SKB

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Plan 86
Costs for management of the radioactive waste from nuclear power production.

Swedish Nuclear Fuel and Management Co

June 1986

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PLAN 86

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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 are planning, building and operating a number of different facilities and systems. The power utilities have commissioned SKB to execute this work.

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, which is described in the report.

Since disposal of the high-level (long-lived) waste will not commence until some time into the 21st century, continued R&D activities may reveal new methods, that can affect both system design and costs. This is expected to lead to overall simplifications in the design.

The facilities and systems that exist or have been planned are:

- Transportation system for radioactive waste products.
- Central interim storage facility for spent nuclear fuel, CLAB.
- Encapsulation station for spent nuclear fuel.
- Final repository for spent fuel and long-lived waste.
- Final repository for reactor waste and decommissioning waste, SFR.

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

The total future costs of the Swedish waste management system, starting in 1987, have been calculated to be SEK 39 billion in January 1986 prices, including contingency allowances for unforeseen costs. These costs will be incurred over a period of about 60 years. SEK 5.3 billion has been spent through 1986.

ABBREVIATIONS

BS	Encapsulation station for spent nuclear fuel and core components
BWR	Boiling water reactor (ASEA-ATOM)
CLAB	Central interim storage facility for spent nuclear fuel
GA	Common facilities
GD	Common parts of a facility
NPP	Nuclear power plant
PWR	Pressurized water reactor (Westinghouse)
SFL	Final 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 2015) and the treatment station
SFL 4	- for decommissioning waste from interim storage facility and treatment station
SFL 5	- for core components etc
SFR 1	Final repository for low- and intermediate-level waste from reactor operation
SFR 3	Final repository for decommissioning waste from the nuclear power plants
SKI	Swedish Nuclear Power Inspectorate
SKN	National Board for Spent Nuclear Fuel
SSI	National Institute of Radiation Protection

1 PREMISES

1.1 GENERAL

According to the "Law concerning financing of future expenses for spent nuclear fuel etc" (1981:669 with amendment 1984:5), the reactor owners are obliged to prepare a calculation of the costs for all of the measures that are required in order to manage the spent nuclear fuel from the reactors and radioactive waste deriving from it and to decommission and dismantle the reactor plants. SKB prepares this cost calculation on behalf of the nuclear power utilities. The calculations are based on a scenario for energy production, waste quantities and required measures that is presented in this report. The cost calculation is submitted to the National Board for Spent Nuclear Fuel and is used as a basis for calculating 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 in such a manner that the future costs are not 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 and has been found to meet high standards of safety and radiation protection.

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

Facilities for which siting decisions have not yet been made have been assumed in the cost calculation to be located in the inland of Norrland, the northern part of Sweden. A siting in south or central Sweden would lead to lower costs.

The storage facilities and the transportation system are designed to accommodate all spent nuclear fuel and radioactive waste that comes from the twelve Swedish nuclear power units in service until the year 2010. This assumption includes margins for changes in both annual waste production and the availability and service life of the reactors.

The Financing Act only deals with the costs that are attributable to management and disposal of spent nuclear fuel and waste deriving from it and to decommissioning and dismantling of the reactor plants. The system reported here has also taken into account waste from non-electricity-generating facilities, mainly in Studsvik, which is estimated to constitute 4% of the total waste volume, as well as operating waste from nuclear power plants.

1.2 ENERGY PRODUCTION AND WASTE QUANTITIES

Energy production in the Swedish nuclear power plants totalled 56 TWh in 1985, which corresponds to an energy utilization factor of 74%. This value is expected to increase during the coming years. In calculating expected future energy production, however, a utilization factor of 74% is assumed in this report - a value that is also used in planning future expansions of power production (ref. 2).

Electricity production in the nuclear power plants has been estimated to reach a total of 1 900 TWh. The quantity of fuel consumed for this production is about 7 800 tonnes of uranium, of which 6 000 tonnes of uranium from BWR reactors and 1 800 tonnes of uranium from PWR reactors. Table 1.1 presents a summary of electricity production and fuel consumption in the different reactor units.

Most of the spent fuel will be stored in CLAB for about 40 years and then encapsulated and emplaced in a final repository. In this report only 140 tonnes of uranium are planned to be reprocessed at BNFL, from which no waste will be returned. No reprocessing of Swedish fuel is planned to take place at Cogema. The fuel that has already been delivered to Cogema (57 tonnes) will be exchanged for West German MOX fuel. This means that no waste from reprocessing will have to be managed and disposed of in Sweden. Some financial commitments for reprocessing still remain, however.

In addition to spent fuel, the Swedish nuclear power program gives rise to low- and intermediate-level operating waste from the nuclear power reactors, CLAB and the treatment plant, as well as decommissioning waste when the plants are dismantled. Estimated waste quantities are summarized in Table 1.2. They are described in detail in Appendix 1. The activity content of the different waste types varies widely. The handling and disposal requirement will therefore be dependent on waste type.

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

Reactor and date of com. operation	Thermal capacity MW	Net electrical capacity MW	Energy production TWh through 1985	per year from 1986	Total	Uranium consumption, tU Discharged through 1985	Total
B1 75-07-01	1800	595	37.833	3.86	134	160	592
B2 77-07-01	1800	595	34.213	3.86	131	140	572
R1 76-01-01	2270	750	41.389	4.86	163	128	704
R2 75-05-01	2432	800	44.772	5.19	174	132	625
R3 81-09-09	2775	915	18.835	5.93	167	46	597
R4 83-11-21	2775	915	14.752	5.93	163	38	583
O1 72-02-06	1375	440	35.996	2.85	107	155	503
O2 74-12-15	1800	595	41.998	3.86	138	170	603
O3 85-08-15	3020	1050	3.839	6.81	174	-	698
F1 80-12-10	2928	972	31.774	6.30	189	129	827
F2 81-07-07	2928	972	26.724	6.30	184	76	764
F3 85-08-22	3020	1050	4.156	6.81	174	-	699
BWR	20941	7019	257.922	45.51	1394	958	5962
PWR	7982	2630	78.359	17.05	504	216	1805
All	**28923**	**9649**	**336.281**	**62.56**	**1898**	**1174**	**7767**

Energy utilization factor assumed to be 74%

Burnup for BWR: 1986-90 32 MWd/kgU After 1990 36 MWd/kgU

Burnup for PWR: 1986-90 38 MWd/kgU After 1990 40 MWd/kgU

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

Product	Principal origin	Unit	No. of units	Volume in final repository m^3
Spent fuel		canisters	5 600	12 600
Alpha-contaminated waste	Low- and intermediate-level waste from Studsvik	drums	18 000	6 000
Core components	Reactor internals	moulds	2 300	19 000
Low- and intermediate level waste	Operating waste from nuclear power plants and treatment plants	drums and moulds	102 700	95 000
Decommissioning waste	From decommissioning of nuclear power plants and treatment plants	10-20 m^3 containers	5 600	113 000
Total quantity			**134 000**	**246 000**

1.3 PRINCIPLES OF THE WASTE MANAGEMENT SYSTEM

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

- Short-lived waste will be disposed of immediately after it is obtained.
- Spent fuel will be stored for about 40 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.

These premises also constitute the planning basis for the research and development activities. The premises may be modified in the future, both in view of the results of the continued R&D work and as a consequence of future political decisions. Studies have shown that the system contains considerable flexibility (ref. 3).

2 FACILITIES AND SYSTEMS

2.1 GENERAL

In order 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. A more detailed description is provided in the appendix portion of this report.

Since the high-level (long-lived) waste will not be finally disposed of until a number of years into the 21st century, new methods may lead to changes in both design and costs.

Figure 2.1 shows what facilities are included and how the waste is planned to be managed. Some of the facilities are under construction or already in operation, which provides a good basis for the cost calculations. In the case of other facilities, the 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 layout drawings have been prepared. Two facilities, SFL 1 and SFR 2, which were previously included in the system, have been excluded as of this year. The timetable for the construction and operation of the facilities is presented in Figure 2.2.

2.2 RESEARCH AND DEVELOPMENT

The purpose of the research activities is to gather the necessary information and data and to develop suitable methods for a safe final disposal of the radioactive waste. An updated research and development programme will be presented in September 1986.

The work includes fundamental studies for the purpose of gaining a deeper understanding of the processes that determine the safety of the final repository as well as studies of possible repository sites and alternative designs of the barrier system in a final repository (ref. 4).

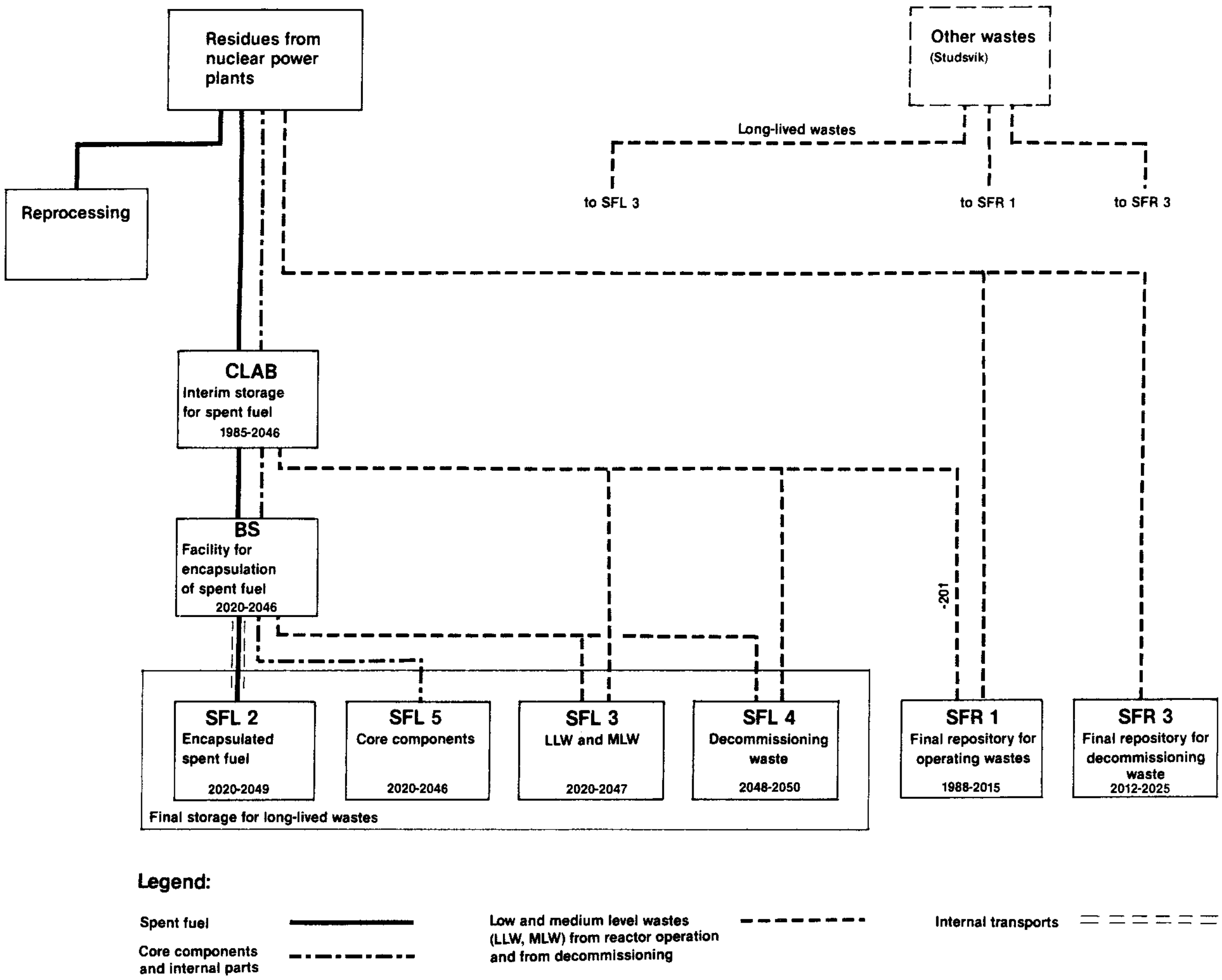

Figure 2.1. Schematic handling chain for the radioactive waste products of nuclear power.

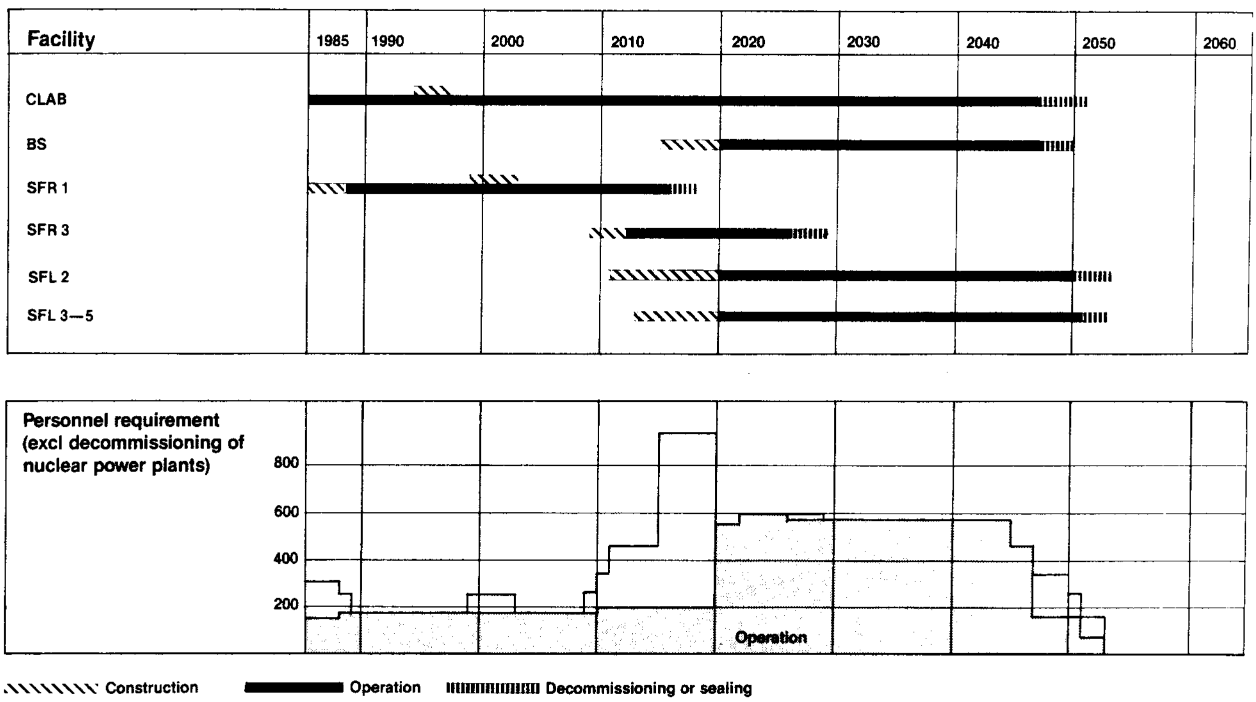

Figure 2.2. Facilities for management of the waste products of nuclear power. Timetable and personnel requirements.

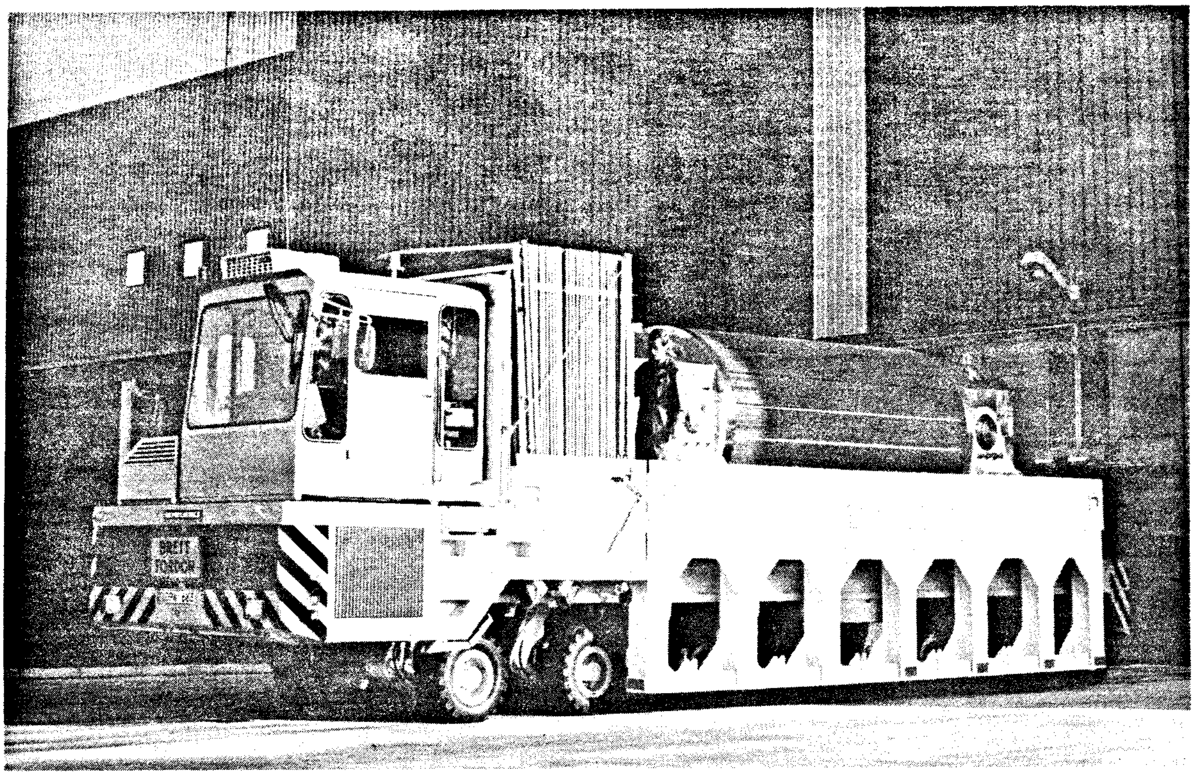

Figure 2.3. Transport cask for spent nuclear fuel loaded on terminal vehicle.

During the 1990s, detailed geological investigations will be carried out on one or a couple of sites. These include sinking of a shaft or tunnel down to repository level. From the latter part of the 1990s, plans also call for pilot tests and test facilities where equipment and work methods will be tested.

Starting in 2010, when the construction of the final repository for the long-lived waste will be commenced, no separate R&D costs will be reported. They will instead be included in the purchaser's planning and design costs, which are included in the investment costs.

2.3 TRANSPORTATION SYSTEM

The transportation system is based mainly on sea transports and its principal components are a ship, M/S Sigyn, transport containers and transport equipment at the nuclear power plants and other facilities (see also Appendix 2). The system is designed for accommodating all types of radioactive waste.

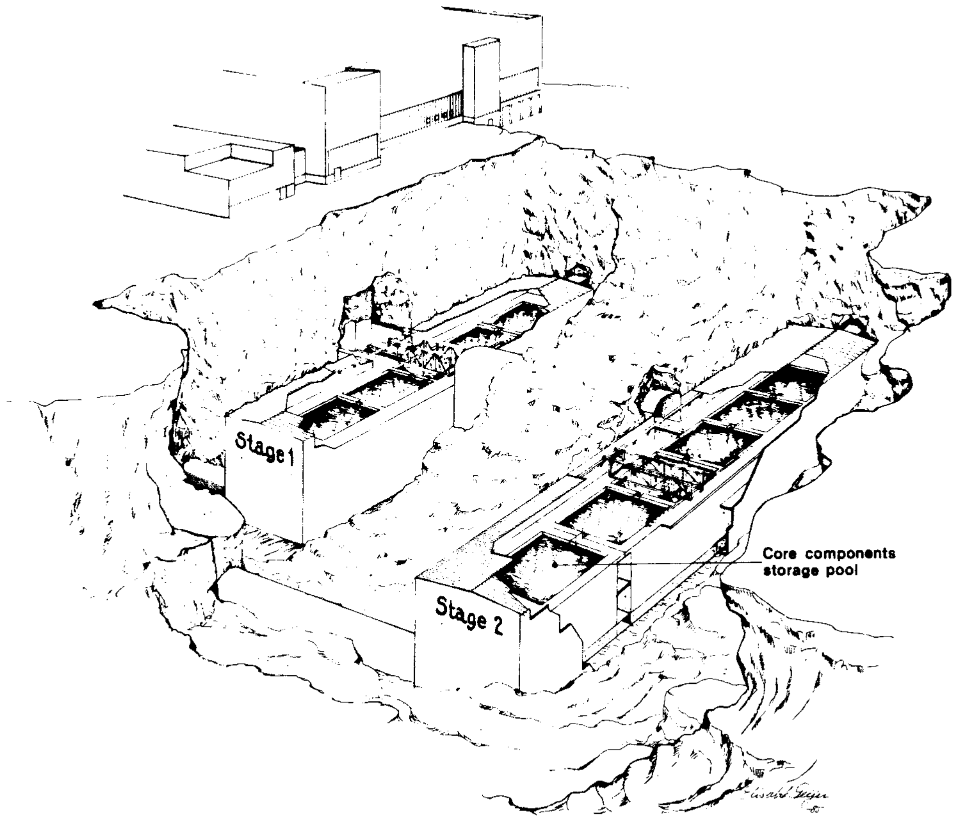

Figure 2.4. CLAB storage section phases 1 and 2.

Containers designed to meet high demands on radiation shielding and to withstand large external stresses are used for the transports.

During loading and unloading, the containers are transported short distances between the vessels and the storage facilities by special terminal vehicles.

The transportation system, has been in operation since 1983.

Since the site of the final repository for long-lived waste, SFL, has not yet been determined, it has been assumed in the cost calculations that in addition to sea transports also railway transports will be used.

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 during 1985 and can store just over 3,000 tonnes of fuel (uranium weight) in four pools in its present size (see also Appendix 3). In the mid-1990s, the capacity of the facility will be expanded so that all fuel from the Swedish nuclear power program, about 8,000 tonnes of uranium, can be stored in CLAB. Core components and reactor internals will also be stored in the facility prior to final disposal in the SFL.

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

The storage pools are located in a rock cavern whose roof is located about 30 m below the surface.

Storage capacity is planned to be expanded by the construction of a new rock cavern parallel to the existing one.

2.5 FINAL REPOSITORY FOR LONG-LIVED WASTE, SFL AND ENCAPSULATION STATION FOR SPENT FUEL, BS

Common facilities

The final repository for long-lived waste, SFL, and the encapsulation station for spent fuel, BS, are assumed in this report to be situated at the same site in the inland of Norrland, the northern part of Sweden. The transports are assumed to take place by ship to an existing harbour and from there by rail to the final repository.

Service facilities such as housing, workshops, water supply and sewerage, electricity supply, concrete station, canteens, guard room etc will be built at the SFL. A compacting plant for bentonite and a crushing plant for rock material will also be provided on the site.

The common facilities also include the central administration building and the site organization.

There are four different final repository areas at the SFL:

SFL 2 for spent fuel

SFL 3 for low- and intermediate-level operating waste from CLAB (after 2015) and long-lived waste from Studsvik

SFL 4 for decommissioning waste from the interim storage facility and treatment station

SFL 5 for core components and reactor internals

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

Encapsulation station for spent fuel, BS

The spent fuel is assumed to be encapsulated prior to disposal in copper canisters in accordance with the method described in KBS-3 (ref. 1). The empty spaces in the canisters are filled with lead in order to enable the canister to resist the high water pressures prevailing at the respository level. Fuel boxes, the core components and other active metal scrap are embedded in concrete moulds.

