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Radioactive waste management plan PLAN 82

Part 2 Facilities and costs

Stockholm, June 1982

SVENSK KÄRNBRÄNSLEFÖRSÖRJNING AB / AVDELNING KBS

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RADIOACTIVE WASTE MANAGEMENT PLAN

PLAN 82

PART 2 Facilities and costs

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A list of other reports published in this series during 1982, is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26) and 1981 (TR 81-17) is available through SKBF/KBS.

This report constitutes Part 2 of SKBF's 1982 submission to the National Board for Spent Nuclear Fuel, NAK, in accordance with the "Financing Act", and describes the facilities required for the management of radioactive residues from nuclear power generation. In addition, it provides an account of the costs involved both for the facilities referred to and for the decommissioning of nuclear power plants.

The report has been prepared by KBS, a department within SKBF, with the assistance of:

VBB	Layout drawings Material flow simulation
ASEA-ATOM	Process equipment Operating costs
ABV	Construction costs Schedules of costs

FOREWORD

This report comprises the first account, prepared by the Swedish nuclear power companies in accordance with the "Law concerning the Financing of Future Expenses for Spent Nuclear Fuel etc." (1981:669), of plans for the final disposal of radioactive residues from nuclear power generation.

The report consists of two parts . Part 1 presents the general premises for the activities as well as plans for R & D and necessary facilities (including decommissioning). Chapters 8 and 9 provide a summary of the time schedules and cost estimates for the activities. Part 2 gives a more detailed account of the facilities and costs.

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APPENDICES

1. BACKGROUND

Radioactive residues from the Swedish nuclear power plants are produced in different forms and with varying properties. The treatment and storage of the waste are primarily determined by its content of activity and decay times. At the nuclear power plants, the low- and medium-level wastes from reactor operations, which have a "dangerous" lifetime of several hundred years, are treated in various ways (cast into bitumen and concrete) in order to facilitate safe transportation and storage. The spent fuel, which is highly radioactive and contains substances with a "dangerous" lifetime of many thousands of years, is stored on a temporary basis in water pools at the power plants for subsequent removal to a central intermediate storage facility (CLAB) or transportation abroad for reprocessing. The reprocessing waste, which contains residues of a long-lived nature, is returned to Sweden for final storage.

A number of facilities are required to handle and store the spent fuel and radioactive waste, see Appendix 1.1, one of which, CLAB, is under construction. The other facilities are in the process of being planned.

Final storage facilities for long-lived waste will not be constructed until the first part of the next century, and will continue to operate for several decades after the power plants have been decommissioned, see Appendix 1.2. Responsibility for management of the waste will rest with the nuclear power companies, who will also have primary responsibility for ensuring that funds are made available for this activity. This is stipulated in the law concerning the financing of future expenses in connection with spent nuclear fuel etc., the "Financing Act" (1981:669), which came into force on July 1, 1981. The law and regulations based on it provide that:

* funds shall be allocated during the operational lifetime of the nuclear power plants to cover the costs of providing a safe system for the handling and storage of nuclear residues, and that these funds shall be administered by the Government through a special committee. The funds shall also cover the cost of decommissioning (including dismantling) the power plants, but not the handling and storage of the low- and medium-level wastes (operating waste) which are generated continuously during the operation of the power plants.

* the size of the fee shall be determined annually by the Government on the basis of current government plans and be charged in relation to the quantity of energy generated by each reactor.

* the owner of the reactor shall submit to the National Board for Spent Nuclear Fuel, NAK, by the end of June of each year at the latest , plans for future research and development work and for the construction and operation of the facilities required for the handling and storage of spent nuclear fuel, or radioactive waste originating from it, and for the decommissioning (including dismantling) of the reactor plant. (The Swedish nuclear power companies have commissioned the Swedish Nuclear Fuel Supply Company, SKBF, which is owned jointly by the power companies, to carry out this work on their behalf.)

It is not possible at present to state in detail how different types of waste will be treated in the future, or how the different facilities will be designed. Ongoing research and development work may result in solutions other than those currently envisaged. Future political decisions may also lead to alternative solutions. However, in order to gain some idea of the costs involved in the handling and storage of nuclear residues, it is necessary to base the estimates on a scenario which is deemed realistic in the light of the current situation. A schematic scenario of the type in question is presented in this report. It must be emphasized that the information presented does not signify a particular standpoint or reflect a policy decision on any single question.

The account given in this report is based partly on safety-related considerations that have been made in other contexts. However, no attempt is made to assess the safety aspects of the systems here, since the sole object of the report is to provide an indication of possible technical designs for the facilities and the costs likely to be incurred by them.

In addition to the costs, the report presents the technical basis on which the cost estimates are founded. The intention is that the estimates should be continuously adjusted and adapted to the results of ongoing development and design work, and to the general price trend.

Estimated sub-costs have been stored in a flexible, computer-based costing system which makes it possible to vary, change or complement the input values. All the items of expenditure are time-linked, which permits capitalized value costing with different values for real rates of interest.

The estimated costs accounted for in this report also include expenditure which does not come under the Financing Act, such as waste originating from the operation of nuclear power plants and radioactive waste from non-power producing operations (Studsvik etc.). Such costs can be separated.

2. PREMISES

When estimating the costs involved in the handling and storage of nuclear residues, a number of assumptions must be made concerning future developments and the Swedish nuclear power programme. In this chapter, an account is given of the premises which have been applied for the first cost analysis presented in this report.

The research and development work which is currently in progress, and which is assumed to continue for several decades to come, may lead to changes in the methods and facilities presented here. In view of this, the intention is to update the cost estimates on a continuous basis.

The Swedish nuclear power programme is assumed to comprise the 12 reactors decided on by the Government following the referendum in March 1980. According to current guidelines for national energy policy, these reactors will be taken out of service by 2010 at the latest, which means that the last reactor to go on-line will have an operational lifetime of about 25 years. This background, coupled with a conservative attitude towards the cost aspect, including total operating time (25 years) and availability, has provided the framework for the estimates. In this way, the total quantity of energy delivered by the nuclear power units has been estimated to amount to approximately 1 460 TWh, which means a uranium consumption of approximately 6 800 tonnes U,[1], see Appendix 2.1. Of this total, contracts have been signed for the reprocessing of 867 tonnes, 727 tonnes by Cogema and 140 tonnes by BNFL. Since the final storage of fuel and wastes returned from reprocessing is not envisaged until after the year 2020, temporary storage facilities will have to be constructed for these residues. It is assumed that these facilities will be in Sweden.

Of the total quantity of radioactive residues, approximately 5 % consists of waste from plants which do not generate electricity. Joint handling and final storage of these products together with waste from nuclear power generation is advantageous in several respects, and has therefore been assumed in the report, although with no consideration given to forms of financing.

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1) "tonne U" or "tonne fuel" applies in the following to the number of tonnes of uranium contained in the fuel.

Table 2.1 Main types of radioactive residues to be disposed of

Product	Origin	Number of Units	Volume m^3
High-level waste	Spent fuel Vitrified waste from reprocessing	5 200 (canisters)	10 000
Alpha-contaminated waste	Low- and medium-level wastes from reprocessing	7 900 (drums)	4 000
Core components	From reactor internals	1 300 (cassettes)	5 000
Low- and medium-level wastes	Wastes from reactor operation and treatment plants	192 000 (drums and moulds)	122 000
Decommissioning waste	From decommissioning of power plants and treatment plants	8 500 (7-20 m^3 containers)	151 000
Total quantity		215 000	292 000

All radioactive material can generally be divided into five main groups, depending on origin and handling requirements. Information on the total quantities and number of handling units, which has been obtained from the assumptions made, is given for each group in Table 2.1. For detailed data, see Appendix 2.2.

It is assumed that all waste, together with the spent fuel which is not reprocessed, will be ultimately stored in bedrock in Sweden in various repositories adapted to suit the particular properties of the waste. Prior to final storage, the spent fuel and high-level waste will be furnished with an outer casing which offers good corrosion resistance and is watertight. It is assumed that the remaining waste will be deposited in its respective repository in the form it acquires at the place of production.

It is assumed that the waste will be transported between production point, intermediate repository and final repository by ship in combination with the shortest possible railway route if a repository should be sited inland. It has been assumed that a 150 km rail link will have to be built to the final repository for long-lived waste. During transportation, the spent fuel and radioactive waste will be placed in transport casks or large concrete containers (20-25 m^3 internal volume) designed in compliance with the demands imposed on radiation shielding and resistance to external influences. Loading and off-loading of vessels will follow the roll-on/roll-of principle with the aid of hydraulic lift trucks.

The handling procedure for the management of nuclear residues is shown in Appendix 1.1. Appendix 1.2 shows the envisaged time schedule for the construction, operation and decommissioning (or sealing) of appurtenant facilities.

The facilities outside the production sites which it is assumed will be constructed in Sweden for the handling and storage of nuclear residues are:

Intermediate storage facilities

* Central storage facility for spent fuel, CLAB

* Central storage facility (intermediate storage) for vitrified waste from reprocessing, CLG

* Central storage facility (intermediate storage) for low- and medium-level waste from reprocessing (alpha-contaminated), CLU

Treatment facilities (encapsulation)

* Treatment plant for vitrified waste, BSG

* Treatment plant for spent fuel, BSAB.

Final repositories

* Final repository for waste from reactor operation and decommissioning, SFR

* Final repository for vitrified waste from reprocessing, SFL 1.

* Final repository for spent fuel, SFL 2

* Final repository for low- and medium-level wastes from reprocessing, SFL 3

* Final repository for wastes from operation and decommissioning, SFL 4

* Final repository for core components, SFL 5.

The final repository for core components may be sited, wholly or in part, adjacent to either the SFL (SFL 5), or the SFR (SFR 2).

In order not to underestimate the costs, it is assumed in this study that the facility will be sited adjacent to the SFL.

The locations of most of the facilities have still to be decided. This means that certain assumptions have to be made when estimating the total costs. The locations given below have been assumed in connection with layout work and costing.

* The CLAB will be located at the Oskarshamn Power Station (the CLAB is under construction).

* The SFR will be operational by 1988 and is proposed to be located at the Forsmark Power Station. Since the SFR is at the design stage, relatively detailed data is available for an accurate cost estimate of the first construction phase. According to the plans, the CLG and the CLU will be operational by 1990 at the earliest and are assumed in this report to be co-sited with the SFR.

* The remaining facilities (BSG/BSAB, SFL 1-5) will be given an inland location in northern Sweden, some 600 km north of Stockholm. This location has been selected primarily to achieve a certain degree of conservatism in the cost estimates and to illustrate the importance for the cost estimates of the fact that there is no harbour in the immediate vicinity of the facility.

Encapsulation of the spent fuel can be carried out in the same facility as that used for the vitrified waste from reprocessing, although after some modifications. The two types of waste will be deposited in adjacent rock vaults for final storage. The vitrified waste will be encapsulated and deposited in the final repository during the period 2020-2023, after which the facility will be modified to the extent required to permit subsequent handling and storage of the spent fuel.

A list is given below of certain assumptions which have been made regarding the final repositories.

* The SFR will be located 50 m below the seabed where the water depth is about 5 m. This corresponds approximately to the land uplift over a period of 1 000 years.

* SFL 1-2 will be located 500 m below ground level and be directly connected to the encapsulation plant via a vertical shaft.

* SFL 4-5 will be located 3 km from SFL 1-2 and 300 m below ground level. The waste will be transported to these repositories via a transport tunnel.

* SFL 3 and SFL 4 will have a common receiving section but SFL 3 will be located 200 m deeper. Waste will be transported to SFL 3 from the receiving section at level -300 via a vertical shaft.

The costing of construction, operation and decommissioning for all the facilities has been based on the January 1981 price level.

Drawings have been prepared to serve as a basis for the cost estimates. The drawings are based on studies of handling methods, operating conditions and system designs, and present-day working methods have been assumed for each phase of the work. For obvious reasons, the degree of detail is greatest for those projects whose realization is most imminent, i.e. the CLAB and the SFR.

For those parts of the facilities for which detailed basic data are lacking, a correspondingly larger adjustment to the cost has been made for contingencies.

3. OVERALL DESCRIPTION OF SYSTEMS

3.1 EXTERNAL TRANSPORTS

The studies performed indicate that the transportation of radioactive material over long distances is effected in the safest and least expensive way by ship. Since all nuclear facilities in Sweden today are located near the coast, planning and design has been carried out on a sea transportation system, which can be utilized for all transports of radioactive material over long distances. A special vessel with a cargo capacity of 1 300 tonnes has been ordered and it will be possible to make the first shipments towards the end of 1982, see Appendix 3.1. Transport containers designed to meet the demands imposed with regard to radiation shielding, cooling and protection against external influences will be used for these shipments. The weight per full container is 60-120 tonnes.

Self-propelled hydraulic lift trucks will be used for loading and off-loading these transport containers. Since the speed at which these vehicles travel is relatively low, transport distances of more than a few kilometres should be avoided. If overland transport is necessary over long distances, as is envisaged for the SFL, it should therefore be by rail.

The transport containers can be divided into two main groups. For radioactive material, which imposes greater demands with regard to radiation shielding or protection against mechanical damage, cylindrical steel tubes will be used, referred to as transport casks. These are 5-6 m long and 1-2 m in diameter and can be provided with cooling flanges if required. 5-6 different types may be used for the transports in question. Other waste will be transported in rectangular transport containers made of concrete. The containers generally hold about 20 m^3 of waste. The maximum number of casks and containers utilized in the transportation system will amount to approximately 25 and 50, respectively. The exact number is largely dependent on whether the vessel at the harbour waits for the casks or containers to be filled or emptied or if full casks or containers can be exchanged for empty ones, and on whether the full cargo capacity of the vessel is utilized on each trip.

In all, 1 800 voyages can be expected to be made during the period 1982-2055 with a maximum annual frequency of 60 trips/year, see Appendix 3.2. On each trip the vessel can carry 12 shipping units (casks/containers) corresponding to approximately 1 300 tonnes. Operational speed is 11.5 knots and draught is 4 m. The time per voyage varies from 2 days to 4 weeks, the latter being for the Forsmark-La Hague route. All voyages have been simulated by computer. It is estimated that the transportation system will require 20 personnel.

3.2 DECOMMISSIONING OF NUCLEAR POWER PLANTS

It is assumed that the power plants will be dismantled after shut-down and that it will be subsequently possible to use the site for any purpose without restrictions.

Decommissioning of a plant can commence when the nuclear fuel, control rods, operating waste etc. have been removed, which is assumed to take a year after the plant has been shut down. The exact times when decommissioning of the different facilities may commence have not been planned in detail. For the purpose of this study, an average time gap of 5 years has been assumed between plant shut-down and commencement of decommissioning. It is estimated that decommissioning will take approximately 5 years per unit and employ an average of 200 people.

Dismantlement starts at the centre of the plant and continues outwards so that the barriers are retained for as long as possible. First the contents of the reactor vessel are dismantled, then the vessel itself and subsequently the radioactive pipe systems etc. The internal components of the vessel are cut up under water by means of plasma arc cutting. the vessel is cut under dry conditions behind special radiation shields and the remaining sections primarily by cold saw, pipe lathe or cutting tools. During the entire course of this work, the ventilation air is monitored and filtered to ensure that no radioactivity is spread to the surroundings.

The dismantling of non-radioactive systems - such as cooling systems, parts of the turbine systems, electrical systems etc. - is carried out in the conventional manner.

The stainless steel lining of the pools is cut along the joints. The surface layer of the concrete behind the lining is chipped away to the extent that it is radioactively contaminated.

The largest and most contaminated section of concrete is the biological shield nearest the reactor tank. This section can be broken up into suitably-sized blocks from the outside by seam drilling and splitting without the need for special protective measures.

All radioactive waste from decommissioning is deposited in special transport containers for transportation to the final storage facility, the SFR.

The remaining inactive parts of the building are demolished by conventional means, primarily by careful blasting to below ground level. The space at the bottom is filled with demolition material, after which the surplus is transported to a refuse landfill site.

3.3 CENTRAL INTERMEDIATE STORAGE FACILITY FOR SPENT FUEL, CLAB

The spent fuel is stored at the power plants in existing water pools for a number of years. Their storage capacity corresponds to the fuel extracted during 4-5 years of operation. Final storage of the spent fuel is expected to commence in the year 2025, i.e. about 15 years after the production period at the plants. For this reason, a central repository for spent fuel is currently being constructed on the Simpevarp peninsula north of Oskarshamn, which, when fully constructed, will have sufficient capacity to store all the fuel and core components originating from the operation of 12 nuclear power plants, excluding the fuel sent abroad for reprocessing.

The CLAB is expected to be able to receive fuel in 1985 and it is estimated that the last fuel rods will leave the facility in 2050. This long operating period means that a large portion of the equipment will have to be replaced during the operating phase.

Above ground, the facility consists of several contignous buildings, see Appendix 3.3. There is a receiving section, in which most of the handling of incoming or outgoing fuel and core components takes place. Directly connected to the receiving section are buildings for the auxiliary systems (cooling and water treatment, waste treatment, ventilation, etc.), for the service systems (pumps, heat exchangers, etc.) and for the electrical systems. The buildings are linked to detached office and staff buildings by separate passages.

The storage sections consist of rock vaults with roofs located at a depth of about 30 m below ground level. They are reinforced with rock bolts and lined with concrete. Below the concrete-lined roof is a ceiling of sheet-metal. The vault for the first development stage is 120 m long, 21 m wide and 27 m high. It contains four storage pools, each with 300 positions for fuel and core components, and a smaller central pool which is connected to a transport channel.

The pools are made of reinforced concrete and lined with stainless steel. Each pool contains 3 000 m^3 of water and can hold 1 000 tonnes U. Final storage capacity is estimated to be 2 800 positions for approximately 6 600 tonnes U and 400 cas settes containing core components.

Fuel is transported from the receiving section to the storage section with the aid of a fuel hoist. The hoist shaft is connected to the pools by means of a channel. The storage section is also linked with the surface buildings by means of a shaft which contains a personnel lift, ventilation ducts, etc. Transport access between the surface and both ends of the storage section is also provided by tunnels. These tunnels can also be used as evacuation routes.

The facility meets stringent requirements with regard to protection of both the internal and external environments. All handling and storage of fuel takes place in water and is to a large extent remote-controlled. There are special safety systems for, among other things, cooling and power supply.

During the construction period, the maximum labour force will be 400, whereas 100-110 persons will be required during the operating period. On occasions when there is no transportation either to or from the facility, it is envisaged that it will be possible to reduce the number of personnel somewhat.

3.4 CENTRAL INTERMEDIATE STORAGE FACILITY FOR VITRIFIED WASTE, CLG

In the CLG, the vitrified waste returned from reprocessing abroad will be stored until the final repository, SFL 1, is ready to receive it, i.e. for a period of some 30 years. During this time, a not inconsiderable quantity of heat will be emitted from the waste which will have to be vented away by ventilation.

The waste arrives in the form of canisters with an outer casing of stainless steel and with a height of 1.34 m and diameter of 0.43 m. In the event of a damaged or contaminated casing, it shall be possible to enclose the outer casing with an extra jacket on reception, a process known as recanning. In the facility, the canisters are stacked seven high in vertical tubes made of stainless steel, which altogether hold 784 canisters. Cooling air is blown through these tubes. The actual storage section is surrounded by 1.5 m thick concrete walls. The facility also houses service systems for cask handling and for inward and outward transport of vitrified waste canisters, ventilation for cooling purposes, etc.

The CLG is an above-ground facility and consists of a process and storage building with a volume of 53 000 m^3, an administration building and an external workshop and store. It is assumed that the facility will be co-sited with the CLU and that the latter buildings will be common for both the CLG and the CLU. The layout of the main building is shown in Appendix 3.4. The building is made of concrete to provide radiation shielding and tightness, and can be subdivided functionally into the following sections:

* Arrival section with temporary holding area for transport casks and a workshop for cask handling.

* Receiving section where the lids are opened and the casks are decontaminated.

* Unloading cell and recanning cell where unshielded glass canisters are handled.

* Storage section with ventilation spaces.

* Transit hall covering both the unloading cell and the storage section and equipped with an overhead travelling crane.

The handling procedure for incoming glass canisters is briefly as follows. The canisters are delivered by truck to the CLG in a transport cask. The cask is lifted off the truck inside the facility and placed on a wagon in the receiving section. The lid is loosened and the wagon proceeds to a position under the unloading cell where the cask is connected to an opening. The lid is removed and the canisters are lifted out of the cask and placed in the unloading cell. The cask is then taken away. If the content of the transport cask is contaminated, the canisters are lowered through an opening into the recanning cell, where they are provided with an extra outer jacket and returned to the unloading cell. A radiation protection bell, manoeuvred by an overhead travelling crane, hoists the canisters from the unloading cell, transports them to the storage section and lowers them into the stainless steel tubes. The openings above the tubes are sealed with concrete plugs sufficiently thick to permit unrestricted access to the transit hall during the storage period.

Removal of the canisters for further transportation to the SFL is carried out in the reverse order.

Air cooling is provided by two exhaust-air fans (2x100 %) which may be combined with textile bag filters. The fans are mounted in such a way that underpressure in the storage section is maintained in relation to the other parts of the building. In the event of temporary fan outage, cooling is maintained by natural convection.

All handling of the canisters is carried out either by remote control or by manipulators, and is observed via TV and shielded windows.

It is estimated that the joint operating personnel for the CLG and the CLU will be in the order of 5-10 persons during the stages when the casks are being received and dispatched, and 2 persons during the storage stage. During the latter stage, the personnel are responsible for general surveillance and the servicing of fans, etc., and in addition for checking that no radioactivity is released in the facility. During the construction phase, a maximum of 130 persons will be employed at the facility.

3.5 CENTRAL INTERMEDIATE STORAGE FACILITY FOR LOW- AND MEDIUM-LEVEL WASTES FROM REPROCESSING, CLU

The low- and medium-level wastes returned from reprocessing abroad will be stored in the CLU until the the final repository, SFL 3, is ready to receive it, i.e. for a period of some 30 years. The wastes will be delivered to the the CLU cast in concrete or bitumen in metal drums of varying size.

The CLU is built up around a system whereby the drums are stored stacked in concrete cells. An air-conditioning plant ensures that temperature and humidity in the cells are maintained within suitable limits during the storage period.

The CLU is an above-ground facility and consists of a single building with a volume of 43 000 m^3. The layout is shown in Appendix 3.5. The storage section, i.e. the part containing the concrete cells, lies below ground level. The building is made mostly of concrete and can be divided functionally into three sections:

* Receiving and dispatch section with service equipment and control room.

* Storage section containing 153 cells, each with a width of 2.6 m, a depth of 2.6 m, and a height of 5 m .

* Transit hall covering both the service section and the storage section and equipped with an overhead travelling crane.

The handling procedure for incoming waste is briefly as follows. The drums are delivered by truck to CLU in a concrete container or B-container (cask) mounted on a standardized chassis. The shipping units are unloaded inside the facility and emptied of their contents. During emptying, the drums are placed in a radiation-shielded trough in the immediate vicinity of the receiving opening where they are sorted and bundled. After this, the drums are transported to the cells in a radiation protection bell manoeuvred by an overhead travelling crane, and are lowered into place. Finally, the cells are covered with concrete lids sufficiently thick to permit unrestricted access to the hall during the storage period. The process is steered from a control room which also permits direct surveillance of the various sections.

Removal of the drums from the facility for further transportation to SFL 3 is carried out in the reverse order.

During the storage period the facility is kept under surveillance, and a small labour force ensure that the drainage system, fans etc. are maintained and check that no radioactivity is released in the facility.

It is assumed that the CLU will be co-sited with the CLG. The administration buildings, workshop etc. and operating staff are thus common for both facilities and are accounted for under Section 3.4, CLG.

3.6 FINAL REPOSITORY FOR LONG-LIVED WASTE, SFL

3.6.1 General

The long-lived waste originating from reactor operation and decommissioning will be stored in rock vaults 300 or, alternatively, 500 m below ground level. There will be four types of repository, intended for different types of waste.

* The SFL 1-2, level -500 m, is intended for vitrified waste and spent fuel. The repository consists of a large number of tunnels in which the waste and fuel are deposited in holes in the tunnel floors.

* The SFL 3, level -500 m, is intended for low- and medium-level reprocessing wastes. The repository consists of a concrete silo partitioned into vertical cells into which the waste is lowered and cast in.

* The SFL 4, level -300 m, is intended for waste from operation and decommissioning. It is the same type of repository as SFL 3.

* The SFL 5, level -300 m, is intended for core components. The repository consists of concrete troughs partitioned into vertical cells in which cassettes containing the core components are deposited and cast in. The troughs are arranged in a row in a long rock cavern.

An illustration of the appearance and arrangement of the repositories is shown in Appendix 3.6.

