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Project on Alternative Systems Study – PASS. Cost comparison of repository systems

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VBB VIAK AB

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PROJECT ON ALTERNATIVE SYSTEMS STUDY - PASS

COST COMPARISON OF REPOSITORY SYSTEMS

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Keywords:

Cost Ranking, Cost Calculation, KBS-3, Medium Long Holes, MLH, Very Long Holes, VLH, Very Deep Holes, VDH, Common Facilities, CF, Encapsulation Station, ES, Underground Repository, SFL, Canister

ABSTRACT

The development of alternative repository systems and different canister alternatives is being studied by SKB within the frame of the "Project on Alternative Systems Study, PASS", with the objective of presenting a ranking of systems being currently studied. The ranking is primarily made for three different headings: technology, long-term performance and safety, and costs. The rankings for each of these headings are eventually to be merged into one ranking. The present report presents the basis for the ranking regarding costs. The following four systems have been studied and are presented in order of cost (the less expensive first): Medium Long Holes (MLH), KBS-3 (modified Plan 92 system), Very Long Holes (VLH), and Very Deep Holes (VDH). A significant outcome of the study was the clear difference in cost between the very expensive system VDH and the other three.

ABSTRACT SWEDISH

Alternativa system för djupförvar och olika typer av kapslar studeras av SKB inom ramen för "Project on Alternative Systems Study, PASS". Avsikten är att presentera en rangordning av de system som studeras. Rangordningen avser i första hand de tre huvudområdena: teknik, långsiktig funktion och säkerhet, samt kostnader. Rangordningen inom dessa tre områden ska slutligen sammanvägas. Den föreliggande rapporten presenterar underlaget för en rangordning avseende kostnader. Följande system har studerats, presenterade i ordning efter kostnad (det system med lägsta kostnaden först): Medium Long Holes (MLH), KBS-3 (modifierad Plan 92 version), Very Long Holes (VLH) och Very Deep Holes (VDH). Ett resultat av vikt från studien var den markerade kostnadskillnaden mellan det mycket dyra systemet VDH och de övriga tre.

PREFACE

This report concerns a study regarding cost comparison between four different repository concepts for the final disposal of spent nuclear fuel. The technical background material and to some extent cost figures have been collected from other studies, previously carried out by experts and specialist groups within the framework of the SKB R&D programme. The more significant studies are included in the attached reference list.

Plan 92, SKB's latest annual cost report on the Swedish nuclear waste programme, is of particular importance, as it has not only been a source of information regarding systems and fundamental cost estimates but has also stated the cost calculation method generally used in the present study. It should therefore be acknowledged that cost calculations pertaining to relevant parts of the Plan 92 work, have been mainly carried out by ABB-Atom (processes and equipment) and Nordic Construction Co., NCC (civil works). NCC has also taken an active part in the review of underground work and cost estimates for the present study.

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1. INTRODUCTION

The KBS-3 concept was presented in 1983 by SKB (SKBF 1983) as required by Swedish legislation before a charging permit could be granted for the latest two nuclear power reactors taken into operation (Oskarshamn 3 and Forsmark 3). After domestic and international peer reviews the Swedish government declared that the concept satisfies the safety and radiation protection requirements set forth in the law. Thus, the annual cost calculations for deciding the appropriate fee on nuclear power electricity for the back-end cycle is based on this concept.

When the work on what became the KBS-3 design started, several different options were at hand. After the government's decision, the most promising of the other options have been developed in parallel with the ongoing research on the KBS-3 design.

During 1986-89 the WP-Cave system was evaluated and compared with the KBS-3 concept /1/. At that time the WP-Cave was the alternative that was most developed after the KBS-3. The result showed that KBS-3 featured major advantages over the WP-Cave system and consequently studies of the WP-Cave system were not continued.

In 1989 the Very Deep Holes (VDH) alternative, based on the disposal of the waste at 2 to 4 km depth, was developed /2/, and in 1990-91 the Very Long Holes (VLH) alternative, based on disposal in 4-5 km long horizontal drifts /3/. These two alternative systems feature other canister dimensions than the KBS-3 system.

During 1992 it was decided that the emplacement of the KBS-3-size canisters in a horizontal position in galleries should be considered as a separate alternative in the comparison of studied systems. The system, called the Medium Long Holes system, (MLH), is described in /4/.

For each of the developed systems different canister designs are considered. The options are, however, few for the VDH and VLH. The KBS-3 size of canister features several in principle different alternatives.

The development of the alternative repository systems and the different canister alternatives is conducted within the frame of "Project on Alternative Systems Study, PASS", with the objective of presenting a ranking of alternatives being currently studied (WP-Cave is not included). The ranking of the repository systems is primarily carried out for three different headings:

- Technology (for construction and disposal),
- Long Term Performance
  and Safety (after repository closure)
- Costs

The rankings for each of these headings are eventually to be merged together into one ranking.

The present report presents the basis for the ranking regarding costs.

2. PREMISES

2.1 BASIS FOR COST COMPARISON

The following repository systems have been studied and compared with respect to construction, operating and decommissioning costs:

- KBS-3
- MLH (Medium Long Holes)
- VLH (Very Long Holes)
- VDH (Very Deep Holes)

Reference is made to Chapter 3 for a brief description of the systems.

The encapsulation of the spent fuel was based on the principle that fuel assemblies will be encapsulated in their intact form. That was the case for all the alternatives. However, for the VDH system, the limitations imposed by the relatively small diameter of the borehole and the limited storage capacity justified an additional study regarding an alternative with rod consolidation prior to encapsulation. In this manner a greater packing density can be achieved. The number of canisters are assumed to be reduced by approximately 50%. The heat output from such canisters will increase correspondingly, a disadvantage which, combined with substantial costs for the fuel preparation, makes the method less feasible for the other, so-called mined, alternatives. In the following, where the two methods have to be clearly distinguished, the so-called consolidated alternative will be indicated by the subscript VDH_{cons}. The non-consolidated or intact method will be indicated VDH_{int}.

As a general basis for the cost calculations the most recent annual cost calculation of the back-end system according to KBS-3, presented in Plan 92 /5/, was used. Thus a consistent methodology was assured, and references to cost findings of Plan 92, modified with respect to differences in technology or operational environment, could be utilized to a certain extent. Costs for VDH components related to drilling or emplacement operations were mainly derived from /2/.

Plan 92 encompasses the whole system for the handling of radioactive waste in Sweden, illustrated schematically in Figure 2-1. The present report, however, only concerns facilities directly involved in the final disposal of spent fuel, i. e. facilities of decisive importance to a cost comparison of repository systems. Referring to Figure 2-1 this includes the encapsulation station ES and the final repository SFL 2 (in the following referred to as SFL).

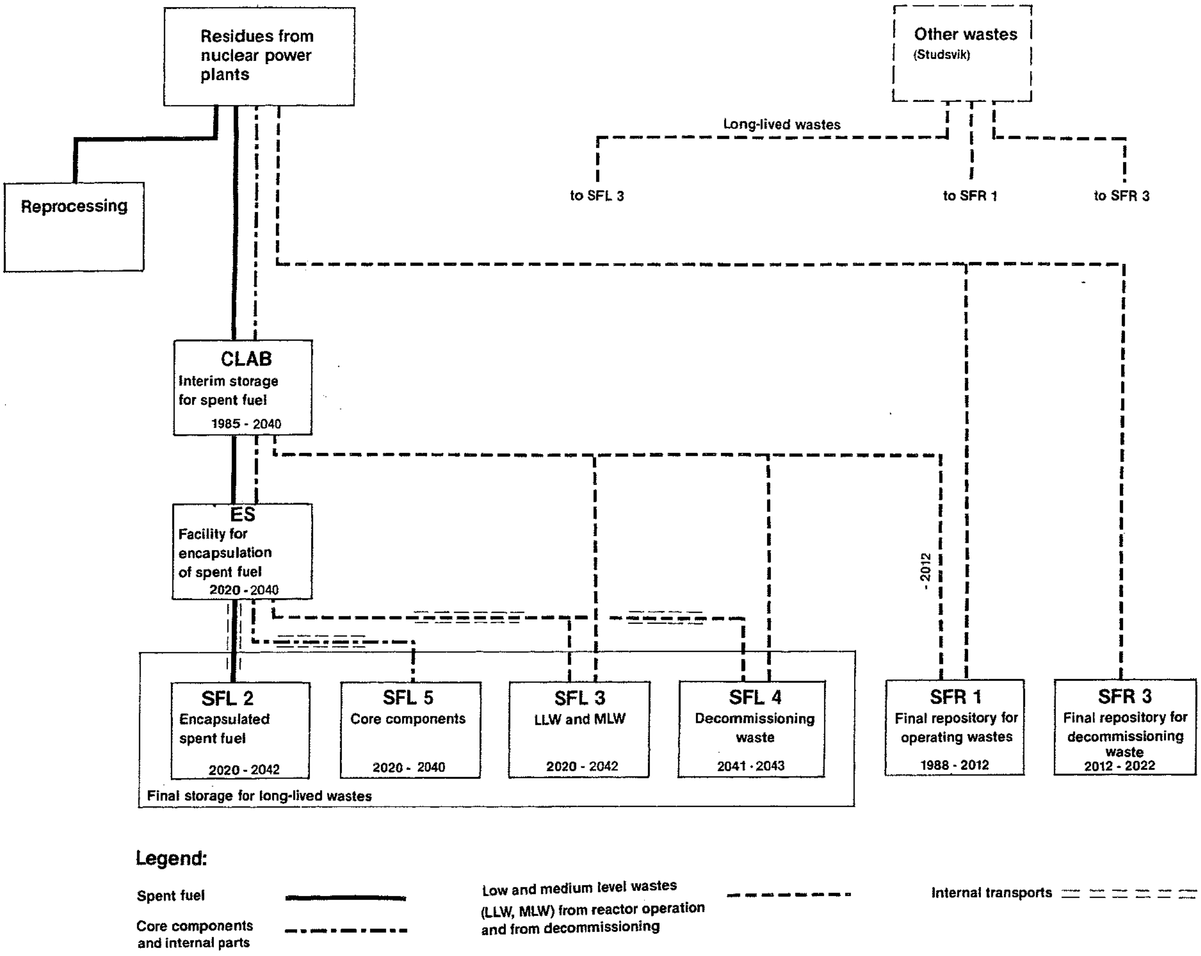


Figure 2-1 Schematic handling chain for the radioactive waste products of nuclear power in Sweden

In accordance with Plan 92, ES and SFL are considered to be co-located in the inland of Sweden. Service facilities and infrastructure for common use by ES and SFL are included in the study and accounted for under the heading "Common Facilities, CF".

Design studies, mainly elaborations of earlier studies (referred to in Chapter 1), were carried out up to a point where quantities could be established for the purpose of a cost ranking with a reasonable level of certainty. This implies that certain simplifications and only a basic level of optimization could be adopted. It should be noted, however, that other studies with the purpose of demonstrating the technical feasibility of various processes and components were carried out in parallel with this study.

2.2 ENERGY PRODUCTION AND AMOUNT OF SPENT FUEL

Table 2-1 presents a summary of electricity production and fuel consumption in the Swedish nuclear power plants if in operation until the year 2010. Of the total amount of spent fuel, 140 tonnes will be reprocessed at BNFL from which no waste will be returned. 57 tonnes have been sent to Cogema but this fuel has been exchanged for 24 tonnes of German MOX fuel. In addition to this, 20 tonnes of fuel originating from the Ågesta and R1 reactors will be disposed of in SFL.

The number of fuel assemblies to be encapsulated and disposed of in SFL corresponding to the amount of fuel given above are:

BWR	33,394
PWR	3,858

Table 2-1 Electricity production and fuel consumption for the Swedish nuclear power plants

Reactor and date of com. operation		Thermal capacity MW	Net electrical capacity MW	Energy production TWh			Uranium consumption, tU	
				through 1991	per year from 1992	Total	Discharged through 1991	Total
B1	75-07-01	1800	600	64	4.1	142	260	611
B2	77-07-01	1800	600	60	4.1	138	233	585
R1	76-01-01	2500	800	70	5.5	174	228	713
R2	75-05-01	2570	870	72	5.6	177	216	630
R3	81-09-09	2780	920	55	5.9	167	153	591
R4	83-11-21	2780	920	51	5.9	163	153	579
O1	72-02-06	1375	440	54	3.0	111	226	519
O2	74-12-15	1800	600	67	4.1	145	250	604
O3	85-08-15	3300	1160	51	7.9	202	131	752
F1	80-12-10	2930	970	72	6.6	198	251	812
F2	81-07-07	2930	970	67	6.6	193	215	772
F3	85-08-22	3300	1150	51	7.9	200	128	747
BWR		21735	7290	557	49.9	1504	1922	6119
PWR		8130	2710	179	17.3	508	522	1797
All		29865	10000	735	67.2	2012	2444	7916

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

2.3 TYPE AND NUMBER OF CANISTERS

Figure 2-2 shows the various types of canisters considered in this study. The KBS-3 and the MLH systems include a self-supporting Cu-Fe composite canister with a capacity of 12 BWR assemblies. The VLH concept includes the same type of canister but larger, with a capacity of 24 BWR assemblies. The VDH concept includes a titanium canister with a capacity of 4 BWR intact assemblies or 8 BWR consolidated assemblies. The voids in the titanium canisters will be filled with concrete.

The canister capacities given above are confined by geometrical as well as thermal conditions. The latter is based on a maximum allowed temperature in the bentonite buffer of 100°C (up to 150°C for VDH), including a 20°C safety margin. This should be compared with 80°C for KBS-3 as presented in Plan 92 /5/. In addition to the higher temperature limit, the thermal conductivity of the bentonite was assumed to be 1.5 W/m,K which allows more spent fuel per canister in comparison with 0.75 W/m,K in /5/. For a summary of design parameters including thermal properties see Section 2.5.

In order to facilitate the calculation of the number of canisters, the PWR assemblies were transposed into an equivalent number of BWR assemblies according to the following formula:

1 [PWR] = (470/178 x 41/38) [BWR] = 2.85 [BWR]

- 470/178 represents the difference in uranium content
- 41/38 represents the difference in burnup which affects the residual heat output.

Number of BWR assemblies	33,394
No. of equivalent BWR assemblies from PWR	10,995
Total number of BWR assemblies	44,389

The number of canisters needed for MOX fuel etc. were taken from Plan 92 /5/, modified with respect to the somewhat higher canister heat output allowed.

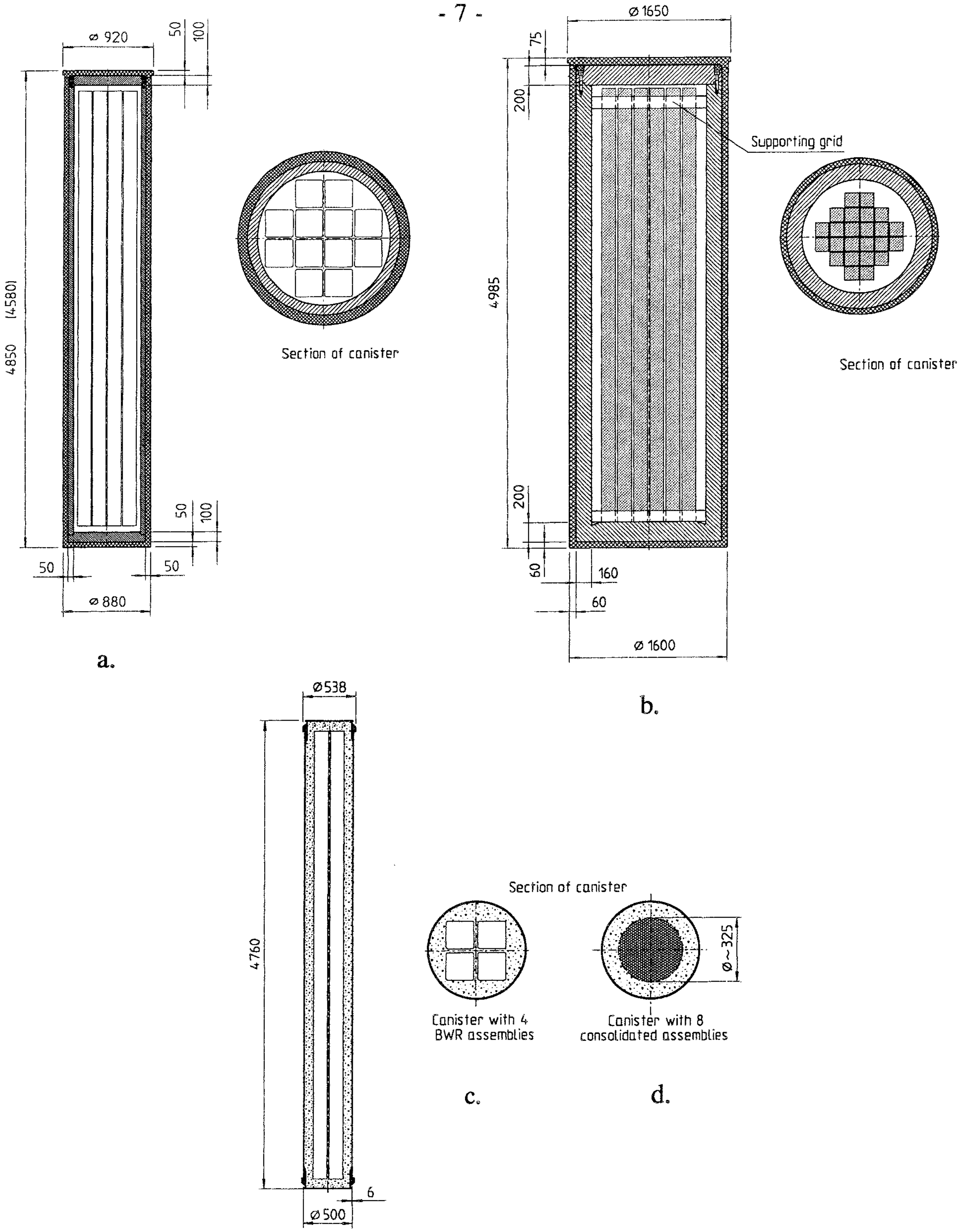


Figure 2-2 Type of canisters used in the study (measures in mm)
Measure within brackets is for BWR fuel assemblies without boxes
a. Cu-Fe canister for 12 BWR (KBS-3, MLH)
b. Cu-Fe canister for 24 BWR (VLH)
c. Titanium canister for 4 intact BWR (VDH_{int})
d. Titanium can. for 8 consolidated BWR (VDH_{cons})

Table 2-2 Number of canisters

System	No. of BWR per canister	Canisters with BWR	Canisters with MOX etc.	Total No. of canisters
KBS-3	12	3,699	46	3,745
MLH	12	3.699	46	3,745
VLH	24	1,850	23	1,873
VDH_{int}	4	11,097	138	11,235
VDH_{cons}	8	5,548	69	5,617

2.4 TIME SCHEDULE

Encapsulation and canister deposition in the repository were assumed to start in January 2020 and continue for a period of 20 years, giving the following time schedule:

Construction	2010-2019
Operation	2020-2039
Sealing/decommissioning	2040-2049

2.5 SUMMARY OF GENERAL DESIGN PARAMETERS

A summary of design parameters including thermal properties is presented in Table 2-3.