In the scenario chosen, the encapsulation station has been located at the SFL, directly above the final repository for the spent fuel. It is situated above ground.

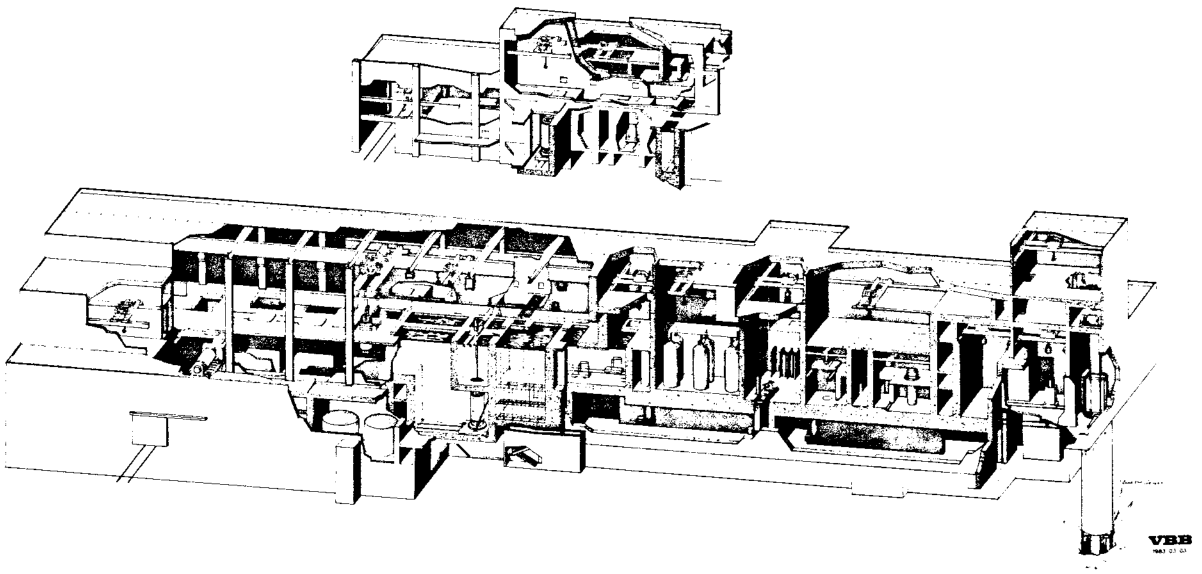

Figure 2.5. Treatment station for spent fuel.

The facility consists of the following main sections (see also Appendix 4):

- Arrival and receiving section.
- Encapsulation and dispatch section for fuel, with elevator down to the repository area.
- Encapsulation section for core components etc.
- Service section containing stores, lead melting equipment etc.
- Auxiliary systems with cooling and purification systems as well as electricity and control equipment.
- A side building that houses personnel and office quarters.

Transport casks containing fuel or core components etc arrive at the treatment station by rail. Reception takes place under water in the same manner as in CLAB. Further handling of the fuel takes place dry in a hot cell.

The facility is designed for an average annual capacity of 210 fuel canisters (one canister per day for 10 months), corresponding to about 300 tonnes U/year. The facility is mainly operated in the daytime.

SFL 2

SFL 2, the final repository for spent fuel, is situated directly below the encapsulation plant at a depth of about 500 m. It consists of a series of parallel deposition tunnels situated in two levels. The deposition tunnels are connected by two transport tunnels.

The waste is emplaced in drilled vertical holes in the floor of the tunnel. The copper canisters are surrounded in the deposition holes by a layer of compacted bentonite.

The deposition tunnels are backfilled with a mixture of bentonite (10-20%) and sand. Backfilling takes place in stages after deposition has been completed in 8-10 tunnels.

SFL 3-5

All low- and intermediate-level operating waste that is to be disposed of after 2015, when SFR 1 has been closed, is placed in SFL 3, 4 or 5, depending on the type of waste in question. The

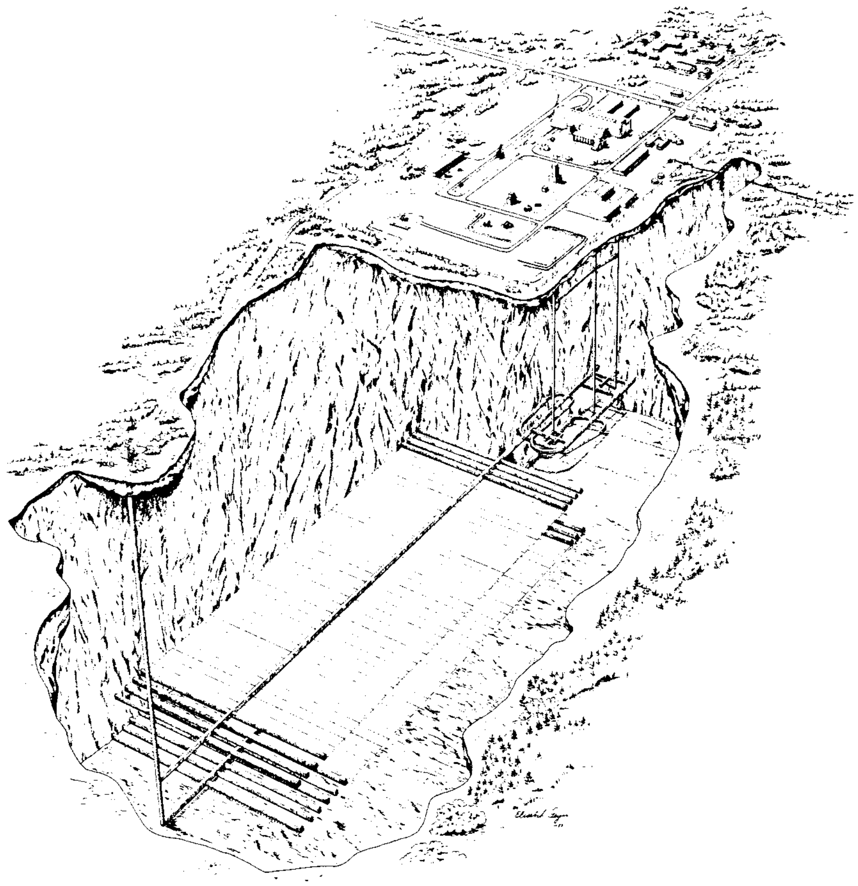

Figure 2.6. SFL-BS (not including SFL 3-5). General plan.

storage chambers, which are located at a depth of about 500 m, are reached through a common shaft. The shaft is situated a few kilometres from SFL 2.

SFL 3 consists of a long rock cavern. The waste is stacked in concrete cells, 2.5 m square, after which the remaining empty space in the cells is filled with concrete. All handling is remote-controlled. The space between the concrete cells and the rock is filled up with sand-bentonite mixture.

SFL 4 consists of the tunnel system that has to be built for SFL 3 and SFL 5. Low-level decommissioning waste from CLAB and the BS, transport casks etc are placed in SFL 4 before the facility is sealed.

SFL 5 consists of two tunnels, in which the concrete moulds for core components etc are placed and grouted-in with concrete.

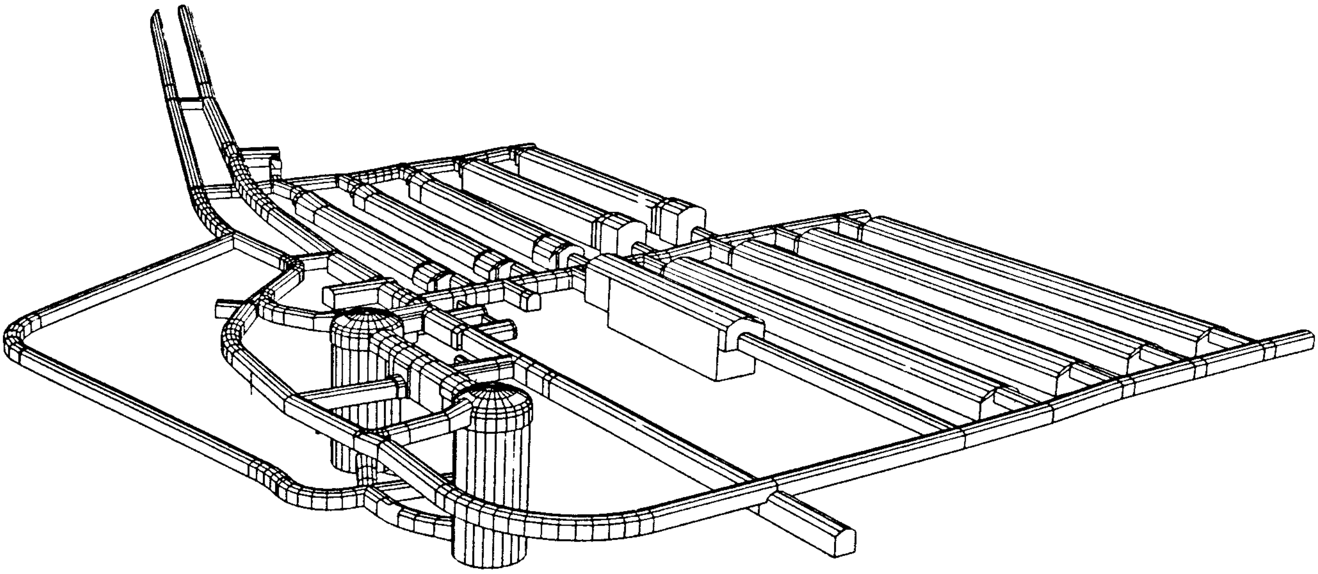

Figure 2.7. SFR in its completed form.

2.6 FINAL REPOSITORY FOR REACTOR WASTE, SFR

A final repository for operating waste from the nuclear power stations is being built at the Forsmark nuclear power station (see also Appendix 5). 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 entrance tunnels lead out to the repository area. A final repository for decommissioning waste from the nuclear power plants, SFR 3, is planned in connection with SFR 1. SFR 2, which is intended for core components etc, is assumed in this report not to be built, being instead 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 the SFR.

SFR 1

SFR 1 will consist of five to six 160 m long rock vaults and two 70 m high cylindrical rock caverns containing concrete silos. The waste containing most of the radioactive substances will be placed in the silos. In all, SFR 1 will hold 90,000 m^3 of waste, of which about 37,000 m^3 in silos.

The facility is expected to be taken into service in 1988 and sealed in the mid-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 5-6 rock vaults of a type similar to those in SFR 1. Most of the decommissioning waste can be transported in standard containers, which are emplaced in the rock vaults without being emptied. A total of 104,000 m^3 of decommissioning waste will be disposed of in SFR 3.

2.7 DECOMMISSIONING OF NUCLEAR POWER PLANTS

The measures required for management of the radioactive waste products of nuclear power also include decommissioning the facilities after they have been taken out of operation. A separate study has been carried out of the technology and costs for decommissioning the Swedish nuclear power plants (ref. 5) and these results are used here (see also Appendix 6).

The timetable for decommissioning of the nuclear power plants is influenced by a number of different factors. Dismantling can be carried out in a safe manner a short time after shutdown, but there are advantages with deferred dismantling. Here it is assumed that the plants are dismantled early, which is conservative from the viewpoint of costs, owing to the effect of the real interest rate.

With regard to resource utilization and the reception capacity in CLAB and in the 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 is begun, removal of fuel, decontamination and preparations for dismantling (shutdown operation) take place. During this period, the personnel force can be gradually reduced. The actual work of dismantlement is expected to take five years per unit and to employ an average of a couple of hundred persons.

The radioactive waste from decommissioning is all low- and intermediate-level. However, the activity level varies considerably between different parts. The waste with the highest activity, the reactor internals, is assumed to be stored in CLAB for a period of about 30-40 years before being disposed of in SFL 5. Other radioactive decommissioning waste will be transported directly to SFR 3 and deposited there. A large quantity can be declassified.

3 COSTS

3.1 GENERAL

All costs for management and disposal of the radioactive waste products described in chapter 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 account, costs incurred up to and including 1986 are distinguished from future costs. The future costs are estimated at January 1986 prices. Previously incurred costs are quoted in current prices.

New cost calculations have been carried out for all facilities and systems. Experience from CLAB, SFR and the transportation system has thereby been incorporated.

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

The costs for different facilities are reported here broken down into the following items: investment, reinvestment, operation, and decommissioning and sealing. Normally, only those costs that arise before a facility or part of a facility is taken into operation are attributed to investment costs. In SFL 2, 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.

Some costs that do not fall under the Financing Act are also reported (operating waste from the nuclear power plants and waste from Studsvik).

3.2 CALCULATION METHOD

The cost calculations are based on functional descriptions for each facility, which result in layout drawings, equipment lists, personnel forecasts etc (see Appendices). For facilities and systems that are in operation or under construction, 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 price, experience gained in construction of the nuclear power plants, CLAB and the SFR has been drawn on.

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

The final item included in the base costs is secondary costs. These include costs for administration, engineering, purchasing and inspection as well as costs for temporary buildings, machines, housing, offices and the like. The amounts allowed for these costs are relatively well known, even though the variations can be large depending on the nature of the work and external circumstances.

A contingency allowance is added to the calculated base costs for unforeseen items. The size of the contingency allowance is determined object-by-object on the basis of the risks of complications and the facility's engineering level. This means that the allowance is greatest for those facilities that are far in the future. On the average it is about 28%.

3.3 REPORTING OF FUTURE COSTS

The costs reported in this section are given in January 1986 prices and are not present-value-calculated. However, the costs are distributed in time, which permits discounting with different values for the real interest rate.

Table 3.1 shows the future costs for waste management. The costs are distributed by object and category of cost. The total future costs from 1987 amount to MSEK 39 300.

Table 3.1. **Future costs (MSEK) from 1987, including contingency allowance for unforeseen items (January 1986 prices).**

Object	**Cost category**	**Total future costs**	**Total future costs per object**	**Future costs under Financing Act 1)**
SKB, Adm, R&D	-	3 158	3 158	3 158
Transports	Investment	56		
	Reinvestment	440		
	Operation	1 013	1 509*)	1 271
Decommissioning NPP	Shutdown operation	873		
	Dismantling	6 690	7 563	7 563
CLAB	Investment	621		
	Reinvestment	594		
	Operation	4 889		
	Decommissioning	228	6 331	6 331
SFL-BS GA	Investment	1 876		
	Reinvestment	116		
	Operation	1 407		
	Decommissioning	132	3 531*)	3 422
BS	Investment	2 310		
	Reinvestment	80		
	Operation	4 241		
	Decommissioning	236	6 866	6 866
SFL 2	Investment	2 614		
	Reinvestment	28		
	Operation	407		
	Sealing	2 136		
	Decommissioning	30	5 216	5 216
SFL 3-5 GD	Investment	472		
	Reinvestment	16		
	Operation	166		
	Decom. + sealing	127	781*)	610
SFL 3	Investment	324		
	Operation	16		
	Decom. + sealing	64	403*)	183
SFL 4	Investment	27		
	Operation	11		
	Decom. + sealing	1	39	39
SFL 5	Investment	103		
	Operation	19		
	Decom. + sealing	50	172	172
SFR GD	Investment	136		
	Decom. + sealing	2	138*)	17
SFR 1	Investment	297		
	Operation	240		
	Decom. + sealing	60	597*)	75
SFR 3	Investment	275		
	Operation	98		
	Decom. + sealing	35	408*)	392
Reprocessing 2)	-	2 614	2 614	2 614
Total			**39 326**	**37 929**

* Also includes costs outside the Financing Act (in accordance with 1)).
Total over all concerned objects: Studsvik waste etc MSEK 588.
Other low- and intermediate-level waste MSEK 788.

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

2) Costs of reprocessing include costs at BNFL and for remaining contracts with COGEMA.

The table also separates costs under the Financing Act, i e the total cost less costs for low- and intermediate-level operating waste and waste from Studsvik. The future costs under the Financing Act from 1987 amount to MSEK 37 900.

Table 3.2 shows the future costs broken down by object and distributed over time.

Figure 3.1 shows the annual future costs.

Table 3.2. **Future costs per object under the Financing Act[1] distributed over time (MSEK, January 1986 prices).**

Year	SKB Adm, R&D	Transp.	Decom. NPP	CLAB	SFL-BS	SFR 1+3	Reproc.	Total costs	Accumulated costs
1987-89	270	96	0	253	0	29	844	1 492	1 492
1990-94	498	73	0	526	0	6	1 141	2 244	3 736
1995-99	483	69	0	920	0	33	629	2 134	5 870
2000-2009	1 907	260	0	906	0	27	0	3 100	8 970
2010-2019	0	158	6 893	924	5 660	322	0	13 957	22 927
2020-2029	0	349	670	1 024	3 135	67	0	5 245	28 172
2030-2039	0	139	0	877	3 621	0	0	4 637	32 809
2040-2049	0	126	0	882	3 002	0	0	4 010	36 819
2050-2059	0	0	0	19	1 089	0	0	1 108	37 927
Total from 1987	**3 158**	**1 271**	**7 563**	**6 331**	**16 508**	**484**	**2 614**	**37 927**	

1) Total costs less costs for Studsvik waste etc and other low- and intermediate-level wastes.

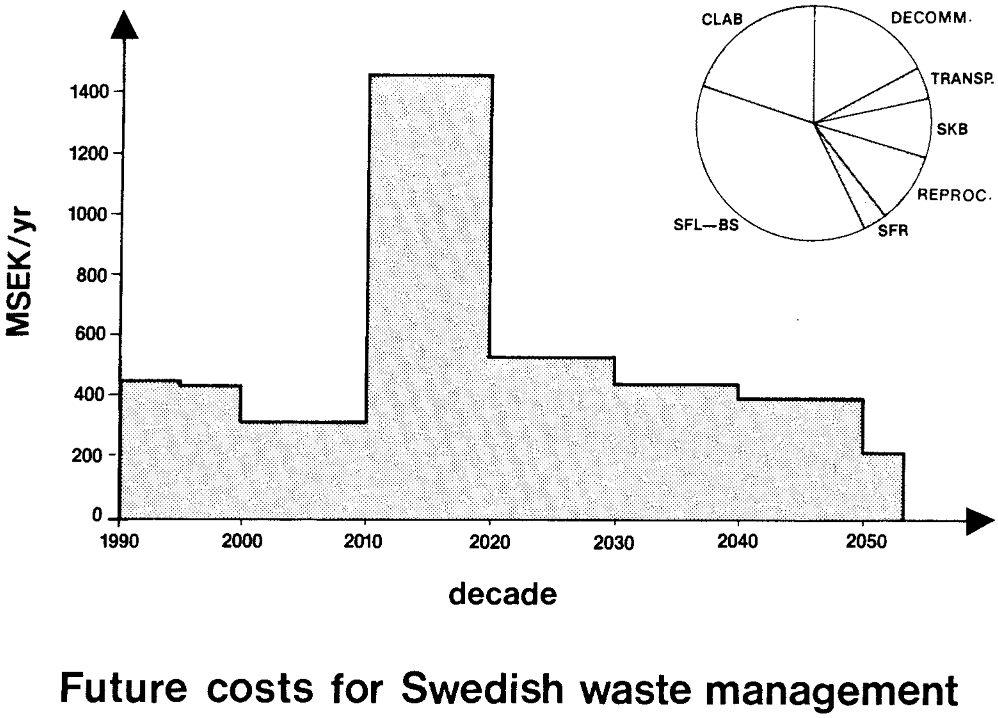

Figure 3.1. Annual future costs and distribution of the total cost among different facilities. (January 1986 prices)

3.4 PREVIOUSLY INCURRED COSTS

Table 3.3 reports costs incurred through 1985 in current prices and 1986 budgeted costs.

Table 3.3. Incurred and estimated costs through 1986 (MSEK current prices).

Object	Cost category	Costs incurred through 1985	Estimated costs 1986
SKB	-	334	82
Transports	Investment	129	3
	Operation	193	57
CLAB	Investment	1 730	20
	Operation	95	158*)
SFR 1	Investment	255	265
	Operation		1
Reprocessing	-	1 414	614
Total		**4 150**	**1 200**

*) Including an one-time-payment of 75 MSEK.

3.5 MARGINAL COSTS

The costs of the facilities per unit are presented in Table 3.4, both as average cost and as marginal cost. The marginal costs have been calculated on the basis of an estimate of the variable cost portion for each facility section. The capacity of the encapsulation station 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 relatively roughly estimated and only apply within a limited interval (approx. 20%) of the quantities given in column 3.

