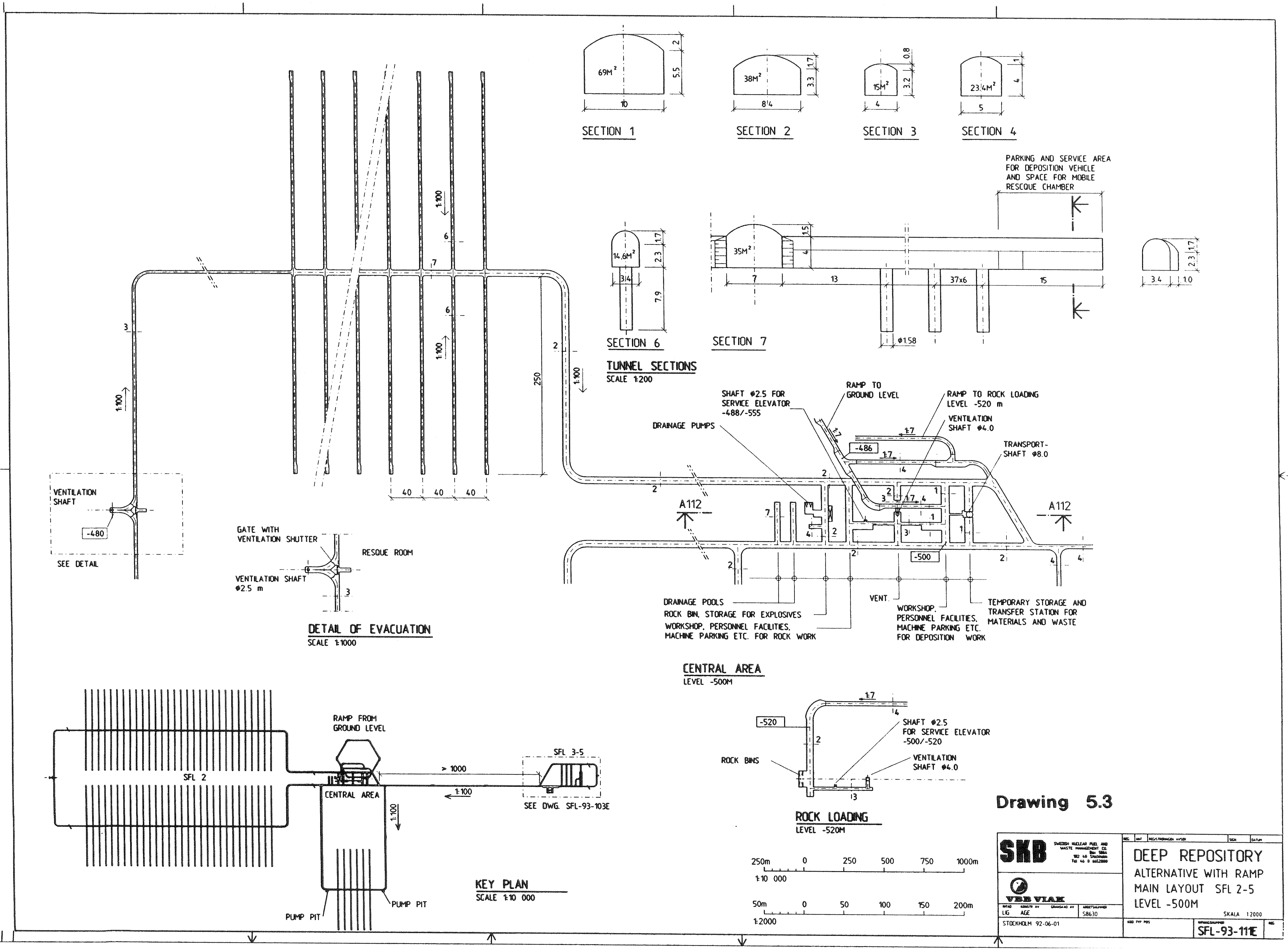
BS-93-114


Personal and storage building
Ventilation building
Excavated rock landfill
Operation building
Entrance and office building
Production building
Information/restaurant building
Bentonite storage
Sand storage
Sand conveyor