All the repositories are based on the principle of a number of barriers surrounding the waste. The object of the barriers is to prevent radioactive matter from leaking into the biosphere in harmful quantities. The barriers in the case of spent fuel, for example, are, in addition to the fuel's low solubility in water, as follows (counting from the centre outwards): the fuel encapsulation, the copper canister, pure bentonite and the surrounding bedrock.

Bentonite will be included in the barrier system surrounding the waste either in a pure form or mixed with sand. Bentonite is a volcanic ash which possesses the property of binding large quantities of water at the same time as it swells. If the swelling is prevented, as will be the case in the final repository, high pressure is built up and the bentonite develops into a plastic mass with very high impervionsness to water. If blended with sand, the bentonite will, on swelling, fill the pores in the material.

The siting of the different repositories in the same geographical locality means that the surface facilities which are required during the receiving stage can to a large extent be made common to all repositories.

The site layout plan in Appendix 3.7 shows the arrangement of the land area above the repositories. The major facility is the treatment plant for vitrified waste and spent fuel, the BSG/BSAB. In addition, there are personnel facilities, a goods reception station, a workshop for servicing and repairing vehicles, a concrete station with crushing plant, bentonite handling, etc. The 150 km-long rail connection, which is assumed to be required for transportation from the harbour, is also counted as belonging to the joint SFL facilities.

Apart from the living quarters and two detached evacuation and ventilation buildings for the rock vaults, all the facilities are located within a fenced-off and guarded area. The SFL 1-2 are reached primarily by a hoist shaft adjacent to the BSG/BSAB. The SFL 3-5 is reached via a tunnel to level -300, and then by elevators to -500 (the latter for SFL 3). The access tunnel opens out into the guarded area.

All the storage and above-ground facilities form an organizational unit operated by some 200 personnel. During the construction stage, some 800 persons will be employed at the facilities.

On completion of deposition, the surface facilities will be demolished. As far as radioactive parts are concerned, the decommissioning of BSAB will be accomplished in the same way as for the nuclear power plants. The waste will be deposited in the SFL 4.

3.6.2 Treatment plant for vitrified waste and spent fuel, BSG/BSAB

Before the vitrified waste from reprocessing and the spent fuel are finally deposited, they are to be furnished with an outer canister of lead-titanium and copper respectively. This is carried out in the treatment plant BSG/BSAB. Vitrified waste will be treated during the first four years of plant operation (BSG) and the plant will then be modified to permit the treatment of spent fuel (BSAB). The number of lead-titanium canisters will amount to approximately 730 and copper canisters to about 4 500 (3 200 for BWR and 1300 for PWR).

The layout of the building is shown in Appendices 3.8-9. The facility has a volume of 185 000 m^3 and a total length of 175 m. In view of the demand for radiation shielding and airtight ventilation system, the building is mostly made of concrete. The facility can be subdivided functionally into the following sections:

* Arrival and receiving section where unloading and fuel dismantling operations, etc., are carried out. This section also houses a workshop for the repair of transport casks.

* Encapsulation and dispatch section with elevator down to the final repository.

* Service section located alongside the encapsulation section and housing stores, lead melting equipment etc.

* Auxiliary systems section, mainly for cooling and treatment systems and for handling of internal radioactive operating waste.

* Electrical and control section.

An adjacent building houses personnel and office premises as well as the superstructure and service system for the central hoist shaft down to the final repository, see Appendix 3.10.

The handling procedure for the encapsulation of spent fuel is briefly as follows. The transport cask is conveyed into the facility still in position on a railway wagon, lifted up and, following several intermediate operations, deposited in one of the water-filled pools in the receiving section. Here the fuel assemblies are extracted, transported to an adjacent pool and dismantled. The detached core components, primarily the fuel boxes, are collected together in cassettes for further transportation to the SFL 5. The fuel rods are collected into bundles and conveyed via a lock into the encapsulation section. The fuel bundles, which are now handled under dry conditions, are deposited in prefabricated copper canisters 4.7 m in height, 0.8 m in diameter and with a wall thickness of 20 cm. The copper canisters are then transported between different treatment stations with the aid of special transport devices. First they are conveyed to casting furnaces where voids in the canisters are filled with lead. The canisters then stand and cool in a cooling cell, after which they are moved into a welding cell where the upper edges of the canisters are machined and lids are welded in place. Before the canisters are subsequently conveyed to the elevator for transportation down to SFL 1-2, they pass an inspection station where they are checked for surface contamination.

The vitrified waste is basically handled in the same way. Apart from the differences in handling which are consequent on variations in the size and form of the waste, there are two essential differences to be observed. Firstly, the vitrified waste is handled under dry conditions, i.e. the pools are not filled with water. Instead the transport casks are connected under airtight conditions to an opening leading into the receiving cell of the encapsulation section. The other difference is that the canisters are made of lead with an outer casing of titanium. The canisters are 1.8 m in height, 0.6 m in diameter and have a wall thickness of 10 cm.

The handling line for spent fuel is duplicated in view of the risk of stoppages due to malfunction, etc. On the other hand, not enough vitrified waste is handled to warrant the increased cost of a duplicate system.

All operations in the encapsulation and dispatch sections are remote-controlled with surveillance via TV and shielded windows.

3.6.3 Final repository for vitrified waste and spent fuel, SFL 1-2

The final repository for the encapsulated vitrified waste and the fuel is located at a depth of 500 m below ground level and can be reached via a hoist shaft from the BSG/BSAB. The facility basically consists of a system of parallel storage tunnels, total length about 35 km, with appurtenant transport tunnels, service space and shafts to the surface, in all occupying an area of about 1 km^2. The extent of the underground facilities is determined primarily by the heat flux in the deposited fuel. The layout is shown in Appendices 3.11-3.13. The waste canisters are lowered into some 5 200 vertical holes drilled in the storage tunnel floors.

The repository is divided symmetrically into two parts in order to facilitate physical separation of the excavation and sealing work from the emplacement work, which are assumed to be carried out simultaneously. The storage tunnels will be excavated as deposition proceeds. It should be noted that in Appendix 3.11 this division is shown schematically. In practice, the design of the facility will be adapted to the fracture geometry of the rock. In order to achieve this adaptation, extensive probe-drilling will be carried out during the excavation phase.

The repository consists of a central section, containing service areas, located directly below the encapsulation station, and a deposition section. Communication between the central section and the ground surface is provided by three shafts:

* The main shaft, which constitutes the main entrance to the repository for both staff and materials. Via this shaft, which is equipped with two elevators, the repository is supplied with air, water, electricity, etc.

* The skip shaft, which is provided with rock hoisting equipment. The skip shaft will be the first shaft to be driven and will thus be a sunk shaft.

* The waste shaft, with elevator for lowering the canisters to storage level.

Another shaft is located at the opposite end of the repository. This normally serves as an exhaust air shaft, but in an emergency situation it can also be used for the purpose of personnel evacuation.

The deposition of copper canisters may be briefly described as follows. (The principles for lead-encapsulated waste are the same. Only the dimensions are different). The deposition hole, which has a depth of 7.7 m and a diameter of 1.5 m, is checked with regard to tightness, i.e. water intrusion. Immediately before deposition, compacted pure bentonite is placed in the hole in such a way that space is left for the canister, see Appendix 3.14. The canister is conveyed from the elevator with the aid of a vehicle which permits shielded transport. The same vehicle is used to lower the canister into the hole. Finally, the canister is covered by further bentonite blocks, the hole is temporarily covered and deposition is completed.

When an entire storage tunnel is full, work may commence on sealing it. The temporary covers are removed from the holes and the tunnel is filled with sand/bentonite, which is compacted. The mouth of the tunnel is plugged with compacted bentonite blocks, temporarily propped in place until it is time for the central tunnel to be finally sealed.

When all the canisters have been deposited, the entire facility is sealed with sand/bentonite. Certain sections of the shafts are at the same time plugged with compacted bentonite.

3.6.4 Final repository for low- and medium-level wastes from reprocessing, SFL 3

The waste to be deposited in the SFL 3 comes from the CLU, where it has been stored for a period of some 30 years. It is in the form of metal drums of various sizes containing reprocessing waste which has been solidified in concrete or bitumen. At the -500 m level, the drums are stacked in a concrete silo partitioned into cells, and are cast in place with concrete. The silo is surrounded by sand/bentonite.

The silo, which has an outer diameter of 22.5 m. and a height of 30 m, is situated in a rock vault of a size sufficient to permit a layer of sand/bentonite at least 1 m thick to be packed around it, see Appendix 3.17. The outer walls of the silo are made of concrete and are at least 1 m thick. 20 cm thick partition walls divide the interior space of each silo into vertical cells with side dimensions of 2.5x2.5 m. This partitioning into cells serves two purposes. First, it makes the structure resistant to external pressure (bentonite and water) and, second, it permits the casting-in of the drums to be carried out under controlled conditions. On completion of deposition, a concrete slab is cast on to the silo and the space above is packed with sand/bentonite.

Access to the storage area is from the -300 m level via two shafts, one for personnel, which also serves as a ventilation shaft, and the other for waste.

At the -300 m level there is an extensive receiving system, parts of which are common for the SFL 3, 4 and 5. The vault is reached by vehicles, including waste transports, via a 3 km long access tunnel. Contact between the vault and the surface is also provided by a shaft intended for transportation of personnel and for ventilation. The same shaft continues down to a depth of -500 m.

The waste arrives at the facility by rail, is transferred on to trucks and is transported down to the receiving section at -300 m level. Immediately before the storage area the access tunnel branches off in two directions, see Appendices 3.15-3.16. Waste in B-containers (casks) is transported in one direction to a station where the casks can be raised upright and placed in a position ready for unloading. Waste in concrete containers is transported in another direction to positions (3 in all, one of which is for the SFL 3) where the container, complete with chassis, can be taken off the truck and placed in a side room ready for unloading. As far as the SFL 3 is concerned, both forms of transport occur to approximately the same extent.

After the casks and containers have been placed in the unloading position, all handling is remote-controlled. When the lids have been removed, the waste units are extracted by a special overhead travelling crane and placed in the elevator for further transportation down to a level of -500 m. There, the units are collected by the same kind of crane, which travels out on the upper edges of the silo walls and lowers the waste units into the cells.

When two layers of drums have been deposited in the silo, the space around them is filled with concrete. The concrete is brought into the storage area in a hopper via the same route as the waste.

3.6.5 Final repository for wastes from operation and decommissioning, SFL 4

The low- and medium-level wastes from operation and decommissioning produced in Sweden from 2025 onwards, and a limited quantity of long-lived waste from earlier periods, will be sent to the SFL 4 for final deposition. The repository is built on the same principles as the SFL 3. There are altogether three silos, each with an external diameter of 23 m and a height of 52 m, see Appendices 3.15-3.17. Although the repository lies at a level of -300 m, and thus requires no elevator for waste transportation, in all other respects it corresponds to SFL 3. However, transports of waste in B-containers are infrequent.

Most of the solidified waste arrives at the repository in the form of concrete moulds, i.e. concrete cubes with side lengths of 1.2 m. The remaining solified waste is in the form of drums. Approximately a third of the overall volume of waste consists of decommissioning waste, mainly from the CLAB and the BSAB. The method of handling the latter category of waste has not been fully investigated to date, but as a working hypothesis it has been assumed that the decommissioning products, mostly process equipment, will be enclosed in metal containers without additional radiation shielding. These containers will be deposited in the cells in the SFL 4.

3.6.6 Final repository for core components, SFL 5

The core components consist of fuel boxes (largest category), control rods, detector probes and other material originating from the reactor core. They arrive at the SFL either together with the fuel or in separate transport casks. In the former case they are sorted out in the BSAB before being transported down to the SFL 5.

The core components are deposited without any form of cutting or compaction, a method known as direct disposal. For this purpose they are placed in cassettes when transported from the CLAB or the BSAB. At the SFL 5, the cassettes are deposited in prefabricated concrete troughs, which are then injected with cement.

The SFL 5 lies at a level of - 300 m and transportation down to the repository is by the same means as for the SFL 3 and 4, see Appendices 3.15-3.17. In contrast to the SFL 3 and 4, radioactive material which is neither cast-in nor surface-coated in any other way is handled in the SFL 5. Greater demands must therefore be imposed on seals, ventilation and decontamination.

The repository consists of 14 concrete troughs with side dimensions of 12x13 m and a height of 6.6 m. Each trough is divided into vertical cells with dimensions permitting one cassette to be housed in each cell. In all there are 1 400 positions. At the bottom of each cell is a pipe for cement injection. The troughs are arranged in a row in a long rock cavern. A travelling crane with a shielded depositing device runs on top of the troughs. A filling of compacted sand/bentonite at least 1 m thick is provided underneath and at the sides of the troughs. At one end of the repository is a receiving section with cask holding area, workshop and decontamination systems. The receiving section can be reached via a separate tunnel run.

The handling procedure for the deposition of core components is briefly as follows. The core components, placed in cassettes, arrive by truck in a transport cask. The cask is lifted up, transported to the receiving section, lowered into the unloading position and the lid is loosened. The cask is placed under the depositing machine, which opens the lid of the cask, lifts out the cassette and recloses the lid. The cassette is now in the shielded depositing machine, which drives out to the right cell, raises the lid of the cell, lowers the cassette into the cell and replaces the lid. The depositing machine has its own ventilation system fitted with filters. It may therefore remain in place above the cell and filter the air which flows out of the cell during cement injection, which is done from an adjacent tunnel.

Deposition, excluding concrete injection, is for the most part carried out by remote control and monitored via TV and shielded windows.

After all the core components have been deposited, the repository is sealed with compacted sand/bentonite.

3.7 FINAL REPOSITORY FOR OPERATING AND DECOMMISSIONING WASTES FROM REACTOR OPERATION, SFR

The SFR comprises two parts: The SFR 1 for operating waste and the SFR 3 for decommissioning waste. The SFR 2, which is not included in this cost estimate, denotes an alternative final repository for core components, which may completely or partially replace the SFL 5. It is intended that the SFR should be constructed in stages and be able to receive waste from 1988 onwards. When the SFL 4 is ready to receive waste in the year 2025, it is assumed that the SFR will be closed down, the main reason being that this permits more rational transports, and that the concentration of handling to two places, the CLAB and the SFL, gives lower operating costs.

The SFR 1 will be the final repository for all operating waste, i.e. not core components or high-level waste, which is generated during the operation of the 12 Swedish nuclear power units. The SFR 1 will also be used for storing operating waste from the CLAB before 2025. It is also proposed that waste from industry and hospitals which is not regarded as being long-lived should also be finally stored in the SFR 1. It is intended that long-lived waste should be finally stored in the SFL 4 after 2024. Decommissioning waste from the nuclear power units and Studsvik will be sent to the SFR 3.

The waste to be deposited in the SFR will vary considerably with regard to both form and radioactive content.

The majority of the operating waste (SFR 1) will be deposited in silos in rock, see Appendices 3.18-3.19. The silos consist of concrete cylinders approximately 50 m high and 25 m in diameter surrounded by a mixture of sand and bentonite. For this type of storage, diffusion is the process by which most radioactive leakage occurs. Each cylinder, which holds approximately 15 000 m^3 of solidified waste, is partitioned into square-shaped cells with 2.55 m sides. The waste is deposited in these cells and cast-in with cement mortar. The deposition of waste in the silos is completely remote-controlled. A minor portion of the operating waste in terms of radioactive content (<10 %) is deposited in a simpler manner in tunnels and rock vaults.

In this report, it is assumed that decommissioning waste (SFR 3) will be deposited in silos, which involves the highest costs. However, the content of radioactivity in this category of waste is less than in operating waste, which means that further studies may lead to reductions in cost.

In all, approximately 180 000 waste units, corresponding to an approximate volume of 245 000 m^3, will be deposited in the SFR, 104 000 m^3 in the SFR 1 and 141 000 m^3 in the SFR 3. 10 silos need to be built and a total of 800 000 m^3 of rock will be excavated.

Waste is transported into the repository via a transport tunnel, and the transport containers are emptied in a shielded unloading station.

When all the waste has been deposited, the artificial barriers are completed, and tunnels and shafts are blocked to prevent access to the storage areas.

During the filling stage, the facility will be ventilated, and water which has leaked in will be pumped out. Otherwise the facility contains equipment for the handling and surveillance of the waste material and arrangements for concrete casting. During the daytime, the facility is staffed by 25 persons. During the construction stage, some 200 persons at the most will be employed at the facility.

4. COSTS

4.1 GENERAL ASPECTS OF COST SCHEDULING SYSTEM

This chapter provides an account of the calculated costs for construction, operation, and decommissioning and sealing of the facilities which have been described in Chapter 3. In addition, costs have been estimated for research and development, transportation, shut-down operation, and decommissioning of the nuclear power plants.

In order to gain an overall picture of these costs, use is made of a specially-developed computerized cost scheduling system, referred to as KOKA.

Costs already incurred for ongoing projects are stored together with the calculated future costs, so that a total sum is obtained for all facilities/operations included.

Each future item of expenditure has been coded by means of a six-digit code. The code, for example 543210, is built up as follows:

Level 0 Type of resource
1 Activity
2 Product
3 Category of cost
4 Facility/operation
5 Location

The distribution of the various levels is shown in Table 4.1. The computer sorts and totals at the next higher level.

All future costs have been calculated at the resource level, mainly material and labour costs. The reason for this is that, even if resources should change according to various indices, simple automatic index updating can be carried out annually.

The costs are also distributed chronologically.

Table 4.1 Coding system for cost scheduling

LEVEL 5 LOCATION		LEVEL 4 FACILITY/ OPERATION	
1	General, not bound to any specific location	11	Unspecified
		12	R&D
		14	Transportation
		16	Operation NPP[4]
2	Barsebäck	21	JF[3]
		22	B1
		23	B2
3	Ringhals	31	JF
		32	R1
		33	R2
		34	R3
		35	R4
4	Forsmark	41	JF
		42	F1
		43	F2
		44	F3
5	Oskarshamn	51	JF
		52	O1
		53	O2
		54	O3
6	Simpevarp	61	JF
		62	CLAB
7	Location x	71	JF
		72	CLG
		73	CLU
8	Location y	81	JF SFL
		82	BSG/BSAB
		83	SFL 1-2
		84	SFL 3
		85	SFL 4
		86	SFL 5
9	Location z	91	JF
		92	SFR 1
		93	SFR 3

LEVEL 3 CATEGORY OF COST	
1	Unspecified
2	SKBF
3	Investment
4	Operation
5	Re-investment
6	Sealing
7	Decommissioning
8	Operation NPP[4]

LEVEL 2 PRODUCT	
1	Unspecified
2	SKBF
3	Process equipment
4	Civil engineering works

LEVEL 1 ACTIVITY	
1	Unspecified
2	SKBF
3	Design
4	Construction

LEVEL 0 RESOURCE	
1	Unspecified
2	Wages/Salaries[1]
3	Materials
4	Copper[2]

1) Wages/salaries for work performed at respective location
2) Complete canister free SFL
3) JF = Joint Facilities
4) Shut-down operation of Nuclear Power Plants

Since certain costs will be incurred at a date far in the future and are in part fairly uncertain, the KOKA model has been designed to process items of expenditure which are variable within certain ranges of probability. The results of such simulation provide the basis for estimating a reasonable risk adjustment. This risk adjustment is not included in the costs presented in this chapter.

For costs already incurred, only the first three digits of the code are used. The costs are totalled and adjusted upwards to the current price level by the use of known weighted indices.

The costs in KOKA are linked to individual facilities and operations, which include the handling of both spent fuel and low-and medium-level wastes (LLW, MLW). The costs per facility/operation must therefore be apportioned so that it is possible to distinguish between the costs for which reserves are to be set up and other costs for which reserves are not necessary. In addition, all costs shall be distributed between the various nuclear power units and Studsvik, in relation to the degree of utilization of each facility/operation.

4.2 ESTIMATES AND ADJUSTMENTS

4.2.1 Description of adjustments

In order to obtain an idea of the degree of certainty in the estimated costs and the size of the cost framework, the cost per facility/operation is computed from a base cost (steps 1-3), an undertainty adjustment (step 4), and contingency adjustment (step 5).

These steps are described below. In addition, the basis for an risk adjustment is obtained through a simulation analysis of the total cost.

In this simulation, a cost interval, with triangular distribution and in part subjectively selected, is substituted for the estimated cost. A certain risk adjustment is then chosen from the estimated distribution function for the total cost. If, for example, this risk adjustment corresponds to one standard deviation, it follows that the probability of the total cost not being exceeded is 84 %. As has been mentioned previously, no risk adjustment has been included in the costs presented in this chapter.

The construction cost is arrived at as follows:

1. The costs of materials and labour are calculated on the basis of available documentation and the assumptions described in Chapter 3. Unit times and material prices are for the most part taken from the CLAB and the O3 nuclear power plant. Where this has not been possible, values based on experience from comparable facilities have been used.

2. Joint costs of 48-61 % are added to the costs of materials and labour. The joint costs are also taken from the CLAB and O3 and comprise the following:

	%
a. offices and sheds	5-6
b. temporary facilities	7-9
c. services for subcontractors	6-10
d. construction plant	7-9
e. site administration	9-10
f. accommodation, leisure facilities	4-6
g. central office	7-9
h. other costs	7-9

For the CLG and CLU facilities, a-e and h are included. Total 48 %.

For the above-ground facilities forming part of the SFL (joint facilities and the BSG/BSAB), a-h are included. Total 61 %.

For the underground facilities (SFL 1-5), a, b, d, e, f, g, h and part of c are included. Total 58 %.

A special investigation has been performed for the rock excavations.

3. A contractor's fee of 10 % is added to the sum of 1 and 2. The sum of 1, 2 and 3 is referred to as the base cost.

4. An uncertainty factor (10-40 %), which depends on the degree of uncertainty in the documentation available for making the estimates, is added to the sum of 1, 2 and 3.

5. An item for contingencies of 10 or 25 % is added to the sum of 1, 2, 3 and 4. This gives the total construction cost for the facility and is entered in the cost scheduling system (KOKA).

The cost for process equipment is arrived at as follows:

1. The cost of materials and installation has been estimated according to available equipment lists. The costs are based on prices for comparable components included in F3, O3 and CLAB, on the basis of direct contact with suppliers, and otherwise on an assessment based on the prices quoted for the components of similar facilities.

2. An adjustment, 15 %, is added for procurement, supervision, inspection and follow-up.

3. A further adjustment, 15 %, is added to the sum of 1 and 2, for work at the site, administration, installation, supervision and inspection, documentation, risk and profit.

   The sum of 1, 2 and 3 is referred to as the base cost.

4. An uncertainty factor of 20 % is added to the sum of 1, 2 and 3 for, among other things, unspecified equipment.

5. An item for contingencies of 10 % is added to the sum of 1, 2, 3 and 4. This gives the total cost of process equipment for the facility.

The required engineering input is assessed for each facility, for estimation of the design cost for process equipment. This input includes design work and the work of the project office.

4.2.2 Adjustments per facility/operation

Table 4.2 shows the adjustments for uncertainty in the documentation available and for contingencies, as a percentage of the base costs (construction and process equipment).

4.2.3 Standard estimates

Some of the costs have been calculated as a percentage of the investment costs.

This applies to

owner's costs (SKBF)	5-7 %
building design	4-9 %
re-investment	3-25 %
parts of the decommissioning costs	5-12 %

Table 4.2 Adjustments for uncertainty in the documentation and for contingencies

Facility/operation		Adjustment %
14	Transportation	10
16	NPP operating costs after shut-down	25
22-53	NPP decommissioning	25
62	CLAB	9
72	CLG	32
73	CLU	32
81	SFL, joint facilities	36
82	BSG/BSAB	29
83	SFL 1-2	40
84	SFL 3	37
85	SFL 4	38
86	SFL 5	40
92	SFR 1	30
93	SFR 3	27
Weighted mean value		25.2 %

Table 4.3 Costs per cubic metre for rock excavation (January 1981 price level)

Activity	Base cost SEK 1000/m^3	Total cost SEK 1000/m^3
Sunk shaft, SFL 1-2,dia 5.5 m	3.9	5.4
Raise and stoping, SFL 1-2, dia 4.5 m	1.3	1.7
Raise and stoping, SFL 1-2, dia 7.5 m	0.9	1.2
Tunnels, SFL 1-2, area 35 m^2	0.6	0.8
Tunnels, SFL 1-2, area 13 m^2	0.7	1.0
Deposition holes, SFL 1-2, dia 1.5 m	2.1	2.9
Repository vault, SFL 5, inc. ancillary areas	0.4	0.6
Access tunnel, SFL 3-5	0.3	0.5
Silos, SFR 1, dia 31 m	0.4	0.5

4.3 REPROCESSING COSTS

For estimating the costs for reprocessing, a price in the range of SEK 2 750-3 500 per kg has been applied.

It is envisaged that a total of 867 tonnes will be reprocessed. 727 tonnes of this will be reprocessed by Cogema and 140 tonnes by BNFL.