Table 3.4. **Marginal costs for different parts of the system. (January 1986 prices)**

Object	Cost MSEK		Quantity	Unit (Parameter)	kSEK/ unit	Marg cost kSEK/unit	Remarks
TRANSPORTS							Includes costs for all transports of the waste
Total	1 950		13 600	trpt unit	143		Ship-transported fuel and waste. The trpt. unit is a cask or container
Spent fuel	1 410		7 627	ton fuel	185	51	Cost incl. core components and LM waste from CLAB. 1 664 tonnes of fuel internally transported OKG-CLAB
Operating waste from NPP	170		59 300	m^3 LM waste	2.9	0.3	With ship transport from NPP to SFR 1 of total 72 800 m^3
Decommissioning waste from NPP	270		68 000	m^3 decommissioning waste	4.0	0.3	With ship transport from NPP to SFR 3 of total 100 000 m^3. Incl. internals to SFL 5
Studsvik waste	100		13 060	m^3 waste	7.7	0.6	Varying waste
INTERIM STORAGE FACILITY							
CLAB	8 700		7 627	ton fuel	1 141	330	Incl. core components and reactor internals (max. 10% of storage voume)
FINAL DISPOSAL							
SFL-BS total	17 008		7 627	ton fuel	2 230	1 020	
		alt.	5 560	copper canister	3 059	1 400	
BS	8 710		7 627	ton fuel	1 142	540	Incl. part of SFL GA
		alt.	5 560	copper canister	1 567	740	and core comp.
SFL 2	6 530		7 627	ton fuel	856	460	Incl. part of SFL GA
		alt.	5 560	copper canister	1 175	640	
SFL 3	910		11 000	m^3 LM waste	83	21	Incl. part of SFL GA and redist. SFL 3-5
SFL 4	50		10 300	m^3 dec. waste	4.9	1.5	Incl. part of SFL GA and redist. SFL 3-5
SFL 5	810		2 350	mould	345	37	Incl. part of SFL GA
		alt.	7 627	ton fuel	106	14	and redist. SFL 3-5
SFR 1	1 270		89 100	m^3 LL waste	14	6	Incl. redistribution SFR 1 and 3
SFR 3	408		104 000	m^3 decom. waste	3.9	2	Incl. redistribution SFR 1 and 3
All facilities excl. LM waste, Studsvik waste, decommissioning waste and reprocessing	**26 150**		**7 627**	**ton fuel**	**3 430**	**1 390**	**Incl. core components and R&D**

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APPENDICES

1 Spent fuel and radioactive waste in Sweden assuming operation of all plants through 2010.

2 Transportation system.

3 Central interim storage facility for spent nuclear fuel, CLAB.

4 Final repository for long-lived waste, SFL and encapsulation station for spent fuel, BS.

5 Final repository for reactor waste, SFR.

6 Decommissioning of the nuclear power plants.

APPENDIX 1

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

Waste category	Dimensions of waste units in m Ø = 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	0.14x0.14x4.383	32 708	1 924	12 600	BS/SFL 2
Spent PWR fuel	0.214x0.214x4.103	3 924	561		
Core components in storage canisters	0.8x0.8x4.6	450	450	19 500*	BS/SFL 5
Reactor internals in storage canisters	0.8x0.8x4.6	555	555		
Crud waste from CLAB to silo	Ø1.1, L = 1.44	150 28	25 5	260 50	SFR 1 SFL 3
Intermediate-level operating waste from CLAB to silo	1.2x1.2/Ø0.6, L = 0.9	3 990 2 850	370 191	6 900 4 030	SFR 1 SFL 3
Low-level operating waste from CLAB to rock vault	Diverse	1 550 440	90 33	2 100 700	SFR 1 SFL 4
Long-lived waste from Studsvik to silo	Ø0.6, L = 0.9	18 000	380	6 000	SFL 3
Intermediate-level waste from Studsvik to silo	Ø0.6, L = 0.9	5 750	100	1 860**	SFR 1
Low- and intermediate-level waste from Studsvik to rock vault	Ø0.6, L = 0.9/ 1.2x1.2x1.2	11 960	195	5 200**	SFR 1
Intermediate-level operating waste from encaps. stations to silo	1.2x1.2x1.2	520	43	900	SFL 3
Intermediate-level operating waste from nuclear power plants to silo	1.2x1.2x1.2/ Ø0.6, L = 0,9	21 400	1 280	23 600	SFR 1
Intermediate-level operating waste from nuclear power plants in concrete tanks to rock cavern	3.3x1.3x2.15	1 540	515	15 400	SFR 1
Intermediate-level operating waste from nuclear power plants to rock vault	1.2x1.2x1.2/ Ø0.6, L = 0.9	22 270	630	13 700	SFR 1
Low-level operating waste from nuclear power plants to rock vault	Ø0.6, L = 0.9 Diverse	30 240	650	20 100	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.	140	140	4 000	SFR 3
Decommissioning waste from CLAB and BS to rock cavern	2.4x2.4x2.4	640	640	8 900	SFL 4
Transport containers		30	30	400	SFL 4
Total approx.		**164 000**	**13 600**	**246 000**	

*) Incl. the grouted-in BWR fuel boxes that are transported with the fuel.
**) Incl. total about 3 500 m^3 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 and from the interim storage facility. All existing nuclear facilities are located on the coast, permitting sea transports. 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 hereby 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 environment 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. Larger casks will be used for transports from CLAB to the final 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 30 mSv/h. There are also larger containers with thinner walls for waste packages with a lower surface dose rate. The container's transport frame 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

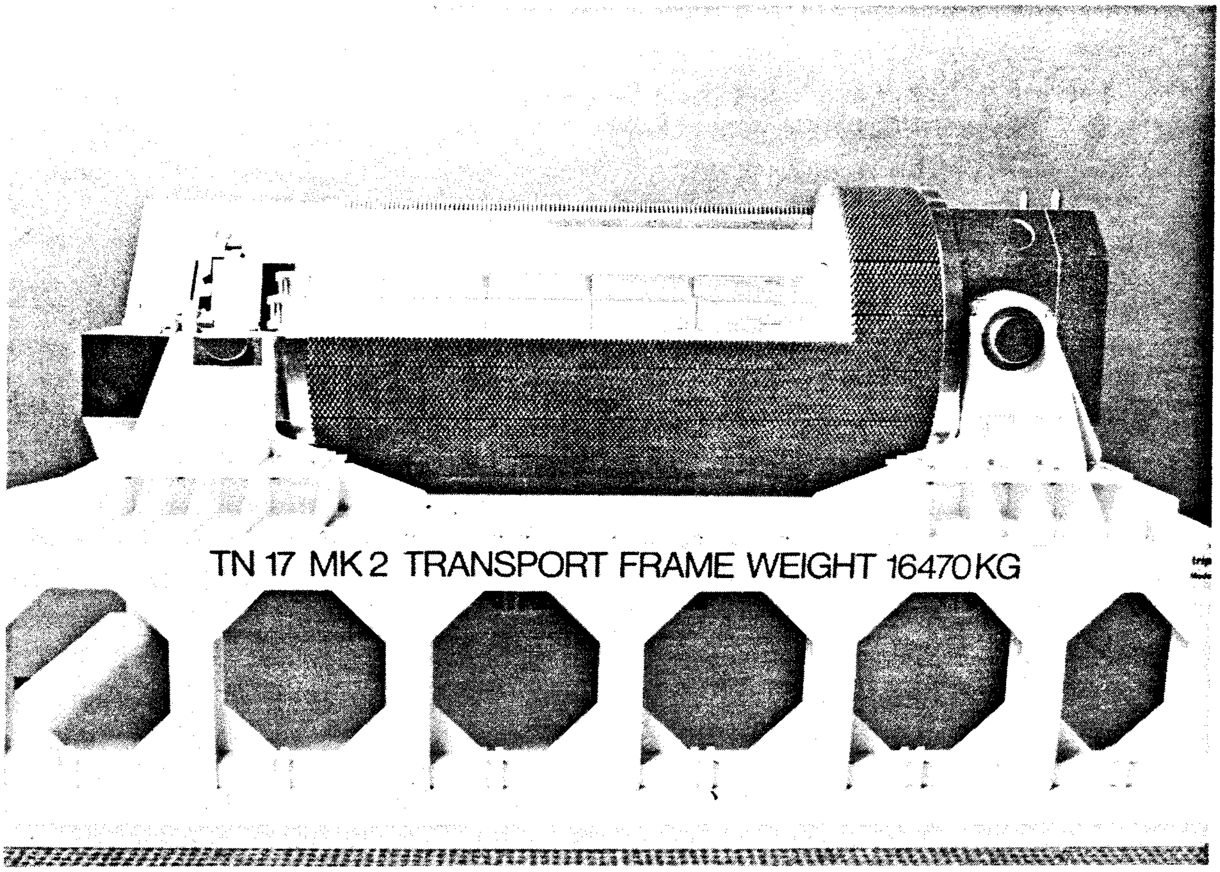

Figure A2.1. Model of TN17/Mk 2 transport cask for spent nuclear fuel.

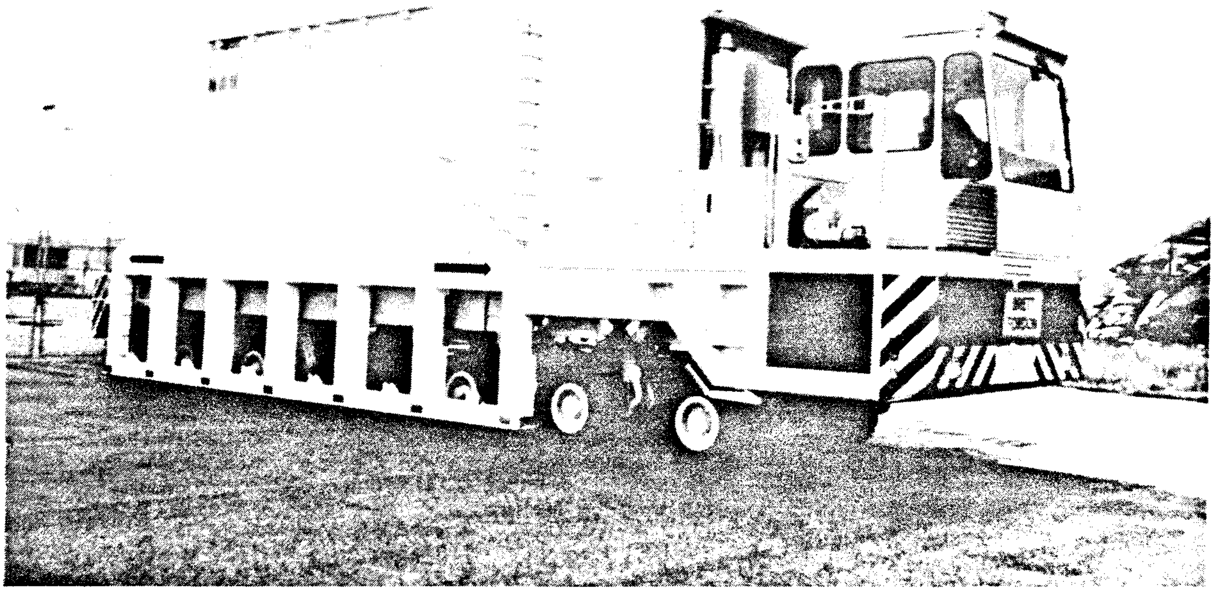

Figure A2.2. Terminal vehicle with ATB-12 K type transport container for intermediate-level waste.

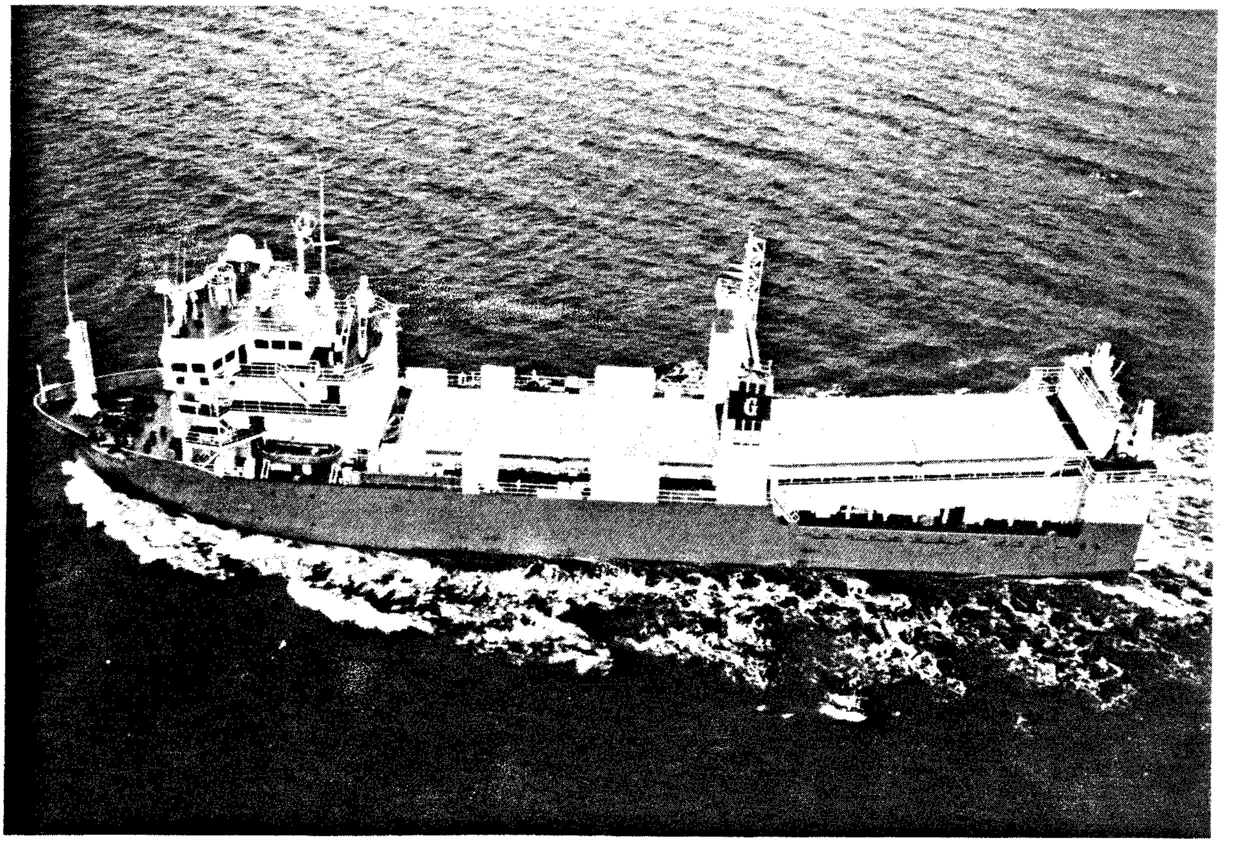

Figure A2.3. M/S Sigyn.

waste accounts for about 50 tonnes. Low-level waste from reactor operation and decommissioning is transported in standard ISO containers, which accompany the waste in the final repository.

Figure A2.2 also illustrates the terminal vehicles that are used. The vehicle consists of a 6-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 lashed to the vessel. Corner and side fittings welded to the deck prevent shifting of the cargo.

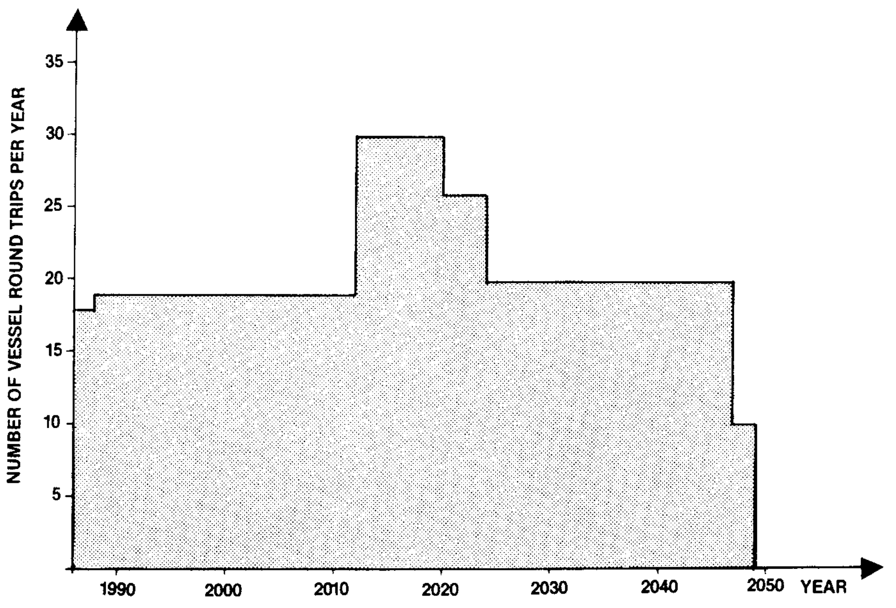

Figure A2.4. Transports of radioactive waste. Number of ship trips per year.

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 250 tonnes to CLAB through June 1986. The system will be in operation until the last of the decommissioning waste from CLAB has been transported to the SFL. This is assumed to occur in 2048. The number of ship trips per year during the operating period is shown in Figure A2.4. Owing to the length of the operating period, about 60 years, it is assumed that the ship will have to be replaced twice.

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 an efficient means of storing all spent fuel discharged from the Swedish nuclear power plants pending encapsulation and final disposal. The storage capacity at the CLAB facility will therefore be sufficient, when fully expanded, to accommodate a fuel quantity equivalent to about 8 000 tonnes of uranium.

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 for approximately 3 000 tonnes of uranium. In phase 2, the storage section will be expanded to full capacity. This will take place in the mid-1990s. In this report, it is assumed that phase 2 will be implemented by construction of a rock cavern parallel to the existing one. See Drawing 3.1.

The above-ground complex consists of several interconnected buildings, see Figure A3.2. 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.

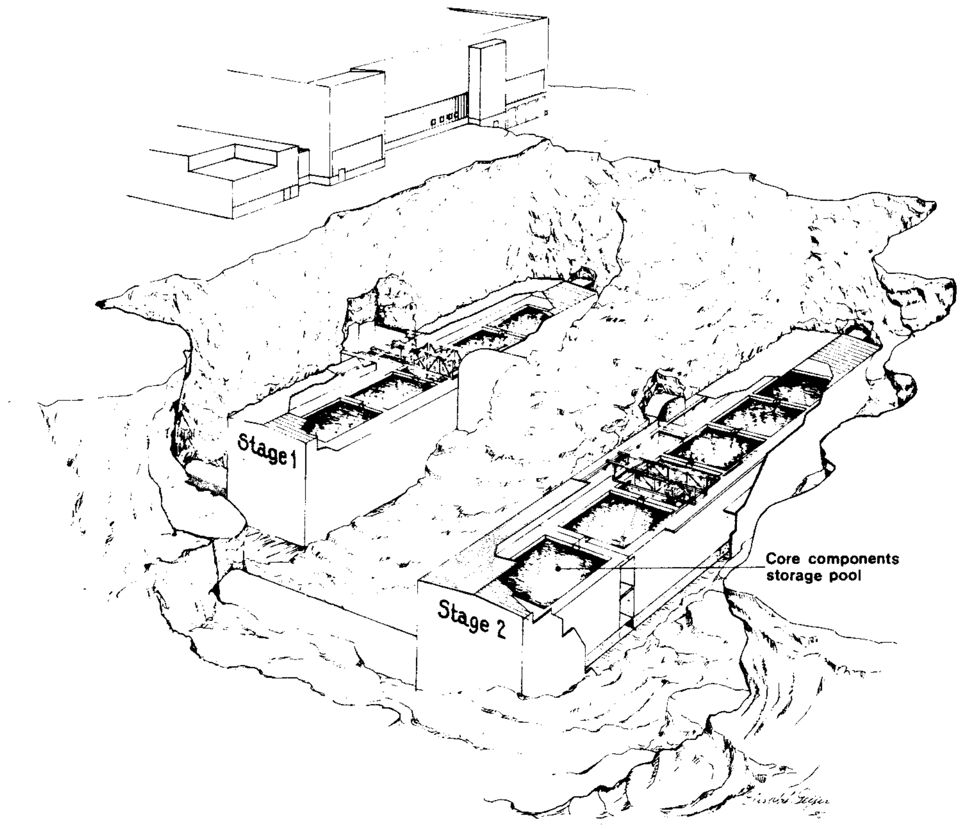

Figure A3.1. CLAB storage section, phases 1 and 2.

All handling of fuel in the reception building, as in the rest of the facility, takes place 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, 4 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 other transport containers 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

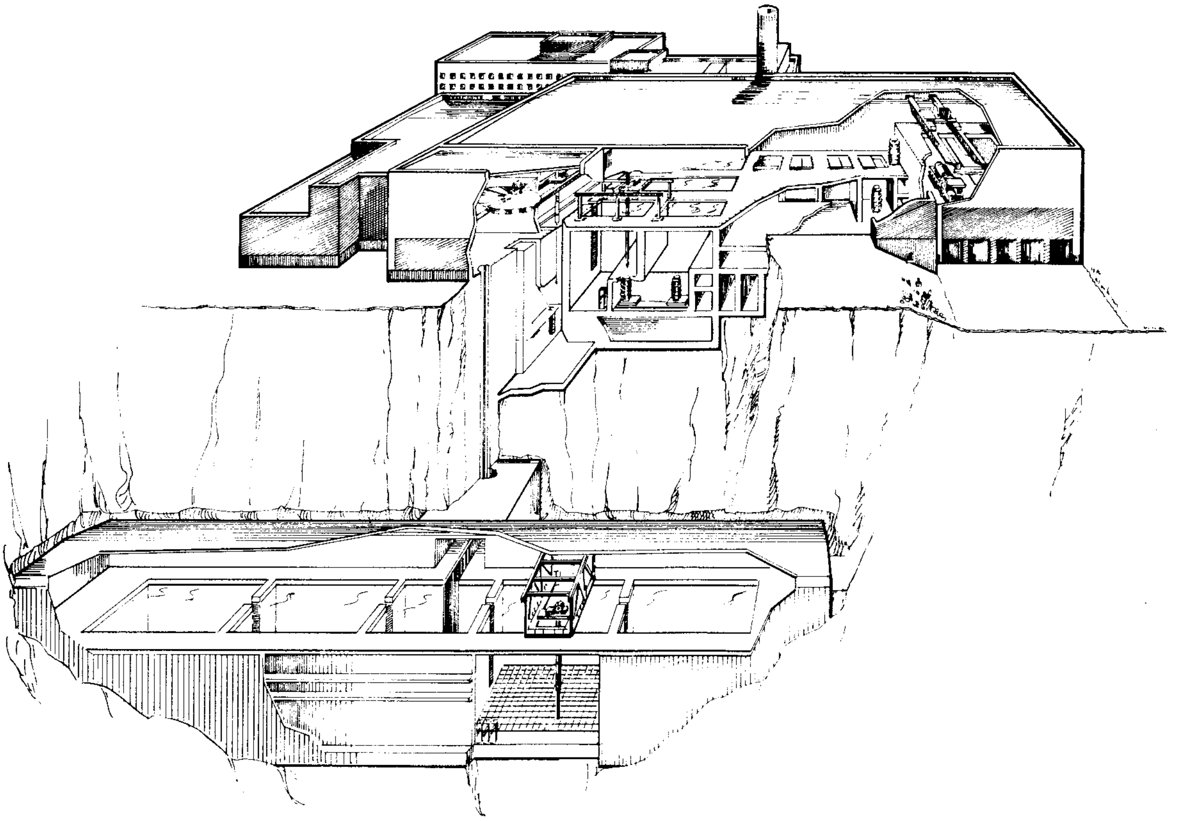

Figure A3.2. CLAB phase 1.

pool connected to an elevator shaft via a transport channel. The pools are made of reinforced concrete and lined with stainless steel. Each pool holds 3 000 m^3 of water and can accommodate about 800 tonnes of uranium.

The second building phase will comprise a rock chamber parallel to the existing one. The basic design will be the same, while the number of pools will be increased to 6 pools for spent fuel and one pool for core components.

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.

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 circulation 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 adapting 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, in two stages, 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.

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

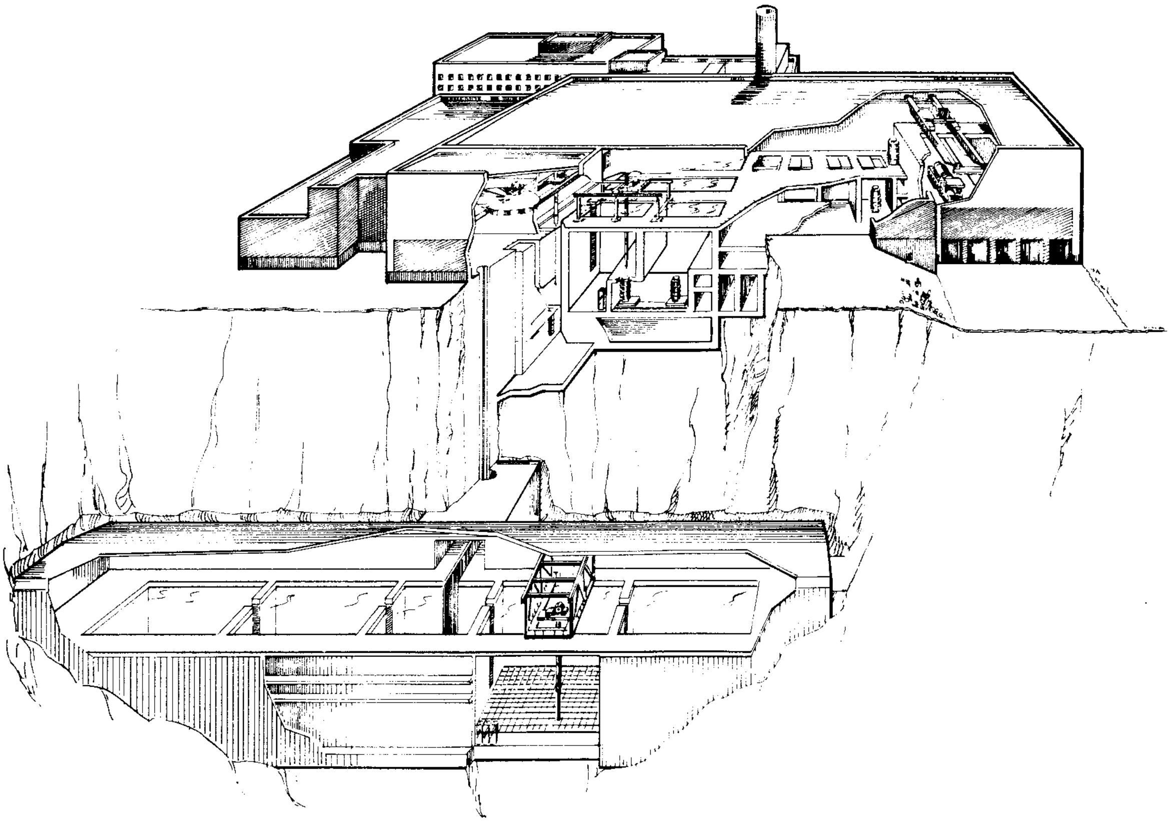

Figure A3.2. CLAB phase 1.

pool connected to an elevator shaft via a transport channel. The pools are made of reinforced concrete and lined with stainless steel. Each pool holds 3 000 m^3 of water and can accommodate about 800 tonnes of uranium.