Table 2-3 General design parameters

	KBS-3	MLH	VLH	VDH_{int}	VDH_{cons}
Operation time (years)	20	20	20	20	20
Repository depth (m)	500	500	500	2,000-4,000	2,000-4,000
Access to the repository level	Ramp	Ramp	Ramp	-	-
Spacing of deposition drifts/holes¹⁾ (m)	25	25	100	500	500
Spacing of canisters (m)	6.0	5.0	5.9	5.4	5.4
Canister dimensions (dia x length) (m)	0.88x4.58	0.88x4.58	1.6x4.99	0.5x4.4	0.5x4.4
Diameter of deposition drifts/holes²⁾ (m)	1.6	1.6	2.4	0.8	0.8
Typical length of deposition drifts (m)	250	250	4,500	-	-
Type of canister	Cu-Fe	Cu-Fe	Cu-Fe	Titanium	Titanium
No. of BWR per canister	12	12	24	4	8
No. of canisters	3,745	3,745	1,873	11,235	5,617
No. of canister positions³⁾	4,120	4,120	2,285	14,040	7,020
No. of deposition drifts/holes⁴⁾	3,745	-	3	-	-
Initial heat generation per BWR (W)	123	123	123	123	123
Max. allowed temp. in bentonite buffer (°C)	100	100	100	120	150
Thermal conductivity of bentonite (W/m,K)	1.5	1.5	1.5	1.5	1.5

Legend

1) Deposition drifts for KBS-3, MLH and VLH
Deposition holes for VDH

2) Deposition drifts for MLH and VLH
Deposition holes for KBS-3 and VDH

3) Including addition due to not used canister positions:
+ 10% for KBS-3 and MLH
+ 22% for VLH (10% + 450 m per drift as provision for major faults)
+ 25% for VDH

4) Deposition drifts for VLH
Deposition holes for KBS-3

3. DESCRIPTION OF THE ANALYZED REPOSITORY SYSTEMS

3.1 AN OVERVIEW OF THE ANALYZED SYSTEMS

3.1.1 General

Each of the analyzed systems has been studied with respect to the three major sub-systems, viz.

- encapsulation station, ES
- underground repository, SFL
- common facilities, CF

The encapsulation station, ES, is practically identical for those systems where the fuel assemblies are encapsulated in their intact form. The minor differences that can be found are consequences of the processing of different types of canisters. The VDH_{cons} concept, however, introduces an additional process line in ES for the disassembling of fuel bundles.

The underground repository, SFL, is in most alternatives a mined repository consisting of excavated tunnels and deposition holes at a typical depth of 500 m below the surface. The VDH concept is different as the repository consists of a number of vertical deposition holes, drilled from the surface to a depth of about 4000 m.

Common facilities, CF, includes various service facilities and infrastructure for common use by ES and SFL, for instance personnel facilities, workshops, storage areas, etc. Included also are roads and railroads as well as harbour facilities.

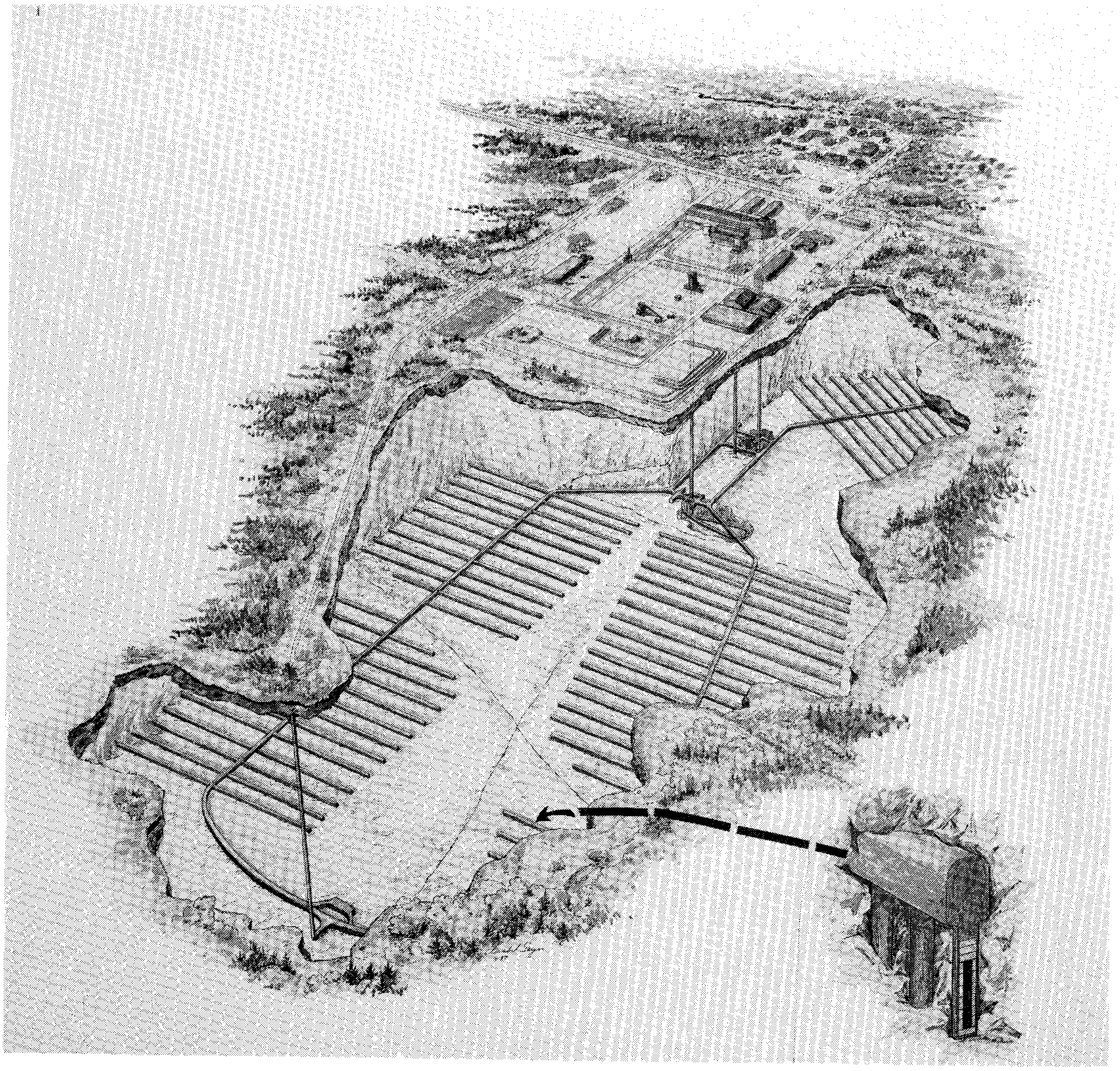


Figure 3-1 KBS-3 System
An overview of the repository site

3.1.2 KBS-3 System

Figure 3-1 illustrates a possible KBS-3 site. The encapsulation station, ES, and a number of service buildings etc. are located within an industrial area of approx. 0.5 km^2. Wastes and materials arrive at the site mainly by railway. The main communication link between the surface and the repository is a ramp (not shown in Figure 3-1) with its entrance situated inside the fenced area.

In the encapsulation station, ES, the spent fuel will be received and encapsulated in copper/steel canisters. ES will also be a receiving station for core components and reactor internals, which are embedded in concrete moulds in a special part of the facility. (The repository for the latter type of waste is not covered by this study.)

The repository, SFL, is located 500 m below ground under the ES and the industrial area. Apart from the ramp, the repository is connected to the surface by a central shaft, equipped with an elevator for transportation of personnel and goods. The supply of air, water, electricity etc. to the repository will also be through this shaft. In the opposite end of the repository there is a combined ventilation shaft and emergency exit. The layout of SFL is shown on the attached Drawing 1.

The canisters are disposed of in a system of parallel 250 m long deposition tunnels connected by transport tunnels. The canisters, surrounded by blocks of compacted bentonite, are placed vertically in separate boreholes drilled from the bottom of the deposition drifts.

3.1.3 Medium Long Holes System, MLH

The MLH alternative can be considered as a variation of the KBS-3 described above. The major difference between the two systems is that the deposition drifts, and the drilled holes in the bottom of those drifts, in the MLH alternative are replaced by a system of 250 m long parallel horizontally drilled holes in which the canisters are placed in a row and surrounded by blocks of compacted bentonite. The principle is illustrated in Figure 3-2.

The deposition holes are assumed to be drilled by means of so called raise boring technique which requires access to both ends of the hole. For that purpose, side tunnels have to be excavated in addition to the central tunnels according to KBS-3. The side tunnels are schematically indicated in Figure 3-2. The layout is shown on Drawing 2.

The change in deposition method, in comparison with KBS-3, will affect the surface activities due to the reduction of excavated rock and backfilling materials that have to be handled during the operation time.

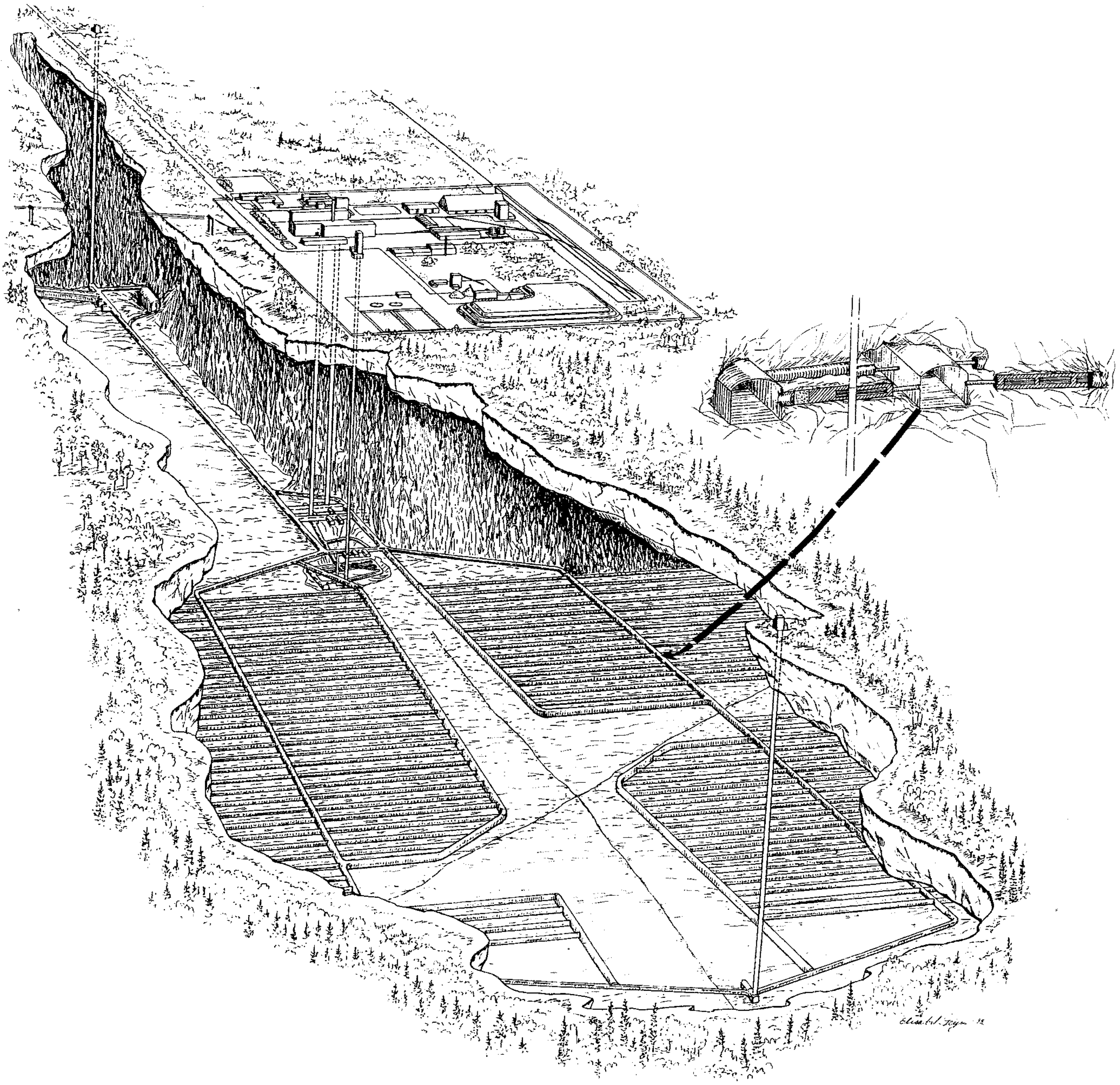
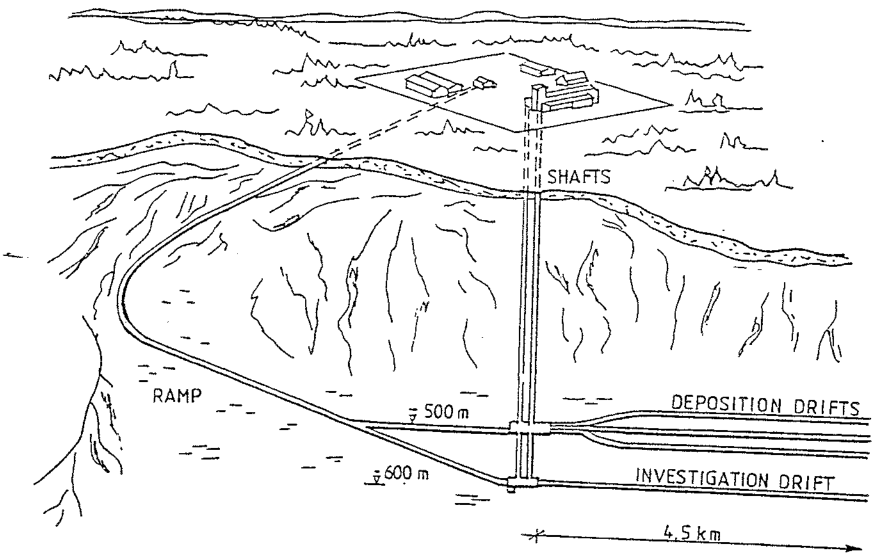
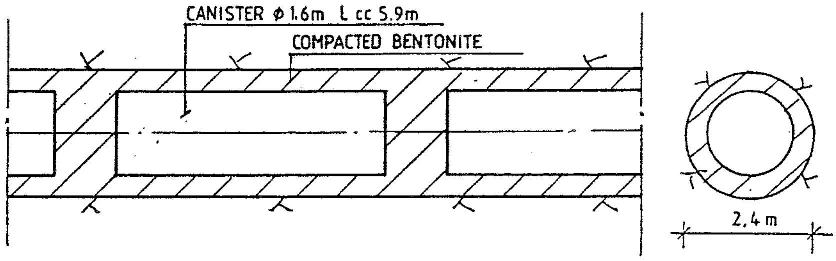


Figure 3-2 Medium Long Holes System, MLH
An overview of the repository site



ARTISTS VIEW OF A VLH REPOSITORY



CANISTER SURROUNDED BY COMPACTED BENTONITE IN THE DEPOSITION DRIFT

Figure 3-3 General view of the Very Long Holes System, VLH /6/

3.1.4 Very Long Holes System, VLH

The major differences between VLH and MLH relate to the canister size and type, and to the dimensions of the deposition holes, see Figure 3-3. In both alternatives the canisters are placed in horizontally drilled holes and surrounded by blocks of compacted bentonite. However, in the VLH alternative, the holes are bored to a substantial length by TBM equipment (Tunnel Boring Machine) and subsequently excavated to a larger diameter. Three deposition drifts will be bored, each with a length of approx. 4 500 m. Furthermore, an investigation drift of the same length will be bored about 100 m below the deposition drifts. Reference is made to Drawing 3 for a description of the main layout.