A credit for recovered uranium has been applied at SEK 400 per kg, whereas no credit at all is allowed at this time for the value of plutonium.

4.4 DESCRIPTION OF CERTAIN ITEMS OF EXPENDITURE

4.4.1 Construction work

Rock excavation

The total volume of rock to be excavated for SFL 1-5 amounts to just over 1 000 000 m^3 (theoretical volume of solid rock). For SFR 1 and 3, the volume of rock is approximately 770 000 m^3.

The total cost for the excavation of these volumes and for reinforcement amounts to SEK 1 200 M at the base cost level. This gives a cost per cubic metre of SEK 630. The adjustments for uncertainty and contingencies are on average 33% for these works, which means that the cost per cubic metre amounts to SEK 850 at the total cost level. The costs per cubic metre

Table 4.4 Costs per cubic metre for civil engineering works (January 1981 price level)

Building	Base cost SEK 1000/m^3	Total cost SEK 1000/m^3
CLAB (Stage 1)	1.6	1.7
CLAB (Stage 1 inc. storage area)	1.7	1.8
CLG	1.2	1.8
CLU	1.3	1.8
BSG/BSAB	1.6	2.2

for rock excavation are shown in Table 4.3. It should be noted that the cost estimates for rock excavation are not worked out on the basis of these costs. A more detailed analysis has been made. The adjustments for uncertainty and contingencies vary from 20 % to 38 %.

For the CLAB, a total of approximately 300 000 m^3 will be excavated in both stages.

Civil engineering works

The total costs for civil engineering works, excluding rock excavation, in connection with the handling and storage of nuclear residues amount to SEK 2 700 M at the base cost level. The adjustments for uncertainty and contingencies amount to 38 % on average, and vary from 10 % to 48 %. Table 4.4 shows the cost per cubic metre for the major above-ground buildings.

In addition to the buildings mentioned, major civil engineering works are required for joint facilities at the SFL, and for the SFL 1-5 and SFR.

Sealing works

Under the heading of sealing works are included the materials, plant and labour required in connection with the handling of bentonite/sand mixtures in the final repositories (the SFL 1-5 and the SFR). The largest single item of material in the costs is bentonite, which has a concentration in the sealing material of 10-30 % depending on where sealing is carried out. Other items of material are sand, gravel, water etc., cf. KBS 1 and 2 and Technical Report 37. The cost of the sealing material (bentonite/sand mixture) at the base cost level varies from SEK 700 to SEK 1 200 per cubic metre of sealed volume, depending on where sealing is carried out.

Sealing works vary in cost from SEK 1 000 to SEK 1 800 per cubic metre at the base cost level. The adjustments for uncertainty and contingencies vary from 38 % to 45 %.

At the total cost level, the sealing costs are SEK 1 400 to SEK 2 600 per cubic metre of sealed volume.

4.4.2 Decommissioning of nuclear power plants

The estimation of costs for the decommissioning of nuclear power plants is based on a study conducted in 1978, an account of which is given in KBS Technical Reports 79-21 and 79-22. The first report deals with the Oskarshamn 2 and Barsebäck 1 nuclear power units. The later report also takes up the costs for decommissioning of the other Swedish nuclear power units. These costs have primarily been arrived at on the basis of the results obtained in the first study.

It is assumed in these studies that decommissioning takes place directly after shut-down and so completely that the site can be classified as suitable for unrestricted use on completion of decommissioning. It is assumed throughout that known technology will be applied, and no consideration has been given to reductions in cost as a result of there being a number of facilities on the same site or of experience gained.

In the present report, the costs from the reports mentioned above have been reduced in view of the fact that operation during shut-down is here accounted for separately. Following index adjustment to the January 1981 price level, the following decommissioning costs per reactor unit have been obtained.

		SEK M
Barsebäck	1	457
	2	457
Ringhals	1	563
	2	423
	3	432
	4	432
Forsmark	1	683
	2	683
	3	803
Oskarshamn	1	364
	2	461
	3	803

4.4.3 Cost of process equipment and operation

The costs for process equipment comprise two main items: investment and operation. In addition, a decommissioning cost estimated at 5 % of the investment cost is taken up.

The estimated investment costs for the process equipment in certain facilities are shown below.

Facility	Investment SEK M
CLG/CLU	125
JF SFL	225
BSG/BSAB	460
SFL 3	11
SFL 4	27
SFL 5	24

The figures include design, initial investment and re-investments. The design costs have been arrived at following an assessment of the engineering input required for each facility. Since it is assumed that the engineering work will be carried out as a separate contract, a cost of SEK 38 000 per manmonth has been assumed. Investments and re-investments have been estimated in accordance with special equipment lists. The adjustments to investments are shown in Section 4.2.1. A 30 % adjustment has been applied on re-investments in order to cover quality control, transportation, etc., since the costs for procurement, etc. are considered to be covered in the operating costs.

The operating costs include labour, spare parts, incidental materials and electricity consumption.

Costs for labour have been estimated on the basis of a labourforce which has been assessed for each part of the respective facilities after analysis of the work which is to be carried out. The labour-cost for one worker per year has been set at SEK 200 000, which is assumed to include unspecified incidental materials.

It has been assumed that spare parts cost 1.5 % of the hardware share of the initial investment every year. This figure has been arrived at after contacts with similar production units, for example ASEA-ATOM's fuel facility.

Essential incidental materials have been specified. Included here are, for example, fuel and spares for motor vehicles, and materials which are consumed in the process. A special study has been made of the cost of the copper canister. Three items of special interest may be mentioned:

	SEK 1000
Bentonite blocks for deposition holes (SEK 1000/tonne), per hole	24
Titanium canister with lead	42
Copper canister with lead (black copper SEK 10/kg)	321

Electricity consumption for the facilities has been estimated in accordance with a list of electrical loads. The major items are the furnaces for the casting-in process, and heating of all buildings. The cost of energy has been set at 15 öre/kWh, which gives an annual cost of SEK 4 M during the period 2020-2050.

4.5 STATEMENT OF TOTAL COSTS

The costs for the facilities and systems which are required for the management of residues from nuclear power generation have been estimated in accordance with what has been stated in Section 4.2. In cases where the premises have been uncertain, assessments have been made which can reasonably be considered as conservative. The costs have been estimated at the January 1981 price level.

It should be noted that the costs presented include cost components which will affect parties outside the nuclear power industry. It should further be noted that the costs for the operating waste (waste from the nuclear power plants) are included in the total. Taken together, these items, which are not covered by the Financing Act, amount to approximately 5 % of the total.

Unless otherwise stated, the total costs given in the following sections are presented according to the KOKA system, i.e. costs as per January 1981 price level, future costs and costs already incurred, real rate of interest 0 %, and costs for waste which does not originate from nuclear power generation.

Total costs

As can be seen from Table 4.5, the total cost of the system described, including decommissioning of the nuclear power plants, amounts to SEK 30 555 M. After deduction of the items which are not covered by the Financing Act, a figure of SEK 29 000 M is obtained.

In view of the fact that a considerable proportion of the activities will take place in the distant future, it cannot be ruled out that the costs will be affected by circumstances which are completely unknown today (cf. Sections 4.1 and 4.2.1). This justifies a special risk adjustment on the order of SEK 3 000 M (January 1981 price level). This risk adjustment should be reduced as more reliable information is gradually obtained.

The total cost to be covered by reserve funds has thus been estimated at SEK 32 000 M at the January 1981 price level. The present value of this amount can be estimated by index-adjustment and discounting. For the period January 1981 to January 1982, a weighted index factor for the facilities described has been calculated at 1.11.

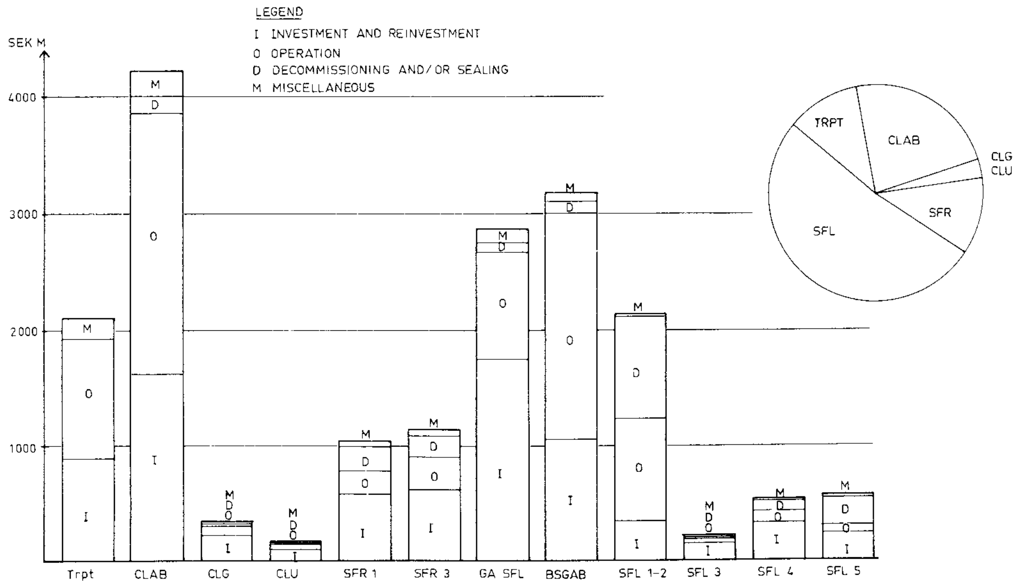
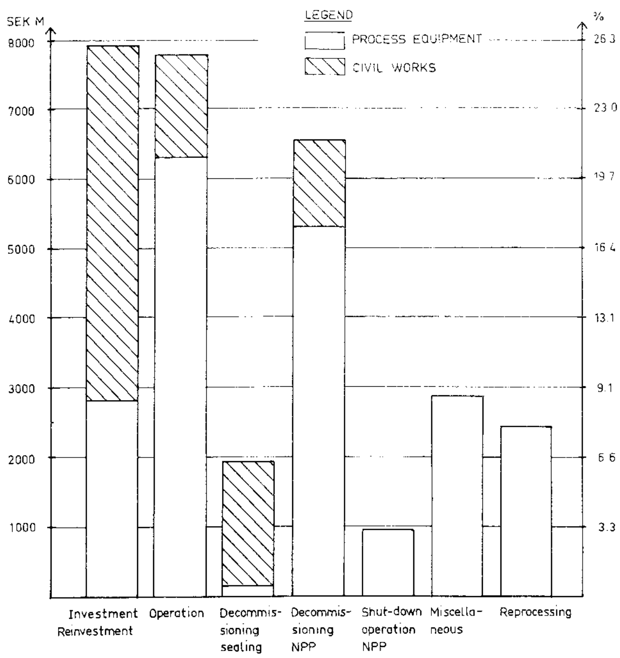


Figure 4.1 Costs per facility/operation (January 1981 price level)

Table 4.5 Schedule of costs (SEK M) (January 1981 price level)

Facility/ operation	Invest Re- invest	Opera- tion	Decom. Sealing	Decom. NPP	Shut- down op.NPP	Reproc.	Misc.	Total
	Cost category							
Trpt	850	1050	-	-	-	-	110	2010
CLAB	1620	2240	150	-	-	-	200	4210
CLG	230	80	10	-	-	-	10	330
CLU	90	50	5	-	-	-	5	150
SFR 1	580	200	210	-	-	-	30	1020
SFR 3	620	290	180	-	-	-	30	1120
JF SFL	1750	940	70	-	-	-	110	2870
BSG/ BSAB	1070	1970	60	-	-	-	70	3170
SFL 1-2	370	790	930	-	-	-	30	2120
SFL 3	160	30	20	-	-	-	10	220
SFL 4	340	100	60	-	-	-	20	520
SFL 5	250	50	220	-	-	-	20	540
Decom.NPP	-	-	-	6560	-	-	-	6560
Shut-d.NPP	-	-	-	-	960	-	-	960
R&D	-	-	-	-	-	-	2240	2240
Reproc.	-	-	-	-	-	2515	-	2515
Total	7930	7790	1915	6560	960	2515	2885	30555



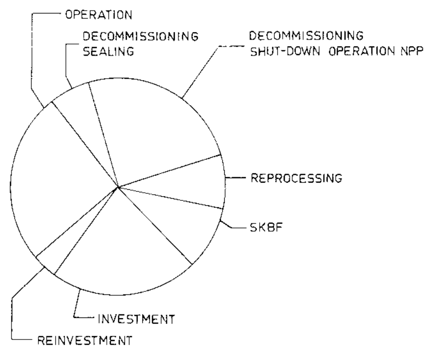


Figure 4.2 Costs per cost category (January 1981 price level)

Costs per facility

The costs for the various facilities are shown in Table 4.5 and Figure 4.1. The distribution of these costs over time may be seen from a comparison with the time schedule, see Appendix 1.2. It should be observed that the costs for the SFL 5 include the complete access tunnel from the ground surface to -300 m. This tunnel is, however, used jointly for the SFL 3-5. The costs for the SFR 1 include the access tunnel from the ground surface to -120 m, which is used jointly for the SFR 1 and the SFR 3.

Costs per cost category

The costs for the various cost categories are shown in Table 4.5 (total) and Figure 4.2. The category referred to under the heading "Miscellaneous" is for the most part R&D, either centrally through SKBF or linked to various facilities/operations. For investment/re-investment, operation, sealing/decommissioning, and decommissioning of NPP, the distribution of costs between process equipment and civil works is also shown. Active systems are counted as "Process equipment" and the remainder as "Civil engineering works".

Costs distributed over time

The distribution of the costs per decade is shown in Table 4.6 and Figure 4.3. According to the current timetables, the activitis in connection with the management of residues from nuclear power generation will be terminated some time during the 2060's.

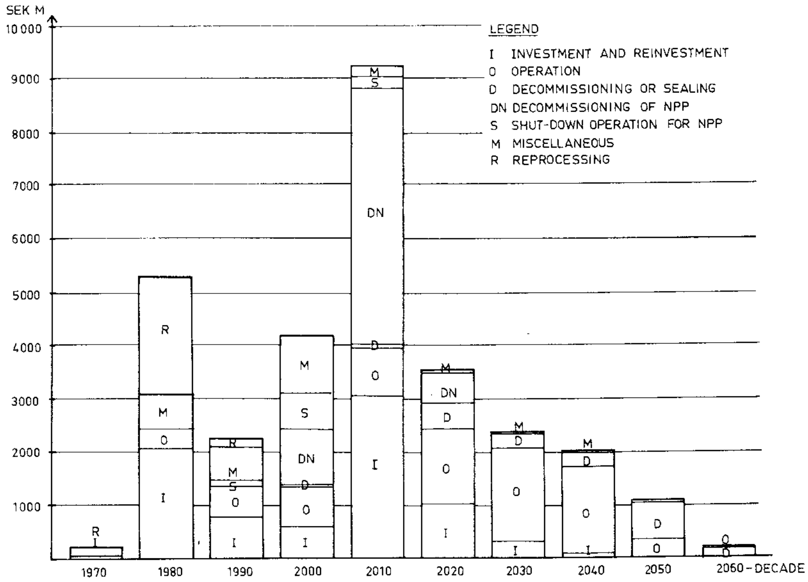


Figure 4.3 Costs distributed over time (January 1981 price level)

Table 4.6 Costs distributed over time (SEK M) (January 1981 price level)

Decade	Invest Re-invest	Opera-tion	Decom. Sealing	Decom. NPP	Shut-down op.NPP	Reproc.	Misc.	Total
	Cost category							
1970	50	-	-	-	-	145	-	195
1980	2020	330	-	-	-	2220	735	5305
1990	780	630	-	-	90	150	680	2330
2000	600	720	30	1060	660	-	1130	4200
2010	3060	800	75	4880	210	-	220	9245
2020	1020	1400	470	620	-	-	70	3580
2030	320	1820	210	-	-	-	15	2365
2040	80	1730	210	-	-	-	15	2035
2050	-	340	730	-	-	-	20	1090
2060	-	20	190	-	-	-	-	210
Totalt	7930	7790	1915	6560	960	2515	2885	30555

Accumulated total costs

The accumulated total costs are shown in Table 4.7 and Figure 4.4.

Tabell 4.7 Accumulated costs (SEK M)
(January 1981 price level)

Costs due before year: 1980	1990	2000	2010	2020	2030	2040	2050	2060	2070
195	5500	7830	12030	21275	24855	27220	29255	30345	30555

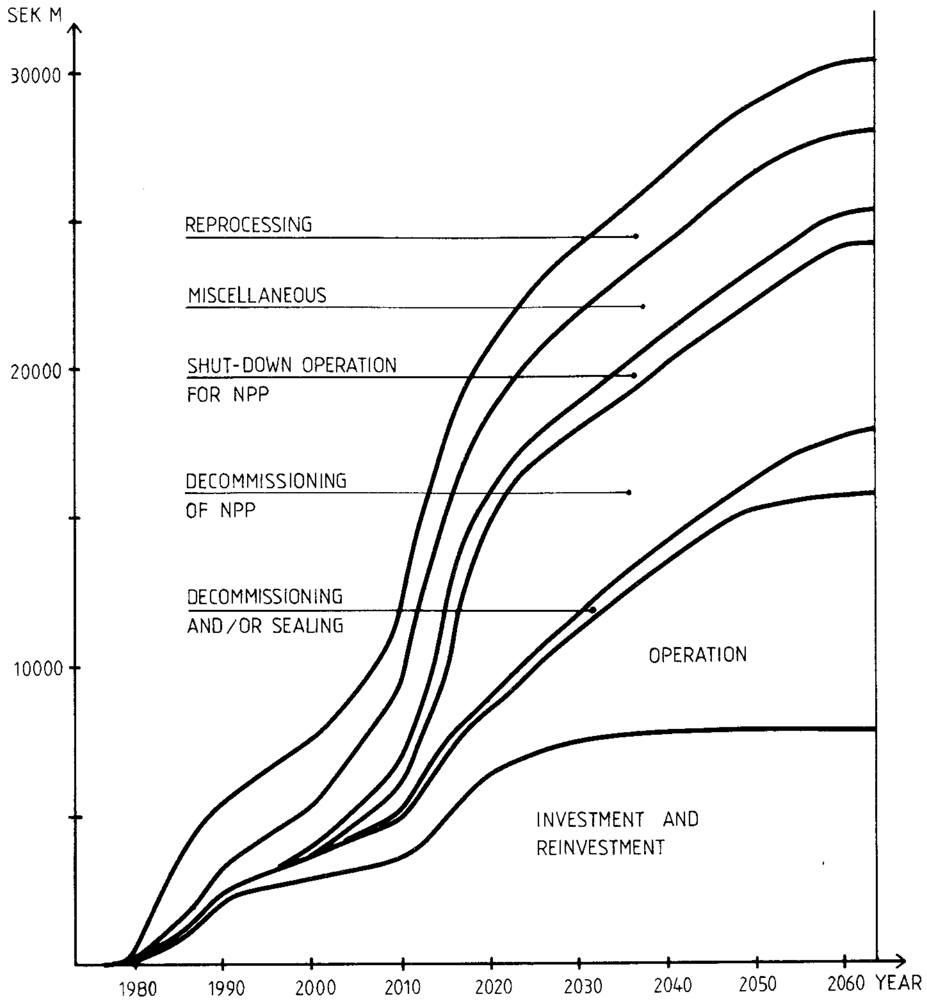


Figure 4.4 Accumulated costs
(January 1981 price level)

5. COST OF FACILITIES PER UNIT OF WASTE

Table 5.1 shows the total cost (excluding reprocessing cost) per unit of handled waste for the facilities and systems described in Chapter 3.

The total cost includes the costs for investment, operation, re-investment, decommissioning and sealing, as well as SKBF costs for each facility (cf. Chapter 4).

It has been necessary to redistribute certain costs in order to permit comparison between them. The redistribution comprises the following:

1. Costs for joint facilities for the SFL (JF SFL) have been distributed between the BSG/BSAB and the SFL 1-5.

2. Costs for access tunnels and common facilities at the -300 m level for the SFL 3-5 have been distributed between the different repositories.

3. Costs for common parts of the SFR 1 and 3 have been distributed between the different repositories.

The distribution has been made on the basis of the quantities of waste handled in the different facilities.

Table 5.1 Cost of facility/operation per unit of waste (Price level January 1981)

	FACILITY/ OPERATION	COST SEK M		QUAN-TITY	UNIT	SEK 1000/ UNIT	NOTES
14.	TRANSPORTATION	2 010		16 444	transp. unit	120	Transp. of fuel and waste by ship. The transp. unit is a cask or a concrete container.
14.1	Transp. to and from reprocessing at La Hague	420		727	tonne fuel	580	Incl. LLW and MLW from La Hague
14.2	Unreprocessed spent fuel	1 070		5 880	tonne fuel	180	Incl. core components
14.3	LLW/MLW from reactor operation	150		49 000	m^3 LLW/MLW	3.0	By ship from NPP to SFR 1, of a total of 75 900 m^3
14.4	Decommissioning waste from NPP	220		92 000	m^3 decommissioning waste	2.4	By ship from NPP to SFR 3, of a total of 135 000 m^3
14.5	Other LLW/MLW	110		38 000	m^3 LLW/MLW	2.9	From CLAB and CLG to SFR 1 and SFL 4, incl.decommissioning waste
14.6	Wastes from Studsvik	40		22 800	m^3	1.9	Various wastes
	INTERMEDIATE STORAGE FACILITIES						
62	CLAB total	4 210		5 880	tonne fuel	720	Incl. core components
62.1	CLAB fuel	3 620		5 880	tonne fuel	620	Only fuel and fuel boxes, 2 202 positions in CLAB
62.2	CLAB core comp.	570		350	cassette (position)	1 630	Only core components
62.3	CLAB fuel from Studsvik	20		25	tonne fuel	660	10 positions in CLAB
72	CLG	330		727	tonne fuel	450	Vitrified waste from reprocessing
73	CLU	150		3 880	m^3 reprocessing waste	39	Reprocessing wastes excl. vitrified waste
	CLG + CLU	480		727	tonne fuel	660	
	FINAL STORAGE FACILITIES						
82	BSG/BSAB	3 930		6 607	tonne fuel	590	Incl. part of JF-SFL
			alt	5 200	canister	760	As above
82.1	BSG	310		727	tonne fuel	430	As above, only vitrified waste
			alt	730	lead-titanium canister	430	As above, only vitrified waste
82.2	BSAB	3 620		5 880	tonne fuel	620	As above, only unreprocessed fuel
			alt	4 470	copper canister*)	810	As above, only unreprocessed fuel
83	SFL 1 and 2	2 630		6 607	tonne fuel	400	Incl. part of JF-SFL
			alt	5 200	canister	510	As above
83.1	SFL 1	360		727	tonne fuel	500	As above, only vitrified waste 730 canisters
83.2	SFL 2	2 270		5 880	tonne fuel	390	As above, only unreprocessed fuel 4500 canisters
84	SFL 3	770		3 880	m^3 LLW/MLW from reprocessing	200	Incl. part of JF-SFL and redistr. SFL 3-5
			alt	727	tonne fuel	1 060	As above. Fuel will not be stored in SFL 3
85	SFL 4	1 520		27 300	m^3 various LLW/MLW	56	Incl. part of JF-SFL and redistr. SFL 3-5
			alt	1 500	transp. unit	1 010	As above. Transp. unit is a B-cask or a concrete container
86	SFL 5	590		4 600	m^3 core components in cassette	130	Incl. part of JF-SFL and redistr. SFL 3-5
			alt	1 300	cassette	540	As above
92	SFR 1	920		104 000	m^3 LLW/MLW	8.8	Incl. redistr. SFR 1 and 3
			alt	5 510	concrete container	170	As above
93	SFR 3	1 200		141 000	m^3 decommissioning waste	8.5	Incl. redistr. SFR 1 and 3
			alt	7 020	concrete container	170	As above
All facilities excl. LLW/MLW, waste from Studsvik, decommissioning waste and reprocessing		2 800**)		727	tonne fuel for reprocessing	3 850	Incl. core components and R&D Excl. 140 tonnes of fuel for reprocessing atWindscale
		15 000**)		5 880	tonne unreprocessed fuel	2 550	Incl. core components and R&D

*) Empty copper canister, free SFL, will cost SEK 310 000

**) Distributed costs

6. SENSITIVITY ANALYSIS

6.1 INTRODUCTION

This chapter deals with how the costs are affected by different types of changes in relation to the premises and costs that are presented in Chapters 2 and 4.

The total cost is defined in this chapter as the total cost according to Section 4.5, i.e. SEK 30 555 M.

It must be pointed out that the changes in cost accounted for here only show order of magnitude and tendencies. The changes in cost in the different subsections (6.2-6.6) cannot be carried over without closer analysis.

6.2 CHANGES IN OPERATIONAL LIFETIME FOR THE NUCLEAR POWER PLANTS

6.2.1 General

A study is made in this section of the marginal costs incurred if the period during which each of the nuclear power plants is operational is increased by 5 years. Corresponding reductions in cost are obtained if the operating period is reduced by 5 years.