The second building phase will comprise a rock chamber parallel to the existing one. The basic design will be the same, while the number of pools will be increased to 6 pools for spent fuel and one pool for core components.

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.

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 circulation 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 adapting 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, in two stages, 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.

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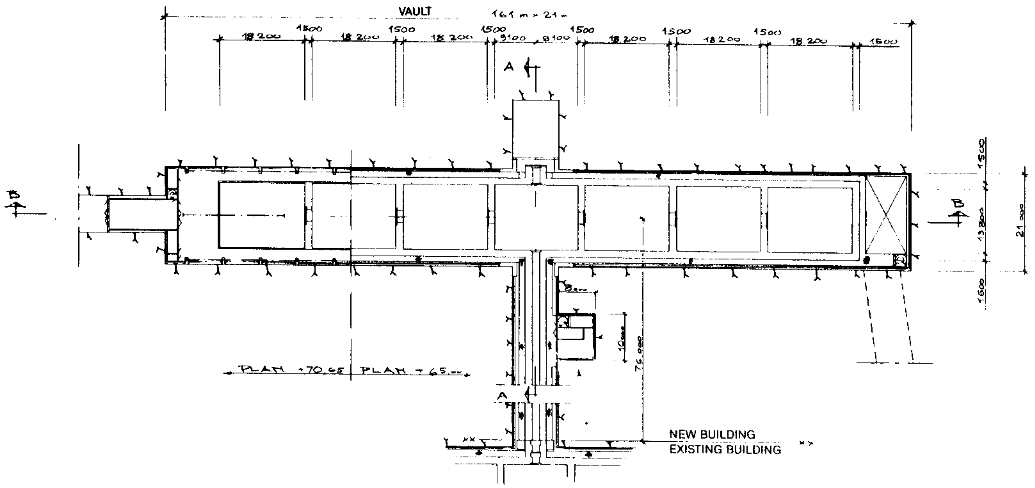
In the storage section, the canister is transferred from the elevator to its storage position by an overhead handling crane.
The empty casks are transported back to the same cooling cell

where they were previously cooled. The water in the cask is drained, and after removed cask components are fitted, a final inspection is carried out of the casks' integrity before they are removed from the facility.

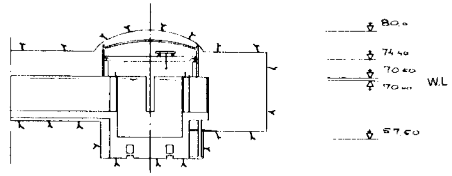
Filling of transport casks for removal of fuel from CLAB follows the same procedure as unloading.

The permanent personnel force during operation is about 75 persons. In addition, service personnel are currently being utilized mainly from OKG's regular operating organization. On average, they are equivalent to about 70 full-time employees. During periods when no loading-in or loading-out is taking place, the work force can be reduced by about 15 men.

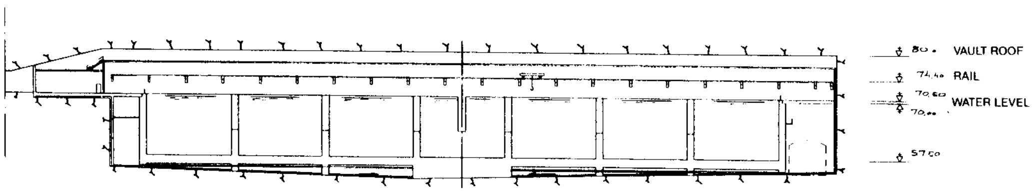
After all fuel and other waste has been removed from CLAB to final disposal, the above-ground complex will be dismantled, along with those parts of the storage pools that have become active. Radioactive waste is sent to the SFL.



PLAN



SECTION A – A



SECTION B – B

DRAWING 3.1

CLAB II
STORAGE BUILDING
7 POOLS
DRAFT

BVB

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132-12-001

APPENDIX 4

FINAL REPOSITORY FOR LONG-LIVED WASTE, SFL AND ENCAPSULATION STATION FOR SPENT FUEL, BS

General

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

- SFL 2, intended for encapsulated spent fuel. The repository consists of tunnels where the waste is deposited in holes drilled in the tunnel floor.

- SFL 3, intended for transuranic waste and intermediate-level operating waste. The repository consists of concrete troughs placed in a rock vault.

- SFL 4, intended for decommissioning waste, mainly from CLAB and BS. The repository consists of the tunnels and other rock chambers that are left over after filling of SFL 3 and 5 are concluded.

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

Prior to deposition in the repository, the spent fuel will be encapsulated in copper canisters. This takes place in the encapsulation station, BS. At present, it is assumed that BS will be cosited with SFL. Cositing means that the fuel can be taken directly after encapsulation via an elevator shaft down to SFL 2. The arrangement is illustrated in Figure A4.1.

At present, it is assumed that SFL 3-5 cannot be located immediately adjacent to SFL 2, but will be situated approximately 3 km away. The repositories are reached via shafts and a separate reception building is provided on ground level. SFL 3-5 are thus located outside the area shown in Figure A4.1, but are included in the same organizational unit.

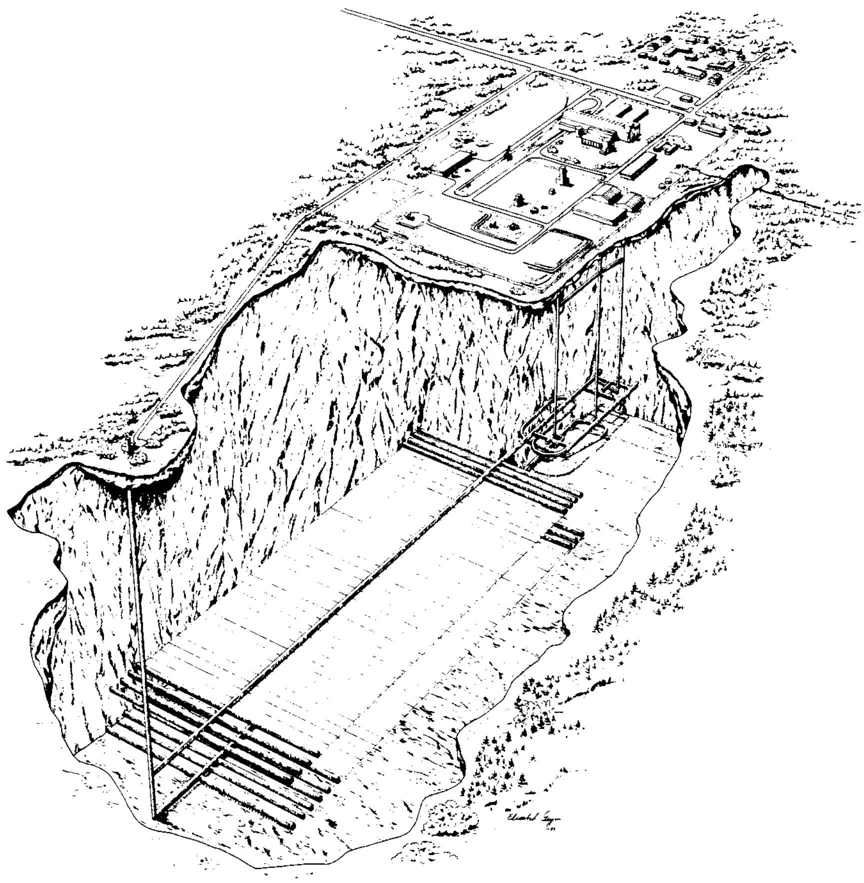


Figure A4.1. SFL 2 - overview.

A total of about 350-400 men will be employed at the SFL and the BS during the operating period. Approximately 800 men will be required during the construction period.

Common facilities

Through cositing of BS and the different SFL repositories, a number of supply and service systems can be made common. This applies above all to the transportation system and the station site.

The waste coming from CLAB 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 navigation channel and the quay area. In the cost calculation, the harbour has been supplemented with a separate ro/ro quay, a widened and deepened approach channel, harbour apron, guard house etc. The waste is then transported in its containers by rail to

SFL. It is hereby assumed that 50 km of railway will have to be built. In addition, rolling stock will have to be acquired, ie locomotives and specially-built cars.

The layout of the station site is illustrated by Drawing 4.1. Aside from BS, which is the dominant building, there will be personnel facilities including housing, goods reception station, workshops, vehicle service, concrete station with crusher, storage and handling of bentonite etc. Water supply and sewerage will also be required.

Facilities for handling of the sealing materials include the following functions. Bentonite granulate will be stored indoors (in a silo), along with the bentonite/sand mixture that will be used to seal tunnels and rock caverns. Storage capacity is equivalent to approximately one year's operation (during the deposition phase). It is assumed that the material will be transported to the site by rail. Some of the bentonite is compacted in a high-pressure press and moulded into blocks for filling out the deposition hole around the copper canister or for other purposes, eg plugging of tunnels and shafts. The remaining bentonite is used in the sand/bentonite mixture (10/90 or 20/80) which is utilized as backfill. Mixing is carried out above ground and the material is then packed in containers that are taken down to repository level by elevator via the central shaft.

The operating staff for the common facilities is estimated to amount to about 150 men, including all administrative personnel for the SFL-BS.

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, primarily from BS, will be placed in SFL 4. All activities are estimated to be concluded by the year 2051.

Encapsulation station for spent fuel, BS

Layout

The spent fuel will be received and encased in copper canisters in the encapsulation station, BS, Figure A4.2. The design of a copper canister is illustrated in Figure A4.3. BS is designed for an encapsulation rate of one canister/day, equivalent to 210/year. The total number of copper canisters will be about 5 600.

BS will also be the a receiving station for core components and reactor internals, which are embedded in concrete moulds in a special part of the facility. A large portion of the core components consists of fuel boxes that are transported together with the fuel. The design of the mould is illustrated in Figure A4.4.

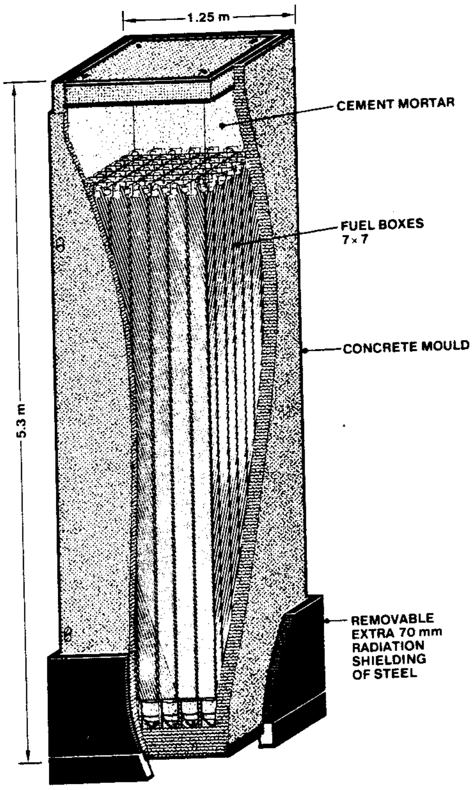


Figure A4.4. Concrete mould with fuel boxes.

water in the two pools will force the leakage water from the cask pool into the unloading pool. In this way, contamination of the outside of the cask can be avoided to as great extent as possible.

The cask's contents of fuel assemblies are transferred to a fuel rack in the buffer pool. The BWR assemblies are thereby lifted in their boxes. The positions in the rack are spaced with due regard to the risk of criticality.

After unloading is completed, the lids are put back and the cask is transported out and moved to the flushing pit for flushing, water drainage and attachment of the lid. If the cask is without defect, it is then lifted back onto the railway car. Otherwise, it can be lifted via an opening in the floor of the receiving hall down to the active workshop for repair of the defects.

Further handling of the fuel assemblies takes place in the buffer pool. The fuel bundles are moved without boxes from the fuel rack and placed in a rack specially designed for the copper canister. The rack with fuel assemblies is transferred via the air lock pool into the encapsulation section's receiving cell.

The boxes remain in the racks. They are taken via another air lock pool into the section for grouting of core components.

In the receiving cell, the copper rack with fuel assemblies is lifted up out of the air lock pool and allowed to drip dry for a short time. The lifting mount consists of the centre tube in the copper rack. The same tube is later used to distribute the lead during lead casting.

An empty copper canister is transferred via the cooling cell into the encapsulation section and placed in one of the transport wagons. At this point, the canister has an external lip that serves as a lifting mount. Later when the lid has been welded on, this lip is machined off.

The transport wagon with canister is positioned underneath the receiving cell and the fuel is lowered into the canister. The wagon is then moved to a furnace position, and the canister is taken up into the furnace, which is sealed. During the heating-up phase and vacuum pumping, the fuel is dried completely. The canister is filled with molten lead, which is allowed to solidify slowly. The canister is then transferred to the cooling cell, where it is allowed to cool for about 4 days.

After cooling, the canister is transferred to the machining cell, where the top surface of the lead and the canister is machined to the necessary smoothness. Chips and the like are collected for subsequent encapsulation. After machining, the lid is placed on the canister and inspected, after which the canister is transferred to the welding cell.

The canister lid is welded on by means of electron beam welding in a fully automatic process. After welding, the canister returns to the machining cell, where ultrasonic inspection is carried out. If the weld is approved, the lifting lip is machined off and the canister is taken to dispatch inspection. All lifts are subsequently performed with the aid of a lifting recess in the top surface of the lid. If the weld is not approved, the canister is cut open and a new lid is welded on. The old lid is discarded after thorough decontamination.

From the machining cell, the finished canister is transferred to the dispatch section, which begins with an inspection and washing position. The canister is then placed in an elevator car and taken down to the final repository.

The core components and reactor internals are assumed to come from storage in CLAB either, like the boxes, together with the fuel or separately in a special transport cask similar to the fuel cask.

The boxes are handled as follows. When a fuel cask is emptied, the fuel assemblies, with boxes, are lifted out of the cask and placed in a fuel rack in the buffer pool. When the fuel assemblies continue in the handling chain to encapsulation, the boxes remain in the rack. The rack holds 49 boxes, ie the same number as the maximum that can be embedded in a mould. In all, the buffer pool contains positions for 12 fuel racks.

From the buffer pool, a smaller air lock pool leads into the casting section. A transport wagon with room for one fuel rack runs along the bottom of this pool into the mould filling cell. There, the rack is lifted up out of the pool and placed in a pit where it is allowed to stand and run off. The boxes can then be picked up one by one to be placed in the concrete mould. Handling in the mould filling cell takes place by remote control.

The empty concrete mould with a well-fitting lid is taken into the casting section lying on a transport wagon. The same wagon is used later to transport out the finished mould. The mould is raised upright and placed on a railbound transport wagon equipped with hydraulic lift. The wagon is driven up to a filling position situated underneath a floor opening into the mould filling cell. The mould is lifted up for tight connection against the floor and the hatch in the floor is opened.

A steel grid with a thickness and openings suited to the end pieces on the boxes lies in the bottom of the mould. The grid stops about 50 mm above the bottom of the mould, providing the necessary space for distribution of the cement mortar. The boxes are picked up and placed in the mould so that the end pieces stick down into the holes in the grid. This prevents the boxes from falling over and thereby impeding the filling process.

After the mould is full, the floor hatch is closed and the wagon is moved to a casting position, where the mould is connected to a hole in the floor leading into the casting cell. The mould is filled with cement mortar up to about 5 cm below the lid lip. When the mortar has solidified, the mould is moved to the lid application position.

After application of the lid, the empty space in the mould is filled up with injection grout.

The mould is then turned to the horizontal position, placed on a transport wagon and driven out to a waiting railway car or truck for further transport to the final repository in SFL 5.

Other metal components to be embedded in moulds consist of different replacement parts, mainly control rods and detector probes, but also of decommissioning products from the internal parts of the reactor vessels.

These are transported in a transport cask of simpler design. Unloading takes place directly in the mould filling cell, where the cask is connected via an air lock. Casting and further handling then proceed in the same manner as for boxes. After unloading, the cask returns for decontamination, inspection and dispatch.

In some cases, owing to a higher radiation intensity, the mould must be arranged so that the concrete cover is considerably thicker than the mould wall. This is achieved by placing a peripheral row of boxes around the sides of the mould before the more active material is placed in the mould.

The operating staff at the BS will consist at the most of about 80 men.

Final repository for spent fuel, SFL 2

Layout

The final repository for spent fuel is situated approximately 500 m below the surface and can be reached via an elevator shaft from BS. The repository consists basically of a system of parallel deposition tunnels, with a total length of about 38 km, with appurtenant transport tunnels, service areas and shafts to the ground surface, occupying a total surface area of about 1 km^2. The total area is determined above all by the heat generation in the deposited fuel. The repository is divided into two levels, 500 m and 600 m below the surface. Its layout is illustrated in Drawing 4.7-4.9. The waste canisters are deposited in vertical holes drilled in the bottom of the deposition tunnels, a total of about 5 600 holes.

The repository is divided symmetrically into two parts, at levels -500 and -600, to permit a simple physical separation of the deposition work from other activities, such as excavation and sealing 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 adopted to the fracture geometry of the rock. In order to determine this fracture geometry, extensive exploratory drilling will be carried out during the excavation phase.

The repository consists of a central section, containing service areas, located directly beneath the encapsulation station, and a deposition section. The central section provides connection with the ground surface via three shafts:

- The central shaft, comprising the main entrance to the repository for both personnel and materials. The repository is supplied with air, water, electricity etc via the shaft, which contains two elevators.
- The skip shaft, provided with rock hoisting equipment. The skip shaft is the first shaft to be excavated and is accordingly driven in the form of a sunk shaft.
- The waste shaft, with elevator for lowering of the canisters.

There is another shaft at the opposite end of the repository. It normally serves as an exhaust air shaft, but in an emergency it can also be used for personnel evacuation.

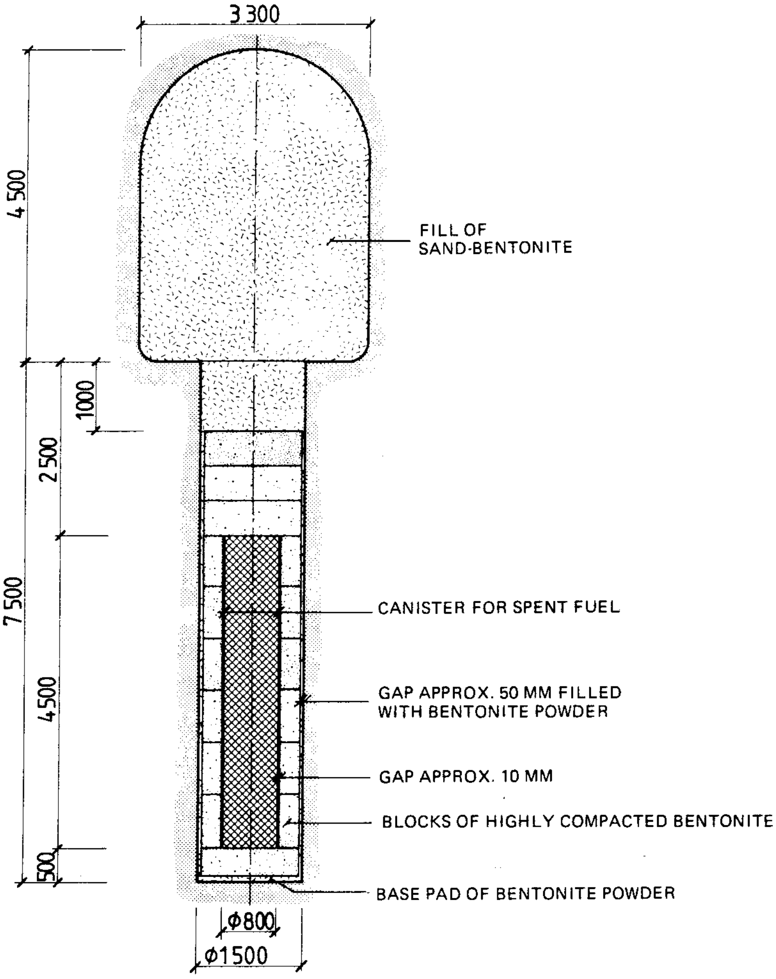


Figure A4.5. Deposition hole with canister and buffer material.

The total excavated rock volume is about 800 000 m^3, of which the deposition tunnels account for about 500 000 m^3. The deposition tunnels have a cross-sectional area of about 14 m^2, which is a minimum area to permit passage of the deposition vehicle. It is assumed that the deposition tunnels are excavated by means of conventional tunnelling technique with a blasting rate that minimizes cracking of the tunnel walls. Blasting and excavation take place with a certain lead time as deposition proceeds, and in stages of about 4 km tunnel length.