The investigation tunnel will be constructed prior to the deposition tunnels and from there investigations will be made with the purpose of deciding the routing of the respective deposition drift.

3.1.5 Very Deep Holes System, VDH

The VDH system is in principle different from the other analyzed systems.

The final repository consists of a number of very deep boreholes, drilled from the surface at some distance from each other which prevents thermal and hydraulic interaction between boreholes (approx. 500 m). The canisters are placed on top of each other in the lower part of the borehole, at a depth range between 4 000 to 2 000 m. The upper part of the borehole is then sealed with a system of bentonite and concrete plugs. All work is carried out from the ground surface.

The canister is relatively small and made of titanium. As mentioned above, the VDH system was also studied for a variation where the spent fuel assemblies are consolidated prior to encapsulation.

At the location of each borehole, a drilling site has to be established and all the drilling sites have to be connected to a central area by means of an extensive road net. The central area will have about the same function as the industrial area for the other systems. The encapsulation station and various common facilities will be located there.

To facilitate the comparison of costs, in spite of the many differences between VDH and the other systems, the following distinctions were made:

- CF includes transport facilities and central area
- SFL includes local road net, drilling sites, boreholes, canister deposition and sealing

The schematic layout which has formed the basis for the cost calculations is shown on Drawing 4. The overall system includes 38 boreholes for the alternative with intact and 19 boreholes for the alternative with consolidated fuel assemblies.

3.2 COMMON FACILITIES - CF

3.2.1 KBS-3 System

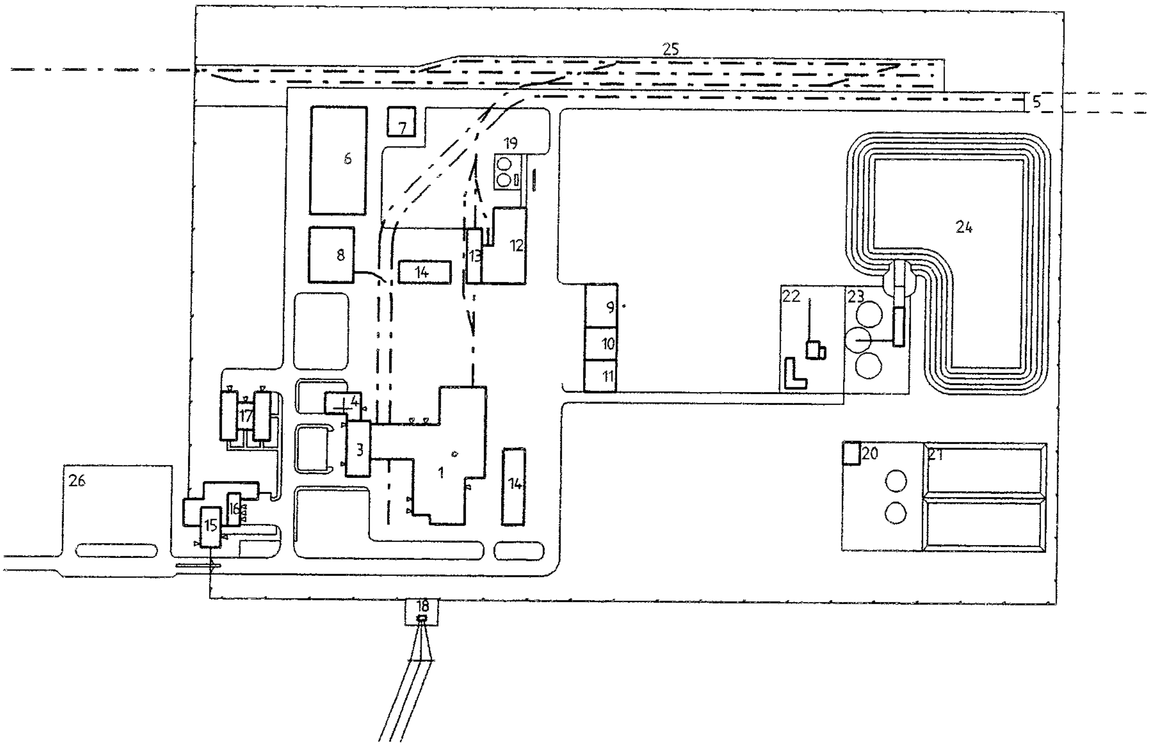
The sub-system Common Facilities, CF, includes the following main groups of facilities:

- Infrastructure including access road and railway and a harbour facility
- Service facilities within the industrial area located at the repository site
- Accommodation facilities located in the vicinity of the site

The spent fuel in transport casks, coming from CLAB, is transported by ship to the nearest available harbour that can be considered suitable for this type of transport. Certain improvements of the navigation channel and the quay area were included in the study as well as a separate ro/ro quay, harbour apron, guard house, etc. From the harbour, the casks are transported to SFL by rail. It was assumed that 50 km of railway will have to be built and rolling stock acquired, i.e. locomotives and specially-built waggons.

The industrial area is a fenced area approximately of 800 by 500 m. Apart from ES, which is the dominant building, there will be personnel facilities, goods reception station, workshops, heating plant, vehicle service building, concrete plant, storage and handling plant for bentonite and sand, water supply and sewerage, etc. The type and number of facilities are about the same as in Plan 92 /5/, the exceptions being that there will be a ramp connection to the underground area, the shafts connection being limited to an elevator for personnel and lighter goods. The layout of the station site is illustrated in Figure 3-4.

Facilities for the handling of buffer and sealing materials include the functions described in the following. Bentonite will be stored indoors along with the sand used in the bentonite/sand mixture for the sealing of drifts and rock caverns. Storage capacity is equivalent to approximately one year's operation (during the deposition phase). It is assumed that the material will be transported to the site by rail. Some of the bentonite is compacted in a high-pressure press and moulded into blocks for filling out the deposition holes around the copper/steel canisters or for other purposes, e.g. plugging of tunnels and shafts. The remaining bentonite is used in the sand/bentonite mixture (85/15). Mixing is carried out above ground and the material is packed into containers and taken down to the repository level via the ramp.



1	Encapsulation plant, ES
3	Administration building
4	Service building for central shaft
5	Ramp to underground repository
6	Sand storage and mixing plant
7	Silos for bentonite
8	Plant for moulding of bentonite blocks
9	Heating plant
10	Water treatment and fire-fighting water reservoir and pumps
11	Workshop
12	Vehicle workshop and transport depot
13	Hall for defrosting and cleaning of cask waggons
14	Store house
15	Entrance and information building
16	Fire station
17	Canteen and first aid
18	Switch gear plant 220/10 kV
19	Tank farm for fuel and heating oil
20	Sewage plant
21	Settling ponds
22	Concrete plant
23	Rock crusher and sorting plant
24	Rock pile
25	Shunting yard
26	Parking

Figure 3-4 Layout of the SFL station site, KBS-3

(It should be pointed out that all costs related to the handling of buffer and sealing materials are accounted for under SFL.)

The operating staff for the common facilities is estimated to be about 150 persons, including the administrative personnel for the SFL-ES site.

After completed deposition, all facilities will be dismantled and the site will be restored as close to the original state as possible. Radioactive decommissioning waste, primarily from ES, will be placed in rock vaults. All activities are estimated to be completed by the year 2049.

3.2.2 Medium Long Holes System, MLH

The common facilities are mainly the same as for KBS-3. However, the drift excavation and the handling of sand/bentonite during the operation phase are excluded which will affect the transport needs and storage capacities and also the extent of the fenced industrial area.

3.2.3 Very Long Holes System, VLH

The common facilities are the same as for MLH apart from a certain upgrading of the bentonite handling equipment due to the increased consumption rate of compacted bentonite.

3.2.4 Very Deep Holes System, VDH

The common facilities for VDH, contrary to the other alternatives, will not include any facilities or equipment that are related to underground works. The cost calculations are based on the KBS-3 site with a number of items excluded or reduced such as sand storage, underground services, rock dump, etc.

3.3 ENCAPSULATION STATION - ES

3.3.1 KBS-3 and Medium Long Holes System MLH

The spent fuel will be received and encapsulated in copper/steel canisters in the encapsulation station, ES, with an encapsulation rate of about one canister/day.

ES will also constitute a receiving station for core components and reactor internals, which are embedded in concrete moulds in a special part of the facility. A large portion of these core components consists of fuel boxes that are transported together with the fuel.

The layout of the encapsulation station is based on available information regarding main functions, rules and regulations, system and process equipment, personnel requirements, etc. Figure 3-5 shows an overview of the encapsulation station.

The encapsulation station is essentially the same as in Plan 92 /5/, the exception being that no lead equipment will be required (the canisters

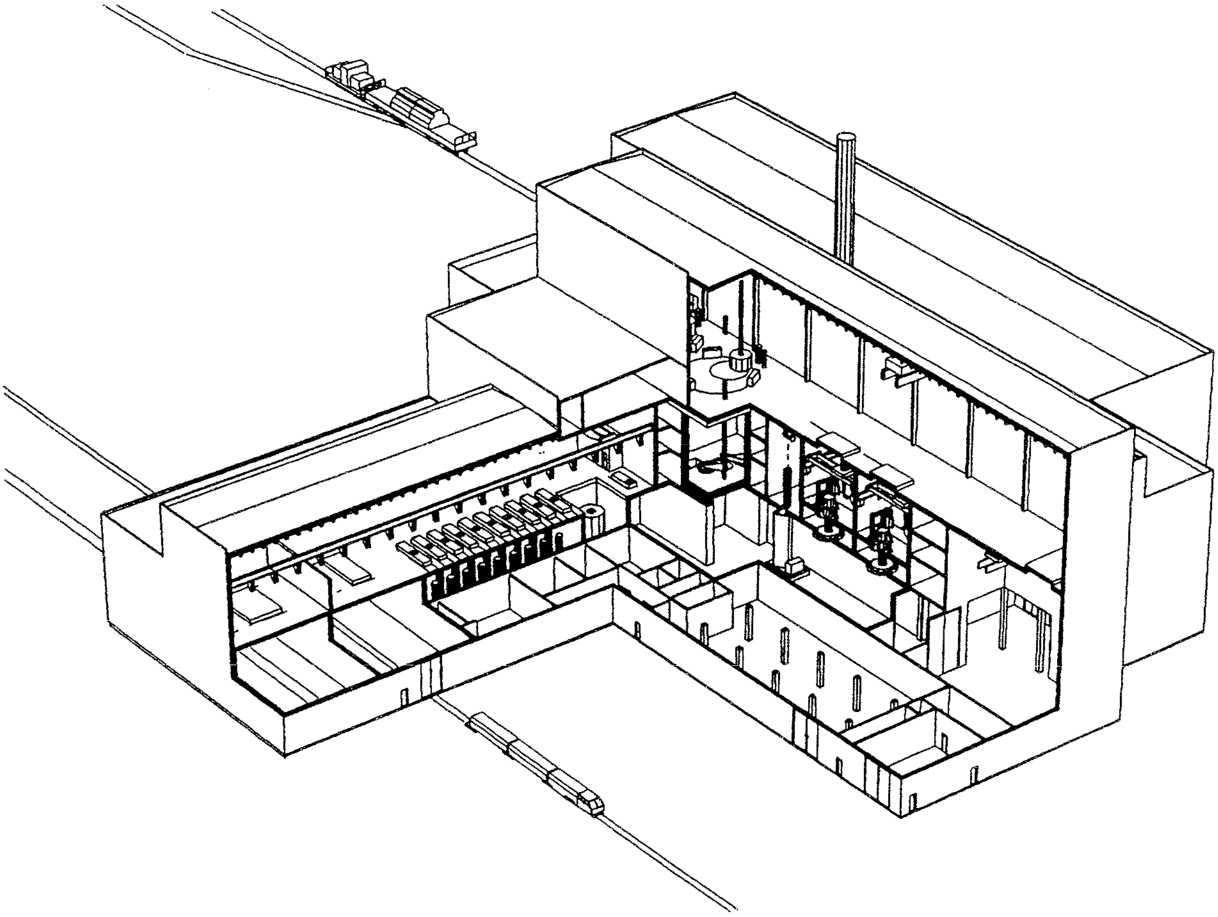


Figure 3-5 Encapsulation Station, Systems KBS-3, MLH and, in principle, VLH

will not be filled with lead) and that the transport of the canisters to the repository level will be made by a railbound vehicle via the ramp. In Plan 92 the transport is assumed to be carried out by a waste elevator directly from the encapsulation station.

The building volume is 165 000 m^3 or approx. 90% of Plan 92, and the maximum length of the building 140 m.

An adjacent building (not shown in Figure 3-5) houses personnel and office quarters as well as a superstructure (head-frame) and service systems for the central shaft down to the repository.

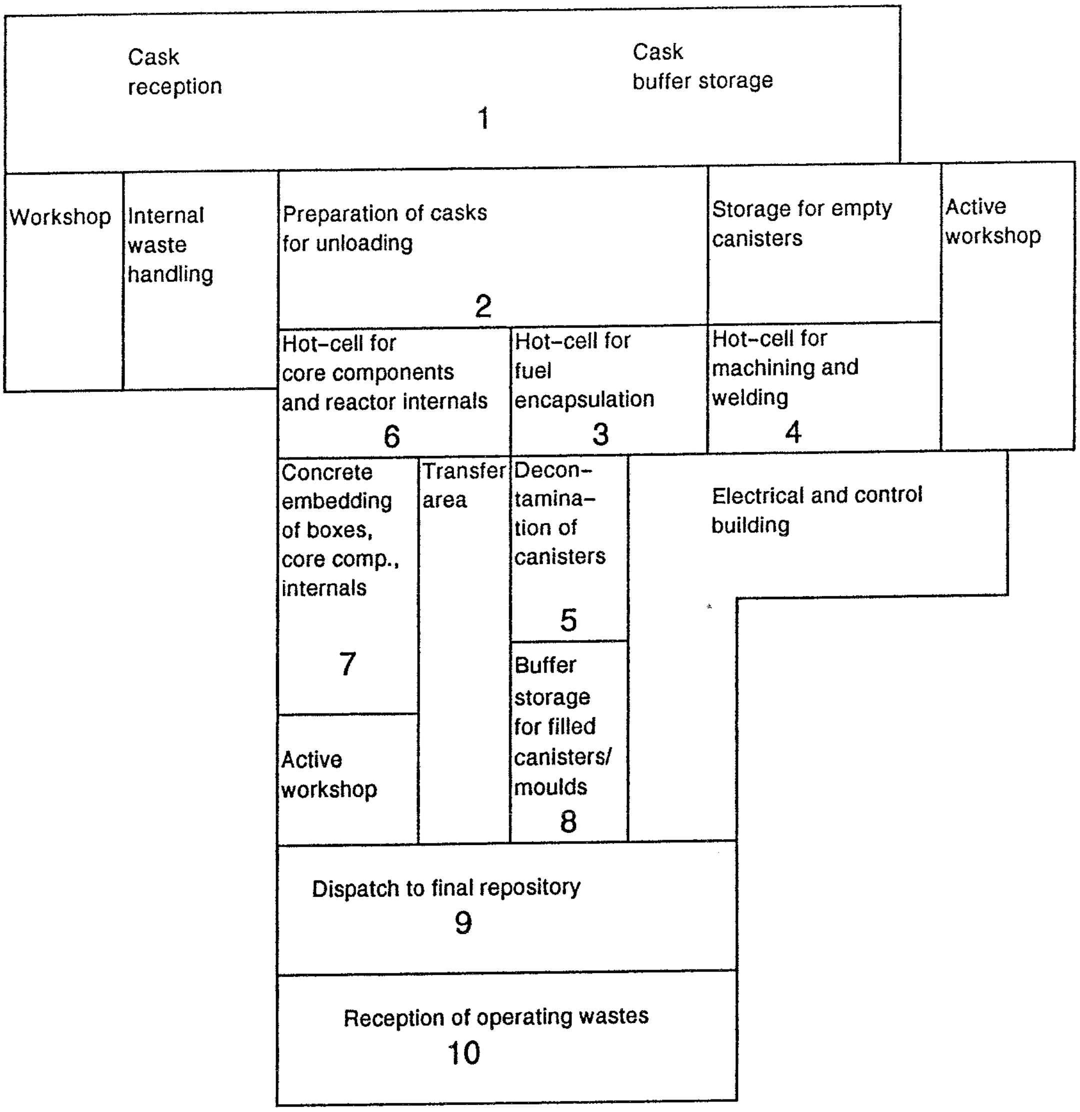


Figure 3-6 Key-plan for the Encapsulation Station

The ES building can be divided functionally according to the key-plan in Figure 3-6. Reception and encapsulation of fuel takes place in functional areas 1-5. Buffer store for filled canisters is located to area 8 and the loading onto transport waggons for transfer down to the repository is carried out in area 9.