6.2.2 Premises

1. A 5-year longer operating period gives a 17.6 % increase in the quantity of spent fuel from the nuclear power plants.

2. Energy production increases by 20 %. (Provided that the efficiency and utilization factors for the power plants are the same as assumed previously, cf Appendix 2.1).

3. The quantity of reprocessed fuel is unchanged.

4. Start-up of the SFL facilities is unchanged.

5. Other consequences for the quantity of nuclear residues are presented for each facility in Table 6.1.

Table 6.1 Marginal costs for a 5-year increase in the operational lifetime of the nuclear power plants (January 1981 price level)

Facility/ operation	Marg. cost SEK M	Change as percentage of cost of facility/ operation	Attributable to:
R&D	-	-	No change
Trans-portation	160	8	17.6 more spent fuel and 20 % more operating waste from NPP. More operating waste from intermediate storage facility (CLAB)
Shut-down operation Decommis-sioning NPP	-	-	No change
CLAB	130	3	More positions in storage area and correspondingly greater quantity handled
CLG and CLU	-	-	No change
JF SFL	20	1	More transports of waste to the SFL by rail
BSG/BSAB	160	5	More spent fuel to be encapsulated
SFL 1-2	280	13	More spent fuel for final storage
SFL 3	-	-	No change
SFL 4	20	4	More waste for final storage in the SFL 4 originating from the CLAB and the BSG/BSAB
SFL 5	30	6	Increased quantity of core components for final storage in the SFL 5. This in turn depends on the increased quantity of fuel
SFR 1	100	10	20 % more operating waste from NPP to final storage in the SFR 1
SFR 3	-	-	No change
TOTAL appr.	900	3.0 %	Change in total cost

6.2.3 Changes in costs

The total cost for all waste handling increases by 3.0 % or approximately SEK 900 M if the period during which the nuclear power plants are operational increases by 5 years. At the same time, the total energy production increases by 20 %. A change in the operating period of less than 5 years gives costs that are proportional to time, i.e. a 1-year change entails a fifth of the cost for a 5-year change in operating time. Changes which are greater than about 5 years entail somewhat greater changes in cost, since jumps in cost increases can be expected. The costs per facility or operation are shown in Table 6.1.

6.3 LOCATION OF SFL ON COAST

One assumption made in the cost estimates is that the BSG/ BSAB and SFL 1-5 will be located inland some 150 km from the nearest existing railway. If these facilities were to be located on the coast in direct connection with the planned harbour, the following items could be discounted:

1. 150 km of railway track with associated rolling stock and other transport equipment
2. 40 km of roads (10 km remain).

The transportation costs for freighting materials during the investment stage will probably decrease, but no consideration has been given to this in the analysis.

The costs for both rail and road connections include investment, operation, re-investment and reinstatement of land as well as the costs incurred by SKBF.

The cost for 1 and 2 above is approximately SEK 1 500 M. This means that if the SFL were to be located on the coast, the total cost for all waste handling would be reduced by 4.9 %.

6.4 POSTPONEMENT OF NUCLEAR POWER PLANT DECOMMISSIONING

6.4.1 General

The costs for decommissioning of the twelve nuclear power units are estimated to amount to SEK 6 560 M. Shut-down operation, i.e. the period of operation between when the plant is shut down and when decommissioning commences, is estimated to cost SEK 960 M. Shut-down operation of a unit during the first year costs SEK 50-70 M depending on the size of the unit. The cost decreases for each successive year.

6.4.2 Premises

Postponing the decommissioning of all units by 10 years has the following consequences:

1. The cost of shut-down operation increases by SEK 200 M.

2. The cost of demolition of the nuclear power plants is deferred by 10 years.

3. The cost of transportation of decommissioning waste is deferred by 10 years.

4. The cost of the final repository for decommissioning waste (SFR 3) is deferred by 10 years.

The costs for decommissioning the nuclear power plants may be lower since by then the decommissioning waste will be less radioactive. However, no consideration is given to this in the estimates below.

6.4.3 Changes in costs

A postponement of the decommissioning of the nuclear power plants by 10 years for all units entails an increased cost of SEK 200 M. This cost will be incurred during the 2000's and 2010's. Postponement also means that a total cost of SEK 8 000 M is deferred by 10 years.

6.5 POSTPONEMENT OF SFL

6.5.1 General

One assumption made in the cost estimates is that the BSG/-BSAB and the SFL 1-5 will become operational 2020-2026, which is shown in Appendices 1.1 and 2.1. If start-up were to be postponed, it would mean that approximately 40 % of the total cost would be deferred, which would give considerable changes in the present value calculations of the costs.

In this section, a study is made of a postponement of the SFL (BSG/BSAB and the SFL 1-5) by 10 years.

6.5.2 Premises

1. Start-up of the SFL is postponed by 10 years. The periods during which the facilities are operational are unchanged.

2. Start-up of the other facilities for the disposal of residues from nuclear power generation is unchanged.

3. Postponement of the SFL results in an extension of the operational lifetime of the CLAB, CLG and CLU by 10 years.

4. Otherwise unchanged premises.

Table 6.2 Cost consequences if the SFL is postponed by 10 years (January 1981 price level)

Facility/ operation SEK M	Deferred cost SEK M	Changed cost	Attributable to:
Transportation	880		Postponed transportation of residues from CLAB, CLG and CLU to SFL
		+10	Increased operating waste from CLAB, CLG and CLU
CLAB	500		Postponed emptying and decommissioning. The deferred operating cost is the difference in costs for the emptying stage and the storage stage (cf. Sections 3.3 and 3.4)
		+260	10-year increase in operating period
CLG and CLU	60		Postponed emptying and decommissioning. The deferred operating cost is the difference in costs for the emptying stage and the storage stage (cf. Sections 3.3 and 3.4)
		+30	10-year increase in operating period
All SFL facilities	9440		Deferment of all costs by 10 years It is possible that the costs for the final repository for spent fuel will be decreased, since the level of radioactivity in the fuel decreases to an extent corresponding to a 10-year longer storage time
SFL 4		+40	Increased quantity of operating waste from CLAB, CLG and CLU
TOTAL	10 880	+340	

6.5.3 Changes in costs

If SFL is postponed by 10 years, the total costs are increased by just over 1 % or approximately SEK 340 M. This is the result of an increase in the period during which the CLAB, CLG and CLU are operational, and a consequent increase in the amount of waste from these facilities, which is to be finally deposited in SFL 4. Postponement also means that a total cost of SEK 10 880 M is deferred by 10 years.

Table 6.2 shows the facilities for which the costs are changed.

6.6 SENSITIVITY OF COSTS

6.6.1 General

The cost estimates are made in accordance with the assumptions described in Sections 4.1 and 4.2. This section shows how a change in the cost of an individual item affects the total cost of waste management. Certain major material and activity costs have been selected for this purpose.

6.6.2 Materials

The materials studied here are those involving the highest costs, namely:

1. Black copper, which is used as the canister material for directly deposited fuel.
2. Bentonite. The cost for bentonite is that which applies when it is being stored at the SFL and the SFR prior to its use as a sealing material.
3. Buffer materials. Bentonite and sand materials which are used for the sealing of tunnels, shafts and deposition holes. The cost is that which applies prior to placement.

Table 6.3 shows how a 10 % change in the costs of the various materials affects the total cost.

Table 6.3 Cost sensitivity of certain materials

Material	Cost SEK M	10% change in cost affects total cost by:
Black copper	750	0.25 %
Bentonite	470	0.15 %
Sealing materials	1120	0.37 %

Table 6.4 Cost sensitivity of certain activities

Activity	Cost SEK M	10% change in cost affects total cost by:
Operation	7790	2.6 %
Decom. of NPP	6560	2.2 %
Civil eng. works	5310	1.7 %
Rock exc.	1640	0.5 %
Process equipm.	1710	0.6 %
Sealing	2100	0.7 %

6.6.3 Activities

Table 6.4 shows how a 10 % change in the cost of certain activities affects the total cost. These activities are:

1. Operation, i.e. the operation of all facilities for the management of residues from nuclear power generation.

2. Decommissioning of nuclear power plants.

3. Civil engineering works, i.e. the building activities in connection with the construction of all facilities for the management of residues from nuclear power generation. This also includes rock excavation.

4. Rock excavation, i.e. excavation of the shafts, tunnels, vaults etc. which are required for intermediate and final storage facilities.

5. Process equipment, i.e. the process equipment for all the facilities for the management of residues from nuclear power generation.

6. Sealing. Sealing refers here to all materials and work in connection with the handling of mixtures of bentonite and sand in the final repositories.

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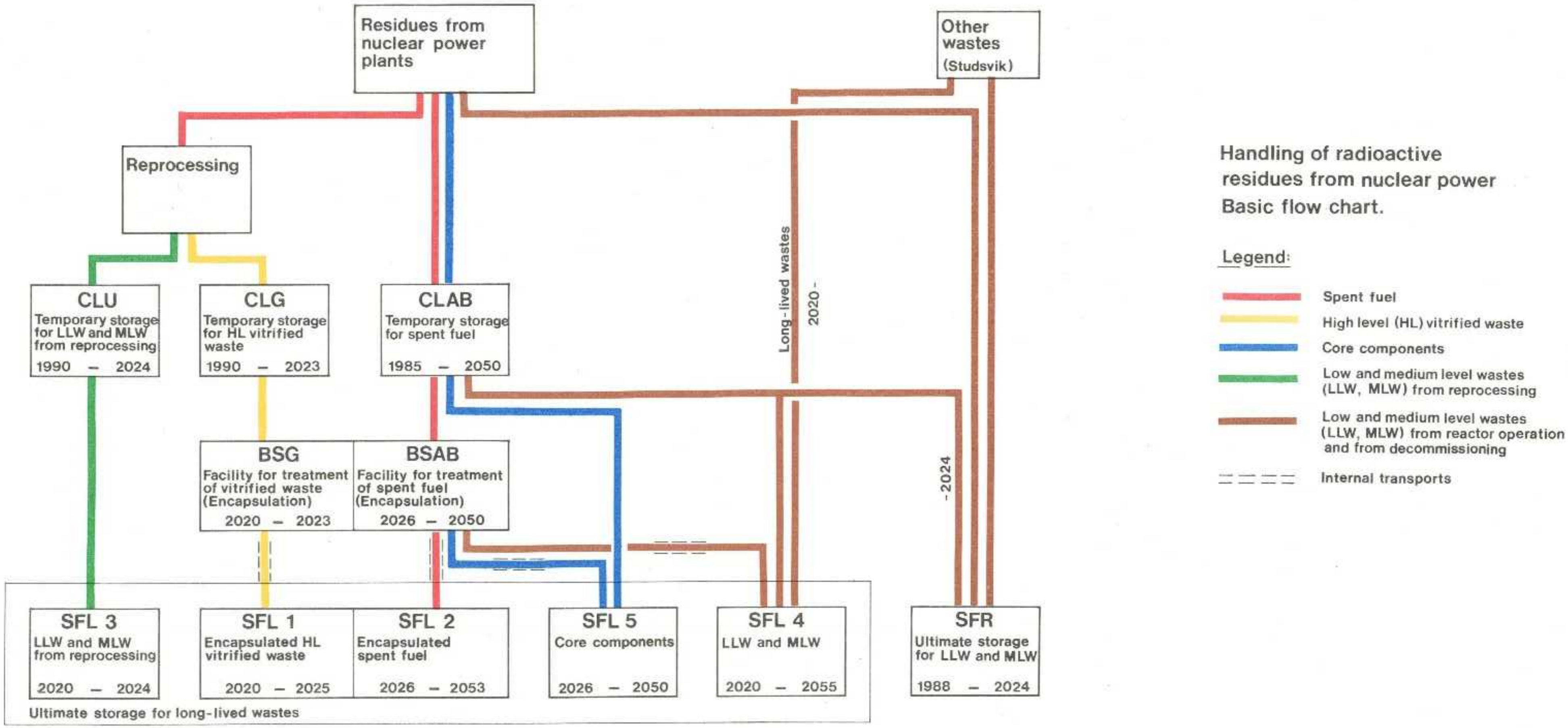
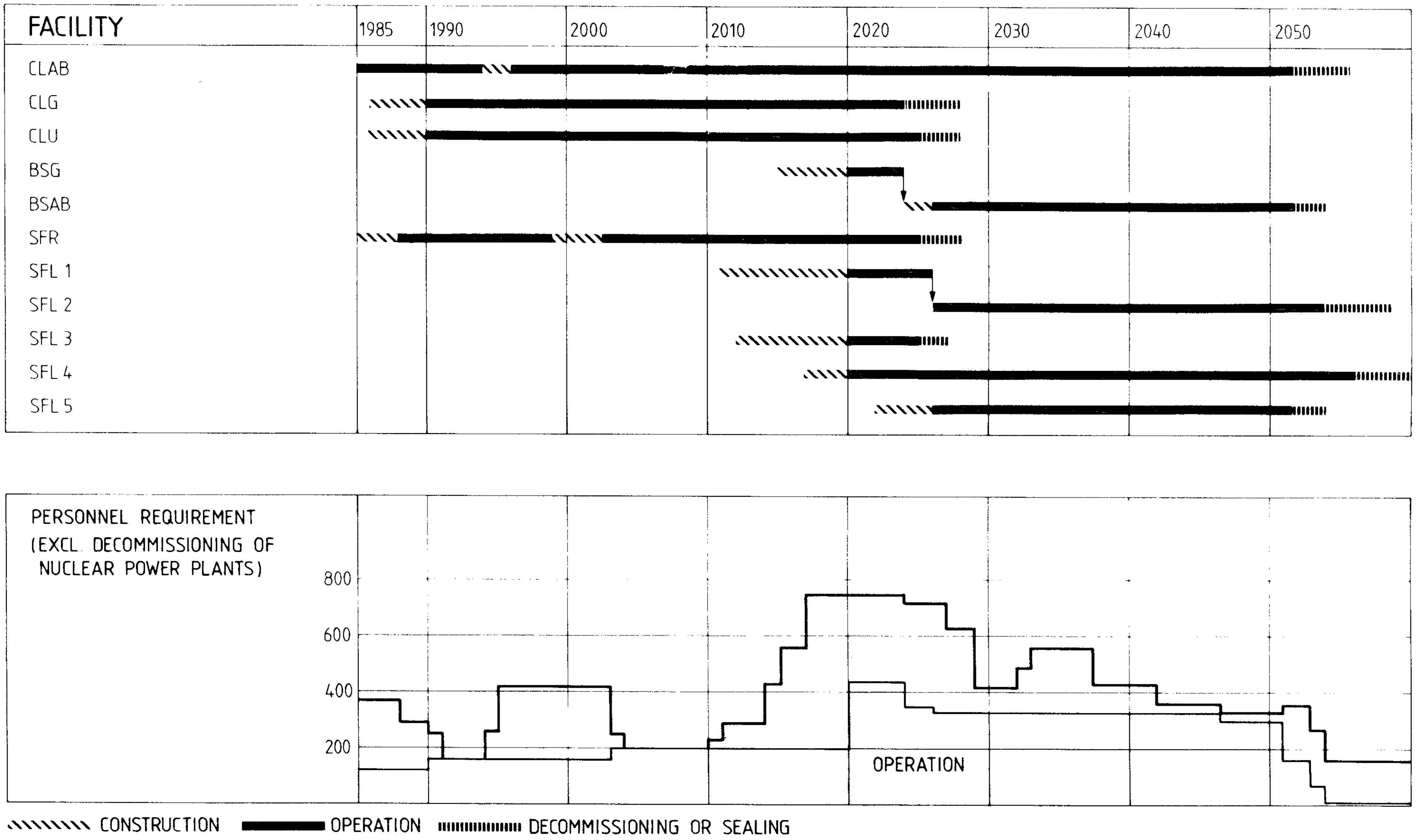
APPENDICES


Residues from nuclear power plants
Other wastes (Studsvik)
Reprocessing
CLU
Temporary storage for LLW and MLW from reprocessing
1990 – 2024
CLG
Temporary storage for HL vitrified waste
1990 – 2023
CLAB
Temporary storage for spent fuel
1985 – 2050
Long-lived wastes
2020 -
- 2024
BSG
Facility for treatment of vitrified waste (Encapsulation)
2020 – 2023
BSAB
Facility for treatment of spent fuel (Encapsulation)
2026 – 2050
SFL 3
LLW and MLW from reprocessing
2020 – 2024
SFL 1
Encapsulated HL vitrified waste
2020 – 2025
SFL 2
Encapsulated spent fuel
2026 – 2053
SFL 5
Core components
2026 – 2050
SFL 4
LLW and MLW
2020 – 2055
SFR
Ultimate storage for LLW and MLW
1988 – 2024
Ultimate storage for long-lived wastes
Handling of radioactive residues from nuclear power
Basic flow chart.
Legend:
Spent fuel
High level (HL) vitrified waste
Core components
Low and medium level wastes (LLW, MLW) from reprocessing
Low and medium level wastes (LLW, MLW) from reactor operation and from decommissioning
Internal transports

Appendix 1.1



FACILITIES FOR HANDLING OF RESIDUES FROM NUCLEAR POWER TIME SCHEDULE AND PERSONNEL REQUIREMENT

Appendix 2.1

Station and date on line	Thermal effect MW	Energy production to 1981 incl. TWh	Assumed annual production from 1982 incl TWh	Remaining number of years of operation 1)	Total energy production TWh	Uranium consumption tonne	Residual core after 25 yrs of operation tonne	Total uranium comsumption tonne	Uranium for re-processing tonne	Unre-processed uranium tonne
R1 76-01-01	2 270	23.41	4.72	19.0	113.1	476	87	563	-	563
R2 75-05-01	2 432	27.74	5.06	18.3	120.3	447	46	493	21	472
R3 81-09-09	2 775	3.25	5.78	24.7	146.0	542	48	590	181	409
R4 83-01-01	2 775	-	5.78	25.0	144.5	537	48	585	62	523
B1 75-07-01	1 700	21.48	3.54	18.5	87.0	366	59	425	20	405
B2 77-07-01	1 700	17.13	3.54	20.5	89.7	378	59	437	174	263
O1 72-02-06	1 375	24.21	2.86	15.1	67.4	284	59	343	88	255
O2 74-12-15	1 700	25.09	3.54	18.0	88.8	374	59	433	52	381
O3 86-01-01	3 000	-	6.24	25.0	156.0	657	93	750	-	750
F1 80-12-10	2 700	8.25	5.62	23.9	142.6	600	90	690	180	510
F2 81-07-07	2 700	4.28	5.62	24.5	142.0	598	90	688	89	599
F3 85-01-01	3 000	-	6.24	25.0	156.0	657	93	750	-	750
BWR	20 145	123.85	41.93		1 042.6	4 390	689	5 079	603	4 476
PWR	7 982	30.99	16.61		410.8	1 526	142	1 668	264	1 404
BWR and PWR	28 127	154.84	58.54		1 453.4	5 916	831	6 747	867	5 880

1) 25-years operation period assumed

Utilization factor 72 %

Efficiency 33 %

Burn-up BWR 720 MWh/kgU, PWR 816 MWh/kgU

<u>ENERGY PRODUCTION AND URANIUM CONSUMPTION AT SWEDISH NUCLEAR POWER PLANTS ON THE ASSUMPTION OF A 25-YEARS OPERATION PERIOD</u>

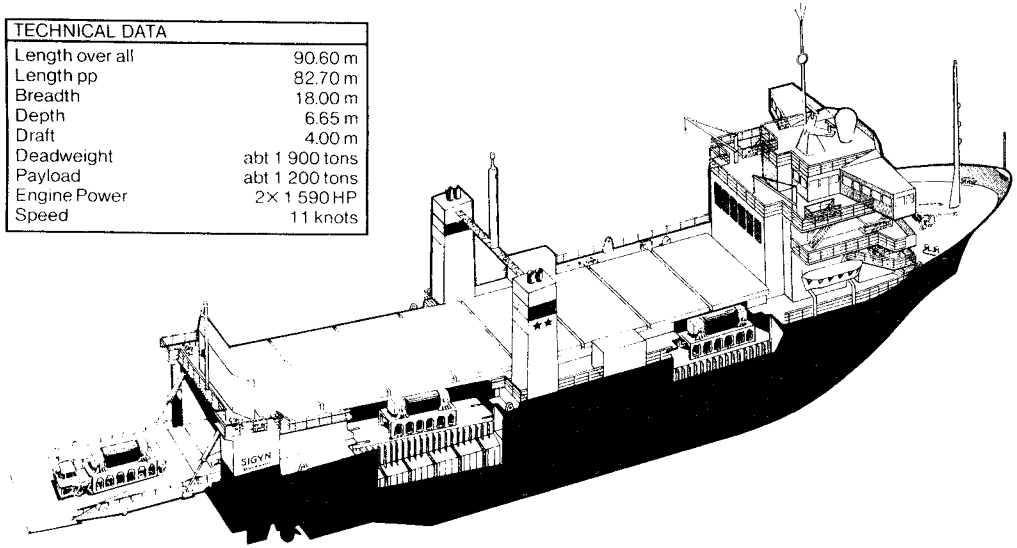
SPENT REACTOR FUEL AND RADIOACTIVE WASTES IN SWEDEN

FIGURES REFER TO DATA VALID BEFORE ENCAPSULATION FOR FINAL DISPOSAL

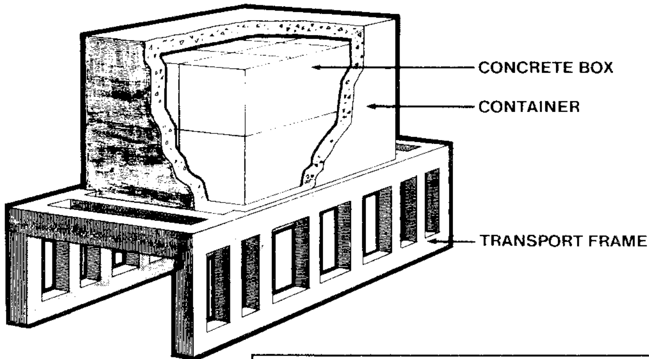
WASTE CATEGORY	WASTE UNIT: DIMENSIONS IN M, Ø = DIAMETER	WASTE UNIT: NUMBER	TOTAL VOLUME IN M^3	NUMBER OF TRANSP. UNITS CASKS/ CONTAINERS	FINAL DESTINATION
VITRIFIED HIGH-LEVEL WASTE FROM REPROCESSING	Ø 0.43, L = 1 335	730	150	50	BSG (SFL 1)
SPENT BWR FUEL	0.14 x 0.14 x 4 383	25 200	2 200	1 500	BSAB(SFL 2)
SPENT PWR FUEL	0.214 x 0.214 x 4 103	3 100	600	520	BSAB(SFL 2)
CORE COMPONENTS IN CASSETTES	0.8 x 0.8 x 5.6	1 300	4 600	1 300	SLF 5
CLADDING WASTE FROM REPROCESSING	Ø 1.1, L = 1.65	300	430	100	SFL 3
BITUMINIZED REPROCESSING WASTE	Ø 0.6, L = 0.9	1 800	450	200	SFL 3
CEMENTED REPROCESSING WASTE	Ø 0.77, L = 1.1	5 800	3 000	480	SFL 3
CRUD WASTE FROM CLAB (OF WHICH TO SFR1)	Ø 0.6, L = 0.9	700 (360)	180 (90)	58 (30)	SFR 1 & SFL 4 (SFR 1)
OTHER WASTES FROM CLAB (OF WHICH TO SFR1)	1.2 x 1.2 x 1.2	15 900 (9 400)	27 500 (16 200)	1 330 (780)	SFR 1 & SFL 4 (SFR 1)
LONG-LIVED WASTES FROM STUDSVIK	VARIOUS	~ 13 000	5 000	350	SFL 4
OTHER WASTES FROM STUDSVIK	VARIOUS	30 800	11 800	600	SFR 1
LOW- AND MEDIUM-LEVEL WASTES FROM ENCAPSULATION PLANTS FOR SPENT FUEL AND VITRIFIED WASTE	1.2 x 1.2 x 1.2	450	780	40	SFL 4
WASTE FROM OPERATION OF INTERM. STORAGE FACILITIES FOR REPROC. WASTES	1.2 x 1.2 x 1.2	60	100	5	SFL 4
LOW- AND MEDIUM-LEVEL WASTES FROM REACTOR OPERATION. CEMENTED	1.2 x 1.2 x 1.2	18 300	31 600	1 530	SFR 1
DITTO IN CONCRETE TANKS	3.3 x 1.3 x 2.145	1 350	12 400	450	SFR 1
DITTO BITUMINIZED	Ø 0.6, L = 0.9	51 900	13 000	1 080	SFR 1
DITTO OTHER WASTES	VARIOUS	59 300	18 900	1 000	SFR 1
DECOMMISSIONING WASTES FROM NUCLEAR POWER PLANTS	2.9 x 4.3 x 3.1	6 700	135 000	6 700	SFR 3
DECOMMISSIONING WASTES FROM STUDSVIK	2.9 x 4.3 x 3.1	300	6 000	300	SFR 3
DECOMMISSIONING WASTES FROM INTERM. STORAGE FACILITIES AND ENCAPSULATION PLANTS	2.4 x 2.4 x 1.2	1 500	10 000	500	SFL 4
		~ 240 000	~285 000	~18 000	TRANSP. UNITS

TRANSPORT VESSEL

TECHNICAL DATA	
Length over all	90.60 m
Length pp	82.70 m
Breadth	18.00 m
Depth	6.65 m
Draft	4.00 m
Deadweight	abt 1 900 tons
Payload	abt 1 200 tons
Engine Power	2× 1 590 HP
Speed	11 knots

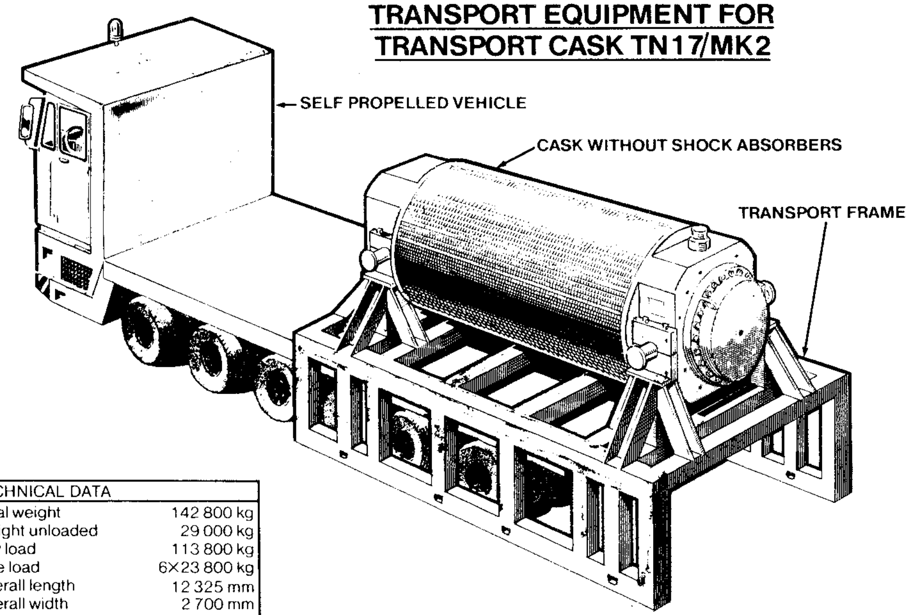


TRANSPORT FRAME AND CONTAINER FOR CONCRETE BOX



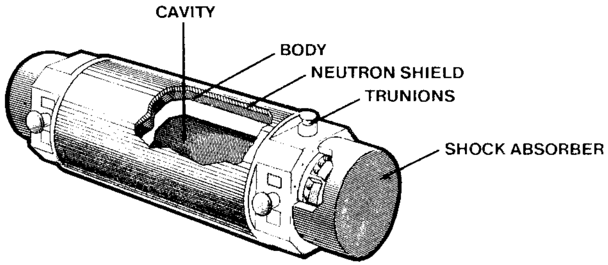
TECHNICAL DATA	
Surface radiation on concrete box	3 Rem/h (max.)
Wall thickness of container	30 cm concrete
Surface radiation on container	30 mRem/h
Number of concrete boxes	12 (max.)
Weight of transport frame + container	58 tons (approx.)
Gross weight	106 tons (approx.)