Operating

Figure A4.5 shows a cutaway illustration of a deposition tunnel with canister after deposition and sealing. The canister is placed in a hole drilled in the bottom of the deposition tunnel. The holes have a diameter of 1.5 m and a depth of 7.5 m and are spaced at a distance of 6.0 m. The drilling procedure is begun by drilling a small pilot hole (Ø150 mm) with a core drill in the centre of the assumed deposition position. Based on this hole and its core, a judgment is made as to whether the site is suitable as a

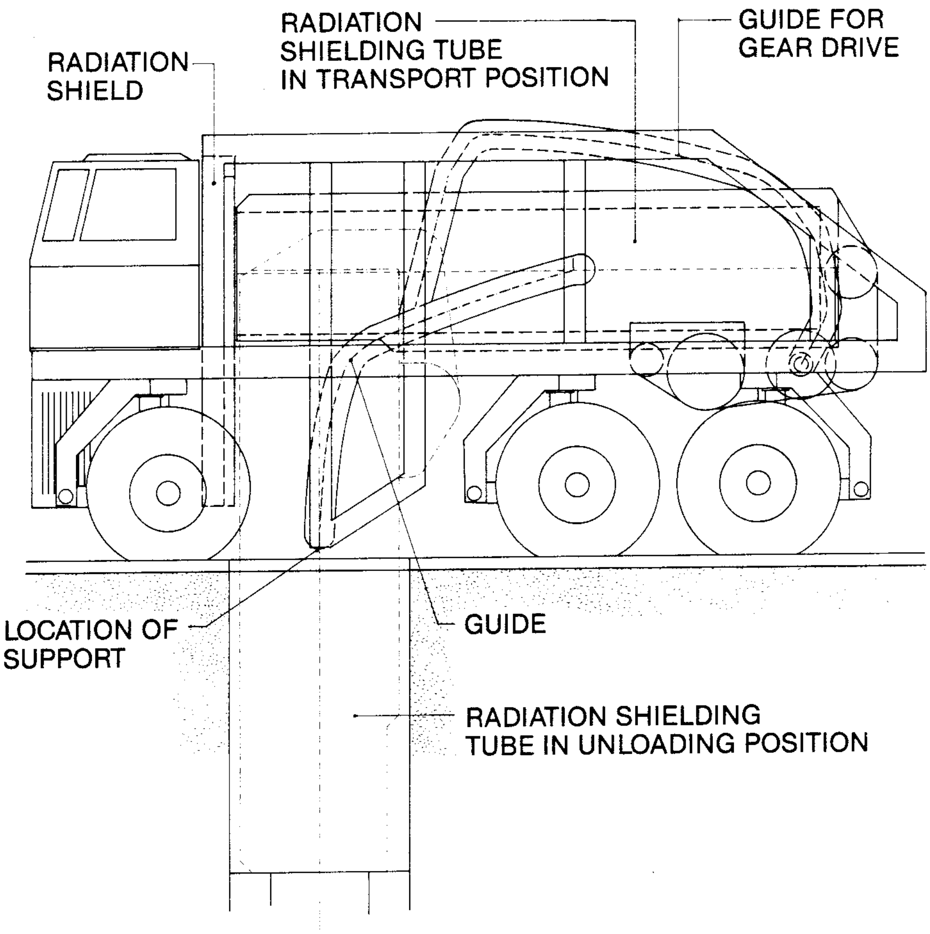


Figure A4.6. Deposition vehicle.

deposition site in view of the structure and permeability of the rock. If the judgment is positive, full-face driving is begun, whereby the pilot hole serves as a guide hole.

The copper canister is lowered into the hole by a deposition vehicle, which also picks up the canister at the elevator and transports it to the deposition tunnel. During its handling, the canister lies protected in a radiation-shielded tube mounted on the vehicle. See Figure A4.6.

The deposition procedure begins with the placement of all ring-shaped bentonite blocks in the hole, which are then aligned with the aid of a steel dummy. The uppermost bentonite block is provided with a temporary collar of steel. The purpose of this is to protect the bentonite edge against damages while the canister is being lowered. The collar also contains a number of sensors used for automatic centering during lowering of the radiation shielding tube.

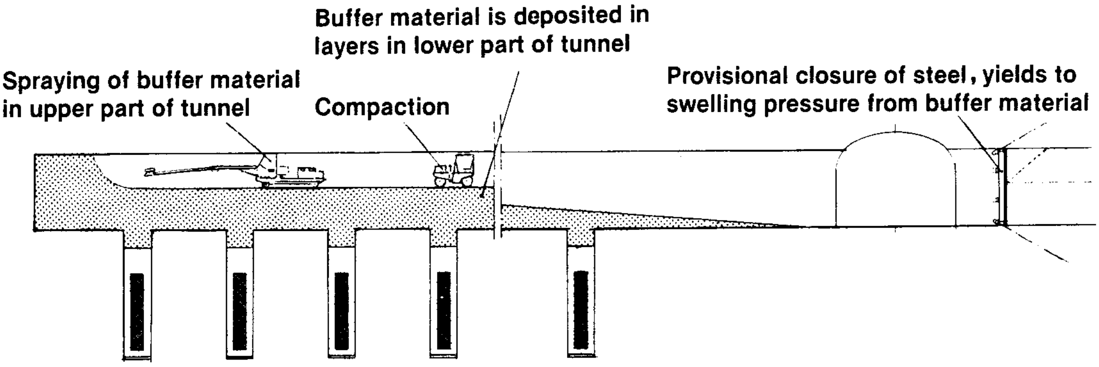


Figure A4.7. Backfilling of deposition tunnel.

The canister is transported down in the elevator from the encapsulation station and is picked up by the deposition vehicle and driven out to the deposition place. After a rough positioning of the vehicle at the deposition hole, hydraulic outriggers are lowered and a fine adjustment of the position is carried out. The radiation-shielding tube is raised to the upright position at the same time it is lowered a couple of metres into the deposition hole, ie down to the uppermost bentonite block. The canister is then lowered and released.

After the canister has been lowered and the deposition vehicle has been driven out of the tunnel, several additional bentonite blocks are placed on top of the canister, rendering the tunnel accessible. The hole is then capped with a watertight seal. The seal is allowed to remain in place until all holes in the tunnel have been finished and backfilling is about to be commenced.

When a number of deposition tunnels are completed, the work of sealing them begins. The temporary seal is hereby removed and the tunnels are filled with sand/bentonite. The tunnel mouths are sealed off with a temporary steel wall, which is removed in connection with backfilling of the central tunnel. See Figure A4.7.

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

At most, the operating staff amounts to about 120 men, including rock workers for excavation of the deposition tunnels.

Final repositories for low- and intermediate-level waste, SFL 3-5

SFL 3, 4 and 5 are combined in a common facility and are thus equipped with a number of common areas and functions. The repositories are located at a depth of about 500 m in the bedrock and are reached via three shafts, one of which is intended solely for ventilation. The rock cavern layout is shown by Drawing 4.10. The total rock volume amounts to 140 000 m^3.

Waste is transported down to the repository level by elevator via one of the shafts, originating from a receiving station on ground level. The elevator is designed to be able to take both small waste packages and other loads, such as the large moulds with core components. The latter weigh about 20 tonnes and comprise the design load for the elevator's capacity. Down in the receiving area at repository level, the waste is transferred to a radiation-shielding transport wagon, which takes it out to the appropriate 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 120 m long rock vault with a width of 18 m and a height of 21 m. Operating waste from CLAB and BS will be deposited in SFL 3 after SFR 1 has been closed. However, the extensive safety arrangements around the repository are occasioned by the disposal of the long-lived Studsvik waste, which has some transuranic content.

The positioning and design of the concrete troughs exhibit many similarities with the silo concept in SFR 1. Thus, the troughs is surrounded by sand/bentonite or by pure bentonite. It is also divided into square cells 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 throughs are covered with a concrete lid and all nearby service areas are filled with concrete. Adjoining tunnels are plugged and the cavities against the rock are filled with sand/bentonite.

SFL 4

SFL 4 is intended to receive the active decommissioning waste from, above all, CLAB and BS as well as transport casks and accordingly enters into function only 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 these repositories have been sealed. The waste, which arrives in small steel containers, is placed in the tunnels and backfilled, possibly with crushed rock material. Finally, the shaft is

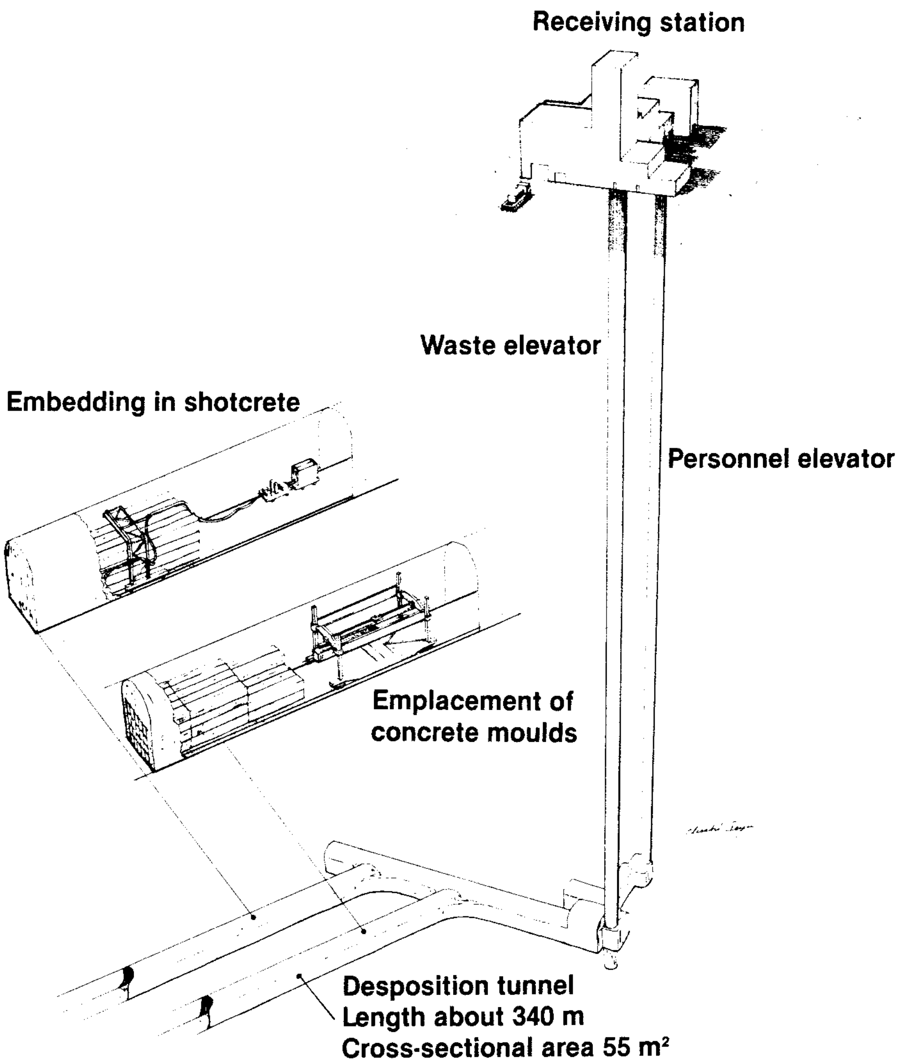


Figure A4.8. Deposition in SFL 5.

backfilled, whereby a number of plugs of compacted bentonite are installed.

SFL 5

SFL 5 consists of two tunnels, each about 340 m long and with a cross section of 55 m^2, in which the concrete moulds with core components are stacked in a lying position five abreast and four high. See Figure A4.8. The handling is made with a remote-controlled straddle carrier. As deposition proceeds, the space between moulds and rock is filled with concrete. The concrete is applied by means of pumping and spraying.

The moulds have dimensions 5.3 x 1.25 x 1.25 m and are designed so that, when they lie stacked in the tunnel, they provide fully adequate radiation shielding through their own concrete thickness and thereby permit access to the tunnel. The total number of moulds is about 2 300.

Receiving station

The receiving station for SFL 3-5 consists of a reloading station for the waste that is to be deposited and a service station and shaft superstructure for the rock caverns. The layout is shown in Drawing 4.11. The total building volume is about 25 000 m^3.

The facility can be divided into the following main parts:

- Receiving section including emptying position for waste container from both truck and rail transport.

- Unloading hall with equipment for emptying of transport casks and buffer storage of waste packages.

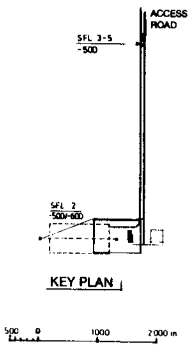
- Dispatch section, constituting an extension of the unloading hall and served by the same overhead crane. The waste elevator connects to this section.

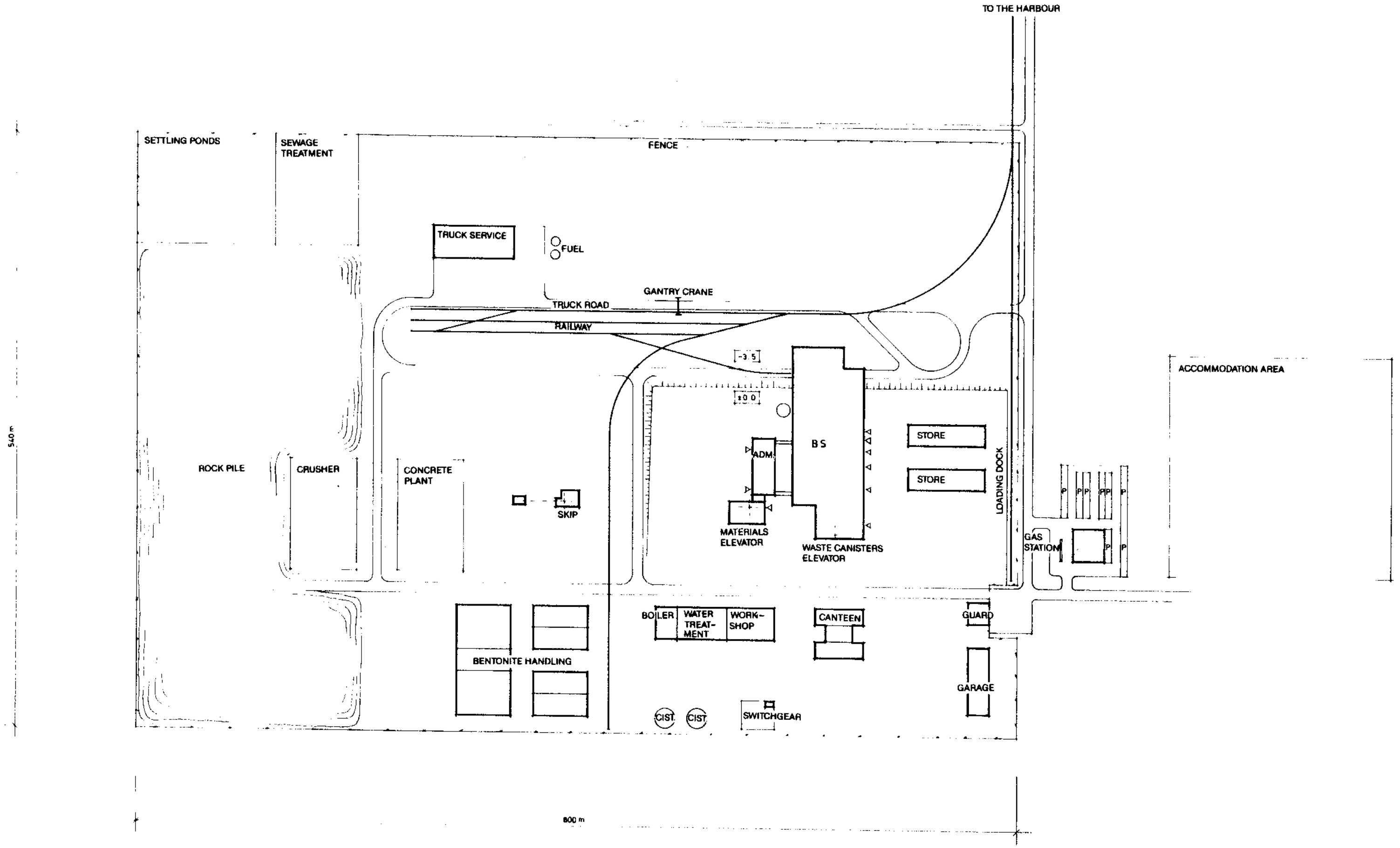
- Waste elevator.

- Service section for rock caverns, with ventilation equipment etc.

- Control and personnel section including electrical and control room as well as personnel quarters such as office, changing room, radiation protection unit etc. The elevator shaft for passenger transport opens out into the personnel section.

The total personnel requirement for operation of SFL 3-5 is about 60 men.





50 0 100 200 m

DRAWING 4.1

REV	ANT	REVIDERINGEN AVSER	RITAD	GRANSK	DATUM

SKB
SFL GA
SITE LAYOUT
GROUND FACILITIES

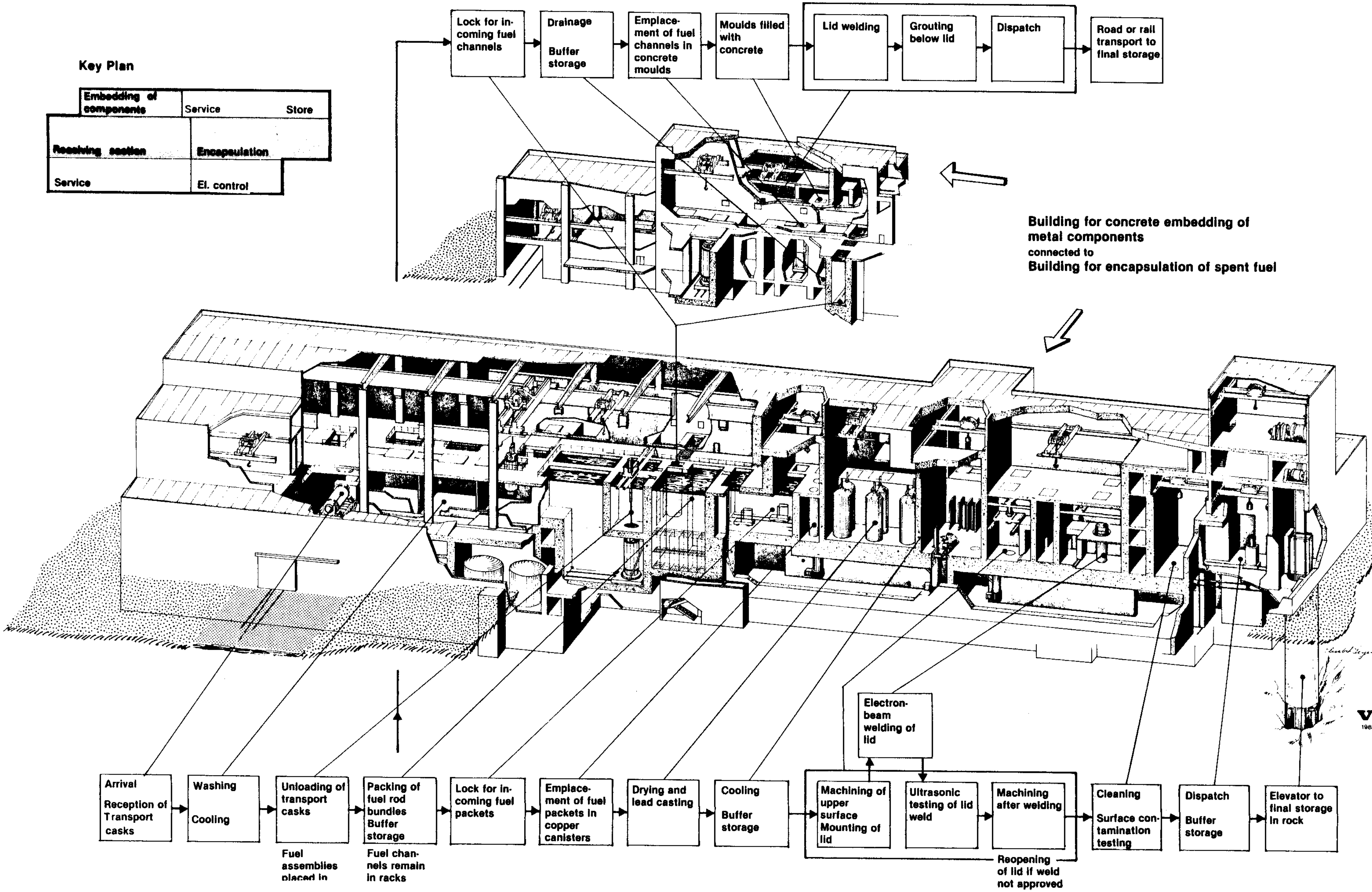
KONSTRUERAD	RITAD	GRANSKAD	REG NUMMER
AGE	PHU	AGE	L7970

SKALA	RITNINGSNUMMER	REV
	70-86-01	

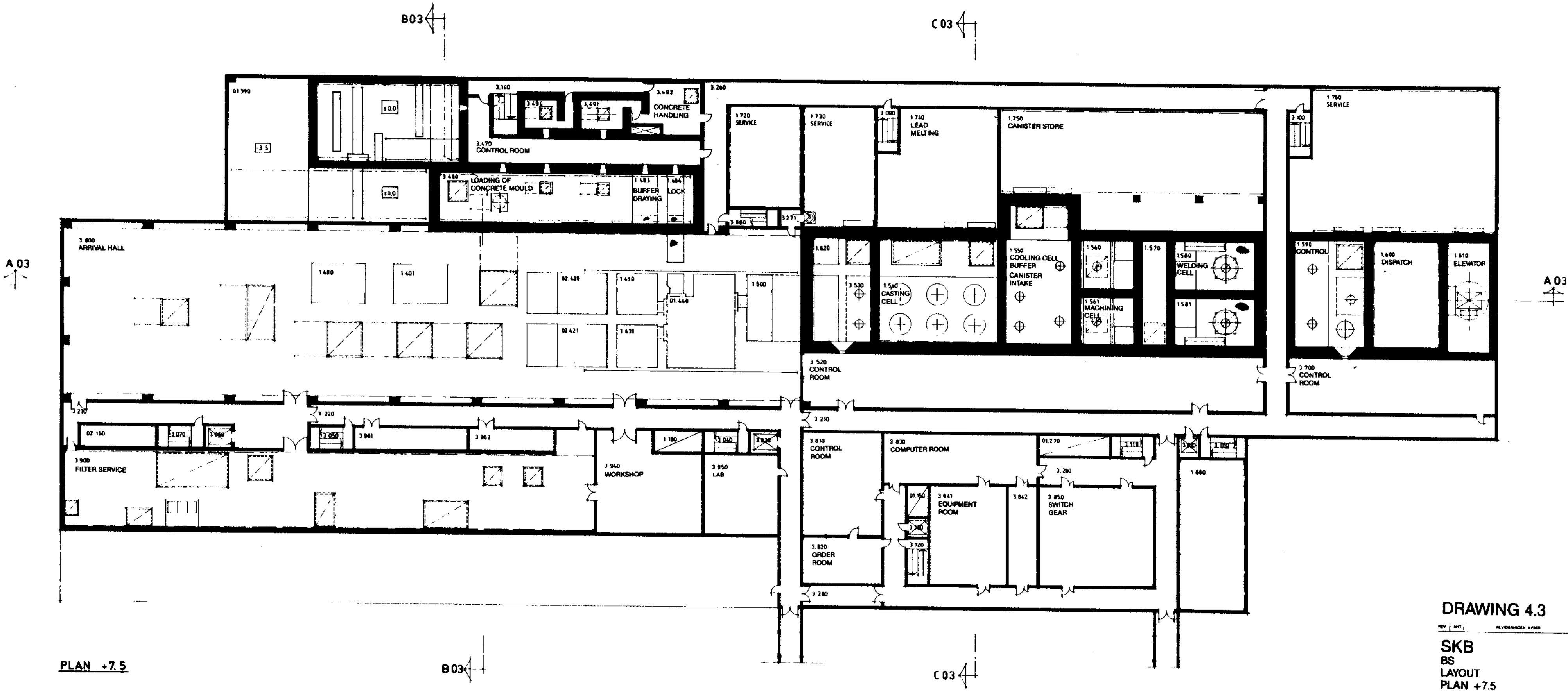
STOCKHOLM DEN
860530

VBB

BOX 5038
102 41 STOCKHOLM 5 TEL. 08-782 7000


Key Plan
Embedding of components
Service
Store
Receiving section
Encapsulation
Service
El. control
Lock for in-coming fuel channels
Drainage
Buffer storage
Emplace-ment of fuel channels in concrete moulds
Moulds filled with concrete
Lid welding
Grouting below lid
Dispatch
Road or rail transport to final storage
Building for concrete embedding of metal components
connected to
Building for encapsulation of spent fuel
Electron-beam welding of lid
VBB
1983-03-03
Arrival
Reception of Transport casks
Washing
Cooling
Unloading of transport casks
Fuel assemblies placed in
Packing of fuel rod bundles
Buffer storage
Fuel chan-nels remain in racks
Lock for in-coming fuel packets
Emplace-ment of fuel packets in copper canisters
Drying and lead casting
Cooling
Buffer storage
Machining of upper surface
Mounting of lid
Ultrasonic testing of lid weld
Machining after welding
Reopening of lid if weld not approved
Cleaning
Surface con-tamination testing
Dispatch
Buffer storage
Elevator to final storage in rock