Encapsulation of core components and reactor internals is carried out in area 6 and 7 and buffer storing of the filled concrete moulds is done in area 8. The dispatch of the moulds follows the same route as the fuel canisters. Operational wastes from other facilities are received in area 10 where the waste is loaded into suitable shielded transport containers for transfer down to the repository.

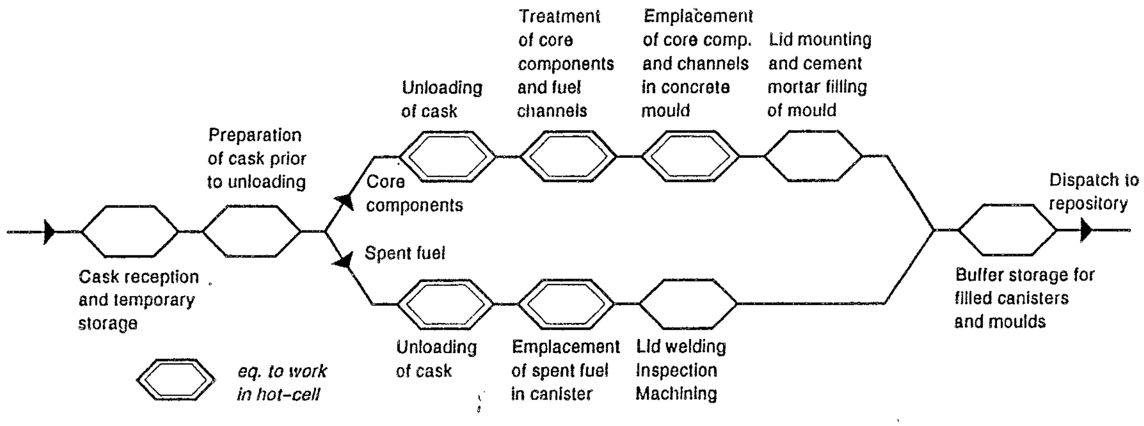


Figure 3-7 Work sequence in the Encapsulation Station Systems KBS-3, MLH and VLH

The handling procedure for encapsulation of spent fuel and core components is illustrated by the flow diagram in Figure 3-7.

The fuel is assumed to be transported to the encapsulation station by rail in transport casks, each with a capacity of 33 PWR or 74 BWR fuel assemblies. In the Cask Receiving and Storage Area, the casks are unloaded and checked for external damages or contamination and, if necessary, placed in a temporary buffer store. From there, all transportation of the casks is done on load platforms moved by four air bearing elements (air cushion pads). The air cushion transport vehicle is used for all internal transport of casks and canisters with their radiation shield.

In the Cask Preparation Area, the cask is prepared for unloading of the waste. The outer lid is removed and the cask is connected to the hot cell for spent fuel.

The Hot Cell Area is where the fuel elements are removed from the cask and placed in racks inside the hot cell or directly into the canister. The canister is connected to the hot cell in the same way as the fuel cask. The inner steel canister lid will be protected from contamination by the use of a lid adapter. The fuel assemblies are placed in the canister by means of a telescopic pole crane. The fuel channels (boxes) of the BWR assemblies are left in the transport cask for later encapsulation in concrete moulds.

In the Machining and Welding Area, the outer copper canister lid is welded to the canister body. For the welding, the electron beam welding method will be applied. There will also be equipment for ultrasonic inspection of the weld joint. In case of defect welding, the work station will be equipped with facilities to make it possible to remove the entire lid and prepare for a new joint. However, if a weld defect should occur, normally that area can be rewelded without any machining work.

After completion of the inspection and approval of the weld the canister is taken to the canister buffer storage area.

The cassettes with core components and reactor internals are transported to the encapsulation station in core components casks. These casks are prepared and connected to a separate hot cell in the same way as the fuel casks. The transport cassettes inside the cask are lifted out by a pole crane and placed into a prefabricated concrete mould which thereafter will be transferred to a concrete filling position outside the cell. The void inside the cassette and mould is filled with a cement mortar. The lid of the mould will be bolted on when the concrete has cured. A contamination check of the surface is done before transferring of the mould to the buffer storage area.

The BWR fuel channels, separated from the fuel as mentioned above, will be handled in the same way. Typically, a concrete mould can hold 49 fuel channels.

The total staff during the operation period has been estimated to be about 70 persons.

3.3.2 Very Long Holes System, VLH

The functions of the encapsulation station for the VLH system are identical with the KBS-3/MLH alternative. Some modifications must, however, be assumed due to the different size of the canister. Since a VLH canister holds twice as much fuel as a KBS-3 canister, an encapsulation rate of one canister every two days gives the same operation time as for the KBS-3 system.

The total staff is about the same as for the KBS-3 system.

3.3.3 Very Deep Holes System, VDH

The typical feature of the VDH system, with respect to ES, is that the canisters are relatively small, diameter only 0.5 m, and made of titanium. Furthermore, an alternative with consolidated fuel is included in the study.

One canister can only hold 4 intact or 8 consolidated BWR assemblies. The void inside the canister will be filled with concrete. The encapsulation rate needed to maintain the same operation time as for the other systems is three canisters per day for intact assemblies and per two days for consolidated assemblies. The work sequences are illustrated by the flow diagrams in Figure 3-8 and Figure 3-9.

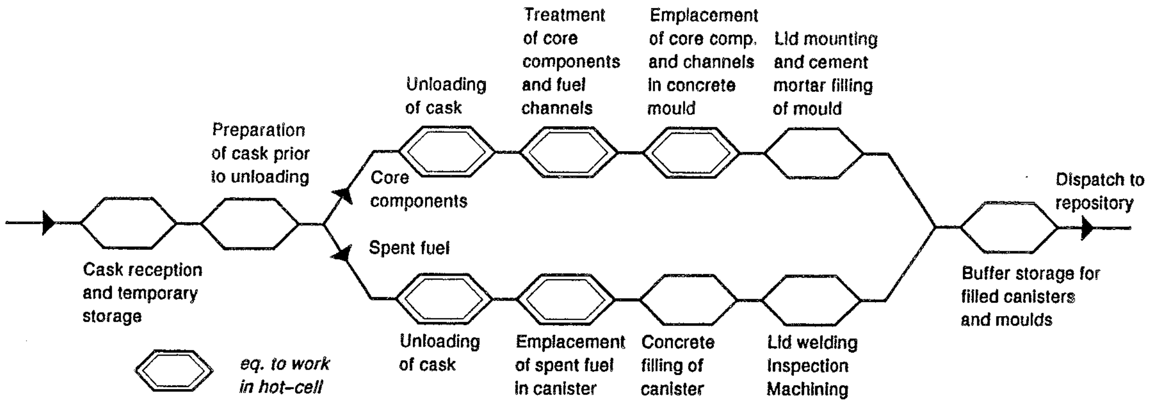


Figure 3-8 Work sequence in the Encapsulation Station, VDH_{int} (canisters with intact fuel assemblies.)

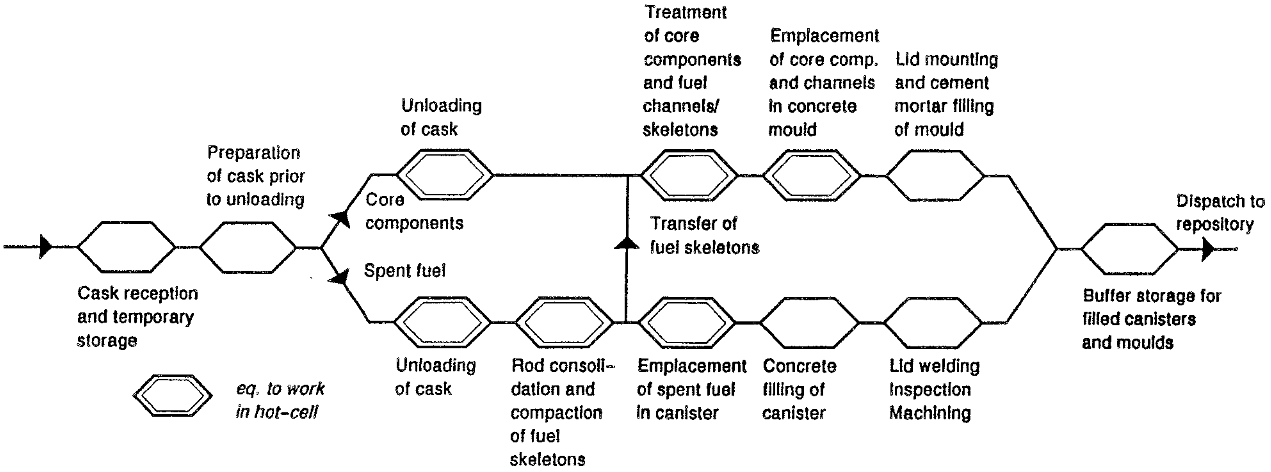


Figure 3-9 Work sequence in the Encapsulation Station, VDH_{cons} (canisters with consolidated fuel assemblies.)

The layout and operation of the VDH system has not been studied to the same extent as the KBS-3/MLH and VLH systems. The functional requirements, handling, system and layout for an encapsulation station were based on information from a German study of rod consolidation and compaction of the skeletons, i.e. the load bearing parts or non fuel parts of the assemblies.

For the VDH_{int} system, the number of VDH canisters with intact fuel assemblies will be three times as many as for the KBS-3/MLH system. The concrete filling of the canisters will be carried out in a separate cell adjacent to the fuel loading cell. The welding of the titanium is done at a separate welding station after the concrete has cured.

For the VDH_{cons} system, the number of VDH canisters with consolidated fuel assemblies will be at least 1.5 times as many as for the KBS-3/MLH system. Additional waste is accumulated as the skeletons of the fuel assemblies must be compacted and conditioned separately. This alternative will require additional handling systems and hot-cell complex for rod consolidation and compaction of skeletons.

The cost for the VDH_{cons} system will increase due to the additional equipment needed for the fuel preparation. It has been assumed that the equipment cost increases by 50% in comparison with the VDH_{int} system. The building volume increases by 30%. The VDH_{int} system was in this respect assumed to be similar to the KBS-3 system.

The staff needed is estimated to be 75 persons for VDH_{int} and 85 for VDH_{cons}, i.e. somewhat higher than for the KBS-3 system.

3.4 UNDERGROUND REPOSITORY - SFL

3.4.1 KBS-3 System

Reference is made to Drawing 1 for a description of the repository layout and the mode of canister deposition. The layout, as shown on the drawing, is schematical in the sense that the geometry of the underground area was drawn without consideration to any site specific data. With respect to quantities, provisions are made for excess rock excavations by an additional 10% of deposition drifts and a substantial distance between the underground central area, which is assumed to be located under the ES, and the deposition area. In principle, this approach to the layout of the repository applies to the other systems as well.

The layout and the operating activities of the underground repository for system KBS-3 are essentially the same as for Plan 92 /5/. There are, however, differences that significantly affect the overall cost and therefore it was deemed necessary to carry out new cost calculations based on updated quantities. Two major differences should be pointed out.

The number of canisters to be deposited is only about 85% of Plan 92 and, together with a less conservative approach with respect to thermal conditions, this will substantially reduce the deposition area needed.

Access to the repository level is accomplished by a combination of ramp and shafts whereas in Plan 92 only shafts are considered. The ramp alternative has not yet been studied in detail. For the purpose of establishing a suitable basis for the cost comparison in this study, certain design and equipment characteristics were chosen. However, the significance of the ramp design, in this context, is low as the same system is applied to all the systems except VDH.

Construction

The ramp is assumed to be full-face bored by means of TBM technique (Tunnel Boring Machine). An example of this technique in Sweden is the Klippen tunnel (hydro power project) where the first 100 m were bored at an inclination of 1:10 downwards. In the present study, a ramp with an inclination of 1:7 was considered. Transportation works during the initial construction phase, including the rock haulage, is carried out by a railbound system similar to that used at Klippen.

After completion of the TBM work, the ramp installations will be rebuilt in order to accommodate a traffic lane also for rubber-tyred vehicles and an emergency escape route. It should be pointed out that the options are many with respect to the ramp design, including even a second TBM tunnel (in which case the diameters of both tunnels will be smaller), and further studies have to be made in order to reach the most feasible solution.

When the ramp has been completed, the central area and transport tunnels are excavated by means of normal profile blasting technique. The shafts are excavated with conventional raise boring technique. The rock haulage at repository level will be carried out by conventional railbound equipment, and the shifting of the rock masses to the special ramp climbing train will be carried out at a transfer station, which also provides buffer storing capacity.

The deposition tunnels will be excavated by means of careful blasting as the deposition proceeds, i.e. during the operation phase. The deposition holes for the canisters are drilled from the bottom of the deposition tunnels.

A deposition hole has a diameter of 1.6 m and depth 7.6 m, and the distance between holes 6.0 m. The drilling operation is started by drilling a pilot hole (diameter 150 mm) in the centre of the assumed hole location. Investigations are then carried out from this hole to assess the suitability for deposition with regard to the structure and permeability of the rock. If found suitable, the deposition hole is subsequently drilled by means of inverted raise boring technique. If the location is not found to be suitable, the pilot hole is plugged.

Operation

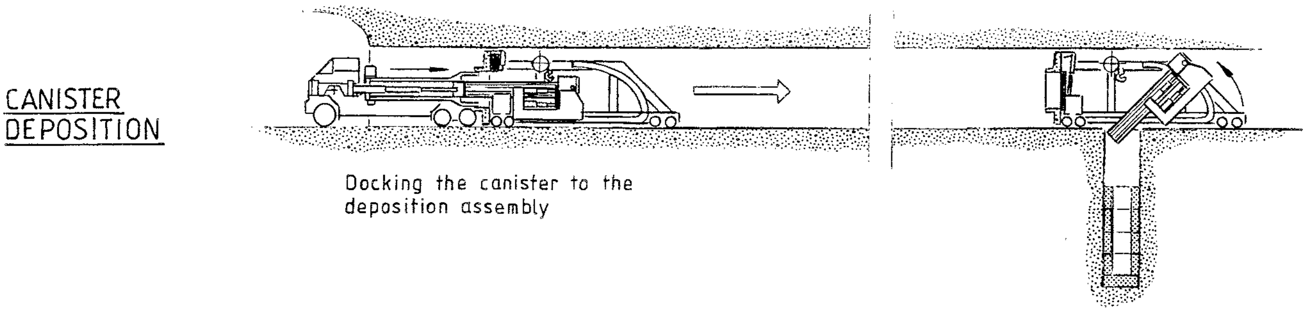
The canisters will be transported down from the encapsulation station in a radiation shielded tube. The transportation in the ramp will be by a train of the same type as in the rock haulage system. From the canister reloading station at the repository level to the entrance of the deposition tunnel further transportation is carried out by means of a diesel driven canister transportation vehicle. The handling inside the deposition tunnel, including the lowering of the canister and bentonite buffer into the deposition hole, is carried out by an electrically driven railbound canister/bentonite deposition vehicle, see Figure 3-10.

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

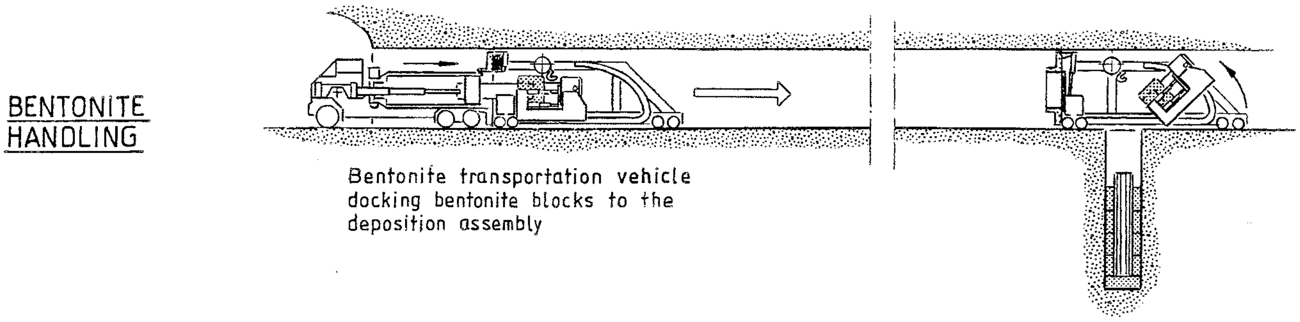
After the canister has been lowered the remaining bentonite buffer is placed in the hole on top of the canister. The hole is then capped with a watertight seal. The seal is allowed to remain in place until all holes in the drift have been finished and backfilling is about to commence.