Drawing 5.1

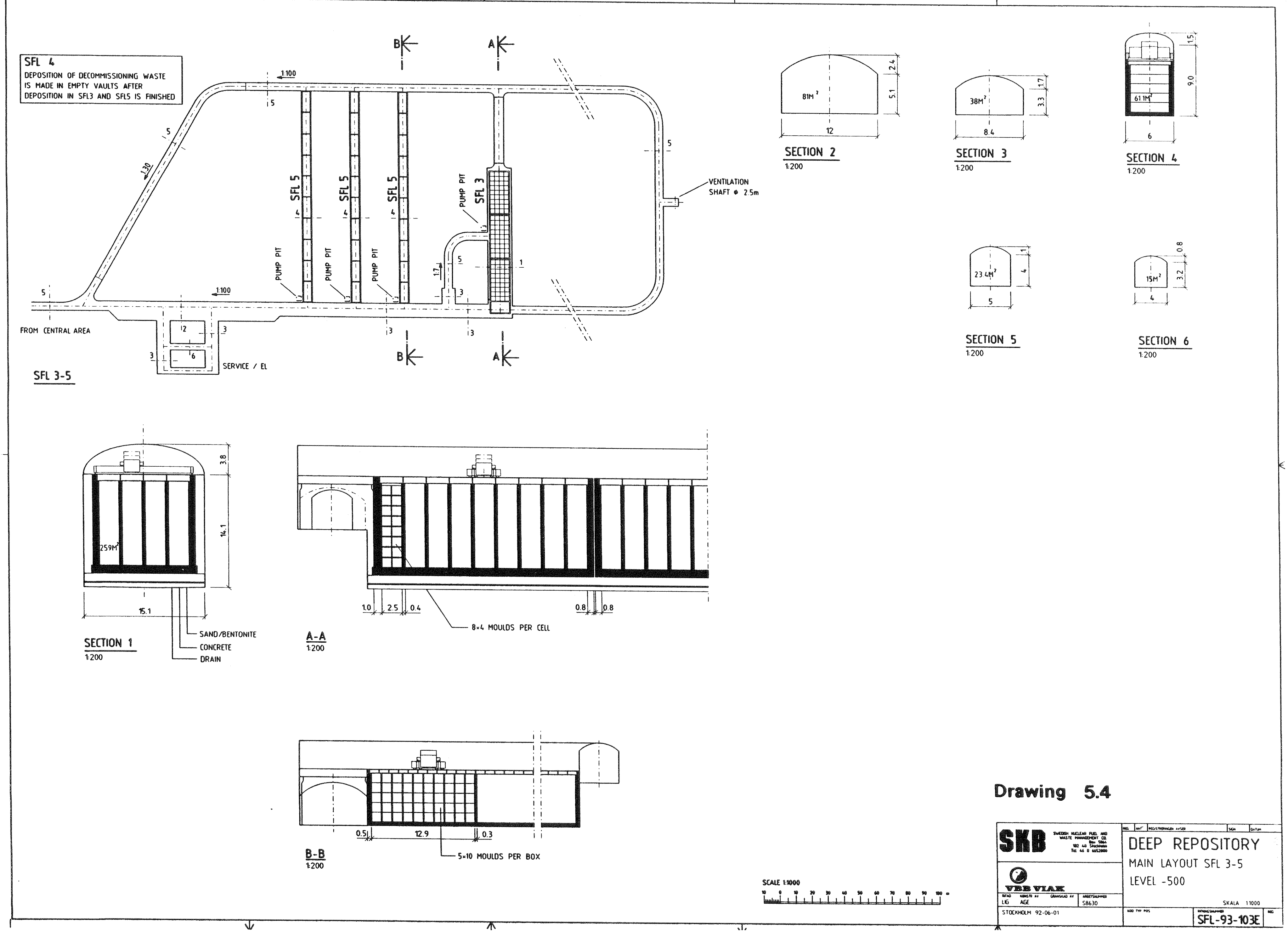

SECTION 1
69M²
SECTION 2
38M²
SECTION 3
15M²
SECTION 4
23.4M²
SECTION 5
81M²
SECTION 6
14.6M²
SECTION 7
35M²
TUNNEL SECTIONS
SCALE 1:200
PARKING AND SERVICE AREA FOR DEPOSITION VEHICLE AND SPACE FOR MOBILE RESCUE CHAMBER
ø1.58
VENTILATION SHAFT
-480
SEE DETAIL
GATE WITH VENTILATION SHUTTER
RESQUE ROOM
VENTILATION SHAFT ø2.5 m
DETAIL OF EVACUATION
SCALE 1:1000
DRAINAGE PUMPS
RAMP TO SERVICE LEVEL
SHAFT ø2.5 FOR SERVICE ELEVATOR -488/-555
SKIP-SHAFT ø5.0
CABEL TUNNEL -488
VENTILATION SHAFT ø2.5
TRANSPORT-SHAFT ø8.0
A102
DRAINAGE POOLS
ROCK BIN, STORAGE FOR EXPLOSIVES
WORKSHOP, PERSONNEL FACILITIES, MACHINE PARKING ETC. FOR ROCK WORK
VENT.
TEMPORARY STORAGE AND TRANSFER STATION FOR MATERIALS AND WASTE
WORKSHOP, PERSONNEL FACILITIES, MACHINE PARKING ETC. FOR DEPOSITION WORK
CENTRAL AREA
LEVEL -500M
SFL 2
CENTRAL AREA
> 1000
SFL 3-5
SEE DWG SFL-93-103E
PUMP PIT
PUMP PIT
KEY PLAN
SCALE 1:10 000
1:10 000
1:2000
SKB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO.
VBB VIAK
DEEP REPOSITORY
MAIN LAYOUT SFL 2-5
LEVEL -500M
LG AGE
S8630
STOCKHOLM 92-06-01
SCALE 1:2000
SFL-93-101E

Drawing 5.2



SECTION 1
69M²
SECTION 2
38M²
SECTION 3
15M²
SECTION 4