DRAWING 4.2



DRAWING 4.3

SKB
BS
LAYOUT
PLAN +7.5

AGE | PHU | AGE | L7970

71-86-01

STOCKHOLM DEN 1986-04-24

VBB

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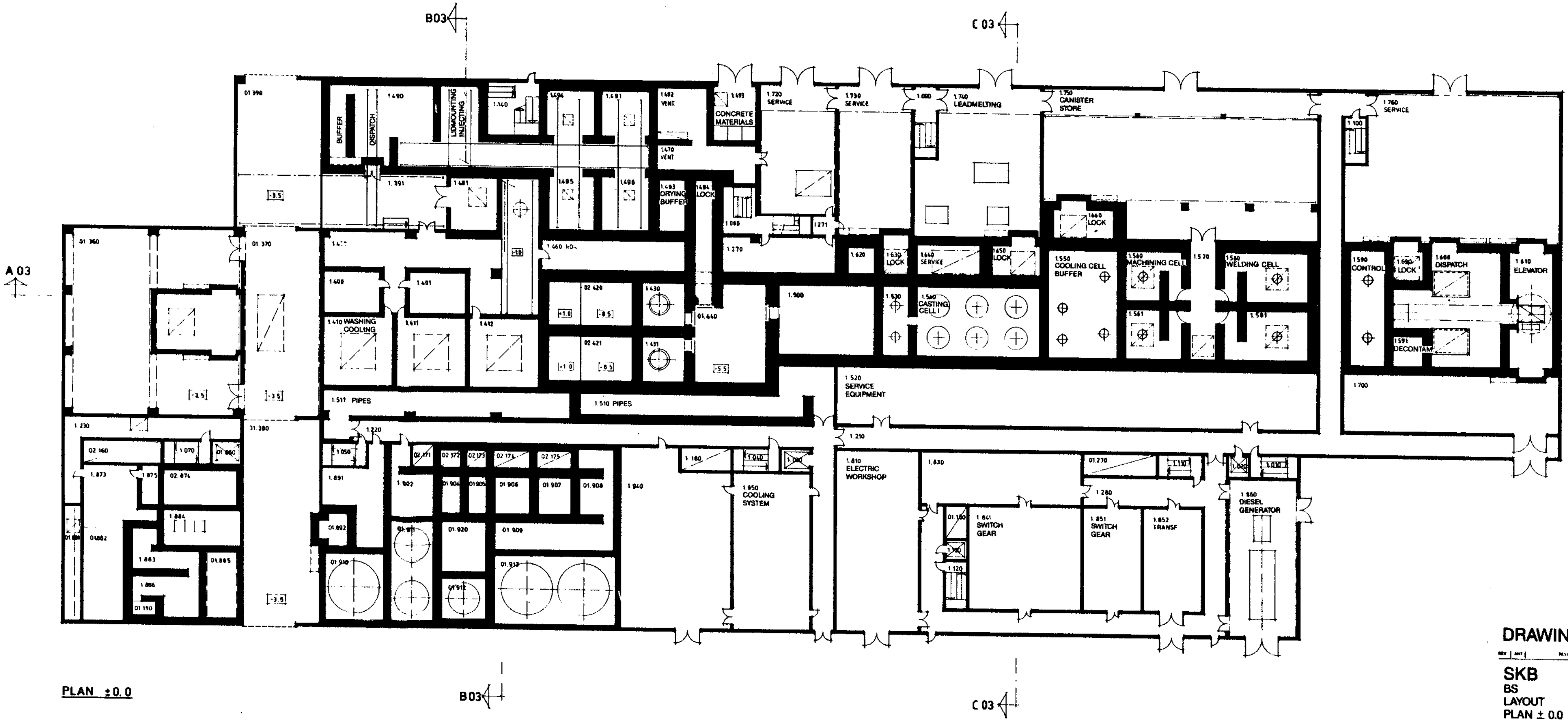
TEL 08 782 7000



PLAN ±0.0

DRAWING 4.4

SKB
BS
LAYOUT
PLAN ± 0.0

AGE	PHU	AGE	L7970
		71-86-02	

STOCKHOLM DEN 1986-04-24

VBB

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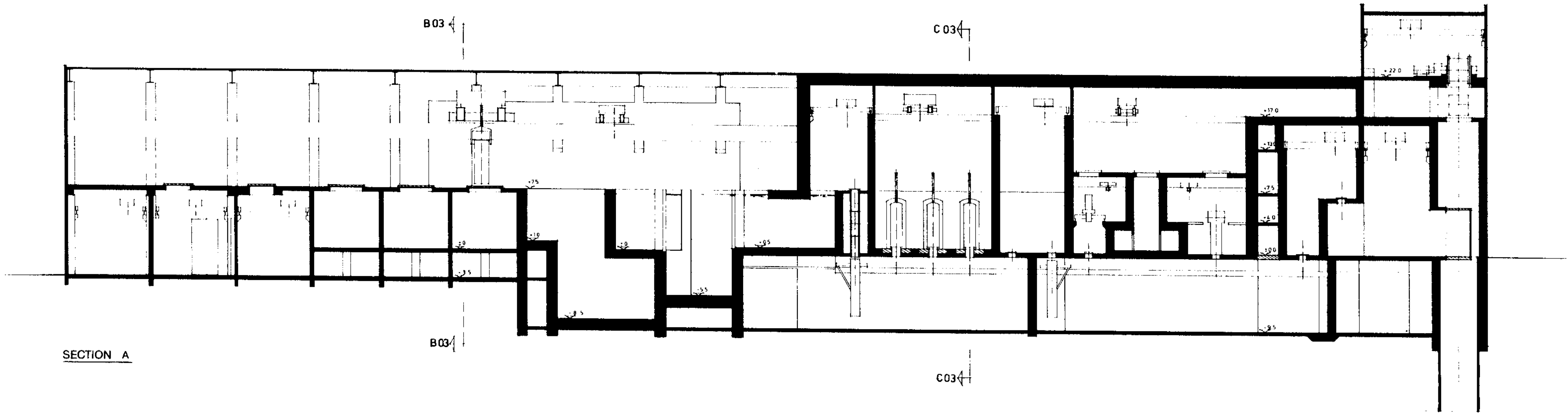
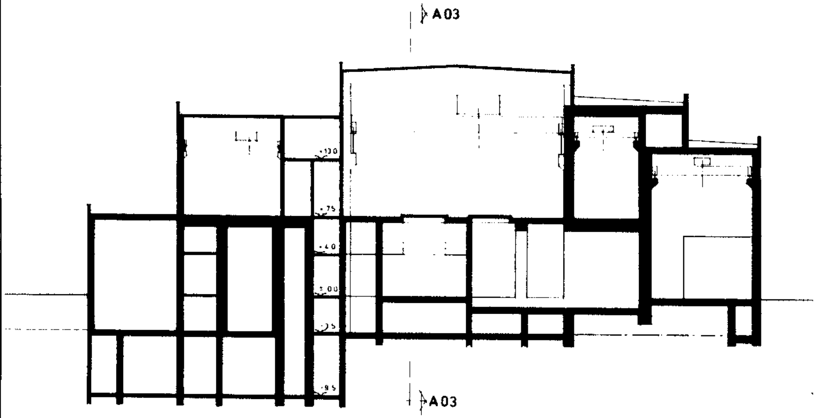
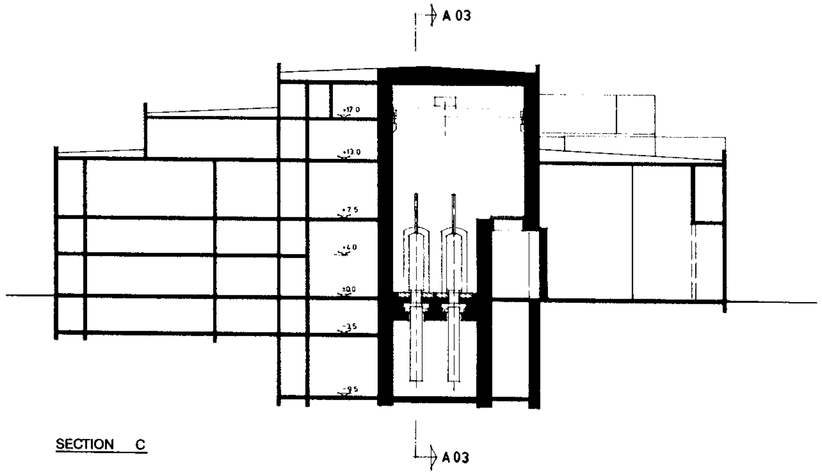
102 41 STOCKHOLM 5



SECTION A



SECTION B



SECTION C

DRAWING 4.5

SKB
BS
LAYOUT
SECTIONS

AGE	PHU	AGE	L7970
		71-86-03	

STOCKHOLM DEN 1986-04-24

VBB

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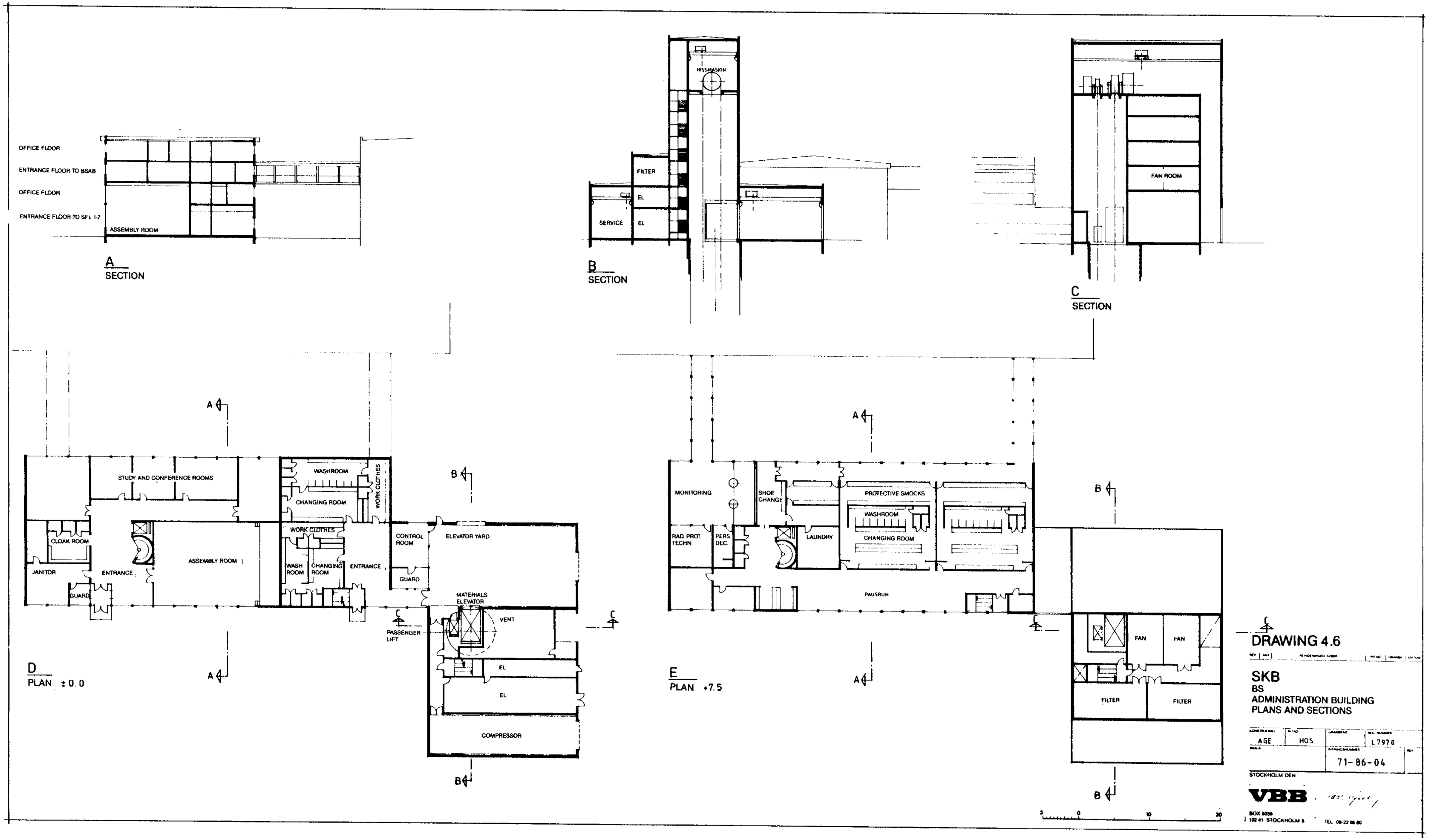
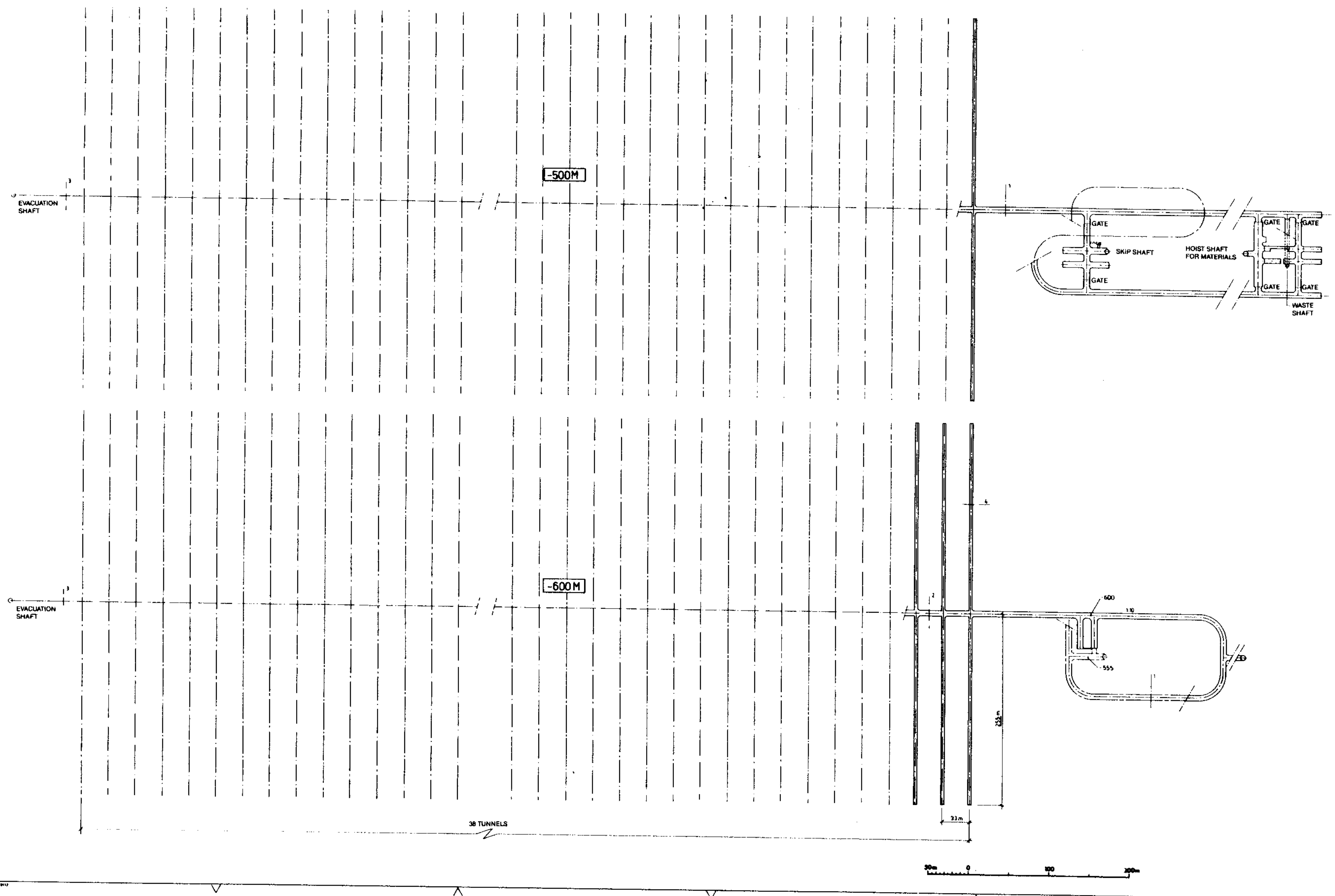
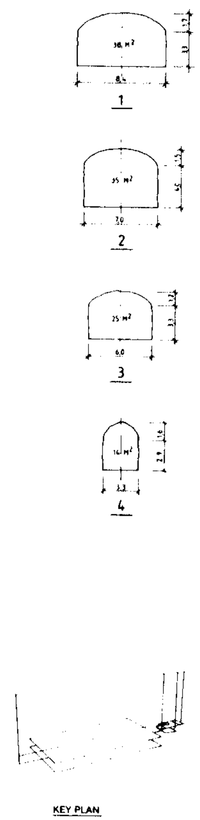

OFFICE FLOOR
ENTRANCE FLOOR TO BSAB
OFFICE FLOOR
ENTRANCE FLOOR TO SFL 1-2
ASSEMBLY ROOM
A
SECTION
HISSMASKIN
FILTER
EL
SERVICE
EL
B
SECTION
FAN ROOM
C
SECTION
STUDY AND CONFERENCE ROOMS
WASHROOM
CHANGING ROOM
WORK CLOTHES
CLOAK ROOM
JANITOR
ENTRANCE
GUARD
ASSEMBLY ROOM
WORK CLOTHES
WASH ROOM
CHANGING ROOM
ENTRANCE
CONTROL ROOM
GUARD
ELEVATOR YARD
MATERIALS ELEVATOR
VENT
PASSENGER LIFT
EL
EL
COMPRESSOR
D
PLAN ±0.0
MONITORING
SHOE CHANGE
PROTECTIVE SMOCKS
WASHROOM
CHANGING ROOM
RAD. PROT. TECHN
PERS DEC
LAUNDRY
PAUSRUM
FAN
FAN
FILTER
FILTER
E
PLAN +7.5
DRAWING 4.6
SKB
BS
ADMINISTRATION BUILDING
PLANS AND SECTIONS
AGE
HOS
L7970
71-86-04
STOCKHOLM DEN
VBB
BOX 6030
102 41 STOCKHOLM 6
TEL 08-22 86 80