TRANSPORT EQUIPMENT FOR TRANSPORT CASK TN17/MK2

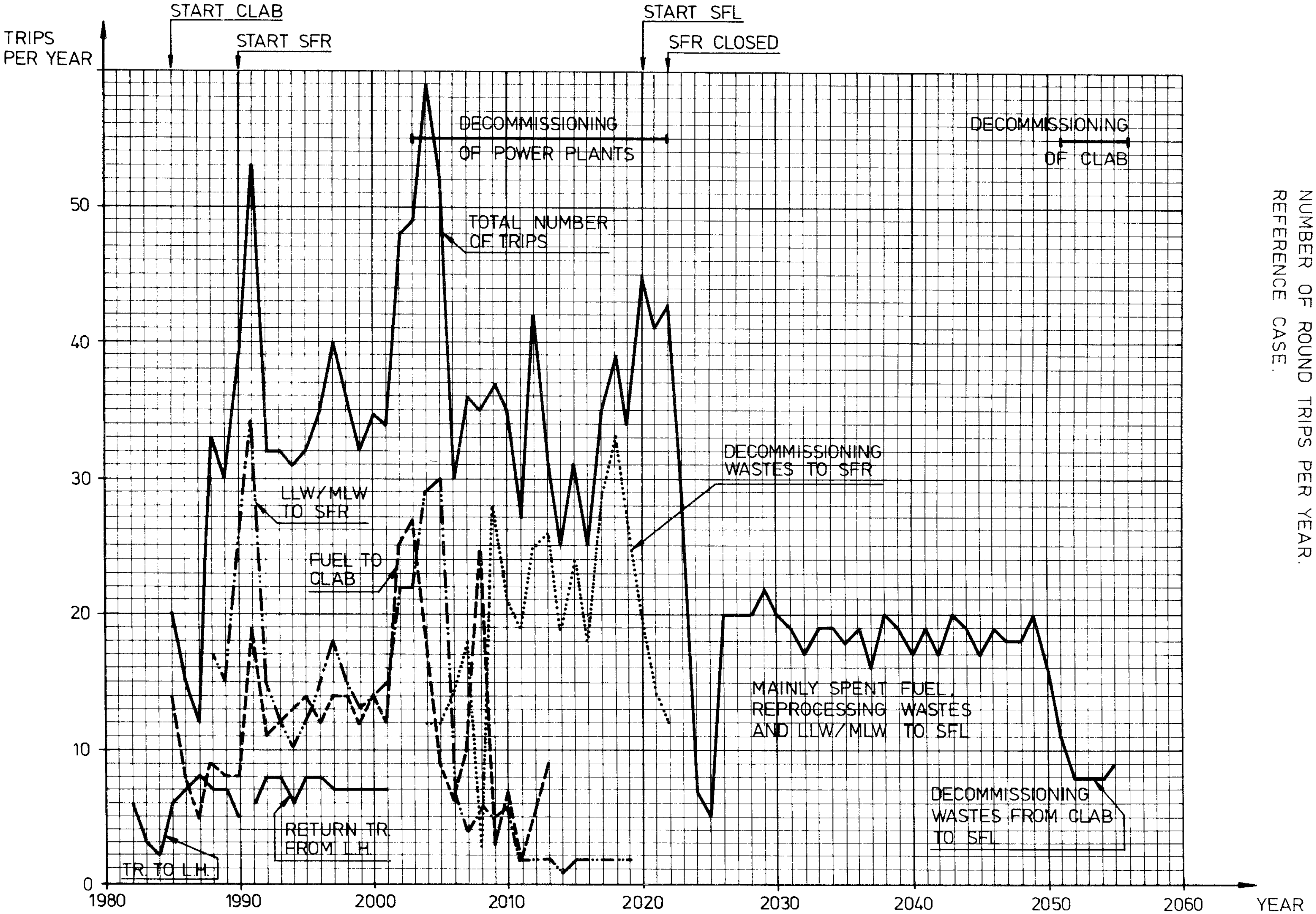


TECHNICAL DATA	
Total weight	142 800 kg
Weight unloaded	29 000 kg
Pay load	113 800 kg
Axle load	6×23 800 kg
Overall length	12 325 mm
Overall width	2 700 mm
Speed inloaded	17 km/h
Speed loaded, 13% ascent	1.5 km/h

TRANSPORT CASK TN17 Mk2

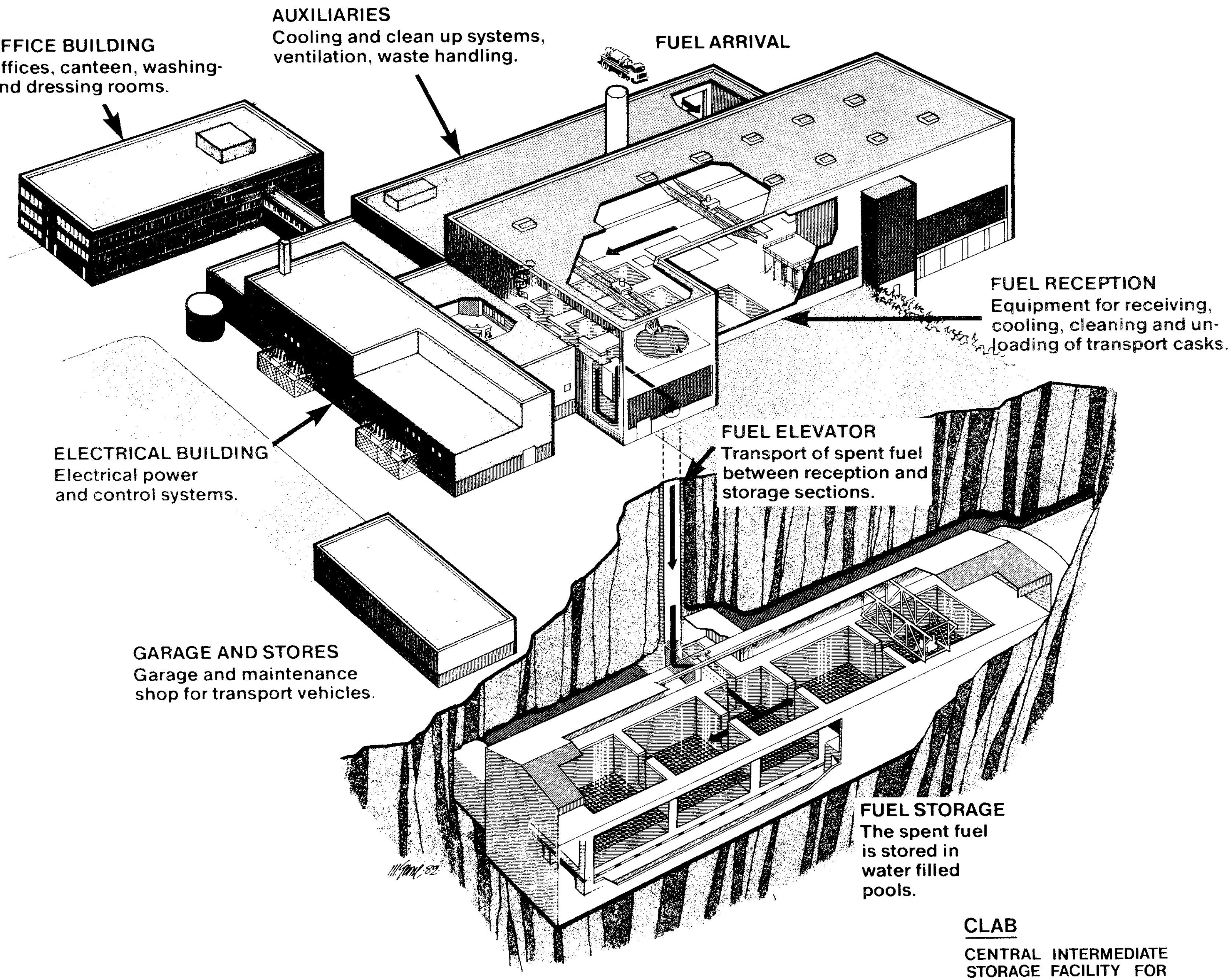


TECHNICAL DATA		
TYPE	BWR	PWR
Fuel assemblies weight (max.)	4 900 kg	3 900 kg
Basket + fuel support weight (max.)	4 700 kg	5 000 kg
Total weight (loaded packaging) (max.)	79 000 kg	78 000 kg
Total heat output	43.5 kW	43.5 kW
Number of fuel assemblies	17	6



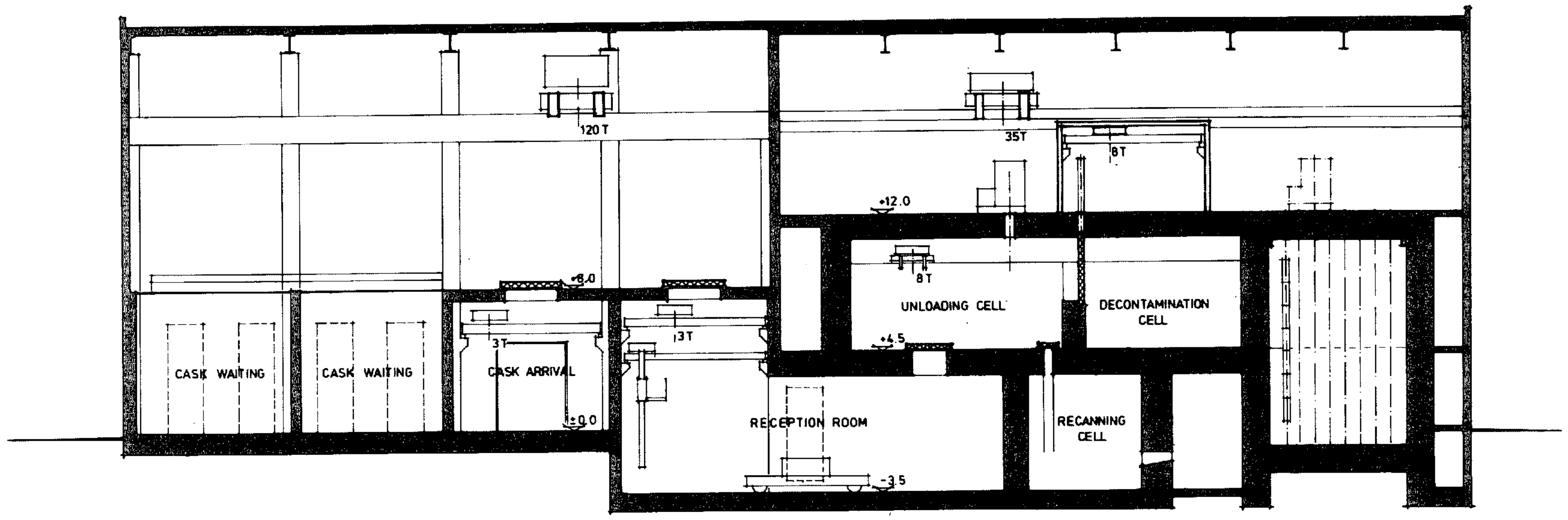
NUMBER OF ROUND TRIPS PER YEAR.
REFERENCE CASE.

Appendix 3.2

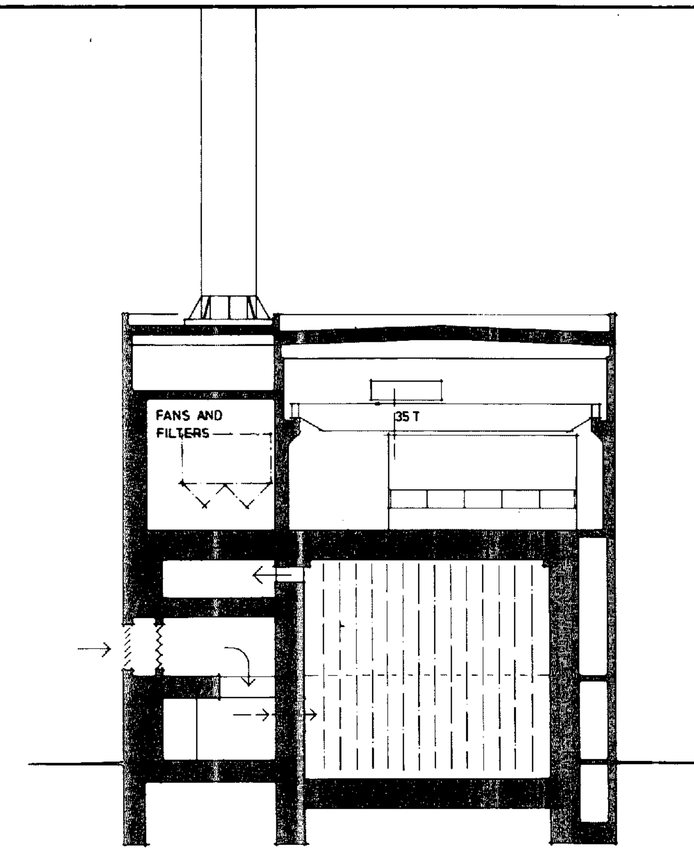


CLAB

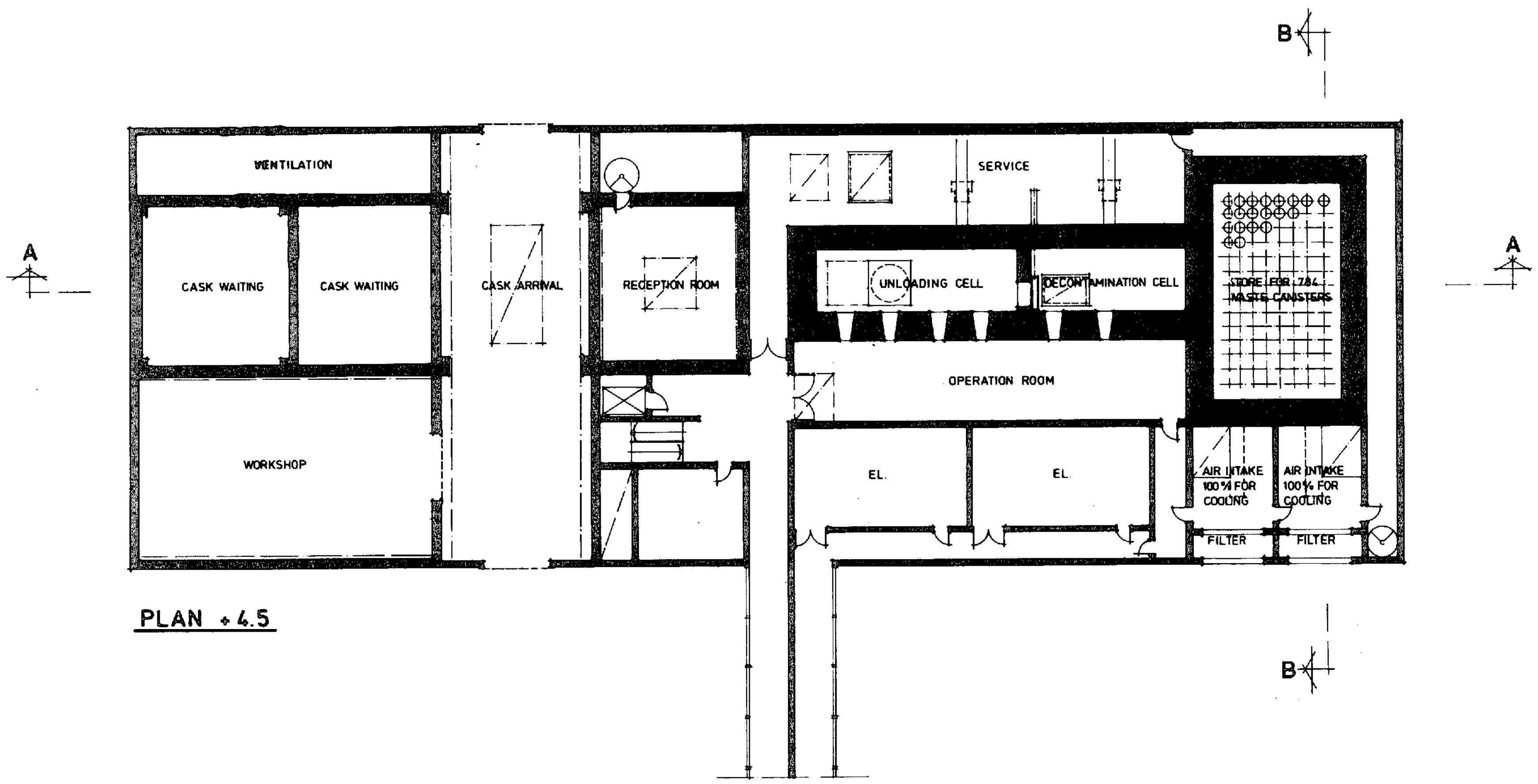
CENTRAL INTERMEDIATE STORAGE FACILITY FOR SPENT FUEL
STAGE 1



SECTION A



SECTION B



PLAN +4.5

5 0 10 20

REV.	ANT.	REVIDERINGEN AVSER	RITAD	GRANSK	DATUM

KBS
CLG
PLAN AND SECTIONS

KONSTRUERAD	RITAD	GRANSKAD	REG-NUMMER
LEA	HOS	.	B 87 95

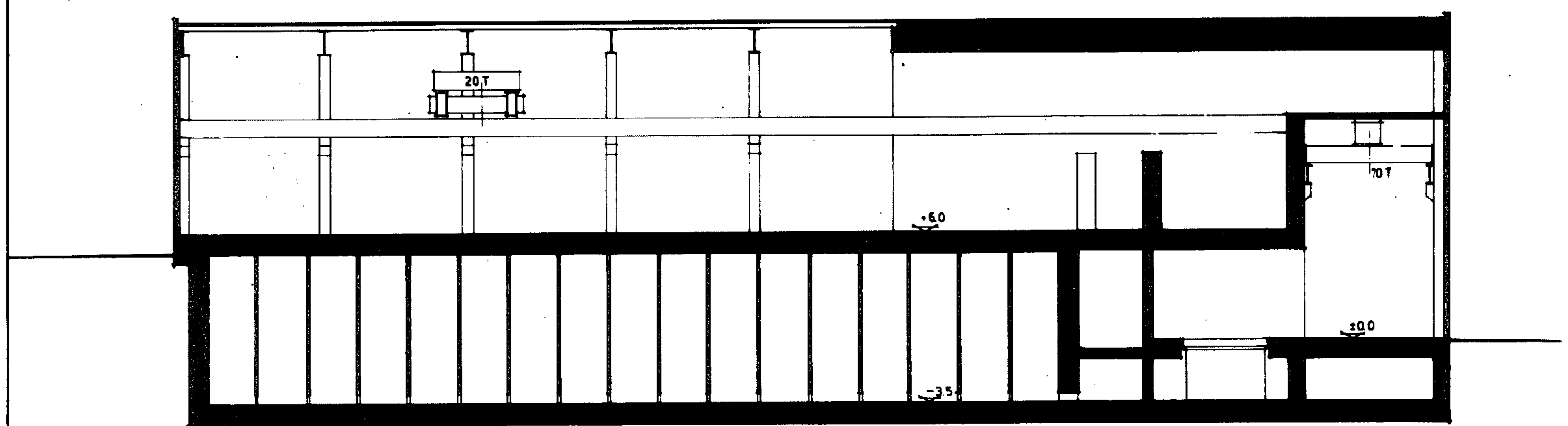
SKALA	RITNINGSNUMMER	REV
1 : 200	CLG .01	