23.4M²
PARKING AND SERVICE AREA FOR DEPOSITION VEHICLE AND SPACE FOR MOBILE RESQUE CHAMBER
SECTION 6
14.6M²
SECTION 7
35M²
TUNNEL SECTIONS
SCALE 1:200
VENTILATION SHAFT
-480
SEE DETAIL
GATE WITH VENTILATION SHUTTER
RESQUE ROOM
VENTILATION SHAFT φ2.5 m
DETAIL OF EVACUATION
SCALE 1:1000
SHAFT φ2.5 FOR SERVICE ELEVATOR -488/-555
RAMP TO GROUND LEVEL
RAMP TO ROCK LOADING LEVEL -520 m
VENTILATION SHAFT φ4.0
TRANSPORT-SHAFT φ8.0
DRAINAGE PUMPS
-486
A112
-500
DRAINAGE POOLS
ROCK BIN, STORAGE FOR EXPLOSIVES
WORKSHOP, PERSONNEL FACILITIES, MACHINE PARKING ETC. FOR ROCK WORK
VENT.
WORKSHOP, PERSONNEL FACILITIES, MACHINE PARKING ETC. FOR DEPOSITION WORK
TEMPORARY STORAGE AND TRANSFER STATION FOR MATERIALS AND WASTE
CENTRAL AREA
LEVEL -500M
-520
SHAFT φ2.5 FOR SERVICE ELEVATOR -500/-520
VENTILATION SHAFT φ4.0
ROCK BINS
ROCK LOADING
LEVEL -520M
SFL 2
RAMP FROM GROUND LEVEL
CENTRAL AREA
> 1000
SFL 3-5
SEE DWG. SFL-93-103E
PUMP PIT
PUMP PIT
KEY PLAN
SCALE 1:10 000
250m 0 250 500 750 1000m
1:10 000
50m 0 50 100 150 200m
1:2000
SKB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO.
VBB VIAK
LIG AGE S8630
STOCKHOLM 92-06-01
DEEP REPOSITORY
ALTERNATIVE WITH RAMP
MAIN LAYOUT SFL 2-5
LEVEL -500M
SKALA 1:2000
SFL-93-111E