DRAWING 4.7

SKB

SFL

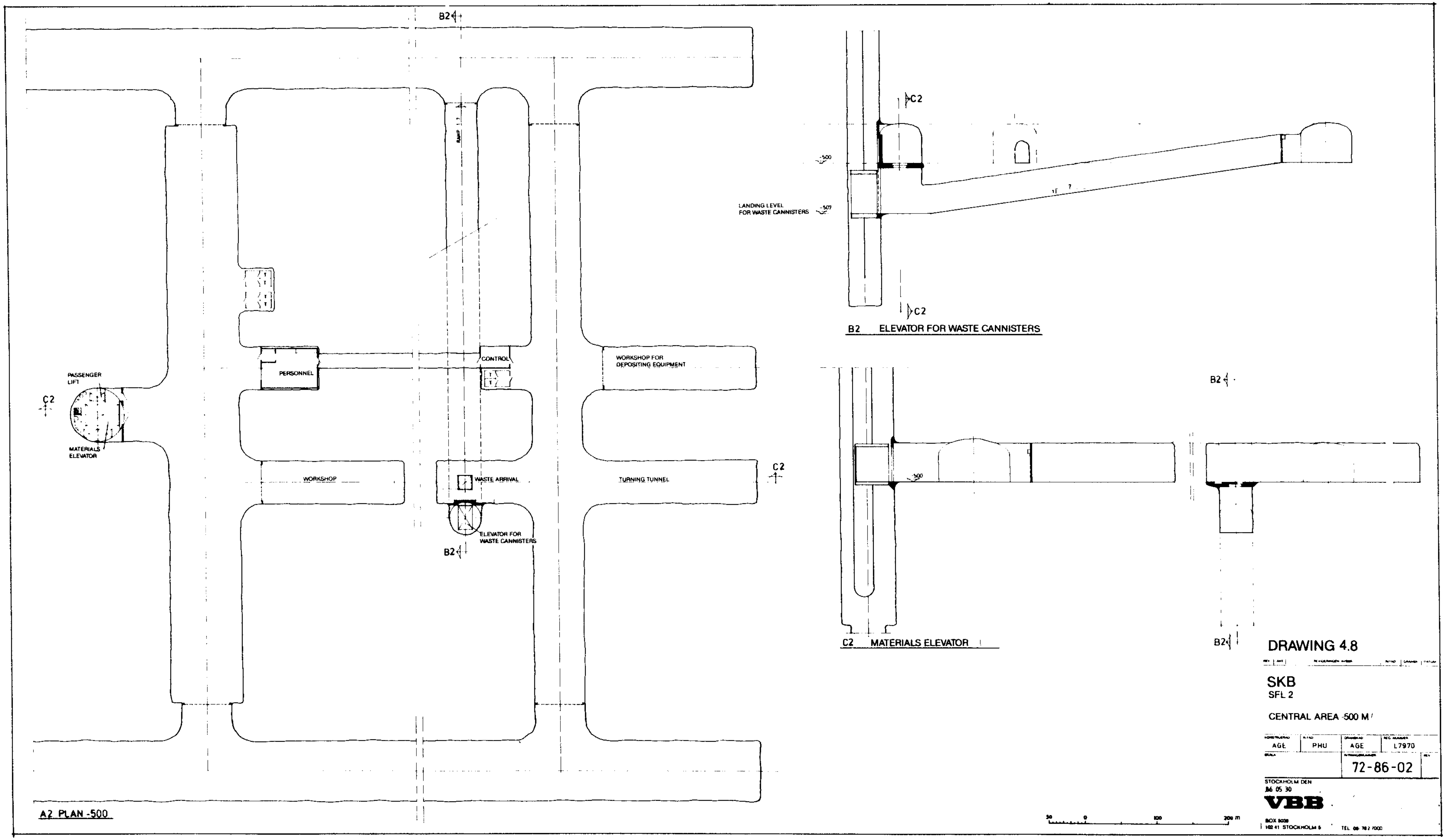
GENERAL LAYOUT -500/-600 M

AGE	PHU	AGE	L7970
			72-86-01

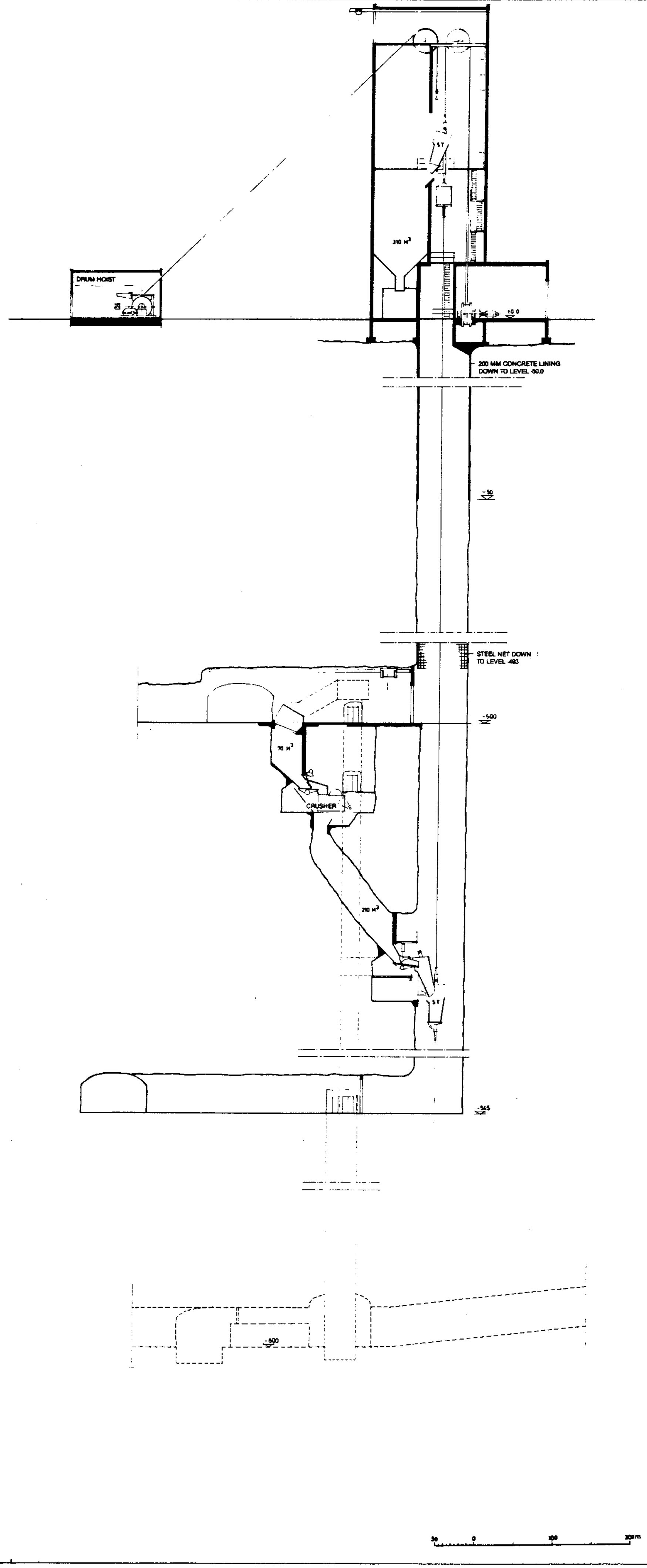
STOCKHOLM LEN
86 05 30

VBB

BOX 5038
102 41 STOCKHOLM 5
TEL 08 7627000



B2
PASSENGER LIFT
C2
MATERIALS ELEVATOR
PERSONNEL
CONTROL
WORKSHOP FOR DEPOSITING EQUIPMENT
WORKSHOP
WASTE ARRIVAL
TURNING TUNNEL
ELEVATOR FOR WASTE CANNISTERS
A2 PLAN -500
-500
LANDING LEVEL FOR WASTE CANNISTERS
-507
B2 ELEVATOR FOR WASTE CANNISTERS
C2 MATERIALS ELEVATOR
50
0
100
200 m
DRAWING 4.8
SKB
SFL 2
CENTRAL AREA -500 M
AGE
PHU
AGE
L7970
72-86-02
STOCKHOLM DEN
86 05 30
VBB
102 41 STOCKHOLM 5



DRAWING 4.9

SKB
SFL 2

ROCK HOISTING
SECTION

AGE	PHU	AGE	L7970

72-86-03

STOCKHOLM DEN
86 05 30

VBB

BOX 5038
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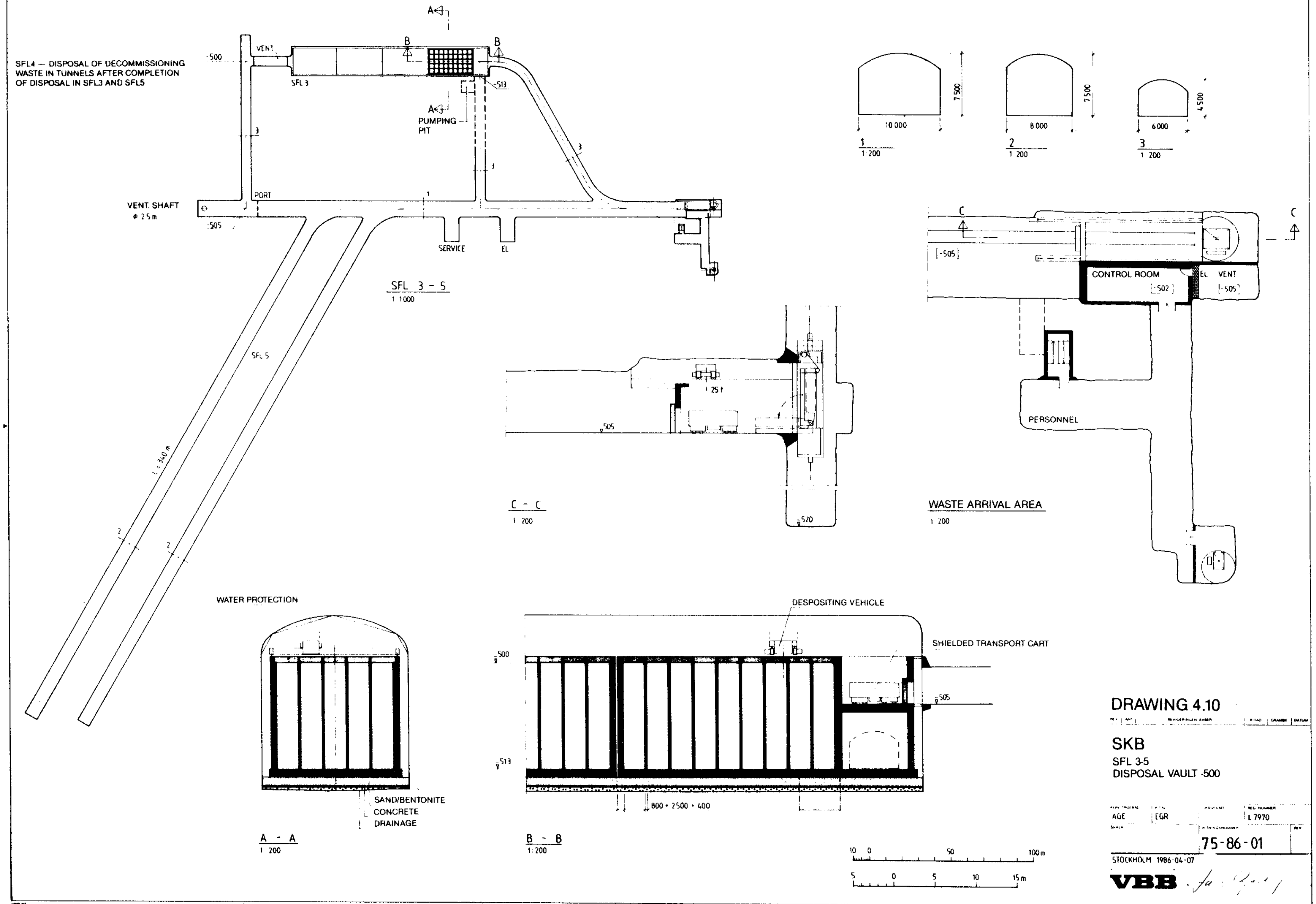


DRAWING 4.10

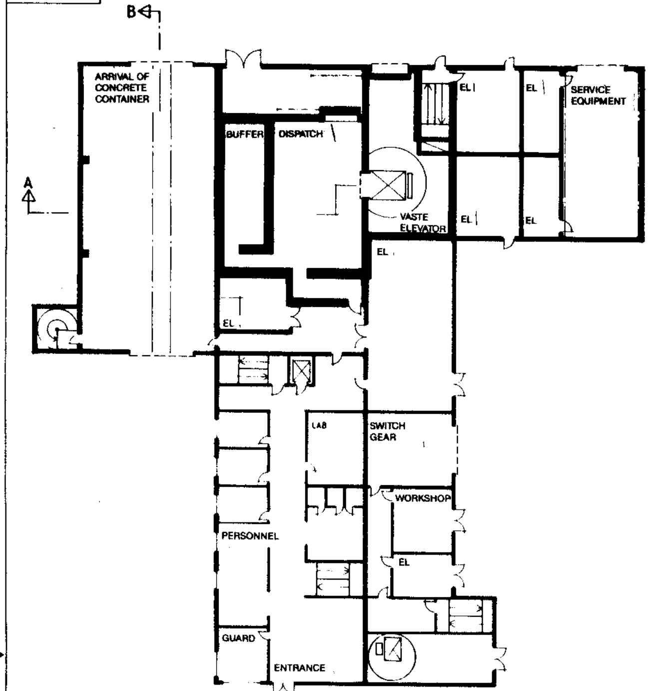
SKB
SFL 3-5
DISPOSAL VAULT -500

AGE | EGR | L 7970

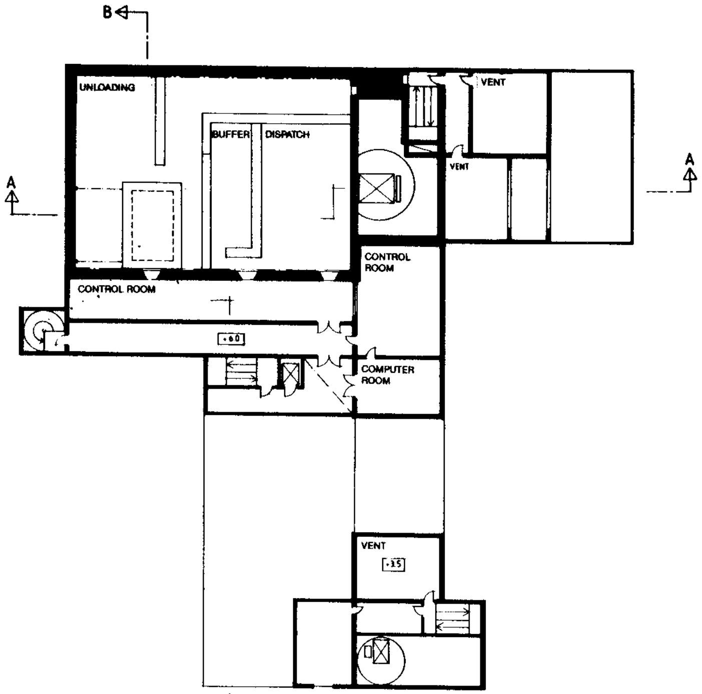
75-86-01

STOCKHOLM 1986-04-07

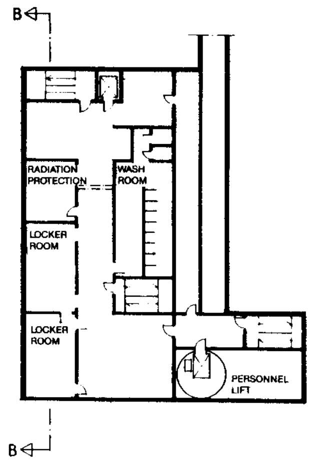
VBB



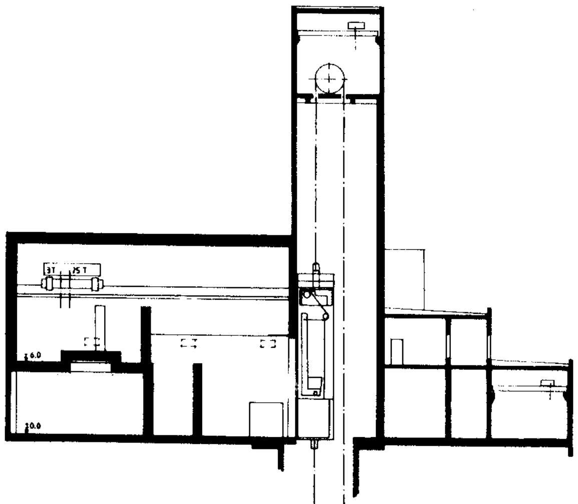
PLAN ±0.0



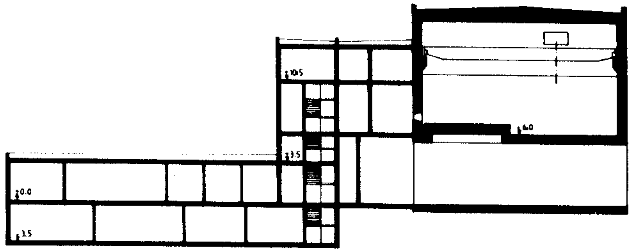
PLAN +6.0 AND +3.5



PLAN -3.5



SECTION B



SECTION A

5 0 5 10 15 m

DRAWING 4.11

SKB

SFL 3-5

RECEIVING BUILDING

AGE | EGR | L 7970

75-86-02

STOCKHOLM 1986-04-08

VBB

APPENDIX 5
FINAL REPOSITORY FOR REACTOR WASTE, SFR

Final repository for reactor operation waste, SFR 1

A final repository for short-lived low- and intermediate-level waste is currently being built at the Forsmark nuclear power station. 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 site plan of the repository is shown in Drawing 5.1. 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 on the site is 5-6 m. The appearance of the repository when fully expanded is illustrated schematically in Figure A5.1.

SFR 1 is being built in two phases. The first phase consists of one cylindrical rock cavern containing a concrete silo plus four 160-m-long rock vaults. The concrete silo will contain intermediate-level waste. Three of the rock vaults will contain low-level waste, which can be handled by a radiation-shielded truck. The fourth rock vault will contain intermediate-level waste and handling there will be remote-controlled. The second building phase comprises one additional silo and one to 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 A5.2. The transport container with the waste packages is brought down into the repository by an electric-powered terminal vehicle and placed in a

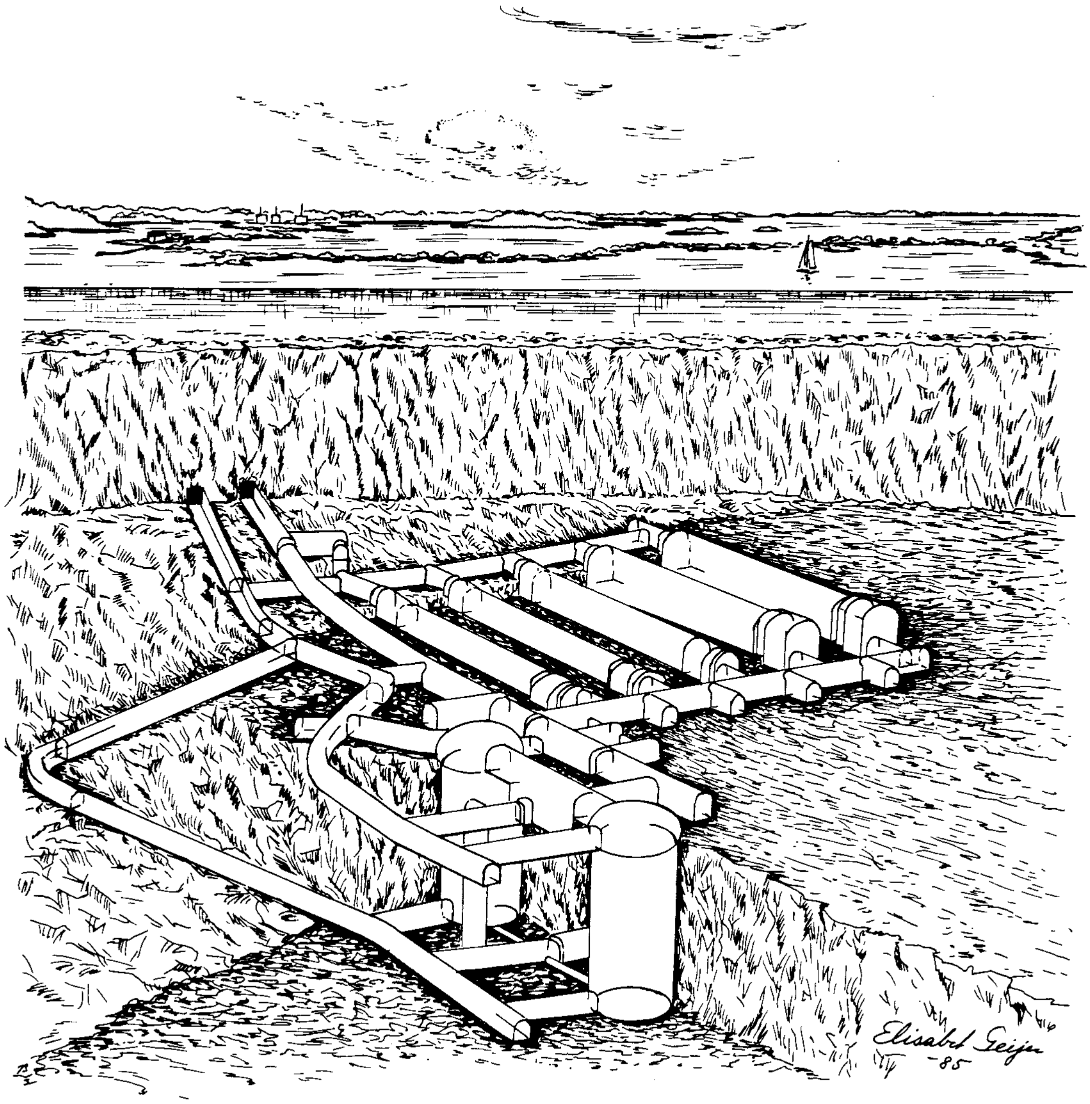


Figure A5.1. SFR 1.

receiving room. Above the room runs a tunnel that is connected to the upper part of the silo and contains a railbound remote-controlled pole crane. The deposition vehicle picks up the waste packages, one at a time, out of the transport container, drives out onto the carousel crane over the silos, goes to the right position and lowers the package into one of the cells. When two 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 intermediate-level waste emplaced in the rock vault is also grouted. While the low-level waste is not grouted.

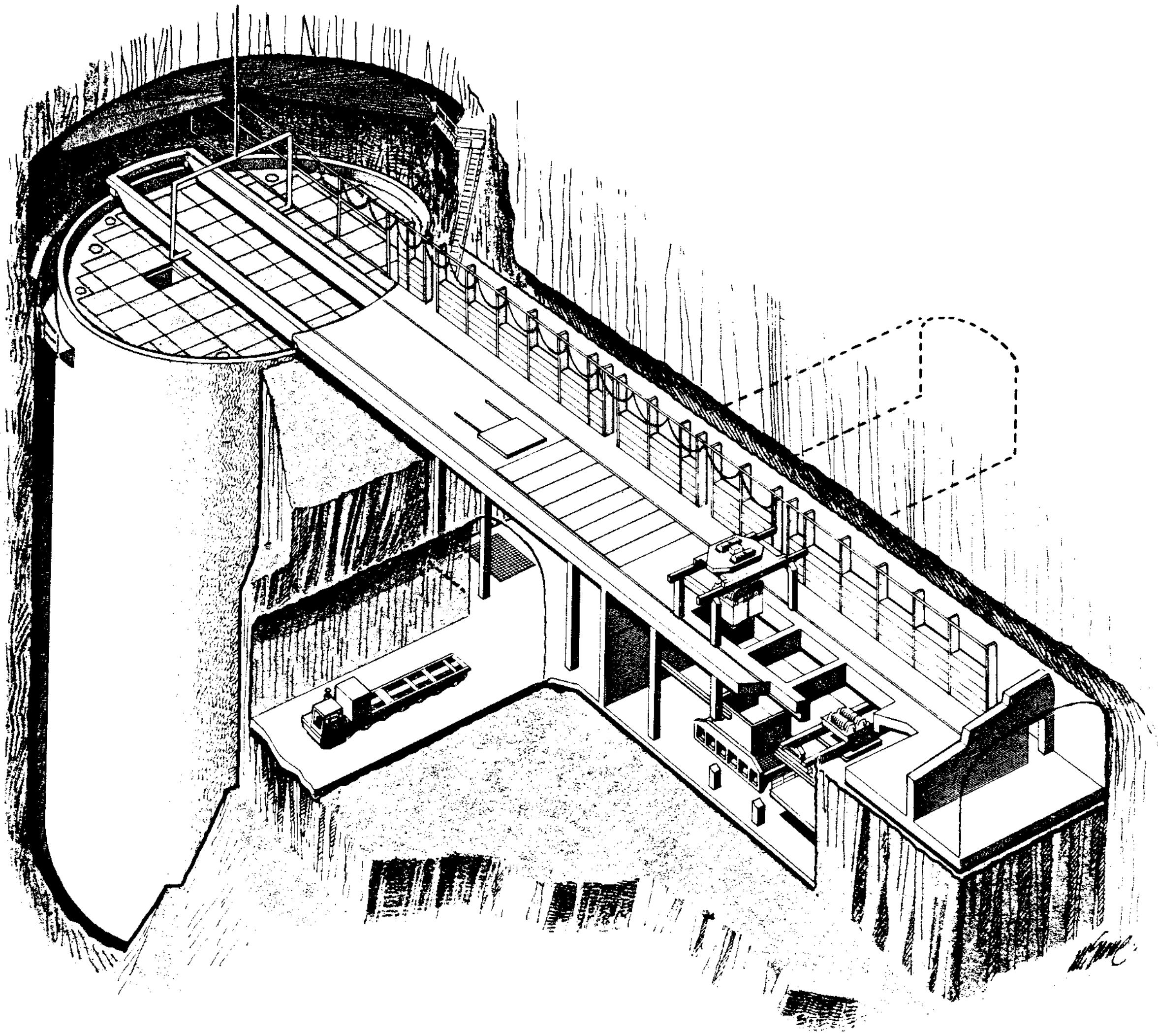


Figure A5.2. Deposition in silo, SFR 1. Schematic illustration.

The repository also includes surface facilities situated in the area around the tunnel mouths. See Drawing 5.2. The total building volume is about 30 000 m^3. The buildings include a ventilation building (for the rock chambers), office and workshop building and terminal building where the transport units are temporarily stored prior to transport down to the repository.

SFR 1 is scheduled to be commissioned in 1988 and to be sealed in the mid-2010s. The operating organization will amount to 20-25 men.