Backfilling and sealing

When a number of deposition drifts are completed, the work of sealing them begins. The temporary sealing of the holes are removed and the



Docking the canister to the deposition assembly



Bentonite transportation vehicle docking bentonite blocks to the deposition assembly

Figure 3-10 Principles for depositing of canister and placement of bentonite buffer

drifts are filled with a sand/bentonite mix. The drift entrances are sealed off with a temporary steel wall, which will be removed during the final sealing of the repository. After completed depositing of all canisters, the entire facility is sealed with a sand/bentonite mix. In addition, the ramp and shafts are provided with plugs made of compacted bentonite and/or concrete.

Key figures

Rock excavation, total	723 000 m^3
- rock vaults (blasting)	212,000 m^3
- deposition tunnels (blasting)	314,000 m^3
- ramp ø 6.5 m; 3,600 m (TBM boring)	120,000 m^3
- shafts ø 5.0 m; 1,020 m (raise boring)	20,000 m^3
- deposition holes ø 1.6 m; 3,745 x 7.6 = 28,500 m	57,000 m^3
Backfilling, total	734,000 m^3
- bentonite blocks	41,000 m^3
- sand/bentonite mix	693,000 m^3
Personnel	
- operation period	120 persons

3.4.2 Medium Long Holes System, MLH

Reference is made to Drawing 2.

Construction

Rock excavation will be carried out as described above for the KBS-3 system with the exception of the deposition drifts which are horizontally bored.

The deposition drifts have a diameter of 1.6 m. They are bored by horizontal raise boring technique from one tunnel to another. As a first step a pilot hole (diameter 300 mm) is drilled slightly upwards starting from the tunnel that later will accommodate the deposition equipment. By starting from that particular tunnel, the tolerances, with respect to the operation range of the deposition equipment, can be met. Thereafter the hole is reamed to full area with the boring machine placed in the opposite tunnel. The reaming will be stopped a few metres from the tunnel wall, leaving a natural plug at that end of the hole, see Figure 3-2. The length of the drift is limited to 250 m mainly due to deviation allowances and the service life of the reamer head cutters. The horizontal raise boring technique has been proven practical for holes up to 4.0 m in diameter.

The assessment of the routing of deposition drifts can be made in several steps. One step is to core drill along the assumed deposition drift somewhere within its contour. Such a core can give, for instance, information on where to expect discontinuities and hydraulic systems. The cost calculations include provisions for such kind of exploratory drilling as well as for an excess length of the deposition drifts in order to avoid such disturbed areas. The excess length, which is backfilled with compacted bentonite, corresponds to about 10 % extra canister positions.

Operation

The canister transportation from the encapsulation station to the reloading station at the repository level will be done in the same way as in KBS-3. In the MLH system the canister and the bentonite lining should be considered as a unit, emplaced as they are in one uninterrupted work sequence. Therefore the train set is assumed to bring down the canister and the bentonite lining package in one trip.

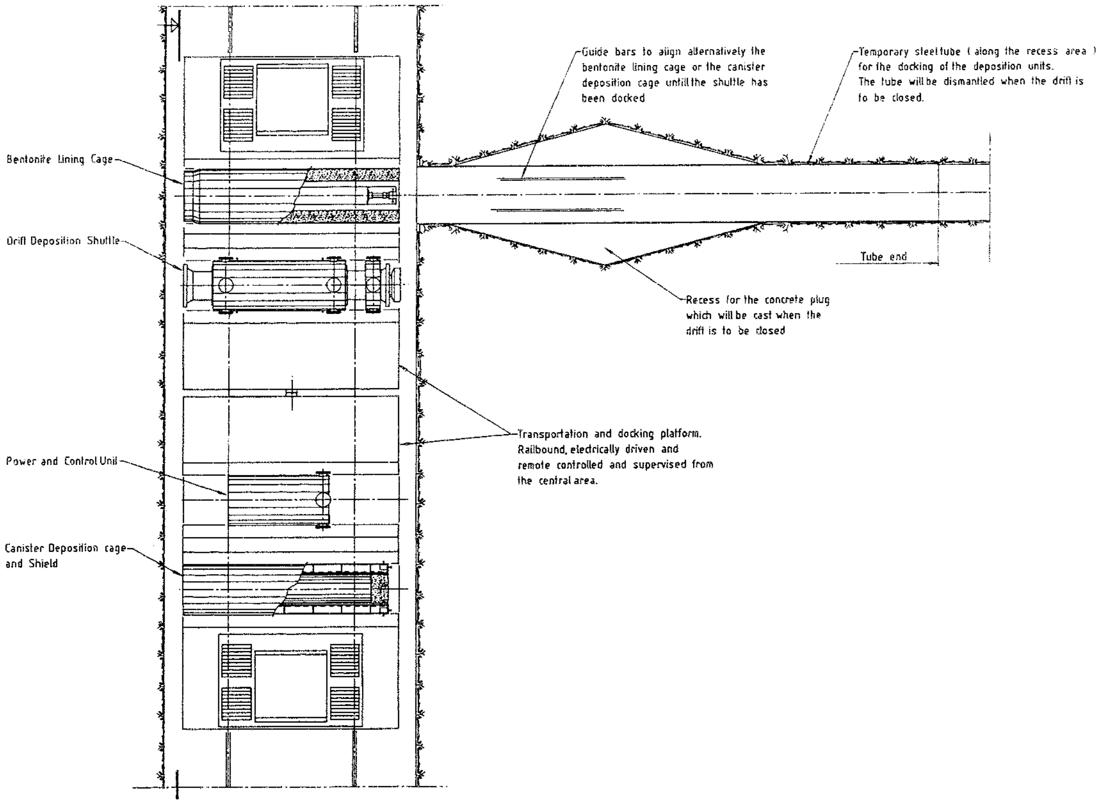


Figure 3-11 Transportation and docking platform in position at the entrance of a deposition drift

At the canister reloading station the canister and the bentonite lining is transferred to deposition cages on a railbound power driven transportation and docking platform, see Figure 3-11. A deposition cage is a steel cylinder designed to hold and carry the bentonite lining package or the canister when pushed into the deposition drift. The bentonite lining package consists of a number of stacked cylinder-shaped compacted bentonite blocks, held together by an inner perforated casing and, temporarily during the emplacement operation, by the bentonite lining cage. The platform also contains a so-called deposition drift shuttle whose function is to propel the cage with its contents into the drift. It operates in the same way as the thrust cylinder of a TBM machine.

Figure 3-12 shows the shuttle and the cages inside the deposition drift for the following two operating steps. In the first step, the bentonite lining package is placed in its position in the hole by means of the shuttle and bentonite lining cage. The shuttle and cage are then withdrawn. Secondly, after a sideways movement of the platform, the canister is inserted into the central hole of the bentonite lining by means of the shuttle and the canister deposition cage. In the same operation, a bentonite plug is left to fill the gap to the next canister.

The equipment and procedures used are described in more detail in /4/.

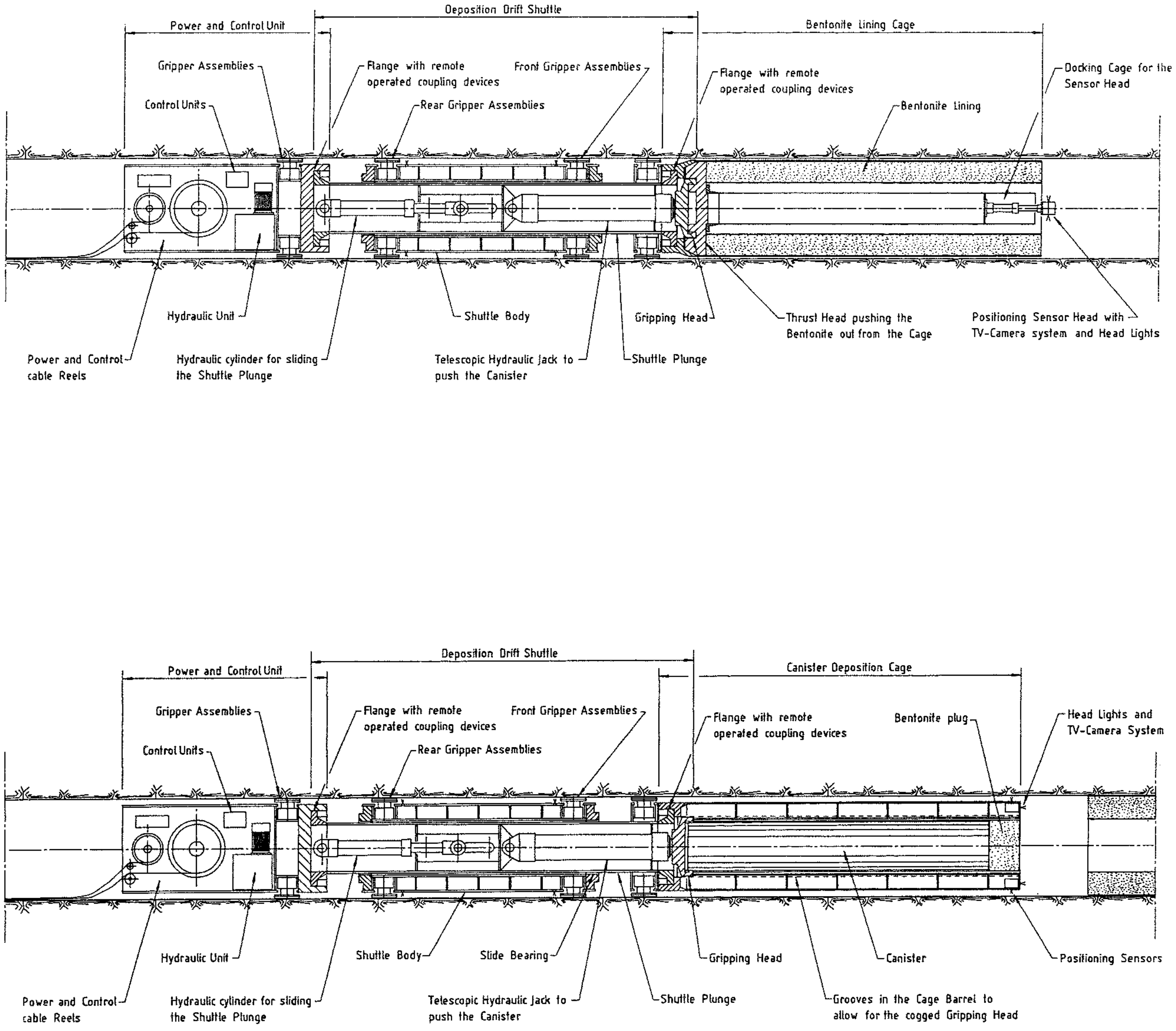


Figure 3-12 Shuttle and deposition cages in operation inside the deposition drift
Upper view: Emplacement of bentonite lining package
Lower view: Emplacement of canister

Backfilling and sealing

When a deposition drift has been completed the entrance is plugged with a cast-in-place concrete plug. Between the concrete plug and the outermost canister, the bentonite plug is made extra long in order to prevent the concrete from interacting with the bentonite closest to the canister.

After the deposition is completed, the entire repository is backfilled with a sand/bentonite mix and the ramp and shafts are plugged as described for KBS-3.

Key figures

Rock excavation, total	533,000 m^3
- rock vaults (blasting)	349,000 m^3
- ramp ø 6.5 m; 3,600 m (TBM boring)	120,000 m^3
- shafts ø 5.0 m; 1,020 m (raise boring)	20,000 m^3
- deposition drifts ø 1.6 m; 88 x 250 (horizontal raise boring) = 22,000 m	44,000 m^3
Backfilling, total	533,000 m^3
- bentonite blocks	34,000 m^3
- sand/bentonite mix	499,000 m^3
Personnel	
- operation period (incl. rock work for deposition holes)	140 persons

3.4.3 Very Long Holes System, VLH

Reference is made to Drawing 3.

The access to the repository level, by ramp and shaft, and the central area is similar to KBS-3 and MLH but from here on the repository is different. The deposition is done in three long TBM bored drifts, diameter 2.4 m. In this study, the drifts are assumed to be parallel at a distance of 100 m. At the entrance opening of each drift there is a rock cavern for the reception of canisters and bentonite and for the transshipment to the deposition vehicles. The three service areas are interconnected by a drift for communication purposes. The length of the deposition drifts will provide for extra canister positions in the same way as in the MLH system.

At the 600 m level, i.e. 100 m below the deposition drifts, an investigation drift with diameter 3.5 m is bored along the assumed routing of the deposition drifts. The ramp and the shaft are extended accordingly in order to reach this lower level.

Construction

Ramp, shaft and other general purpose rock vaults is excavated according to the KBS-3 description above.

The investigation drift and the three deposition drifts are bored using TBM technique. The muck from the deposition drifts is collected at the drift openings and dumped into rock bins under which the haulage waggons are loaded via chutes. Two drifts will be bored simultaneously, requiring two sets of boring equipment.

Operation

Canister transportation from the encapsulation station to the reloading stations at the repository level is carried out in the same way as in KBS-3, however with some modifications, mainly to the rolling stock, due to the much larger canister.

In the service area at the entrance to the deposition drift, the canister is taken out of the transport tube and placed on a canister waggon specially designed to travel inside the drift and place the canister on a bed of bentonite blocks. The canister is then no longer surrounded by

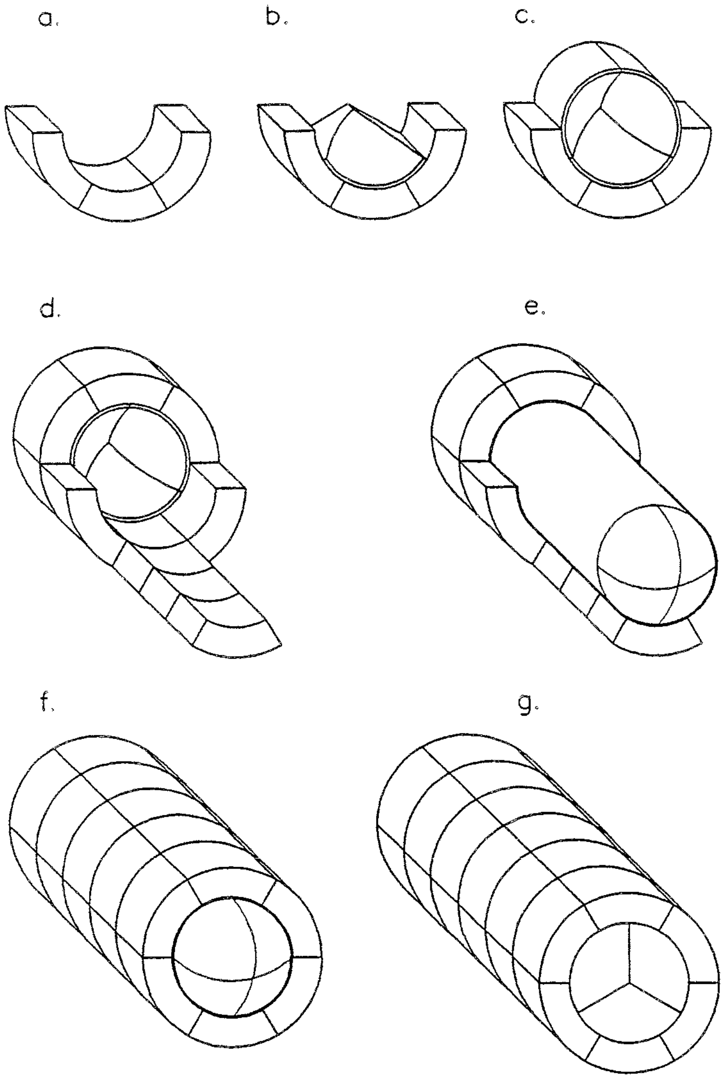


Figure 3-13 Phases of deployment, VLH, assuming a canister design with hemispherical ends /3/

a radiation shield. In a similar way the bentonite blocks are transferred to a bentonite waggon to bring the bentonite to the location of deposition and, in a remote control mode, stack the blocks around the canister.

The emplacement sequence is illustrated in Figure 3-13 for a canister design with hemispherical ends. In Phase 1, the bentonite blocks according to (a-d) in Figure 3-13 are emplaced. The handling is completely remotely controlled and certain movements will probably be automated. In Phase 2, the canister waggon brings the canister to the disposal area and places it on the bottom blocks (e). Finally, in Phase 3, the bentonite waggon installs the rest of the surrounding blocks between the canister and the rock, leaving a flat end to start at in the next disposal sequence (f-g). The bentonite block handling is somewhat less complicated in the case of a canister design with flat ends.

Procedures and equipment are presented further in /3/ and /6/.