Drawing 5.3


SFL 4
DEPOSITION OF DECOMMISSIONING WASTE IS MADE IN EMPTY VAULTS AFTER DEPOSITION IN SFL3 AND SFL5 IS FINISHED
SFL 5
SFL 5
SFL 5
SFL 3
PUMP PIT
VENTILATION SHAFT ⌀ 2.5m
FROM CENTRAL AREA
SERVICE / EL
SFL 3-5
SECTION 2
1:200
SECTION 3
1:200
SECTION 4
1:200
SECTION 5
1:200
SECTION 6
1:200
SECTION 1
1:200
SAND/BENTONITE
CONCRETE
DRAIN
A-A
1:200
8×4 MOULDS PER CELL
B-B
1:200
5×10 MOULDS PER BOX
SCALE 1:1000
SKB
VBB VIAK
DEEP REPOSITORY
MAIN LAYOUT SFL 3-5
LEVEL -500
SKALA 1:1000
STOCKHOLM 92-06-01
SFL-93-103E

Drawing 5.4

List of SKB reports

Annual Reports

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The KBS Annual Report 1980
KBS Technical Reports 80-01 – 80-25
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KBS Technical Reports 81-01 – 81-16
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Stockholm, June 1985

1985
TR 85-20
Annual Research and Development Report 1985
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Stockholm, May 1986

1986
TR 86-31
SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

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Including Summaries of Technical Reports Issued during 1987
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SKB Annual Report 1991
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Stockholm, April 1992

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SKB Annual Report 1992
Including Summaries of Technical Reports Issued during 1992
Stockholm, May 1993

Technical Reports
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TR 93-01
Stress redistribution and void growth in butt-welded canisters for spent nuclear fuel
B L Josefson[1], L Karlsson[2], H-Å Häggblad[2]
[1] Division of Solid Mechanics, Chalmers University of Technology, Göteborg, Sweden
[2] Division of Computer Aided Design, Luleå University of Technology, Luleå, Sweden
February 1993

TR 93-02
Hydrothermal field test with French candidate clay embedding steel heater in the Stripa mine
R Pusch[1], O Karnland[1], A Lajudie[2], J Lechelle[2], A Bouchet[3]
[1] Clay Technology AB, Sweden
[2] CEA, France
[3] Etude Recherche Materiaux (ERM), France
December 1992

TR 93-03
MX 80 clay exposed to high temperatures and gamma radiation
R Pusch[1], O Karnland[1], A Lajudie[2], A Decarreau[3],
[1] Clay Technology AB, Sweden
[2] CEA, France
[3] Univ. de Poitiers, France
December 1992

TR 93-04
**Project on Alternative Systems Study (PASS).
Final report**
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TR 93-05
**Studies of natural analogues and geological systems.
Their importance to performance assessment**
Fredrik Brandberg[1], Bertil Grundfelt[1], Lars Olof Höglund[1], Fred Karlsson[2], Kristina Skagius[1], John Smellie[3]
[1] KEMAKTA Konsult AB
[2] SKB
[3] Conterra AB
April 1993

TR 93-06
Mineralogy, geochemistry and petrophysics of red coloured granite adjacent to fractures
Thomas Eliasson
Chalmers University of Technology and University of Göteborg, Department of Geology, Göteborg, Sweden
March 1993

TR 93-07
Modelling the redox front movement in a KBS-3 nuclear waste repository
L Romero, L Moreno, I Neretnieks
Department of Chemical Engineering, Royal Institute of Technology, Stockholm, Sweden
May 1993

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Annual Report 1992**
SKB
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Verification of the geostatistical inference code INFERENS, Version 1.1, and demonstration using data from Finnsjön
Joel Geier
Golder Geosystem AB, Uppsala
June 1993

TR 93-10
Mechanisms and consequences of creep in the nearfield rock of a KBS-3 repository
Roland Pusch, Harald Hökmark
Clay Technology AB, Lund, Sweden
December 1992

TR 93-11
**Post-glacial faulting in the Lansjärv area, Northern Sweden.
Comments from the expert group on a field visit at the Molberget post-glacial fault area, 1991**
Roy Stanfors (ed.)[1], Lars O Ericsson (ed.)[2]
[1] R S Consulting AB
[2] SKB
May 1993