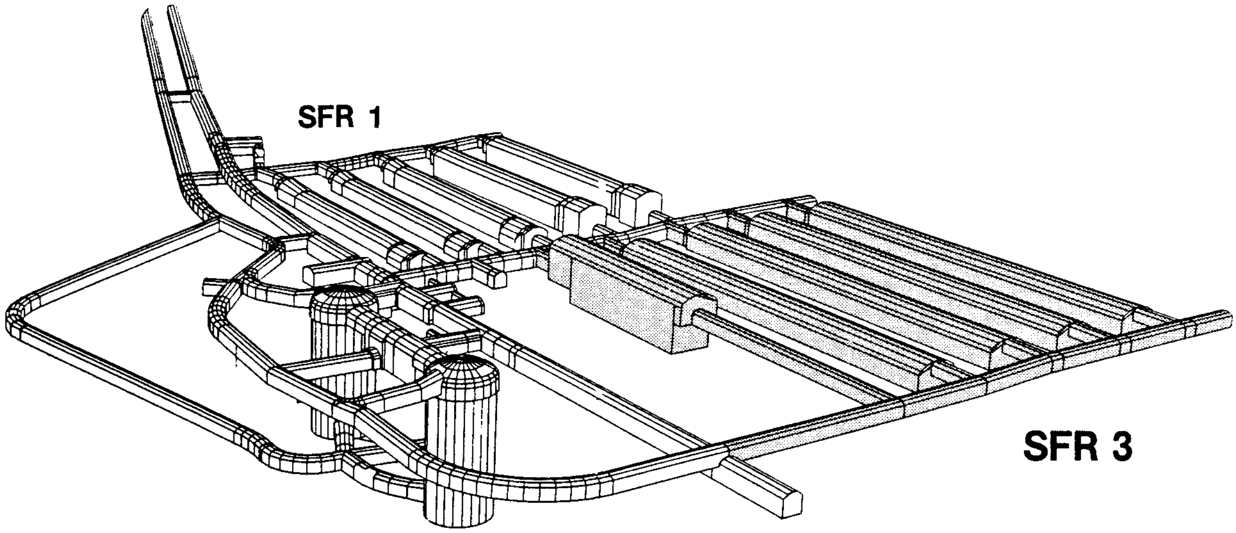
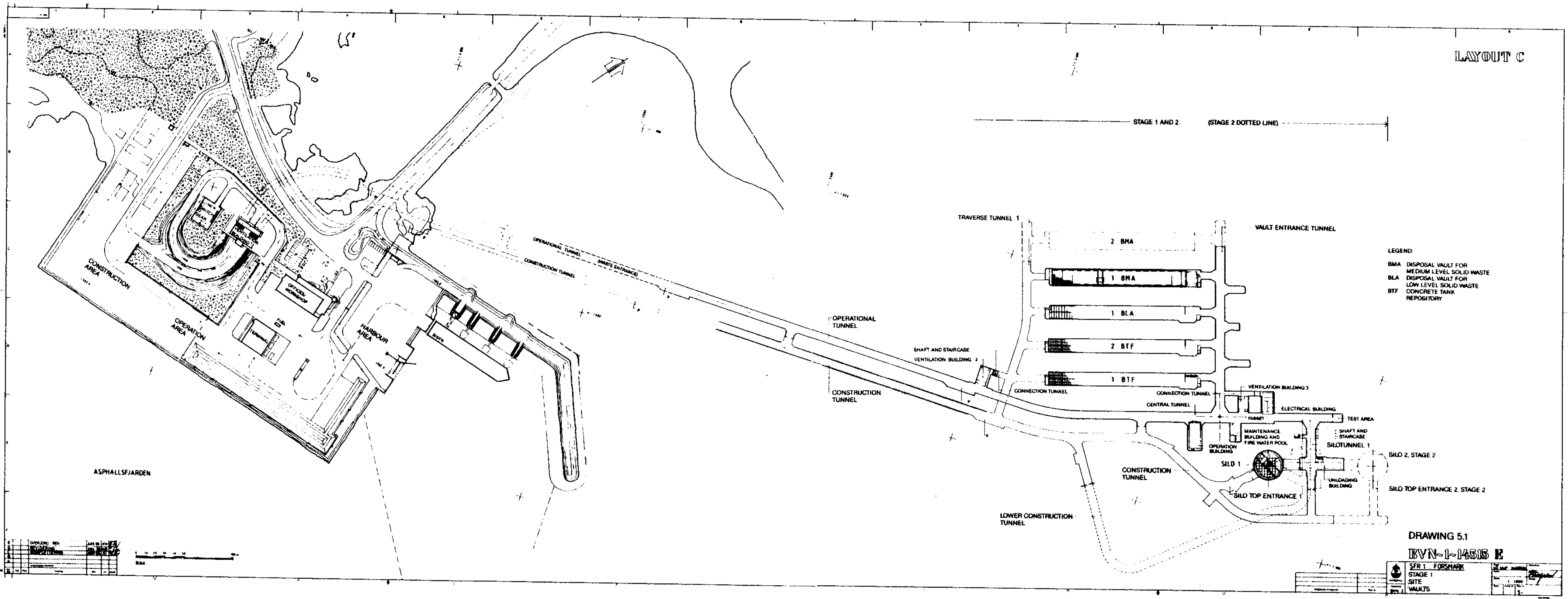


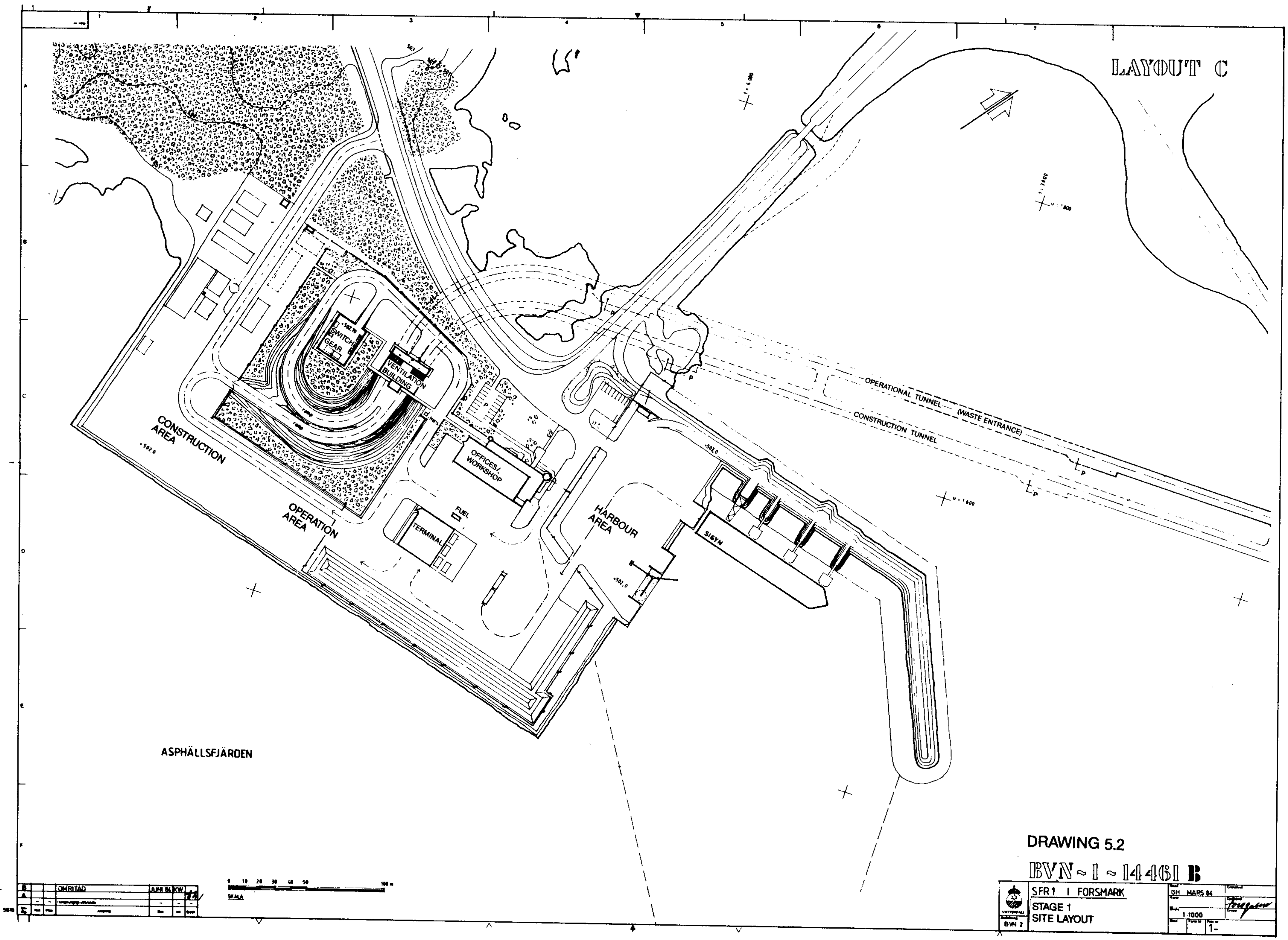
Figure A5.3. SFR 3.

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 force as SFR 1, and the operating and service buildings constructed for SFR 1 can also be utilized.

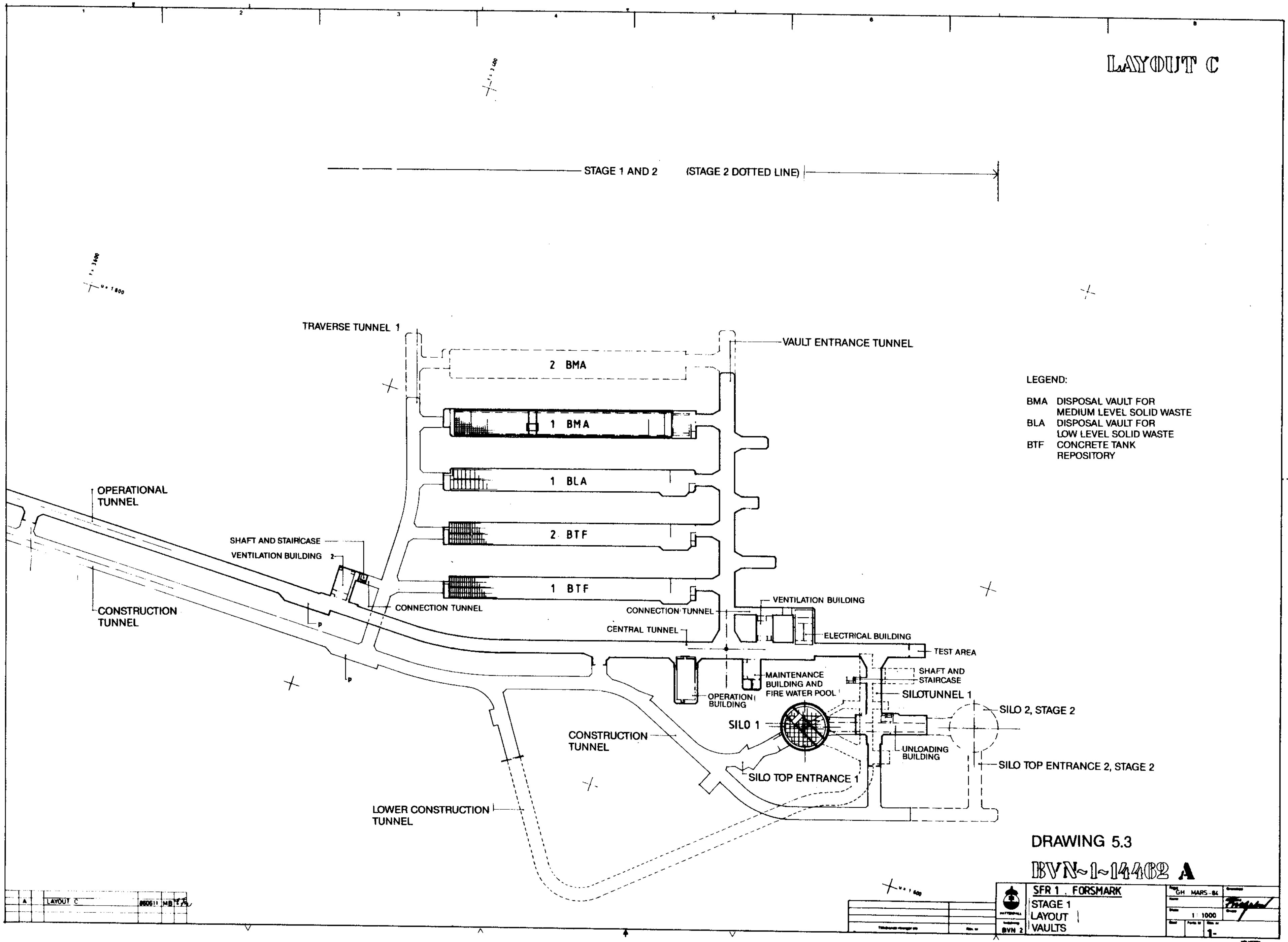
SFR 3 will consist of four rock vaults of a similar type as in SFR 1. See Figure A5.3. The decommissioning waste will primarily be transported to the repository packed in standard ISO containers that are deposited with their contents. ATB containers are used for waste that requires radiation shielding during transport and are emptied by means of a remote-controlled overhead crane.


LAYOUT C
STAGE 1 AND 2
(STAGE 2 DOTTED LINE)
TRAVERSE TUNNEL 1
VAULT ENTRANCE TUNNEL
2 BMA
1 BMA
1 BLA
2 BTF
1 BTF
LEGEND:
BMA DISPOSAL VAULT FOR MEDIUM LEVEL SOLID WASTE
BLA DISPOSAL VAULT FOR LOW LEVEL SOLID WASTE
BTF CONCRETE TANK REPOSITORY
OPERATIONAL TUNNEL
CONSTRUCTION TUNNEL
OPERATIONAL TUNNEL
CONSTRUCTION TUNNEL
SHAFT AND STAIRCASE
VENTILATION BUILDING 2
CONNECTION TUNNEL
CONNECTION TUNNEL
VENTILATION BUILDING 3
CENTRAL TUNNEL
ELECTRICAL BUILDING
TEST AREA
MAINTENANCE BUILDING AND FIRE WATER POOL
OPERATION BUILDING
SHAFT AND STAIRCASE
SILOTUNNEL 1
SILO 2, STAGE 2
SILO 1
CONSTRUCTION TUNNEL
UNLOADING BUILDING
SILO TOP ENTRANCE 1
SILO TOP ENTRANCE 2, STAGE 2
LOWER CONSTRUCTION TUNNEL
CONSTRUCTION AREA
OPERATION AREA
OFFICES/WORKSHOP
HARBOUR AREA
ASPHALLSFJARDEN
DRAWING 5.1
BVN-1-14515 E
SFR 1 FORSMARK
STAGE 1
SITE
VAULTS



DRAWING 5.2

BVN-1-14461 B



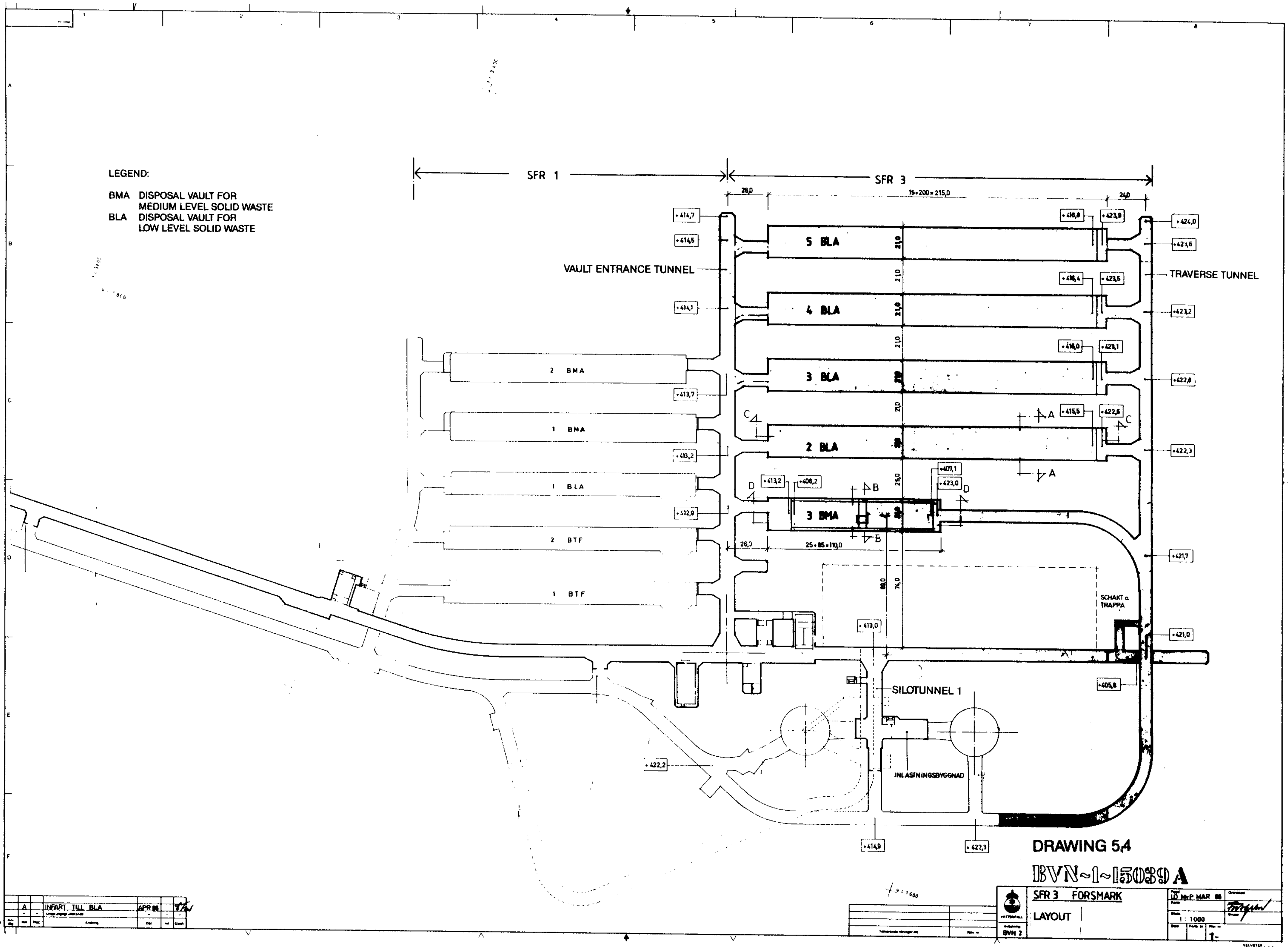
DRAWING 5.3

BVN-1-14462 A

A	LAYOUT C	860611	MB

SFR 1 . FORSMARK
STAGE 1
LAYOUT
VAULTS

GH MARS-84
1 : 1000
BVN 2
1-


LEGEND:
BMA DISPOSAL VAULT FOR MEDIUM LEVEL SOLID WASTE
BLA DISPOSAL VAULT FOR LOW LEVEL SOLID WASTE
SFR 1
SFR 3
26,0
15 × 200 = 215,0
24,0
VAULT ENTRANCE TUNNEL
TRAVERSE TUNNEL
5 BLA
4 BLA
3 BLA
2 BLA
3 BMA
2 BMA
1 BMA
1 BLA
2 BTF
1 BTF
25 × 85 = 110,0
SCHAKT o. TRAPPA
SILOTUNNEL 1
INLASTNINGSBYGGNAD
+414,7
+414,5
+414,1
+413,7
+413,2
+412,9
+413,0
+422,2
+414,9
+422,3
+405,8
+421,0
+421,7
+422,3
+422,8
+423,2
+423,6
+424,0
+407,1
+423,0
+406,2
DRAWING 5,4
BVN-1-15039 A
SFR 3 FORSMARK
LAYOUT
1 : 1000
BVN 2
A INFART TILL BLA APR 86

APPENDIX 6

DECOMMISSIONING OF THE NUCLEAR POWER PLANTS

(Summary from Ref. 5)

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 dismantlement of the reactor vessel and for demolishing of heavy concrete structures. Examples of existing equipment that can be used for this after minor modifications 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.

The cost of decommissioning a boiling water reactor (BWR) of the size of Ringhals 1 has been estimated to be about MSEK 540 in January 1986 prices, and for a pressurized water reactor (PWR, Ringhals 2) about MSEK 460. The costs for the other Swedish nuclear power plants lie in the range of MSEK 410-760. 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 to be about MSEK 600 for the 12 Swedish reactors. /1/.

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 heavily dependent on the pace at which the plants are shut down and 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 900. 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 for decommissioning etc of the Swedish nuclear power plants (MSEK).

	Oskarshamn 1-3	**Barsebäck 1-2**	**Ringhals 1-4**	**Forsmark 1-3**
Shutdown operation[1)]	190	110	310	190
Decommissioning	1630	950	1920	2090
Transport and final disposal of waste	150	90	190	170
Total	**1970**	**1150**	**2420**	**2450**
Residual value	**-230**	**-150**	**-300**	**-230**

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

List of SKB reports

Annual Reports

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TR 121
KBS Technical Reports 1 – 120.
Summaries. Stockholm, May 1979.

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Summaries. Stockholm, March 1980.

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Summaries. Stockholm, March 1981.

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The KBS Annual Report 1981.
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Summaries. Stockholm, April 1982.

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The KBS Annual Report 1982.
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1983
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The KBS Annual Report 1983.
KBS Technical Reports 83-01 – 83-76
Summaries. Stockholm, June 1984.

1984
TR 85–01
Annual Research and Development Report 1984
Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01– 84-19)
Stockholm June 1985.

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Annual Research and Development Report 1985
Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01-85-19)
Stockholm May 1986.

Technical Reports

1986

TR 86-01
I: An analogue validation study of natural radionuclide migration in crystalline rock using uranium-series disequilibrium studies
II: A comparison of neutron activation and alpha spectroscopy analyses of thorium in crystalline rocks
J A T Smellie, Swedish Geological Co, A B MacKenzie and R D Scott, Scottish Universities Research Reactor Centre
February 1986

TR 86-02
Formation and transport of americium pseudocolloids in aqueous systems
U Olofsson
Chalmers University of Technology, Gothenburg, Sweden
B Allard
University of Linköping, Sweden
March 26, 1986

TR 86-03
Redox chemistry of deep groundwaters in Sweden
D Kirk Nordstrom
US Geological Survey, Menlo Park, USA
Ignasi Puigdomenech
Royal Institute of Technology, Stockholm, Sweden
April 1, 1986

TR 86-04
Hydrogen production in alpha-irradiated bentonite
Trygve Eriksen
Royal Institute of Technology, Stockholm, Sweden
Hilbert Christensen
Studsvik Energiteknik AB, Nyköping, Sweden
Erling Bjergbakke
Risö National Laboratory, Roskilde, Denmark
March 1986

TR 86-05
Preliminary investigations of fracture zones in the Brändan area, Finnsjön study site
Kaj Ahlbom, Peter Andersson, Lennart Ekman, Erik Gustafsson, John Smellie,
Swedish Geological Co, Uppsala
Eva-Lena Tullborg, Swedish Geological Co, Göteborg
February 1986

TR 86-06
Geological and tectonic description of the Klipperås study site
Andrzej Olkiewicz
Vladislav Stejskal
Swedish Geological Company
Uppsala, October, 1986

TR 86-07
Geophysical investigations at the Klipperås study site
Stefan Sehlstedt
Leif Stenberg
Swedish Geological Company
Luleå, July 1986

TR 86-08
Hydrogeological investigations at the Klipperås study site
Bengt Gentzschein
Swedish Geological Company
Uppsala, June 1986

TR 86-09
Geophysical laboratory investigations on core samples from the Klipperås study site
Leif Stenberg
Swedish Geological Company
Luleå, July 1986

TR 86-10
Fissure fillings from the Klipperås study site
Eva-Lena Tullborg
Swedish Geological Company
Göteborg, June 1986

TR 86-11
Hydraulic fracturing rock stress measurements in borehole Gi-1, Gideå Study Site, Sweden
Bjarni Bjarnason and Ove Stephansson
Division of Rock Mechanics,
Luleå University of Technology, Sweden
April 1986