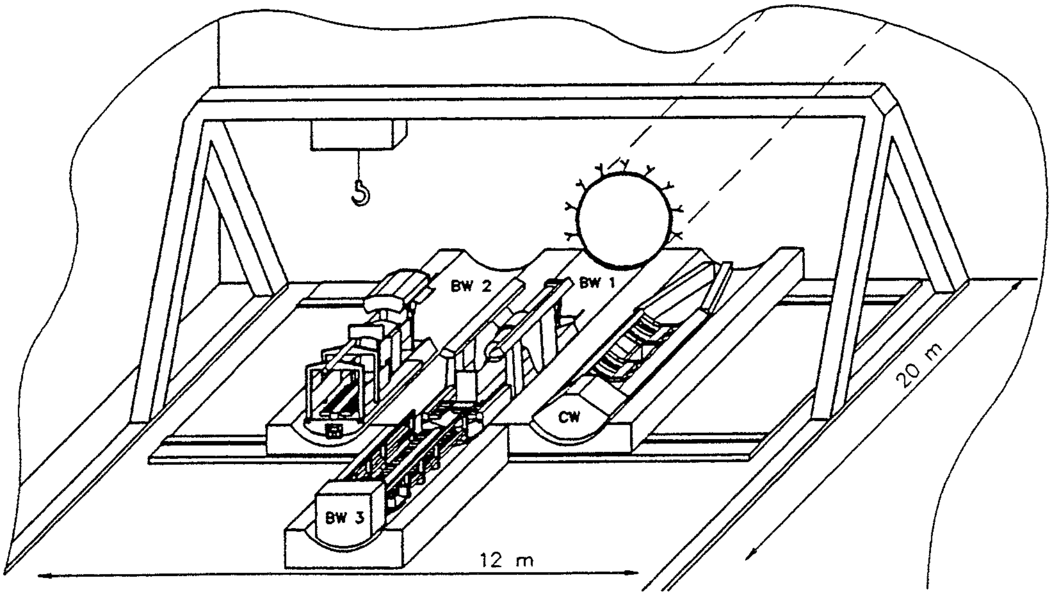


Figure 3-14 Canister reloading station at the entrance to the deposition drift, VLH. CW stands for Canister Waggon and BW for Bentonite Waggon /6/

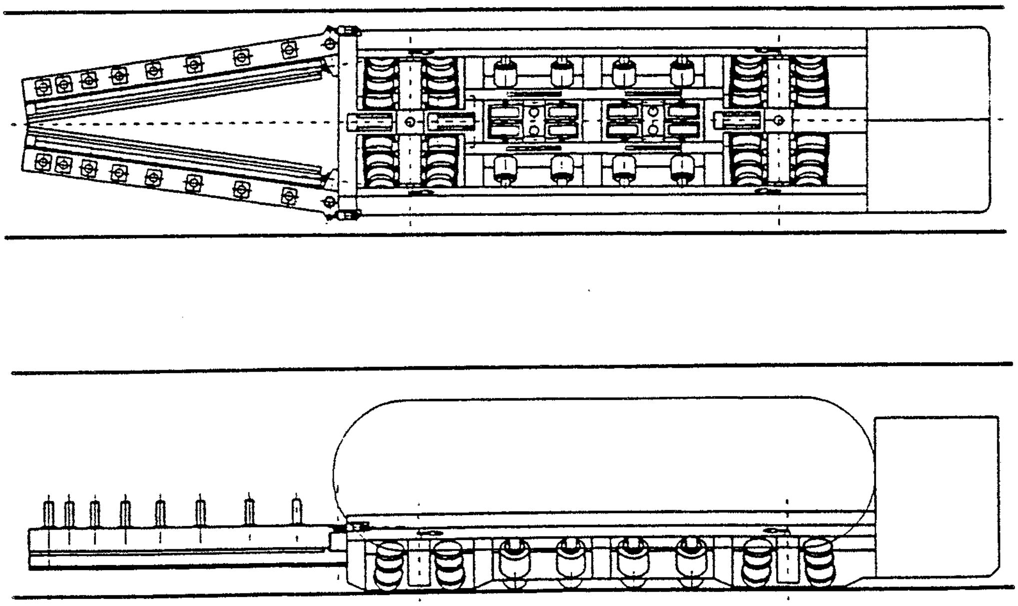


Figure 3-15 Canister Waggon, VLH /6/

The bentonite and canister waggons have wheels which are in direct contact with the drift walls. Thus, no rails are required. A schematic sketch of the service area is presented in Figure 3-14. The principle of the wheelbound canister waggon is shown in Figure 3-15.

Backfilling and sealing

When a deposition drift has been completed, the entrance is plugged with a combined concrete/bentonite plug.

After the depositioning is completed, the entire repository incl. the investigation drift is backfilled with a sand/bentonite mix and the ramp and shaft are plugged as described for KBS-3.

Key figures

Rock excavation, total	332,000 m^3
- rock vaults (blasting)	51,000 m^3
- ramps ø 6.5 m; 4,900 m (TBM boring)	163,000 m^3
- shafts ø 5.0 m; 600 m and ø 2.5 m; 330 m (raise boring)	13,000 m^3
- deposition drifts ø 2.4 m; 3 x 4,500 = 13,500 m (TBM boring)	61,000 m^3
- investigation drift ø 3.5 m; 4,600 m (TBM boring)	44,000 m^3
Backfilling, total	315,000 m^3
- bentonite blocks	44,000 m^3
- sand/bentonite mix	271,000 m^3
Personnel	
- operation period (incl. TBM work for the third dep. tunnel)	150 persons

3.4.4 Very Deep Holes System, VDH

Reference is made to Drawing 4.

Alternative VDH is described in more detail in /2/. The principle layout of a borehole including deposition and plug zones is presented in Figure 3-16. Those parts of the borehole which pass highly fractured, water bearing zones will not be used for deposition of waste but will be backfilled with bentonite only.

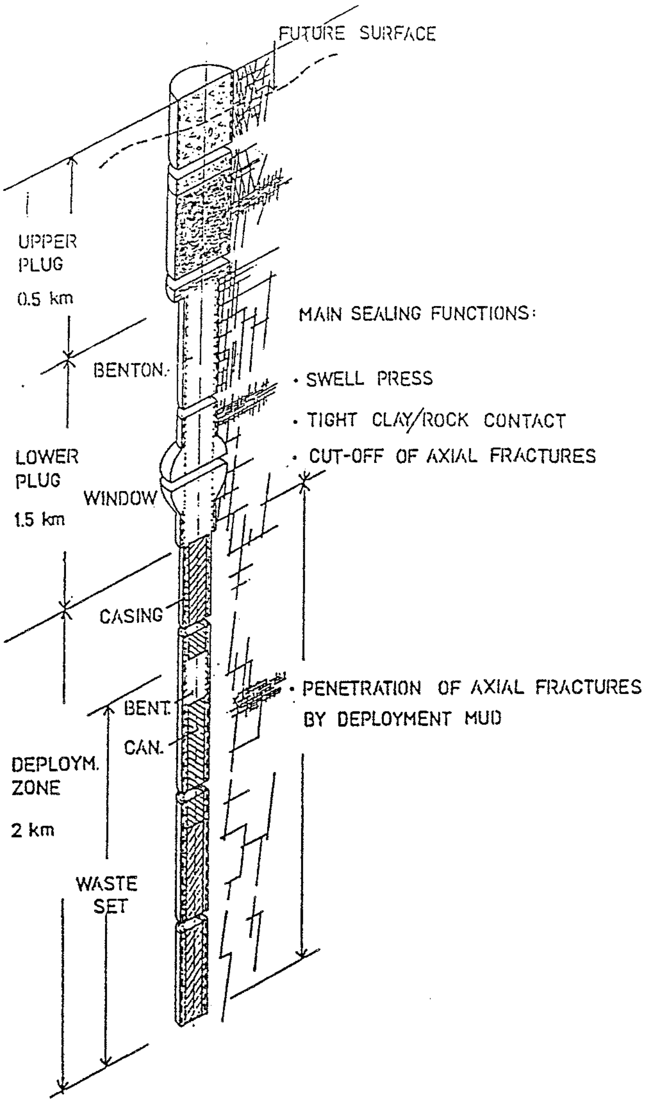


Figure 3-16 The VDH System /2/

The cost for the drilling operation and for the canister emplacement and sealing is taken from /2/ without any further elaboration apart from minor adjustments with respect to actual price level, time schedule, etc.

Construction

For each deposition hole a drilling site has to be established, in total 38 sites for the VDH_{int} system and 19 sites for VDH_{cons}. A local road net connecting all sites to the central area has to be built as well as water distribution system and communication lines.

The technique for drilling of deposition holes is assumed to be conventional oil drilling technique, slightly modified with respect to experiences gained at the deep borehole project at Gravberg in Sweden.

The drilling is assumed to be carried out by rotary drilling and with a light bentonite mud. The diameter of the hole in the deposition zone is assumed to be 0.8 m, which is the largest diameter that today is considered feasible down to a depth of 4 km.

Operation

Prior to emplacement of the canisters, the light bentonite drilling mud in the hole is replaced by a thicker bentonite slurry. The emplacement is carried out with the drilling rig. One or several canisters with intermediate bentonite plugs are taken down to deposition level through the casing. Sensors indicate when the canister has reached its position in the hole. The bentonite around the deployed canister will absorb water and expand, thereby keeping the canister in position.

Backfilling and sealing

The upper approx. 2,000 m of the hole is plugged in order to stop water transportation axially along and within the borehole. Two plug zones can be identified.

A lower plug, between approx. 500 m and 2,000 m depth, consisting of compacted bentonite blocks within the slotted casing. The blocks are forced down into the thick bentonite slurry. An upper plug from 500 m depth to the ground surface, consisting of asphalt covered by concrete.

Key figures

VDH_{int} (non-consolidated fuel elements)

Rock excavation	
- deposition holes (rotary drilling)	160,000 m^3
ø 0.8 m; 38 x 2,000 = 76,000 m	
ø 1.4 m; 38 x 2,000 = 76,000 m	
Backfilling	
- bentonite blocks	154,000 m^3

VDH_{cons} (consolidated fuel elements)

Rock excavation	
- deposition holes (rotary drilling)	80,000 m^3
ø 0.8 m; 19 x 2,000 = 38,000 m	
ø 1.4 m; 19 x 2,000 = 38,000 m	
Backfilling	
- bentonite blocks	77,000 m^3

4. COSTS

4.1 DESCRIPTION OF COST CALCULATION METHOD

For the common facilities, CF, and encapsulation station, ES,the costs were taken from SFL-ES GA and ES according to Plan 92 /5/ with minor adjustments due to differences in technology or operational environment.

For the final repository, SFL, the cost estimates were based on updated layouts and quantity specifications. Where applicable information was gathered from the cost calculations for SFL 2 in Plan 92. As mentioned above, the VDH system was in this respect treated differently. Information regarding costs was collected from /2/ and modified to a certain extent with respect to price level, time schedule etc.

Generally the costs have been calculated at the resource level, mainly material and labour costs, with an ordinary percentage adjustment regarding joint costs, contractor's fee, installation etc. Some of the costs have been calculated as a percentage, e.g. Owner's cost, design and decommissioning. Uncertainties in the cost estimates have been compensated for by normal contingency adjustments and, in addition, a particular overall adjustment covering uncertainties with respect to unforeseen events of technical, economic or regulatory implications. The following overall adjustments, corresponding to those applied in Plan 92, are accounted for and included in the cost estimates:

- Common Facilities	20 %
- Encapsulation Station	20 %
- Repository	15 %

The cost estimates for the various facilities are accounted for as cost per category:

Investment:	Capital costs including design, construction, supervision and all other costs related to the construction phase. Also including reinvestments, i.e. replacement of systems in the case of extensive service lifetime. For SFL, however, the capital costs for deposition drifts and holes, with the exception of end plugging of drifts, are referred to Operation as this work is to a major extent related to the operation phase, i.e. 2020-2039. Interest costs during construction are not included.
Operation:	Operation and maintenance costs, personnel as well as materials, power etc. Capital costs for deposition drifts and holes with the exception of end plugging of drifts. One major item regarding ES is the cost for canisters, i.e. empty canisters as delivered to the plant.
Sealing:	Only relevant to SFL. Backfilling of rock caverns with a mixture of sand and bentonite and end plugging of deposition drifts, ramp and shafts.
Decommissioning:	Decommissioning of buildings and equipment and reclamation of used land areas. The costs are calculated as a percentage on building investments (7 %) and equipment costs (8 %).
Overall adjustment:	See above.

All costs are presented in SEK (Swedish kronor) and with price level January 1992.

For the comparison between the different systems, as presented in Section 4.3, the costs were discounted to January 1992 based on a real interest rate of 2.5 %.

4.2 SUMMARY OF COSTS FOR EACH SYSTEM

KBS-3 System

Table 4-1 Costs per facility and cost category (MSEK), KBS-3 Price level January 1992.

Facility	Cost category		Sum
Common Facilities CF	Investment Operation Decommissioning Overall adj. 20%	3 173 1 108 210 898	5 389
Encapsulation Station ES	Investment Operation Decommissioning Overall adj. 20%	2 236 3 243 175 1 131	6 785
Final Repository SFL	Investment Operation Sealing Decommissioning Overall adj. 15%	1 038 1 775 1 907 18 711	5 449
Total			17 623

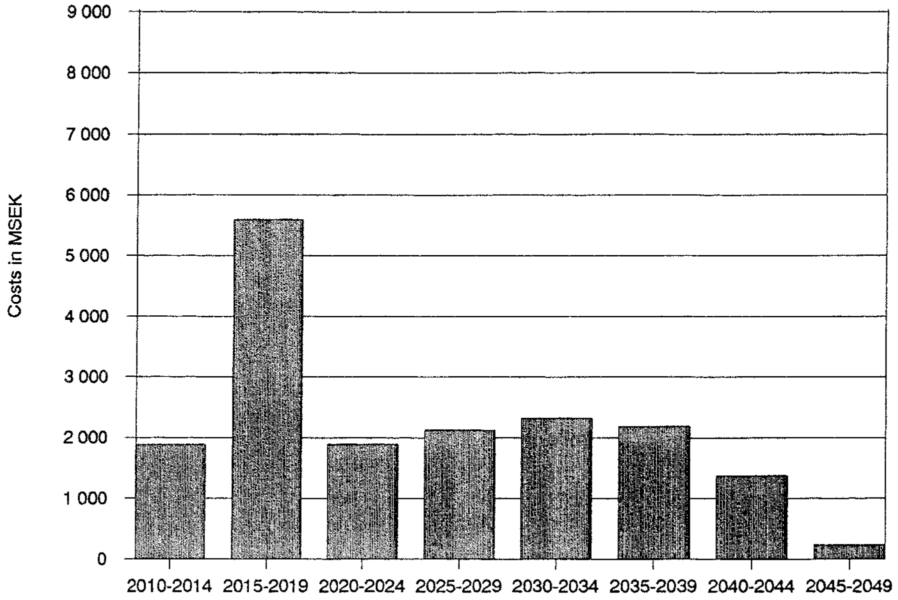


Figure 4-1 Total costs distributed over time, KBS-3 Price level January 1992

Medium Long Holes System, MLH

Table 4-2 Costs per facility and cost category (MSEK), MLH
Price level January 1992.

Facility	Cost category		Sum
Common Facilities CF	Investment Operation Decommissioning Overall adj. 20%	3 121 1 108 207 887	5 323
Encapsulation Station ES	Investment Operation Decommissioning Overall adj. 20%	2 236 3 243 175 1 131	6 785
Final Repository SFL	Investment Operation Sealing Decommissioning Overall adj. 15%	1 385 942 1 383 20 559	4 289
Total			16 397

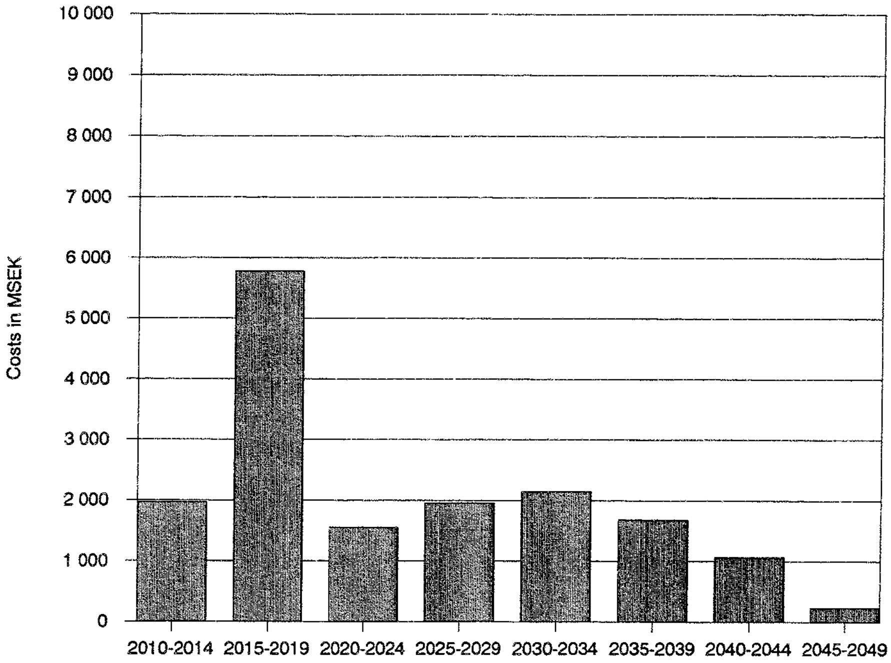


Figure 4-2 Total costs distributed over time, MLH
Price level January 1992

Very Long Holes System, VLH

Table 4-3 Costs per facility and cost category (MSEK), VLH
Price level January 1992.