STOCKHOLM DEN 81 10 20

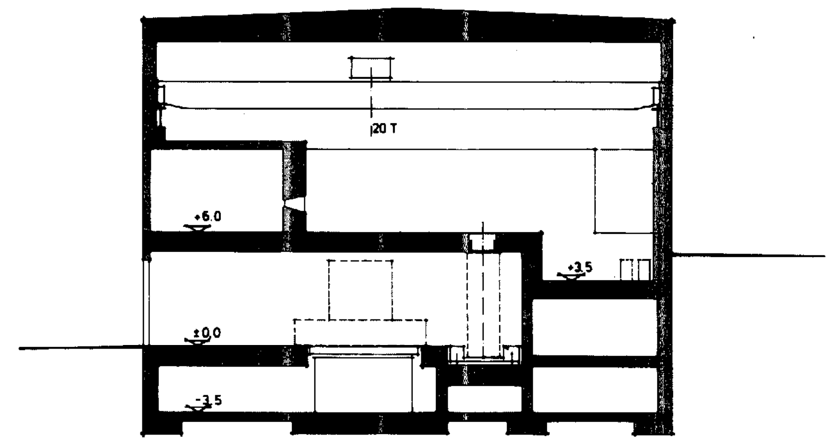
VBB

BOX 5038
102 41 STOCKHOLM 5 TEL. 08-22 65 80

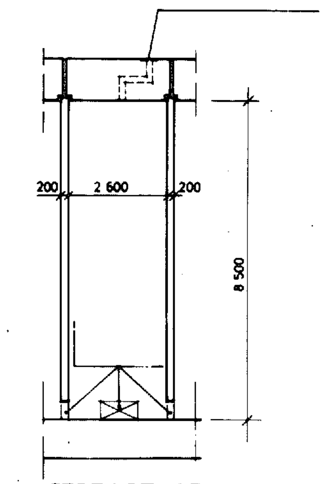
Appendix 3.5



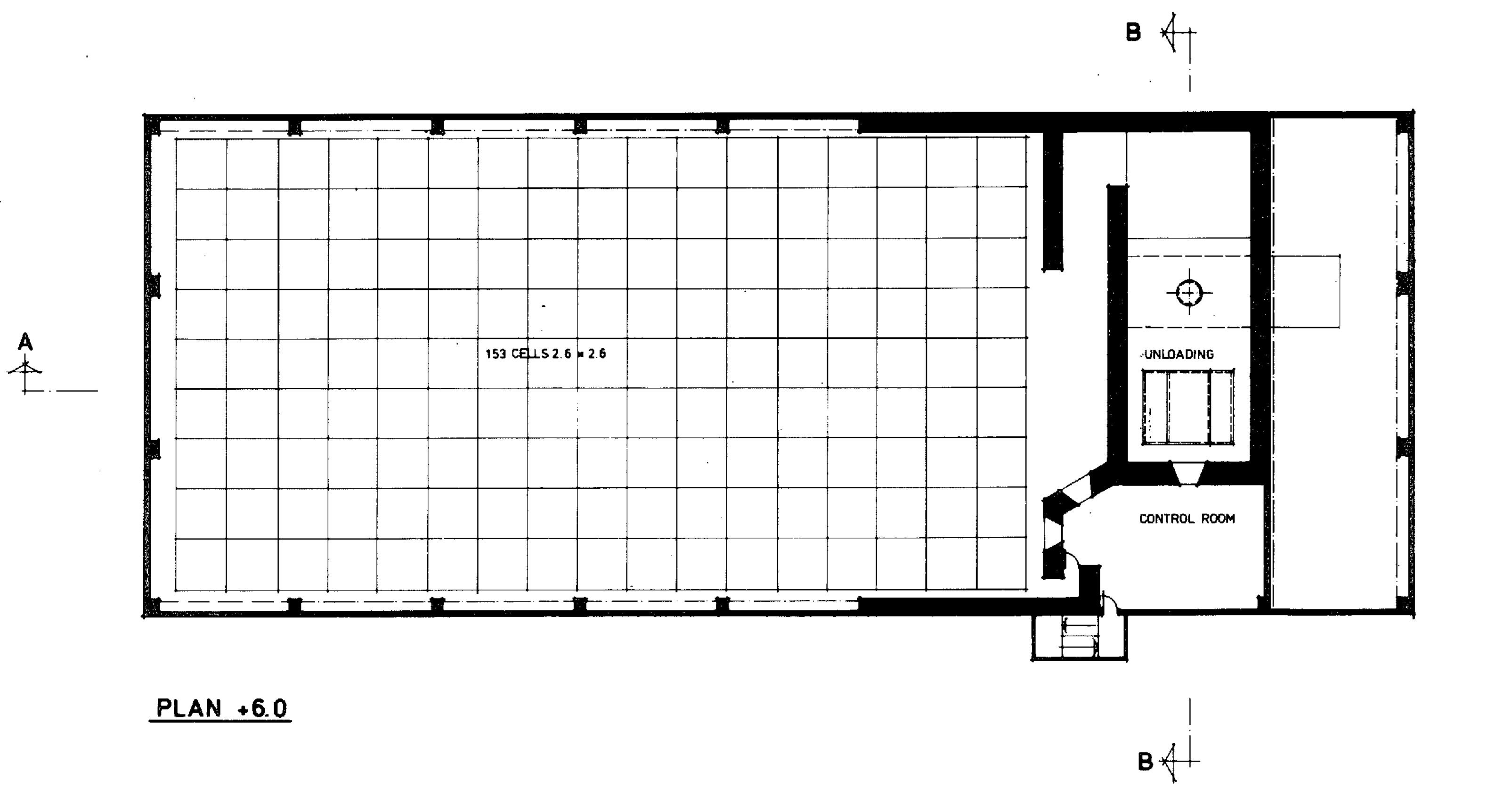
SECTION A



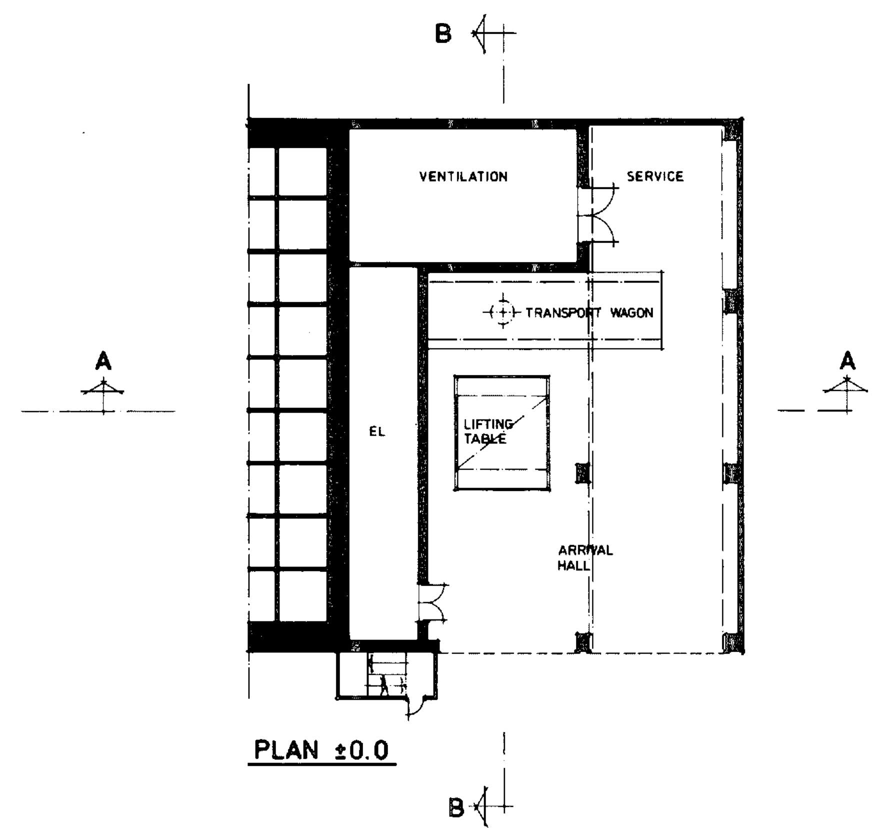
SECTION B



STORAGE CELL
DETAIL SECTION 1:100



PLAN +6.0



PLAN ±0.0

REV.	ANT.	REVIDERINGEN AVSER	RITAD	GRANSK	DATUM

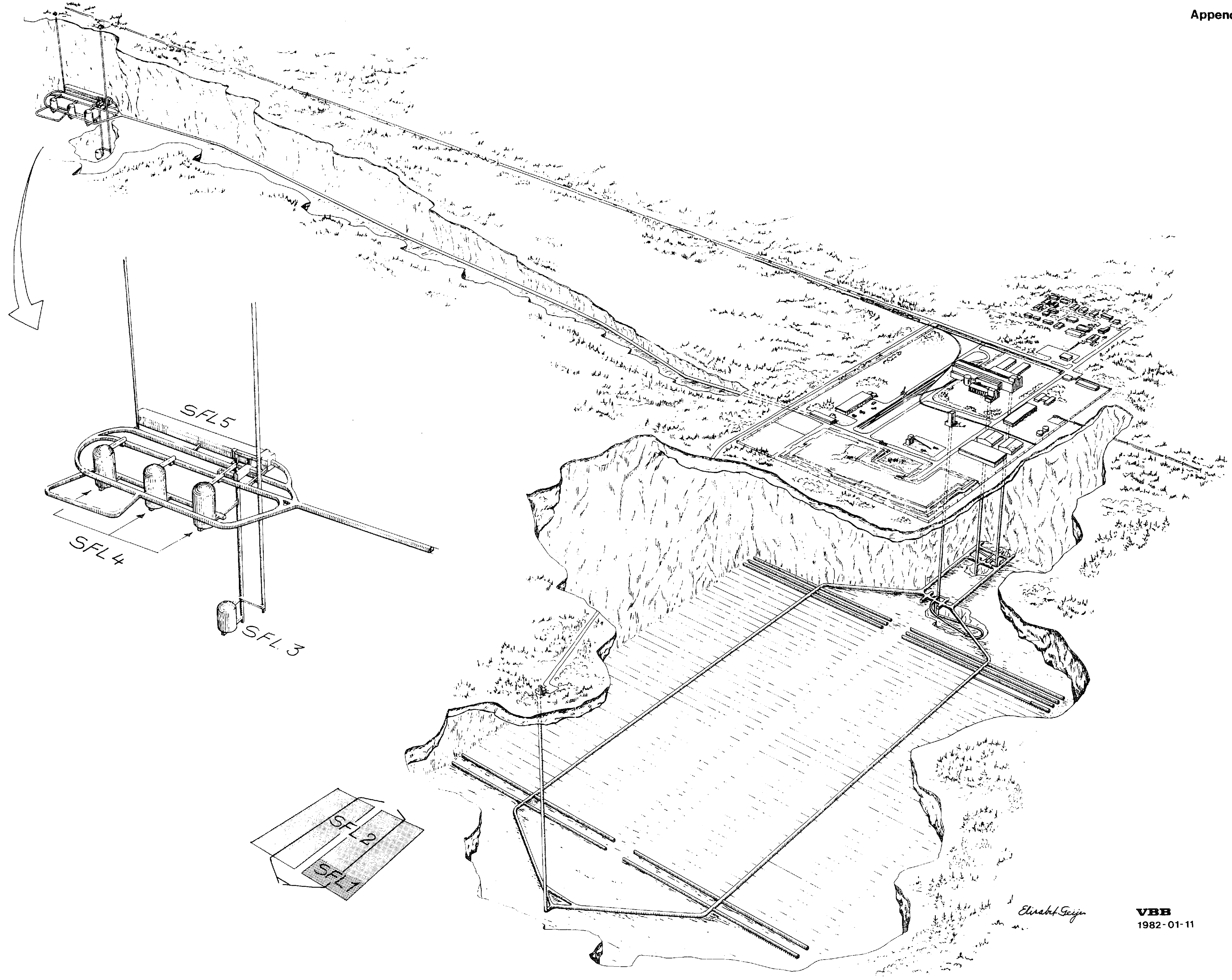
KBS
CLU
PLAN AND SECTION

KONSTRUERAD	RITAD	GRANSKAD	REG.-NUMMER
LEA	HOS		B 87 95
SKALA 1:200 , 1:100		RITNINGSNUMMER CLU 01	REV

STOCKHOLM DEN 81 10 20

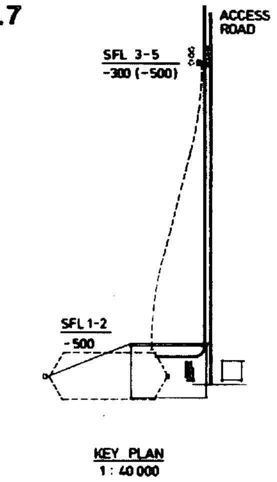
VBB

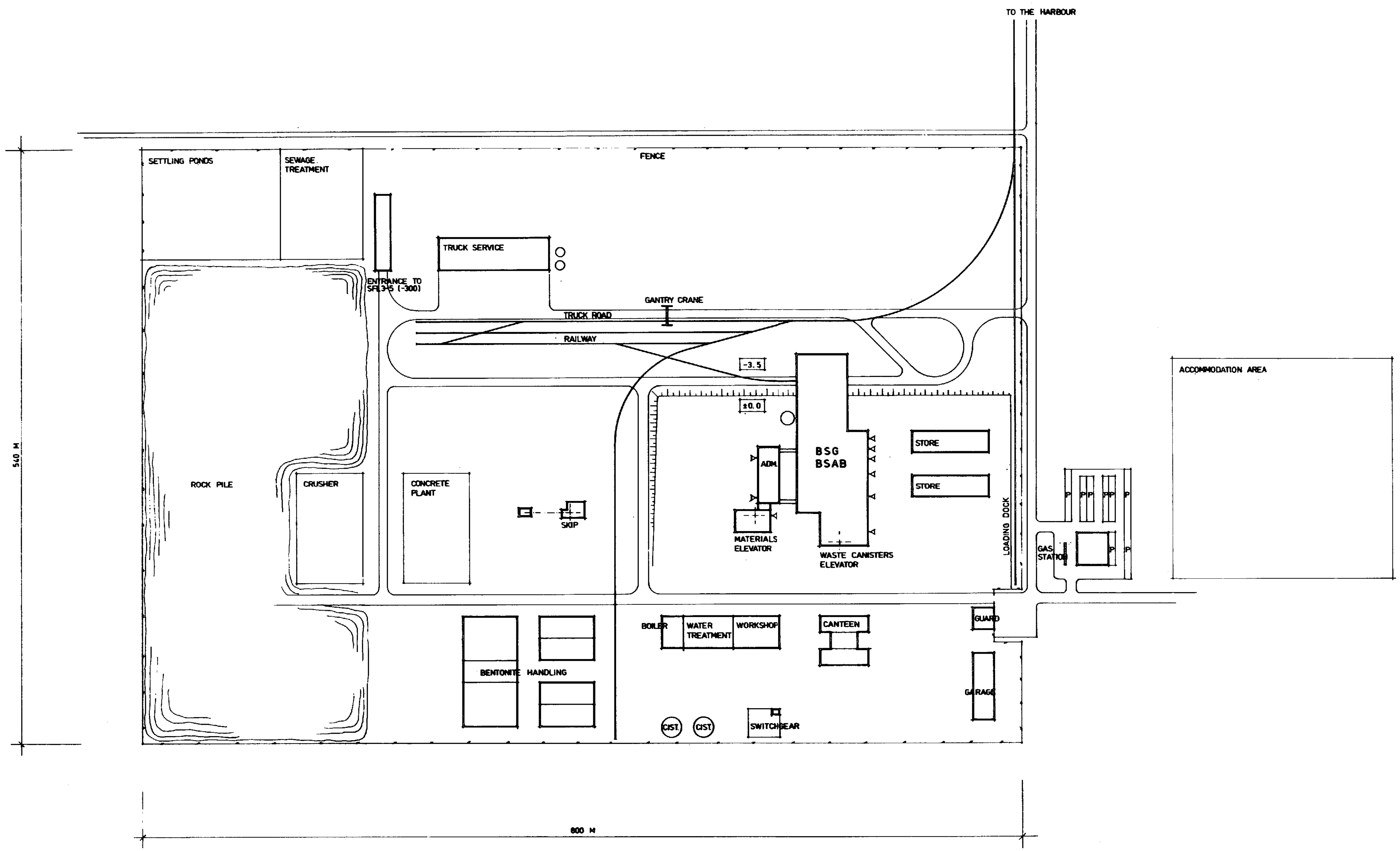
BOX 5038
102 41 STOCKHOLM 5
TEL. 08-22 85 80



VBB
1982-01-11

Appendix 3.7





REV.	ANT	REVIDERINGEN AVSER	RITAD	GRANSK	DATUM

KBS
BSG / BSAB, SFL 1-5
SITE LAYOUT
GROUND FACILITIES

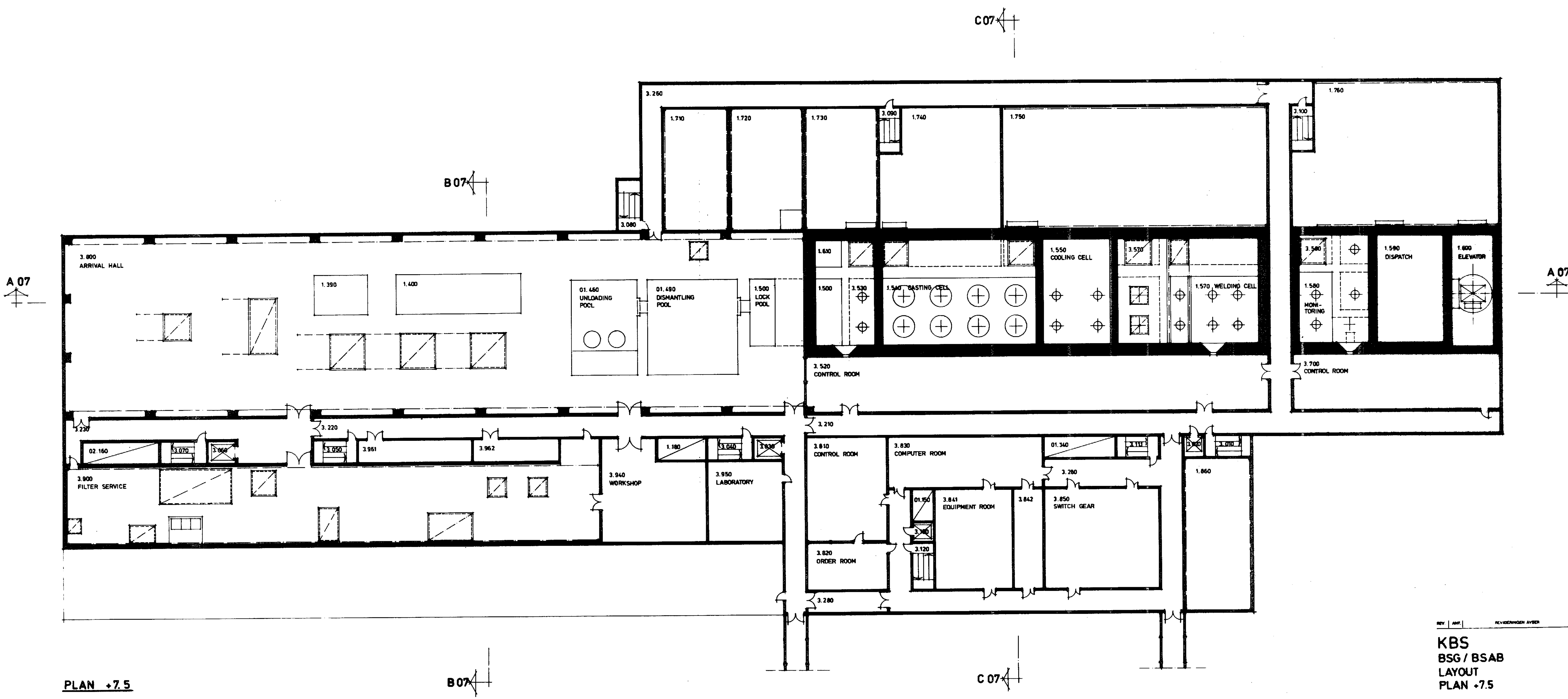
KONSTRUERAD	RITAD	GRANSKAD	REG NUMMER
LEA	HOS		B 87 95
SKALA 1 : 2 000		RITNINGSNUMMER SFL – 01	REV

STOCKHOLM DEN 81 10 01

VBB

BOX 5038
102 41 STOCKHOLM 5 TEL. 08-22 85 80

5 0 10 20



PLAN +7.5

REV.	ANT.	REVIDERINGEN AVSER	RITAD	GRANSK.	DATUM

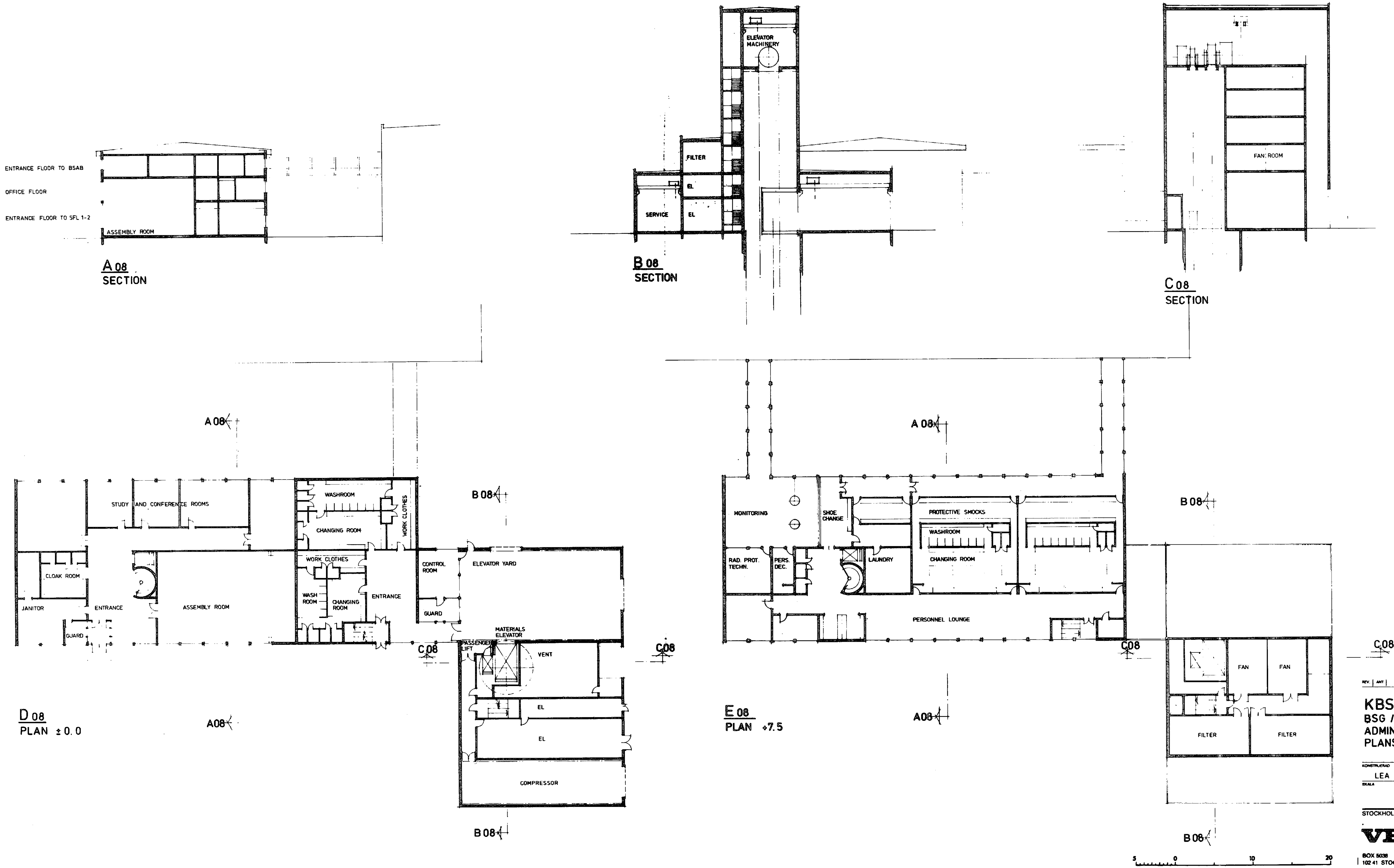
KBS
BSG / BSAB
LAYOUT
PLAN +7.5

KONSTRUERAD	RITAD	GRANSKAD	REG.-NUMMER
LEA	HOS		B 87 95

SKALA	RITNINGSNUMMER	REV
1:200	BSAB 03	

STOCKHOLM DEN 81-12-12

VBB
VATTENBYGGNADSBYRÅN
BOX 5038
102 41 STOCKHOLM 5 TEL. 08-22 85 80



REV.	ANT.	REVIDERINGEN AVSER	RITAD	GRANSK	DATUM

KBS
BSG / BSAB
ADMINISTRATION BUILDING
PLANS AND SECTIONS

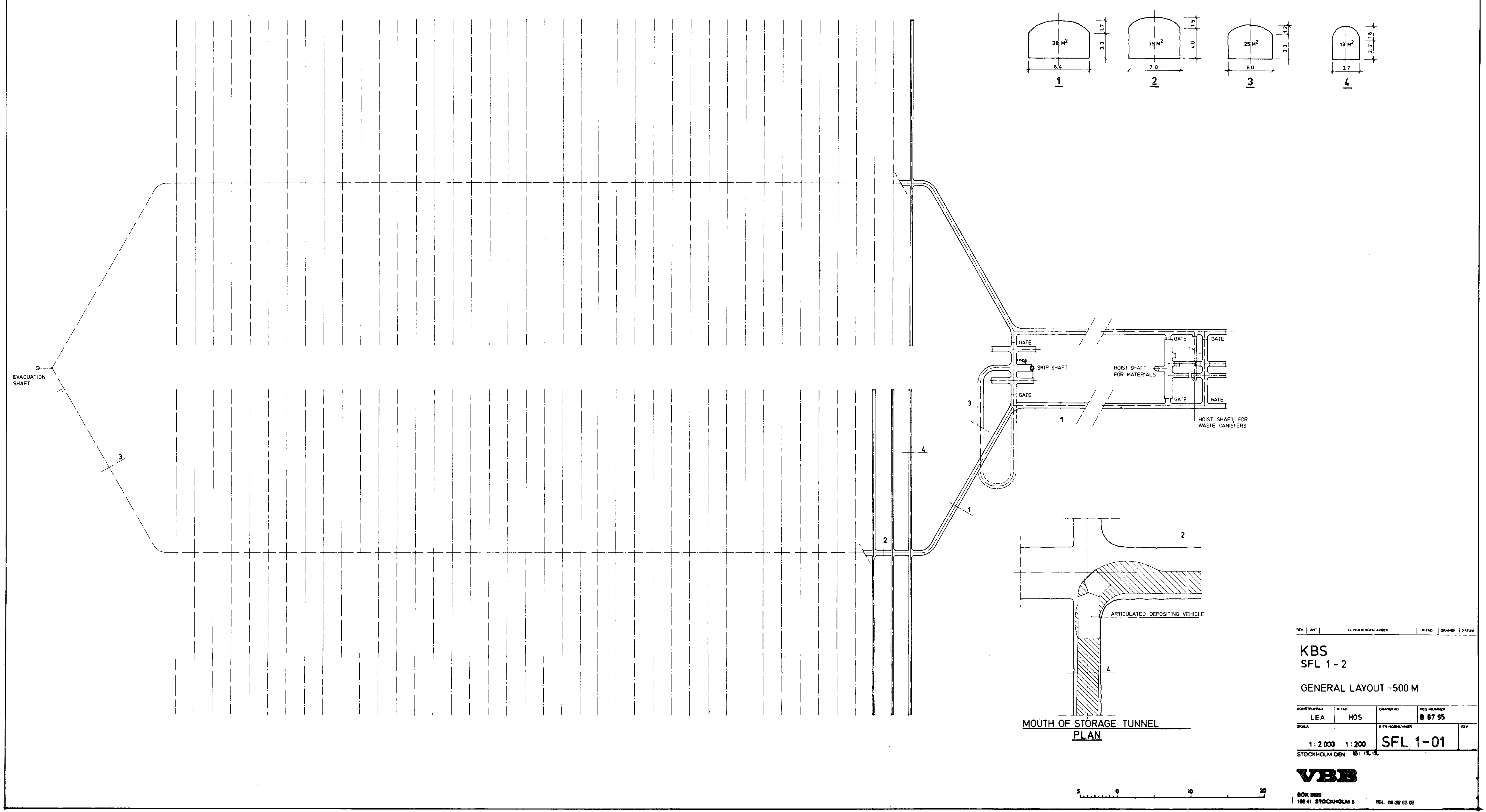
KONSTRUERAD	RITAD	GRANSKAD	REG NUMMER
LEA	HOS		B 87 95