TR 93-12
Possible strategies for geoscientific classification for high-level waste repository site selection
Lars Rosén, Gunnar Gustafson
Department of Geology, Chalmers University of Technology and University of Göteborg
June 1993

TR 93-13
A review of the seismotectonics of Sweden
Robert Muir Wood
EQE International Ltd, Warrington, Cheshire, England
April 1993

TR 93-14
Simulation of the European ice sheet trough the last glacial cycle and prediction of future glaciation
G S Boulton, A Payne
Department of Geology and Geophysics, Edinburgh University, Grant Institute, Edinburgh, United Kingdom
December 1992

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Analysis of the regional groundwater flow in the Finnsjön area
Anders Boghammar, Bertil Grundfelt, Hans Widén
Kemakta Konsult AB
June 1993

TR 93-16
Kinetic modelling of bentonite - canister interaction.
Implications for Cu, Fe, and Pb corrosion in a repository for spent nuclear fuel
Paul Wersin, Jordi Bruno, Kastriot Spahiu
MBT Tecnologia Ambiental, Cerdanyola, Spain
June 1993

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Oxidation of uraninite
Janusz Janeczek, Rodney C Ewing
Department of Earth & Planetary Science, University of New Mexico, Albuquerque, NM, USA
June 1993

TR 93-18
Solubility of the redox-sensitive radionuclides ^{99}Tc and ^{237}Np under reducing conditions in neutral to alkaline solutions. Effect of carbonate
Trygve E Eriksen[1], Pierre Ndalamba[1], Daqing Cui[1], Jordi Bruno[2], Marco Caceci[2], Kastriot Spahiu[2]
[1] Dept. of Nuclear Chemistry, Royal Institute of Technology, Stockholm, Sweden
[2] MBT Tecnologia Ambiental, Cerdanyola, Spain
September 1993

TR 93-19
Mechanical properties of fracture zones
Bengt Leijon
Conterra AB
May 1993

TR 93-20
The Fracture Zone Project - Final report
Peter Andersson (ed.)
Geosigma AB, Uppsala, Sweden
September 1993

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Development of "CHEMFRONTS", a coupled transport and geochemical program to handle reaction fronts
Catharina Bäverman
Department of Chemical Engineering, Royal Institute of Technology, Stockholm, Sweden
October 1993

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Carbon transformations in deep granitic groundwater by attached bacterial populations characterized with 16S-rRNA gene sequencing technique and scanning electron microscopy
Susanne Ekendahl, Johanna Arlinger, Fredrik Ståhl, Karsten Pedersen
Department of General and Marine Microbiology, University of Göteborg, Göteborg, Sweden
October 1993

TR 93-23
Accelerator transmutation of wastes (ATW)
– Prospects and safety
Waclaw Gudowski, Kjell Pettersson, Torbjörn Thedéen
Royal Institute of Technology, Stockholm, Sweden
November 1993

TR 93-24
Direct fault dating trials at the Äspö Hard Rock Laboratory
R H Maddock, E A Hailwood, E J Rhodes, R Muir Wood
October 1993

TR 93-25
Radially convering tracer test in a low-angle fracture zone at the Finnsjön site, central Sweden.
The Fracture Zone Project – Phase 3
Erik Gustafsson, Rune Nordqvist
Geosigma AB, Uppsala, Sweden
October 1993

TR 93-26
Dipole tracer experiment in a low-angle fracture zone at Finnsjön – results and interpretation.
The Fracture Zone Project – Phase 3
Peter Andersson, Rune Nordqvist, Tony Persson, Carl-Olof Eriksson, Erik Gustafsson, Thomas Ittner
Geosigma AB, Uppsala, Sweden
November 1993

TR 93-27

An approach to quality classification of deep groundwaters in Sweden and Finland

Marcus Laaksoharju[1], John Smellie[2],
Paula Ruotsalainen[3], Margit Snellman[4]
[1] GeoPoint AB, Stockholm, Sweden
[2] Conterra AB, Uppsala, Sweden
[3] Fintact Ky, Helsinki, Finland
[4] Imatran Voima Oy, Vantaa, Finland

November 1993