Facility	Cost category		Sum
Common Facilities CF	Investment Operation Decommissioning Overall adj. 20%	3 122 1 108 207 887	5 324
Encapsulation Station ES	Investment Operation Decommissioning Overall adj. 20%	2 256 4 920 177 1 471	8 824
Final Repository SFL	Investment Operation Sealing Decommissioning Overall adj. 15%	961 1 360 754 22 465	3 562
Total			17 710

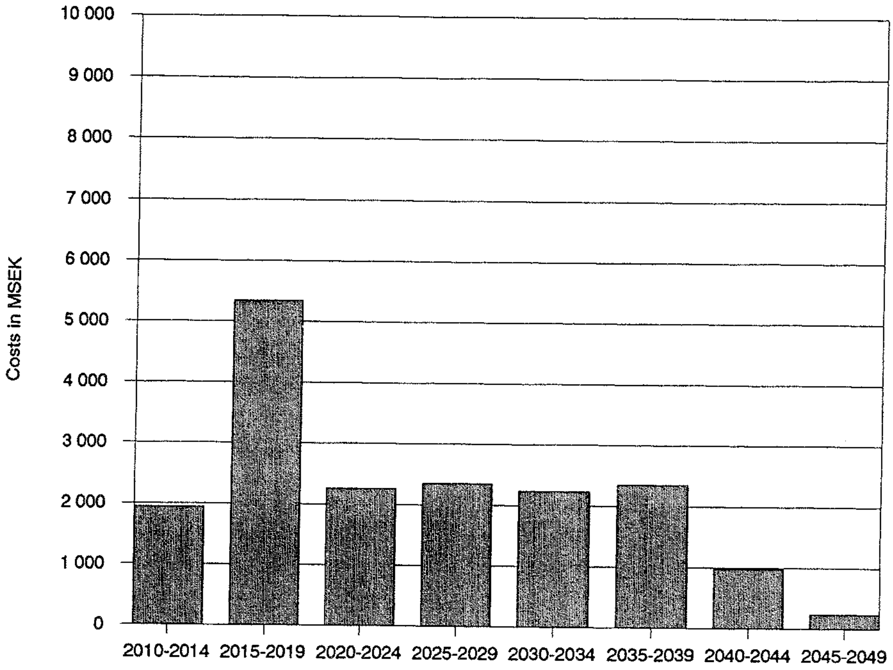


Figure 4-3 Total costs distributed over time, VLH
Price level January 1992

Very Deep Holes System, VDH_{int}

Table 4-4 Costs per facility and cost category (MSEK), VDH_{int}
Price level January 1992.

Facility	Cost category		Sum
Common Facilities CF	Investment	3 086	
	Operation	1 108	
	Decommissioning	204	
	Overall adj. 20%	879	5 277
Encapsulation Station ES	Investment	2 343	
	Operation	3 287	
	Decommissioning	191	
	Overall adj. 20%	1 164	6 985
Final Repository SFL	Investment	0	
	Operation	27 986	
	Sealing	0	
	Decommissioning	0	
	Overall adj. 15%	4 198	32 184
Total			44 446

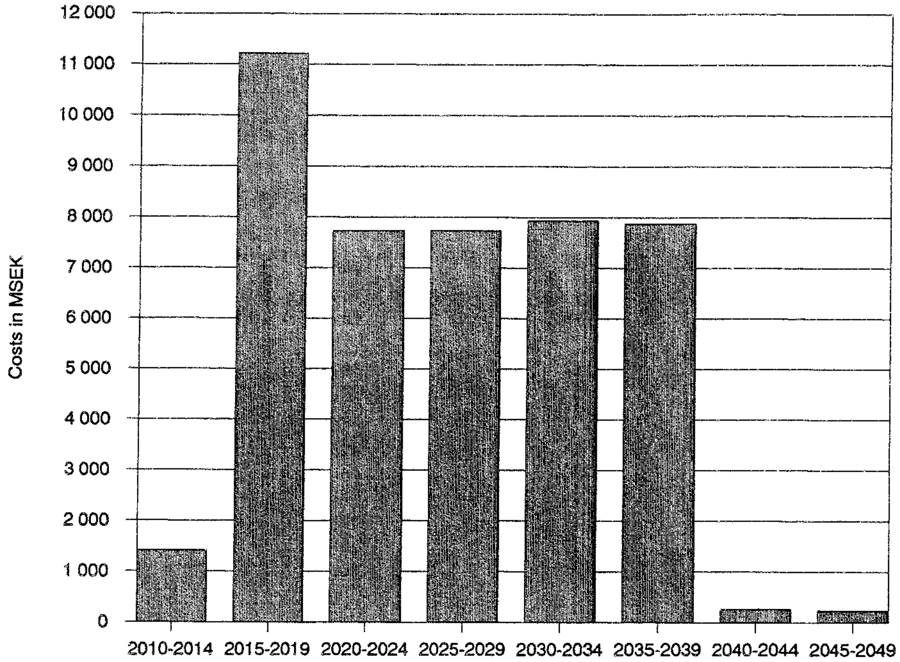


Figure 4-4 Total costs distributed over time, VDH_{int}
Price level January 1992

Very Deep Holes System, VDH$_{cons}$

Table 4-5 Costs per facility and cost category (MSEK), VDH$_{cons}$ Price level January 1992.

Facility	Cost category		Sum
Common Facilities CF	Investment Operation Decommissioning Overall adj. 20%	3 081 1 108 204 879	5 272
Encapsulation Station ES	Investment Operation Decommissioning Overall adj. 20%	3 388 2 253 261 1 181	7 083
Final Repository SFL	Investment Operation Sealing Decommissioning Overall adj. 15%	0 13 994 0 0 2 099	16 093
Total			28 448

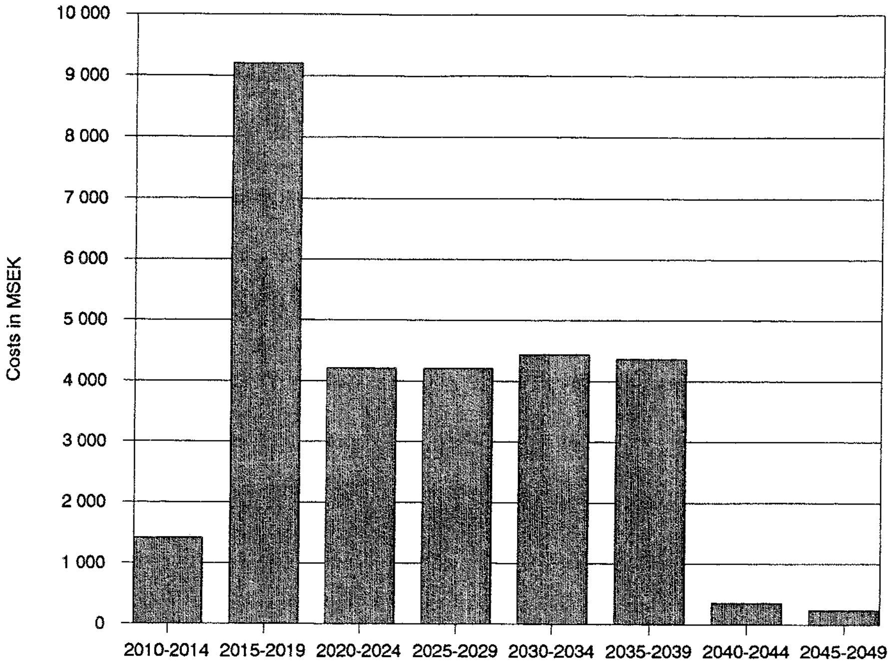


Figure 4-5 Total costs distributed over time, VDH$_{cons}$ Price level January 1992

4.3 COST COMPARISON OF THE ANALYZED SYSTEMS

Table 4-6 Summary of costs and comparison between the analyzed systems. Price level January 1992

System	Cost (rounded) [MSEK]	Sum [MSEK]	Comp. factor	Discounted 2.5% [MSEK]	Comp. factor
KBS-3					
- CF	5 400				
- ES	6 800				
- SFL	5 400	17 600	1.07	8 000	1.05
MLH					
- CF	5 300				
- ES	6 800				
- SFL	4 300	16 400	1.00	7 600	1.00
VLH					
- CF	5 300				
- ES	8 800				
- SFL	3 600	17 700	1.08	8 100	1.06
VDH_{int}					
- CF	5 300				
- ES	7 000				
- SFL	32 100	44 400	2.71	19 600	2.58
VDH_{cons}					
- CF	5 300				
- ES	7 100				
- SFL	16 000	28 400	1.73	12 900	1.70

4.4 SENSITIVITY ASPECTS OF THE COST COMPARISON

According to Table 4-6 the VDH system is by far the most expensive of the systems studied and it seems unlikely that cost variations or future development in the technical area could change this position. The relative differences between KBS-3, MLH and VLH are, on the contrary, small and could possibly be changed by even minor variations of the premises. The sensitivity of the cost comparison outcome regarding these systems was therefore investigated by a number of plausible variations studies.

The uncertainties of the calculations can be related to either technology, systems, general premises and other fundamentals or to the assessment of prices, cost adjustments etc. A selection of variations from both these categories is described below (a-f) in order to demonstrate the sensitivity of the cost comparison.

a Blind raise boring in MLH

The MLH design includes side tunnels, see Drawing 2, which are required for the drilling of the deposition drifts by means of horizontal raise boring. The width of the side tunnels has been chosen to enable depositing (7 m width). Otherwise, half the width would be sufficient.

There is a major development possibility in a blind hole drilling of the deposition holes. The cost reduction potential is of the order MSEK 500-600 if the side tunnels are excluded, and half of that if the tunnel area can be reduced to half.

b Smaller deposition tunnels in KBS-3

The cost reduction possibilities of KBS-3 involve the reduction of the height of the deposition drifts from 4.0 m, used in the calculations, to the required minimum of 3.7 m for the composite canisters. The cost saving potential is of the order MSEK 100.

c No investigation tunnel in VLH

A subject for discussion has been the investigation drift 100 m below repository level, deemed to be required for investigation and final localization of the deposition drifts. The cost for this investigation drift is about MSEK 200.

d Thermal conductivity of the bentonite

If a lower value for the thermal conductivity of the compacted bentonite is applied this will have the largest influence on VLH and the least on KBS-3. For VLH, a reduction from 1.5 W/m,K to 0.75 W/m,K will result in a temperature increase at the canister surface of approximately 20 %.

The effect from this will be that either the load in the canister must be reduced by approx. 20 % and more canisters required or the canister must be made larger corresponding to an increase of the cooling area by approx. 20 %. More canisters and corresponding longer deposition drifts will result in a cost increase of approx. MSEK 1,100 (of which about MSEK 950 refers to an increased number of canisters). An increase of the canister size will probably have a greater effect.

For MLH, the changes would most probably be the same as for VLH expressed as a percentage. The cost increase would then be approximately MSEK 600 (of which MSEK 500 relates to more canisters).

KBS-3 is not affected by lower thermal conductivity in the bentonite since the vertical deposition holes are distanced relatively far from each other for layout reasons.

e Canister cost for VLH

The difference in costs between KBS-3/MLH and VLH canisters respectively has been estimated at a factor 4.0 (approximately a weight increase by a factor 3.5). Since the total cost for the canisters in the calculations is approximately MSEK 4,700 for VLH and about MSEK 2,500 for KBS-3/MLH the total difference between VLH and KBS-3 (MSEK 100 according to Table 4-6) appears to be less than the uncertainties in the calculations. An overestimation of the canister cost for VLH by 10% will give a total of about MSEK 500.

f Cost of backfilling material

The difference between KBS-3 and MLH is mainly related to SFL and is only to a minor degree influenced by various uncertainties. The determining factors are the amount of rock to excavate and the volume of sand/bentonite to backfill. These quantities are less for MLH.

A matter for discussion has been the quality and properties of the backfill material. In Plan 92 a mixture of rather expensive quartz sand and bentonite granulate has been assumed. Could, however, the sand be substituted by crushed rock, possibly in combination with a slight increase of the bentonite portion, a substantial saving would be obtained. This would favour the KBS-3 concept with a cost decrease by MSEK 600. Corresponding figures for MLH and VLH will be MSEK 400 and MSEK 200 respectively.

5. CONCLUSIONS

The result of the cost comparison, as presented in Table 4-6, shows a great difference between the mined repository concepts as a group (KBS-3, MLH, VLH) and the VDH concept. The VDH is far more expensive than the others, in fact by a factor of about 2.5 or 1.7 depending on whether consolidation of fuel bundles is carried out or not. The cost difference if related to the SFL facility only, will raise the comparison factors to about 6.0 and 3.0 respectively. The conclusion of this is that, even if it could be argued that the potential for future development is rather unknown, the VDH system can not be considered competitive with respect to costs. (Technology and safety are not the issues of this study.)

The ranking of the other three alternatives (with respect to costs) is more uncertain. Relatively small variations in the premises or in the unit price estimates could shift the balance as presented in Table 4-6.

By means of variation studies, possibly with a weight factor included, a high-low cost comparison between the three mined alternatives can be obtained. (The weight factor should reflect the probability for a certain variation to occur.) This is exemplified in Figure 5-1. The diagram is based on the variations a-f accounted for in Section 4.4, however, without any weight factors. A ranking of the alternatives with respect to costs, even if not definite (with the exception of VDH), can then be the following:

Alternative	Ranking
MLH	1
KBS-3	2
VLH	2
VDH	4

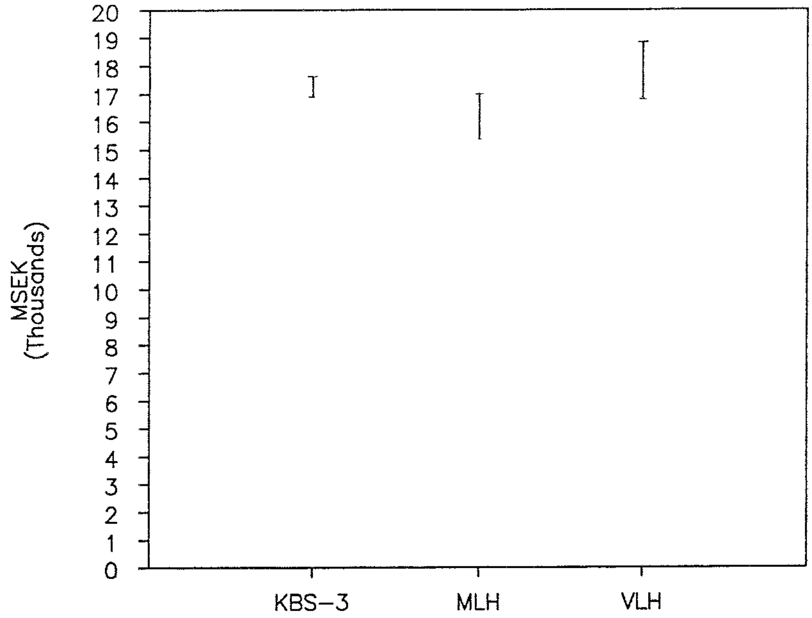


Figure 5-1 High-low cost diagram for the systems KBS-3, MLH and VLH based on the variations a-f according to Section 4.4