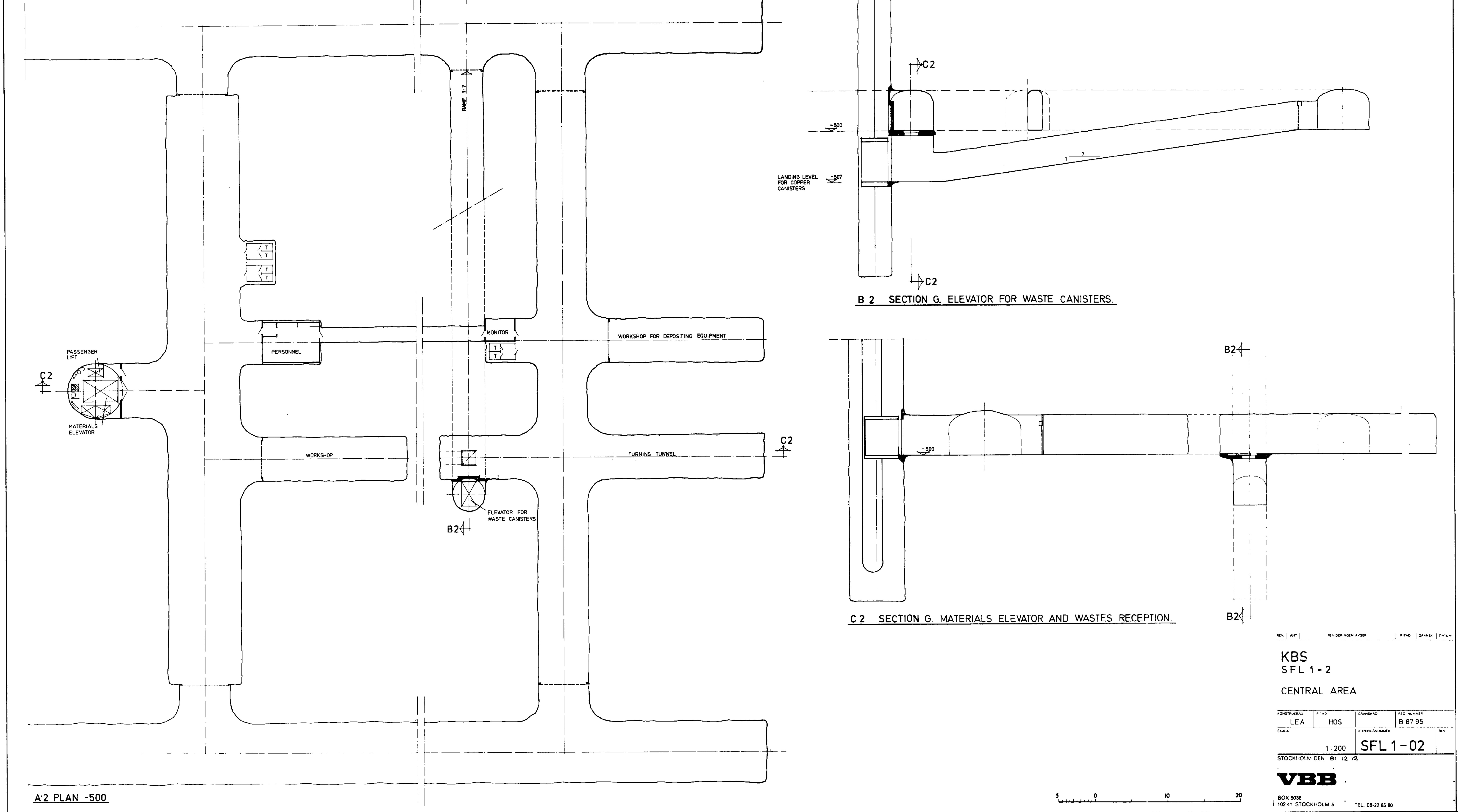
SKALA	RITNINGSNUMMER	REV
1 : 200	BSAB 08	

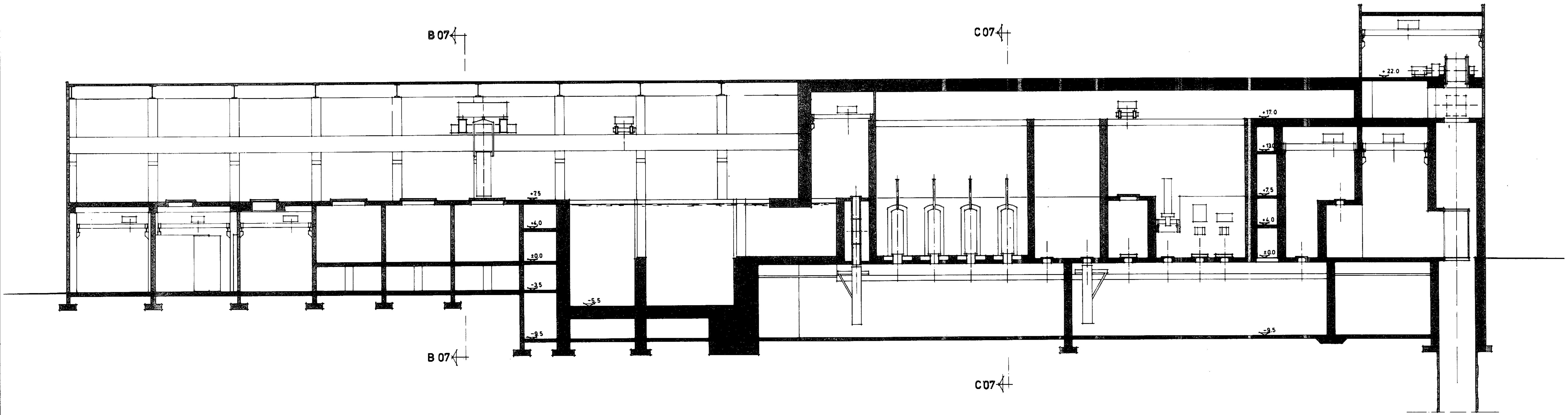
STOCKHOLM DEN 81 12 12

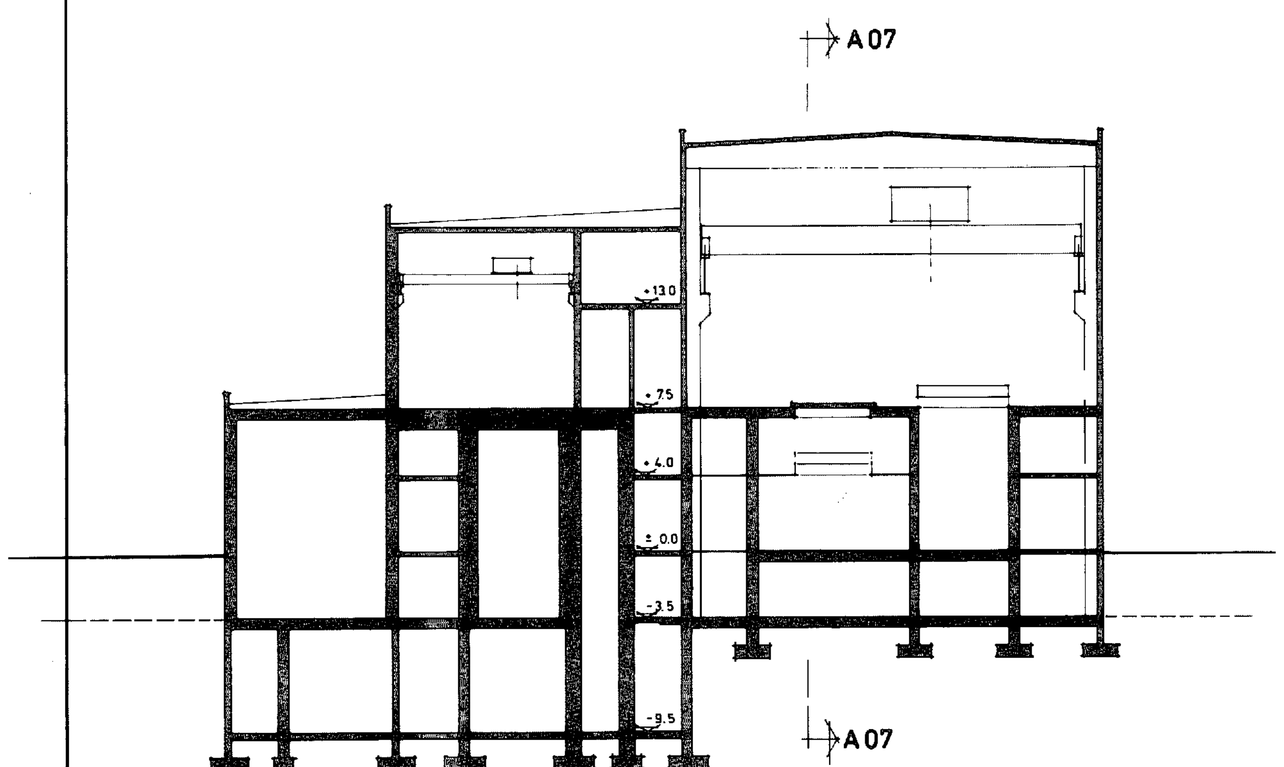
VBB

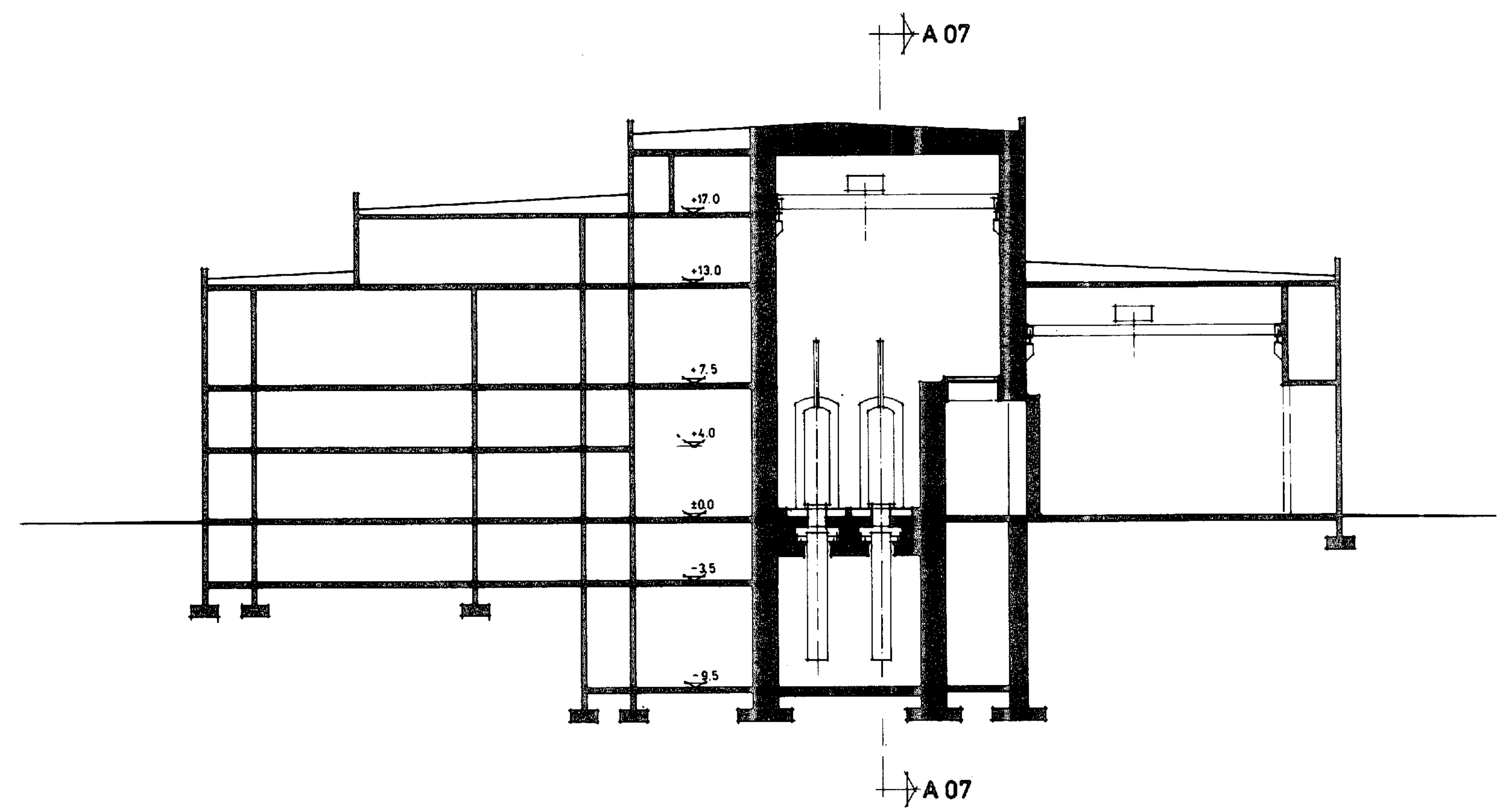
BOX 5038
102 41 STOCKHOLM 5 TEL. 08-22 65 80


38 M²
8.4
1.7
3.3
1
35 M²
7.0
1.5
4.0
2
25 M²
6.0
1.2
3.3
3
13 M²
3.7
1.8
2.2
4
EVACUATION SHAFT
GATE
SKIP SHAFT
HOIST SHAFT FOR MATERIALS
HOIST SHAFT FOR WASTE CANISTERS
ARTICULATED DEPOSITING VEHICLE
MOUTH OF STORAGE TUNNEL
PLAN
REV. | ANT | REVIDERINGEN AVSER | RITAD | GRANSK | DATUM
KBS
SFL 1 - 2
GENERAL LAYOUT -500 M
KONSTRUERAD LEA
RITAD HOS
GRANSKAD
REG-NUMMER B 87 95
SKALA 1 : 2 000 1 : 200
RITNINGSNUMMER SFL 1-01
REV
STOCKHOLM DEN
VBB
BOX 5038
102 41 STOCKHOLM 5
TEL. 08-22 05 00


B2
RAMP 1:7
T
T
T
T
PASSENGER LIFT
C2
MATERIALS ELEVATOR
PERSONNEL
MONITOR
T
T
WORKSHOP FOR DEPOSITING EQUIPMENT
WORKSHOP
TURNING TUNNEL
C2
ELEVATOR FOR WASTE CANISTERS
B2
A2 PLAN -500
C2
-500
LANDING LEVEL FOR COPPER CANISTERS
-507
1
7
C2
B 2 SECTION G. ELEVATOR FOR WASTE CANISTERS.
B2
-500
C 2 SECTION G. MATERIALS ELEVATOR AND WASTES RECEPTION.
B2
5
0
10
20
REV. | ANT | REVIDERINGEN AVSER | RITAD | GRANSK | DATUM
KBS
SFL 1-2
CENTRAL AREA
KONSTRUERAD LEA
RITAD HOS
GRANSKAD
REG NUMMER B 87 95
SKALA 1:200
RITNINGSNUMMER SFL 1-02
REV
STOCKHOLM DEN 81 12 12
VBB
BOX 5038
102 41 STOCKHOLM 5
TEL. 08-22 85 80







5 0 10 20

REV.	ANT.	REVIDERINGEN AVSER	RITAD	GRANSK	DATUM

KBS
BSG / BSAB
LAYOUT
SECTIONS

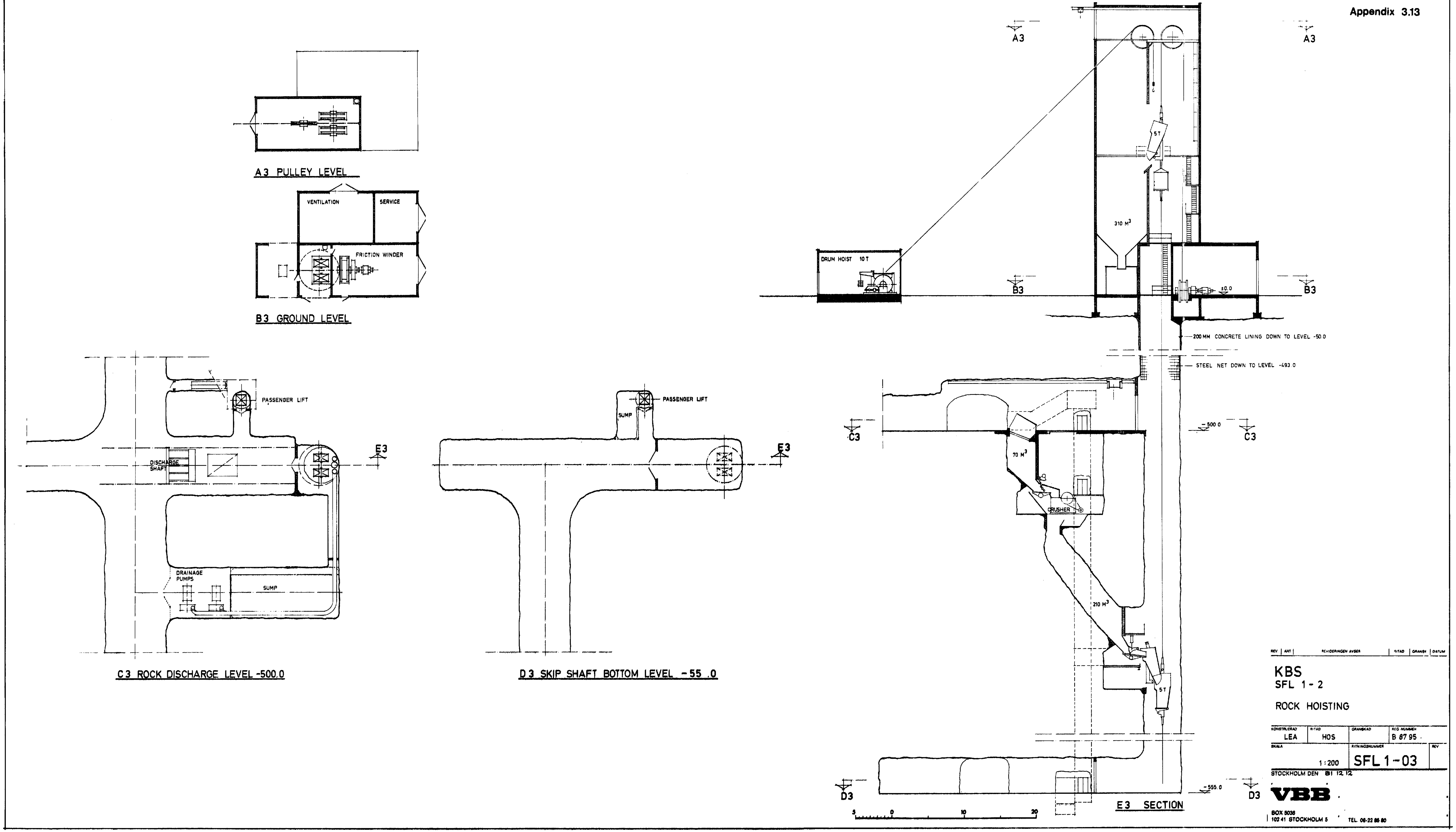
KONSTRUERAD	RITAD	GRANSKAD	REG. NUMMER
LEA	HOS		B 87 95