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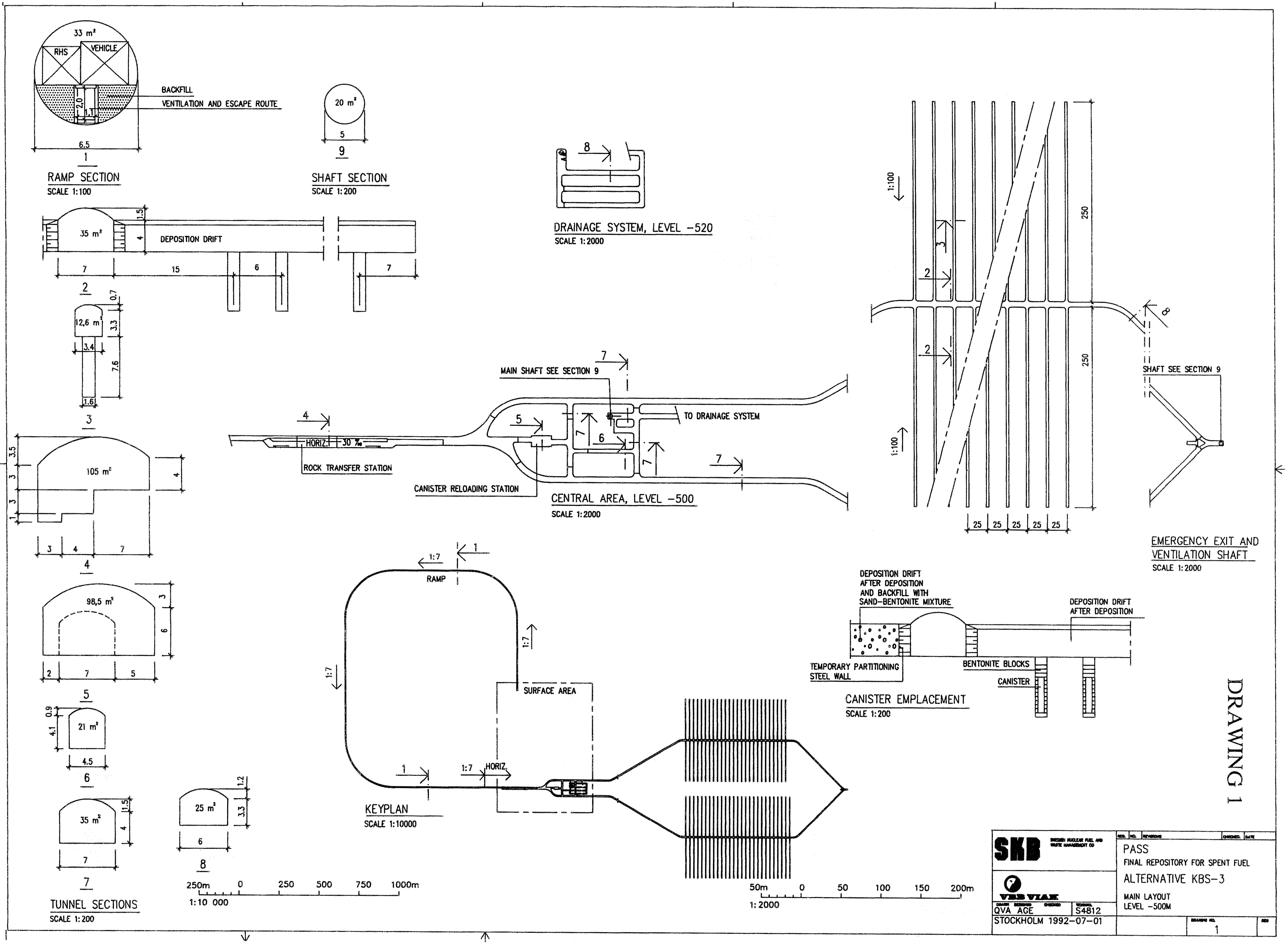


DRAWING 1

SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

VBB VIAK

QVA AGE

S4812

STOCKHOLM 1992-07-01

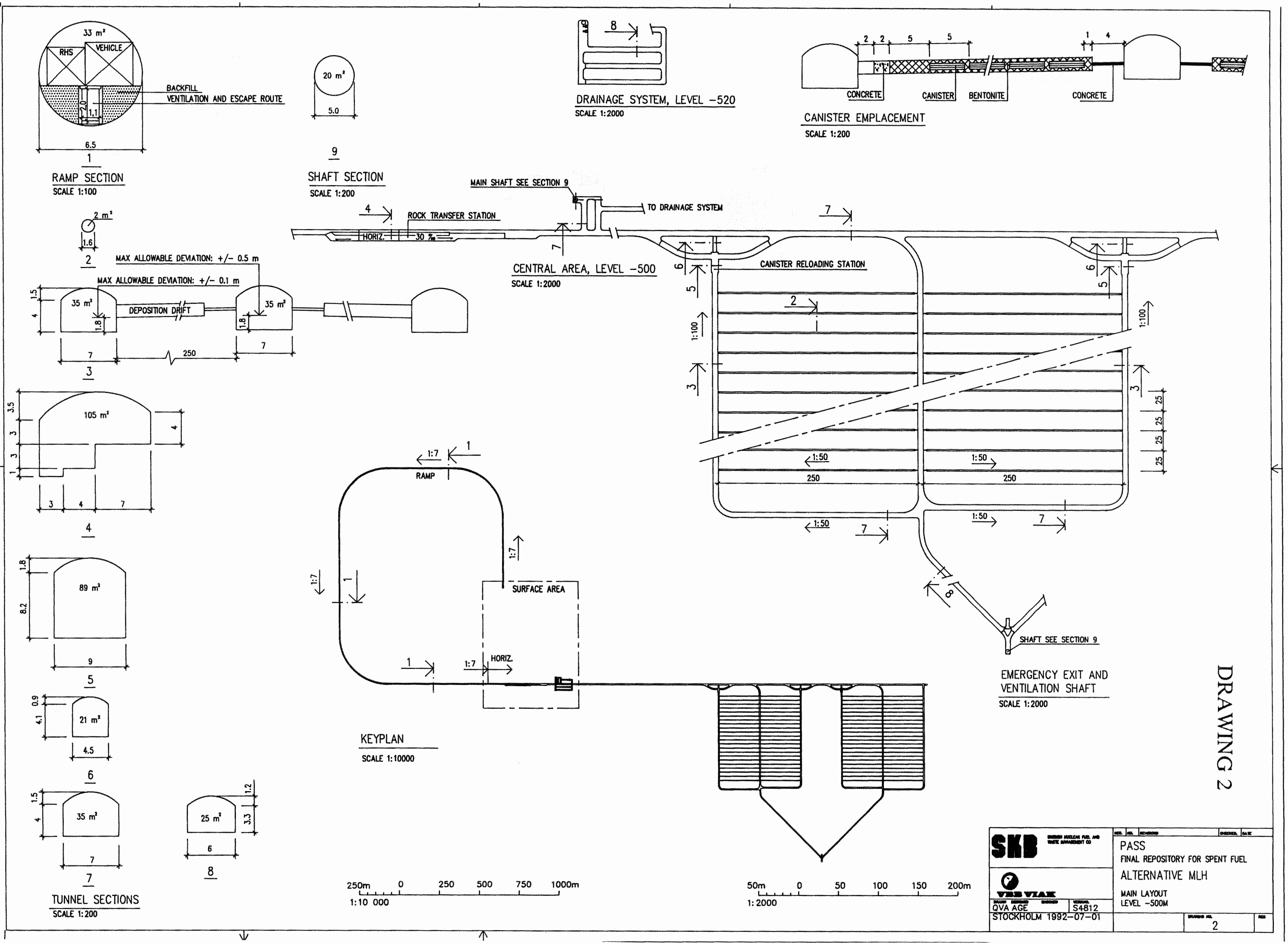
PASS

FINAL REPOSITORY FOR SPENT FUEL

ALTERNATIVE KBS-3

MAIN LAYOUT
LEVEL -500M

1



RAMP SECTION
SCALE 1:100

SHAFT SECTION
SCALE 1:200

DRAINAGE SYSTEM, LEVEL -520
SCALE 1:2000

CANISTER EMPLACEMENT
SCALE 1:200

CENTRAL AREA, LEVEL -500
SCALE 1:2000

KEYPLAN
SCALE 1:10000

EMERGENCY EXIT AND VENTILATION SHAFT
SCALE 1:2000

TUNNEL SECTIONS
SCALE 1:200

DRAWING 2

SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

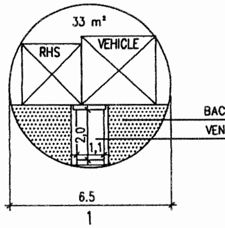
VBB VIAK

QVA AGE | S4812

STOCKHOLM 1992-07-01

PASS
FINAL REPOSITORY FOR SPENT FUEL
ALTERNATIVE MLH
MAIN LAYOUT
LEVEL -500M

DRAWING NO. 2



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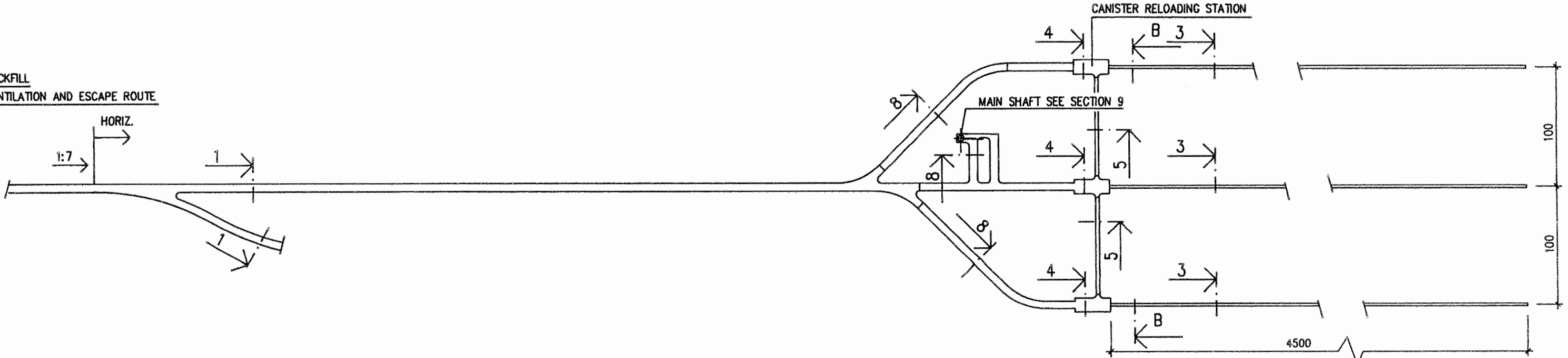

CENTRAL AREA, LEVEL -500
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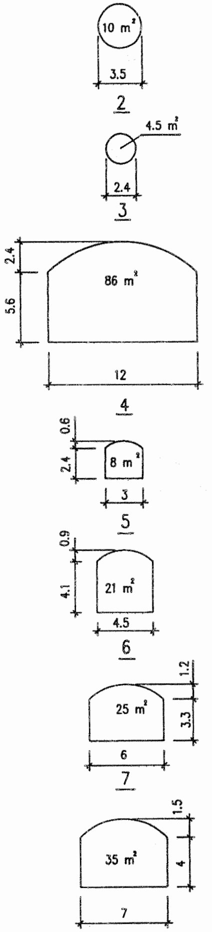

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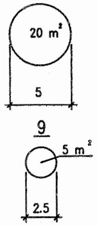

SHAFT SECTIONS
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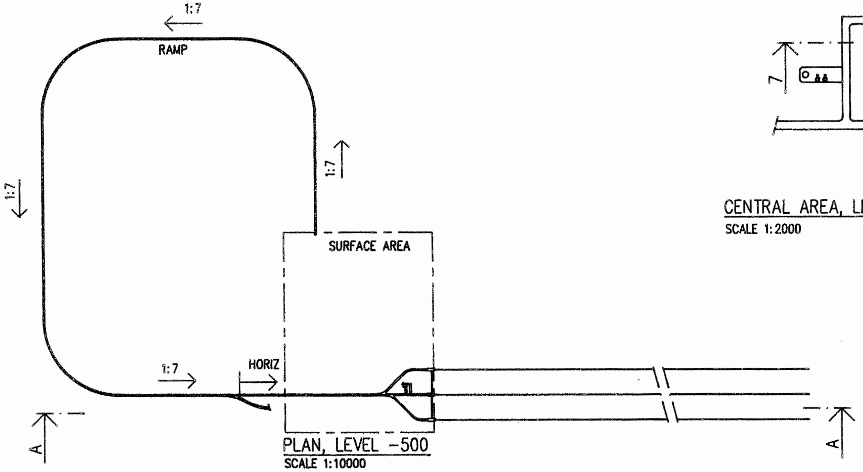
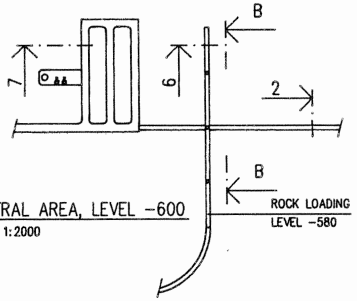


PLAN, LEVEL -500
SCALE 1:10000



CENTRAL AREA, LEVEL -600
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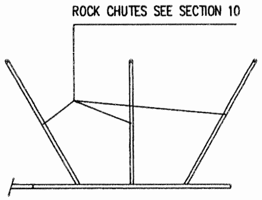
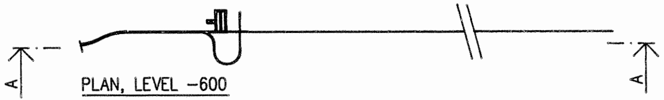


B-B
SCALE 1:2000



PLAN, LEVEL -600
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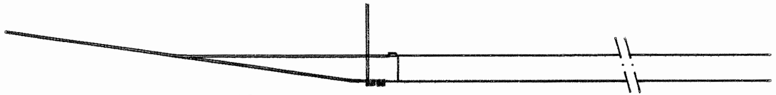

SECTION A-A
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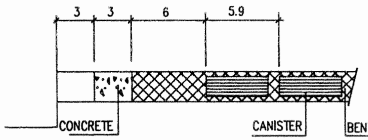


CANISTER EMPLACEMENT
SCALE 1:200

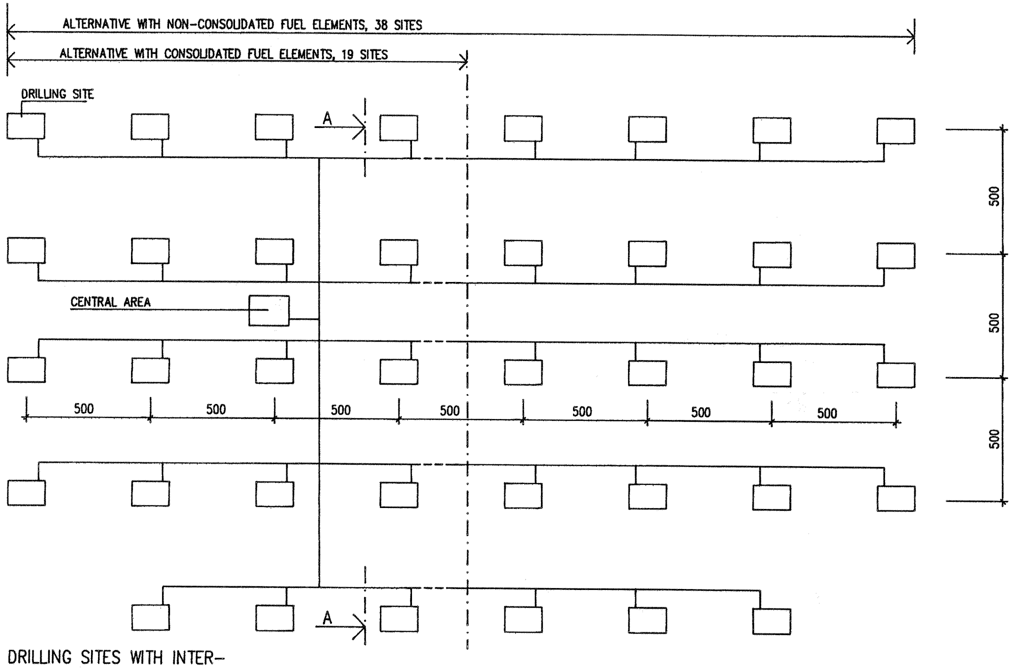
250m 0 250 500 750 1000m
1:10 000

50m 0 50 100 150 200m
1:2000

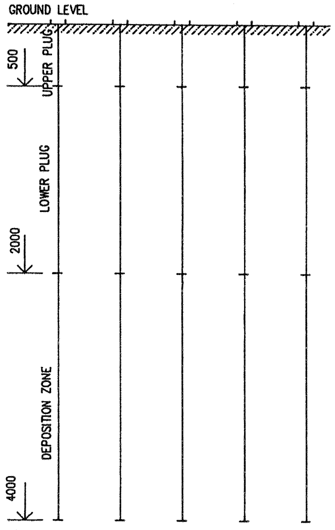
DRAWING 3

SKB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
VBB VIAK
QVA AGE
S4812
STOCKHOLM 1992-07-01

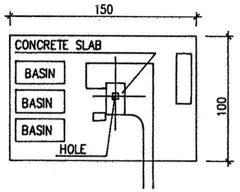
PASS
FINAL REPOSITORY FOR SPENT FUEL
ALTERNATIVE VLH
MAIN LAYOUT
LEVEL -500M
3



DRILLING SITES WITH INTER-CONNECTING ROAD NET
SCHEMATIC PLAN
SCALE 1:10000



A–A
SCALE 1:20000



DRILLING SITE
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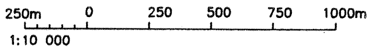

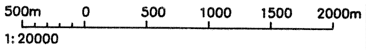

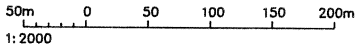

DRAWING 4

SKB SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

VBB VIAK

QVA AGE S4812

STOCKHOLM 1992-07-01

PASS

FINAL REPOSITORY FOR SPENT FUEL

ADTERNATIVE VDH

MAIN LAYOUT
LEVEL -500M

4

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[1]IVL, Stockholm
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[1]MBT, Barcelona Spain
[2]SKB, Stockholm, Sweden
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Numerical calculations on heterogeneity of groundwater flow
Sven Follin
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Kamlunge study site.
Scope of activities and main results
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[1]Golder Associates Inc., Seattle, Washington, USA
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Scope of activities and main results
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