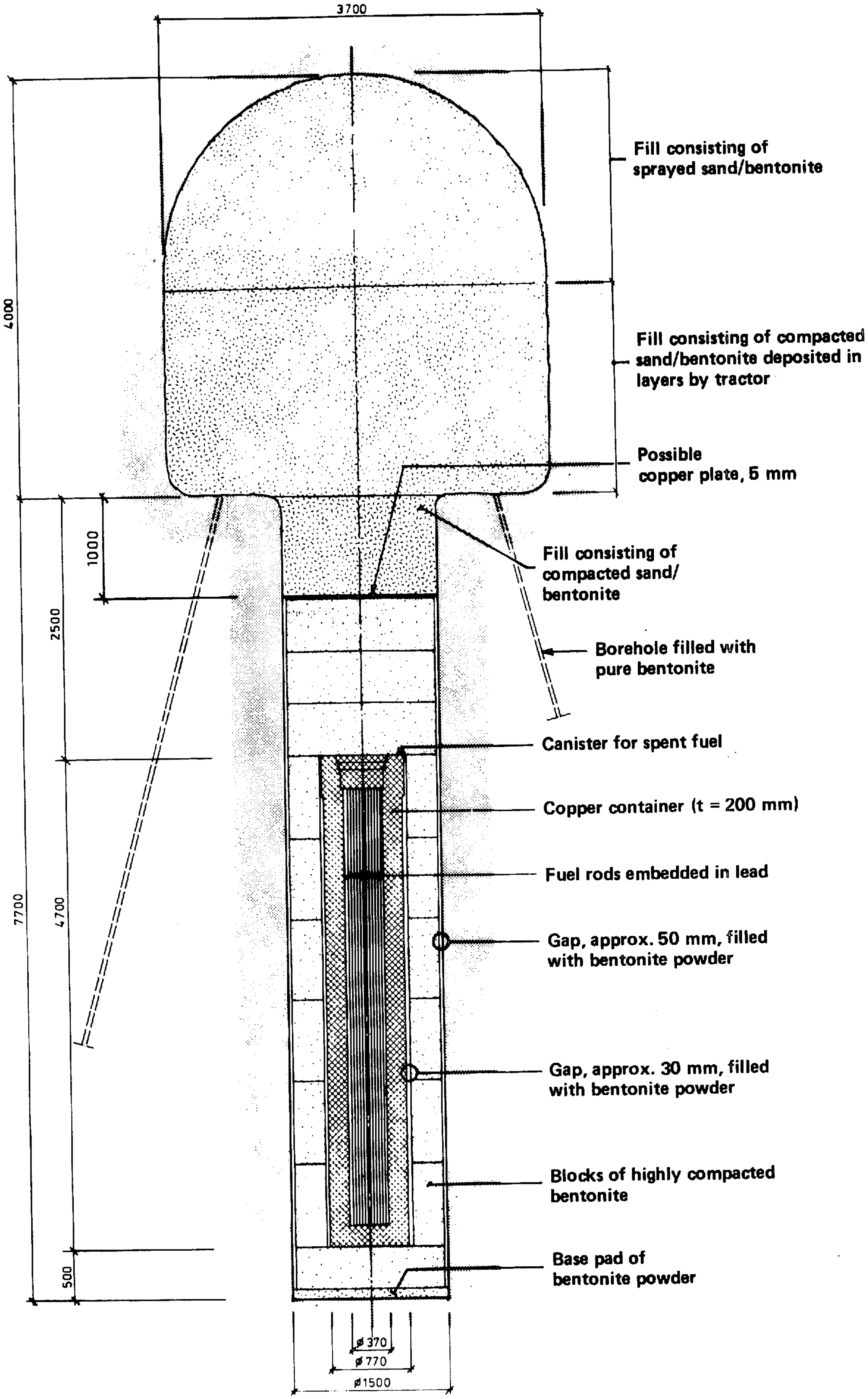
SKALA	RITNINGSNUMMER	REV.
1:200	BSAB 07	

STOCKHOLM DEN 81-12-12

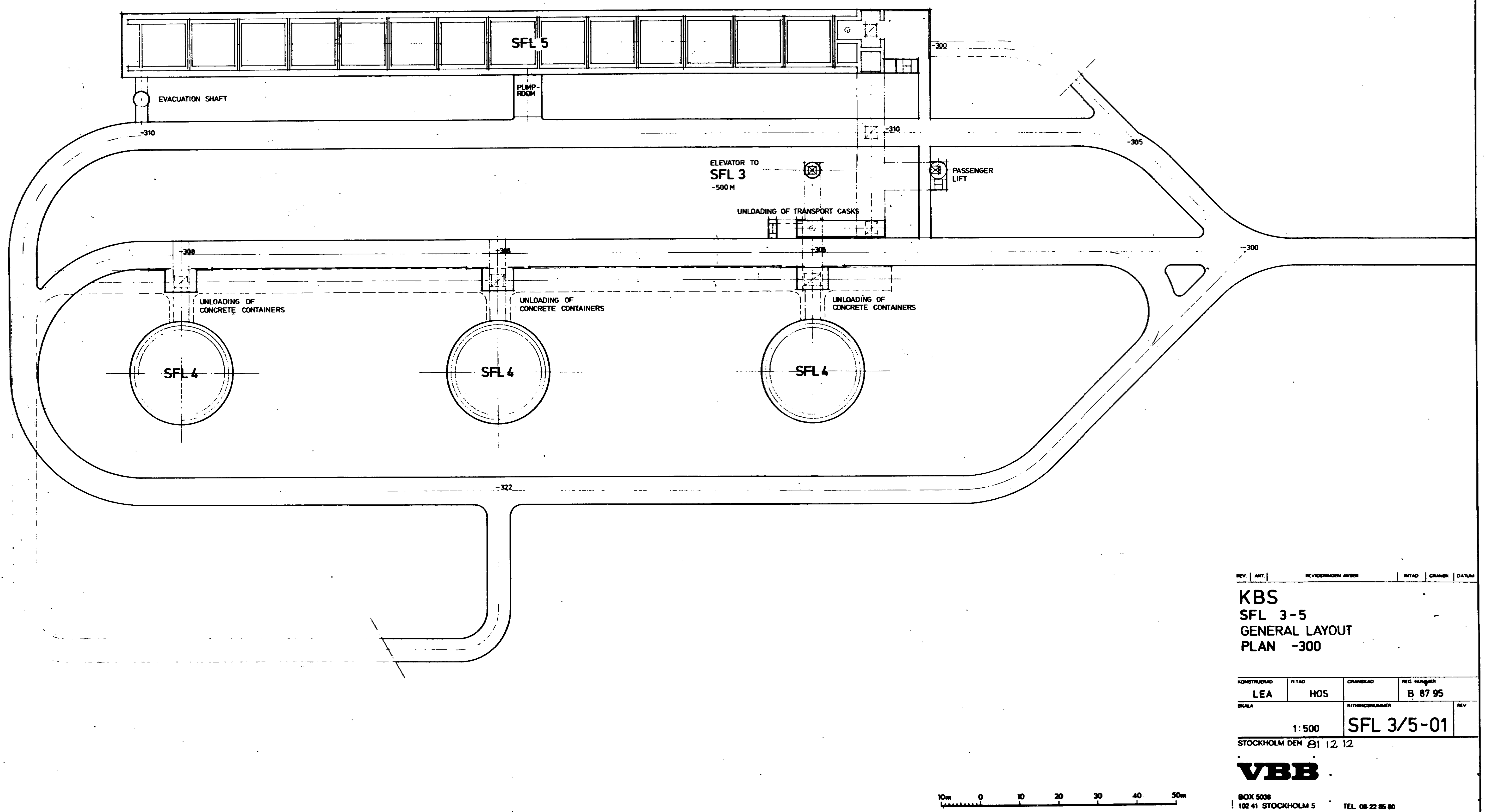
VBB
BOX 5038
102 41 STOCKHOLM 5
TEL. 08-22 86 00

Appendix 3.13





The sealed final repository. The canister is surrounded in the storage hole by highly compacted bentonite. The gaps are filled with bentonite powder. The tunnel is filled with a mixture of quartz-sand and bentonite. A copper plate can, if desired, be placed on top of the bentonite block to serve as a diffusion barrier.



REV.	ANT.	REVIDERINGEN AVSER	RITAD	GRANSK	DATUM

KBS
SFL 3-5
GENERAL LAYOUT
PLAN -300

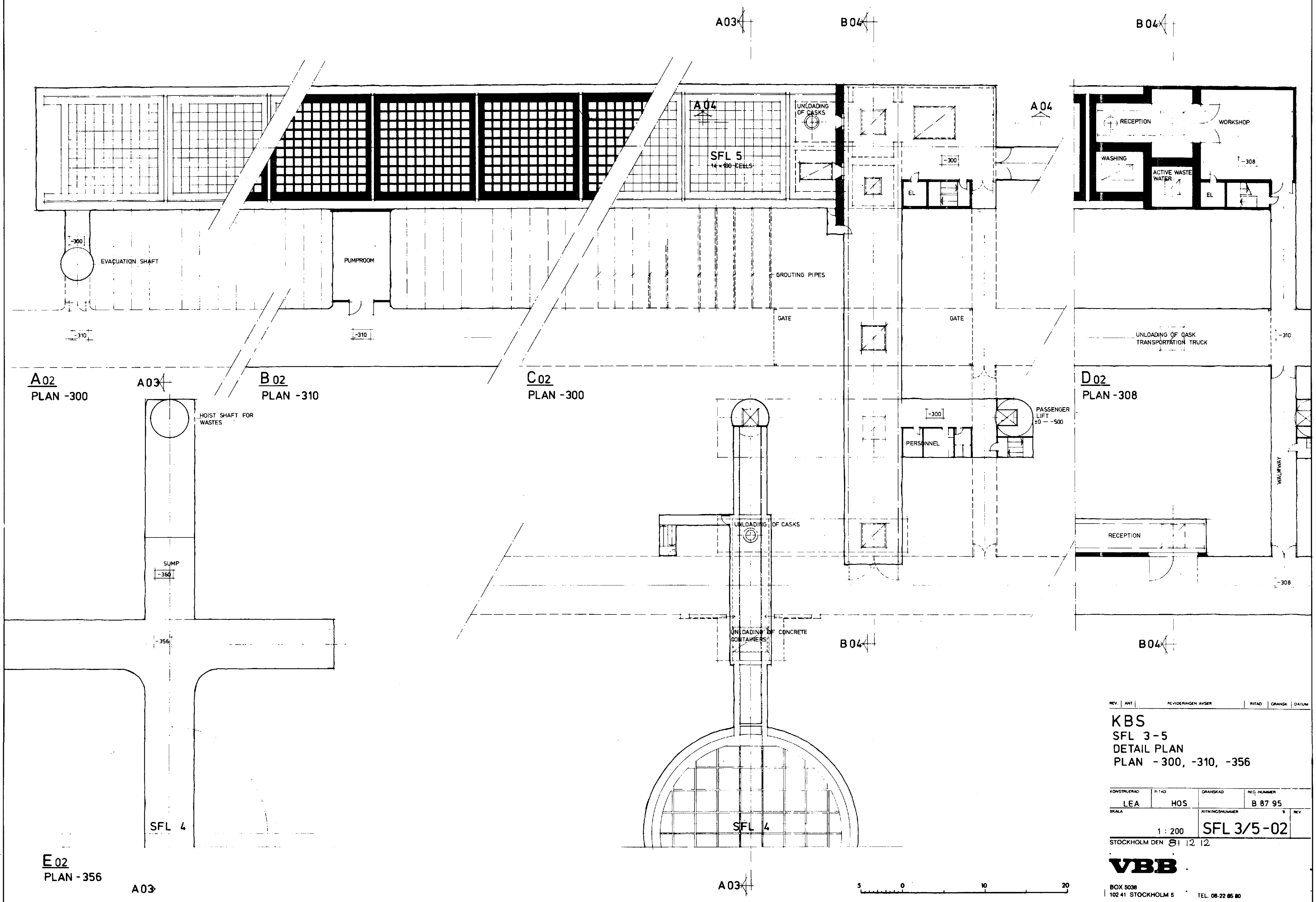
KONSTRUERAD	RITAD	GRANSKAD	REG NUMMER
LEA	HOS		B 87 95

SKALA	RITNINGSNUMMER	REV
1:500	SFL 3/5-01	

STOCKHOLM DEN 81 12 12

VBB

BOX 5038
102 41 STOCKHOLM 5 TEL. 08-22 85 80



REV.	ANT.	REVIDERINGEN AVSER	RITAD	GRANSK.	DATUM

KBS
SFL 3-5
DETAIL PLAN
PLAN -300, -310, -356

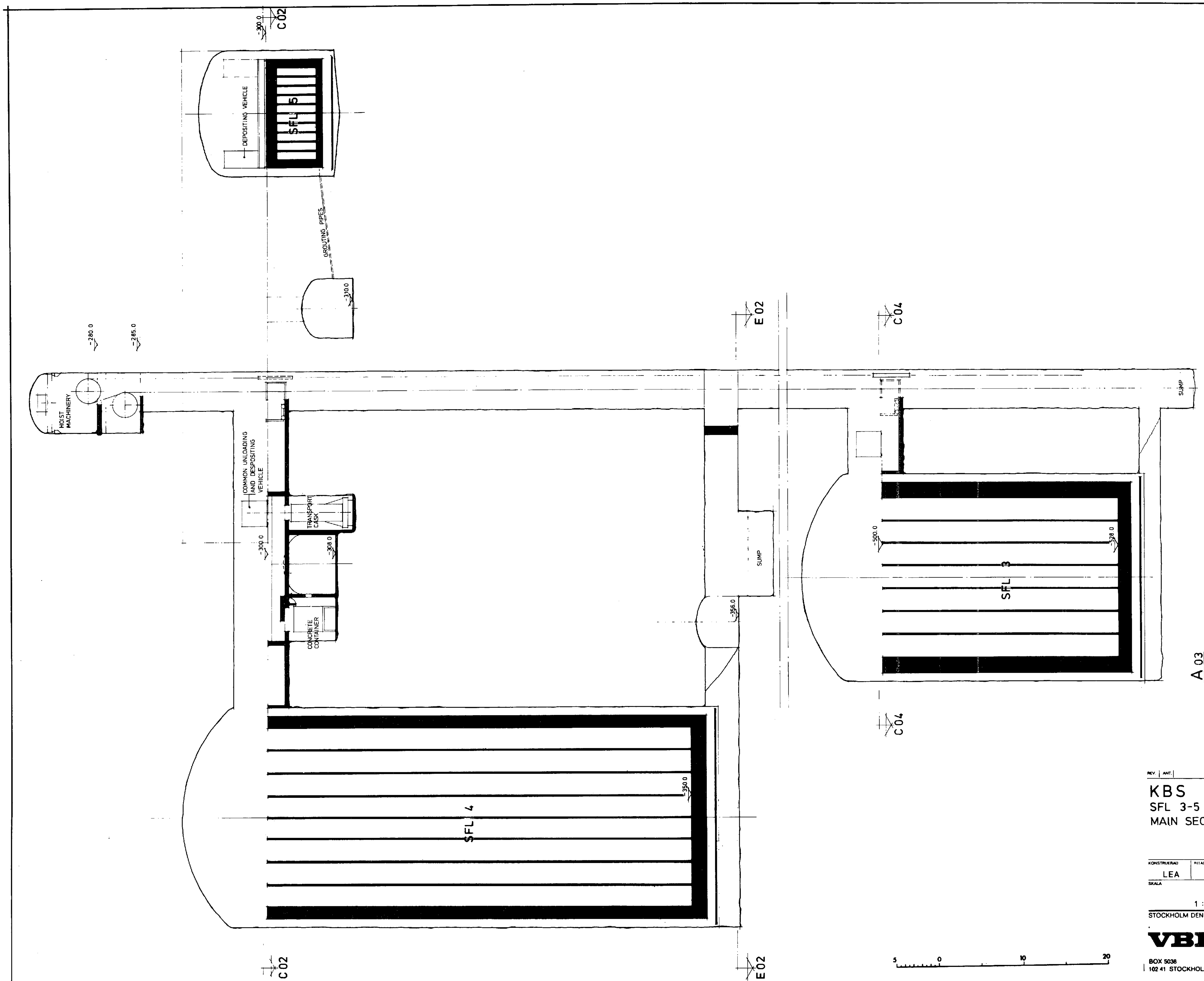
KONSTRUERAD	RITAD	GRANSKAD	REG.-NUMMER
LEA	HOS		B 87 95

SKALA	RITNINGSNUMMER	REV
1 : 200	SFL 3/5-02	

STOCKHOLM DEN 81 12 12

VBB

BOX 5038
102 41 STOCKHOLM 5 TEL. 08-22 85 80



REV	ANT.	REVIDERINGEN AVSER	RITAD	GRANSK	DATUM

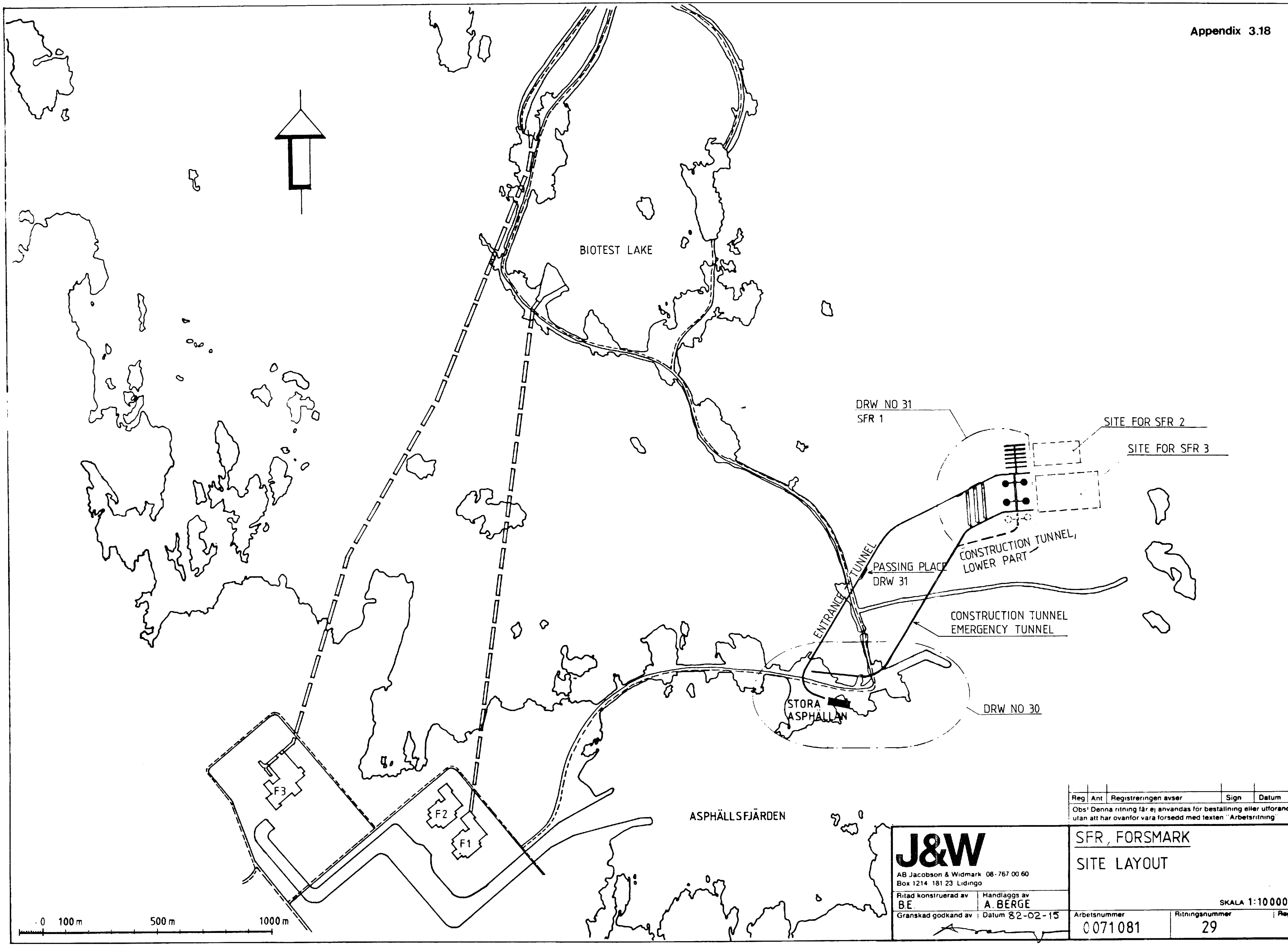
KBS
SFL 3-5
MAIN SECTION

KONSTRUERAD	RITAD	GRANSKAD	REG-NUMMER
LEA	HOS		B 87 95
SKALA		RITNINGSNUMMER	REV
1 : 200		SFL 3/5-03	

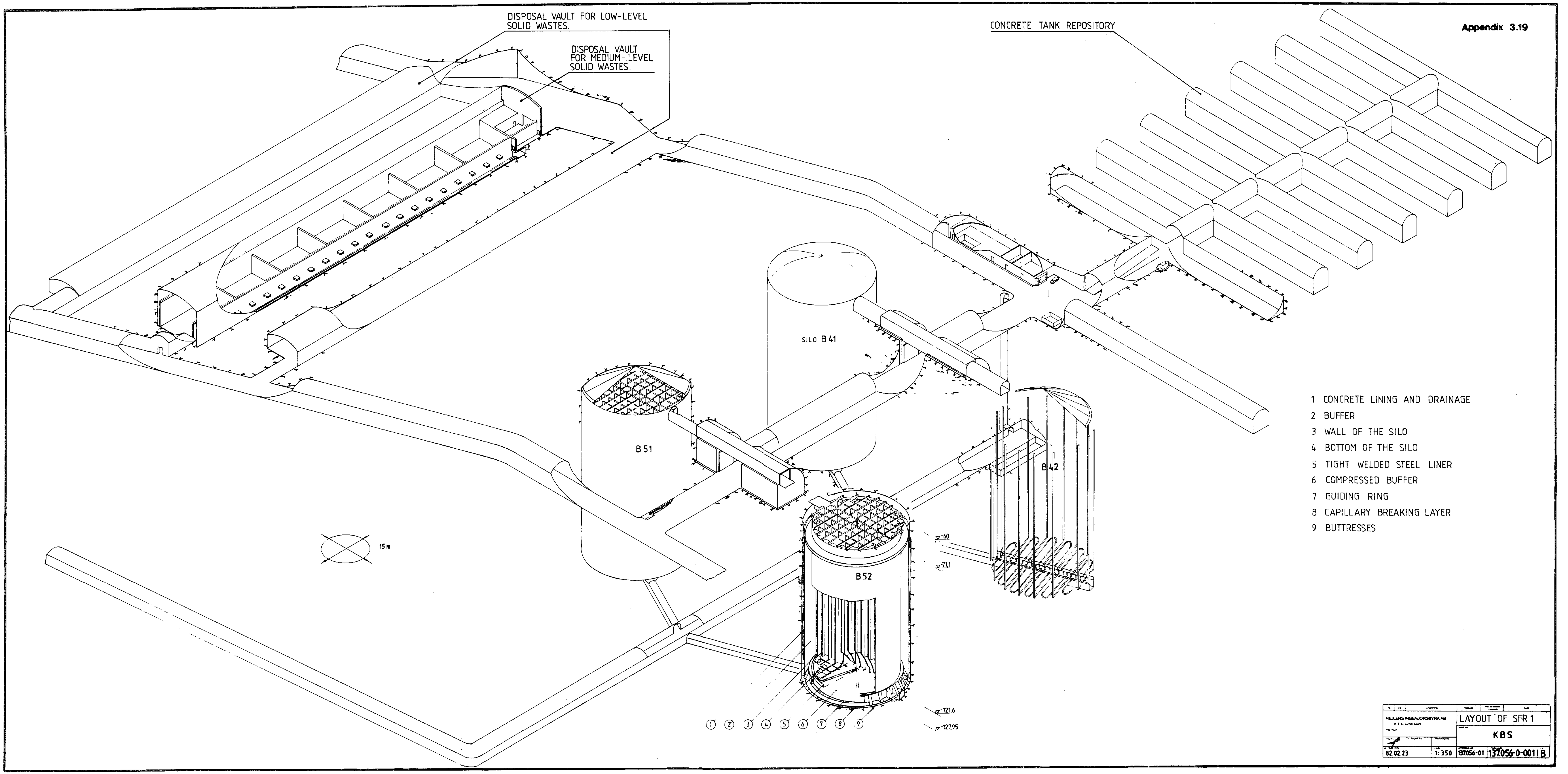
STOCKHOLM DEN 81 12 12

VBB

BOX 5038
102 41 STOCKHOLM 5
TEL. 08-22 85 80


BIOTEST LAKE
DRW NO 31
SFR 1
SITE FOR SFR 2
SITE FOR SFR 3
CONSTRUCTION TUNNEL, LOWER PART
PASSING PLACE
DRW 31
ENTRANCE TUNNEL
CONSTRUCTION TUNNEL
EMERGENCY TUNNEL
STORA ASPHÄLLAN
DRW NO 30
F3
F2
F1
ASPHÄLLSFJÄRDEN
0 100 m 500 m 1000 m
Reg | Ant | Registreringen avser | Sign | Datum
Obs! Denna ritning får ej användas för beställning eller utförande utan att har ovanför vara försedd med texten "Arbetsritning"
J&W
AB Jacobson & Widmark 08-767 00 60
Box 1214 181 23 Lidingö
Ritad konstruerad av B.E.
Handläggs av A. BERGE
Granskad godkänd av
Datum 82-02-15
SFR, FORSMARK
SITE LAYOUT
SKALA 1:10000
Arbetsnummer 0071081
Ritningsnummer 29
Reg

Appendix 3.19



FÖRTECKNING ÖVER KBS TEKNISKA RAPPORTER

1977-78

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

1979

TR 79-28 The KBS Annual Report 1979.
KBS Technical Reports 79-01--79-27.
Summaries. Stockholm, March 1980.

1980

TR 80-26 The KBS Annual Report 1980.
KBS Technical Reports 80-01--80-25.
Summaries. Stockholm, March 1981.

1981

TR 81-17 The KBS Annual Report 1981.
KBS Technical Reports 81-01--81-16
Summaries. Stockholm, April 1982.

1982

TR 82-01 Hydrothermal conditions around a radioactive waste repository
Part 3 - Numerical solutions for anisotropy
Roger Thunvik
Royal Institute of Technology, Stockholm, Sweden
Carol Braester
Institute of Technology, Haifa, Israel
December 1981

TR 82-02 Radiolysis of groundwater from HLW stored in copper canisters
Hilbert Christensen
Erling Bjergbakke
Studsvik Energiteknik AB, 1982-06-29

TR 82-03 Migration of radionuclides in fissured rock: Some calculated results obtained from a model based on the concept of stratified flow and matrix diffusion
Ivars Neretnieks
Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden, October 1981

TR 82-04 Radionuclide chain migration in fissured rock - The influence of matrix diffusion
Anders Rasmuson *
Akke Bengtsson **
Bertil Grundfelt **
Ivars Neretnieks *
April, 1982

* Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden

** KEMAKTA Consultant Company
Stockholm, Sweden

TR 82-05 Migration of radionuclides in fissured rock - Results obtained from a model based on the concepts of hydrodynamic dispersion and matrix diffusion
Anders Rasmuson
Ivars Neretnieks
Royal Institute of Technology
Department of Chemical Engineering
Stockholm, Sweden, May 1982

TR 82-06 Numerical simulation of double packer tests Calculation of rock permeability
Carol Braester
Israel Institute of Technology, Haifa, Israel
Roger Thunvik
Royal Institute of Technology
Stockholm, Sweden, June 1982

TR 82-07 Copper/bentonite interaction
Roland Pusch
Division Soil Mechanics, University of Luleå
Luleå, Sweden, 1982-06-30

TR 82-08 Diffusion in the matrix of granitic rock Field test in the Stripa mine Part 1
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TR 82-09:1 Radioactive waste management plan
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TR 82-09:2 Radioactive waste management plan
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TR 82-10 The hydraulic properties of fracture zones and tracer tests with non-reactive elements in Studsvik
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