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Project JADE

Long-term function and safety Comparison of repository systems

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Kemakta Konsult AB

December 2001

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Preface

Following the results of several comparisons of the KBS-3 reference system with other repository systems for geological disposal of spent nuclear fuel the KBS-3 system was maintained as the reference system in the SKB programme, which was launched in 1992 and aimed at start of deep disposal in Sweden at the earliest convenience. The field activities are scheduled to progress stepwise, and start with site investigations on more than one site and include continuous evaluations and intercomparison of geoscientific conditions as well as of other technical and socio-economical issues of importance. The information gained during site investigations is also scheduled to be used for site adaptation of repository design and layout, activities that also will progress stepwise with more detailed studies in each step. Before start all technical systems to be considered are suggested to be identified.

A study in 1992 (Project on Alternative Systems Study – PASS) identified several variations of the KBS-3 system as potentially interesting, and the project JADE (Jamforelse Av DEponeringsmetoder, in English: Comparison of disposal methods) was initiated in 1996 with the aim of evaluating if any of these variations should be considered for future studies.

The JADE study has concentrated on more detailed analysis of key technical issues related to KBS-3 variants with horizontal deposition followed by a new comparison between those variants and the reference KBS-3 system with vertical deposition. The conclusions are that KBS-3 with vertical deposition holes should remain as reference concept, and that deposition in medium long horizontal deposition holes should be studied further with the aim of clarifying the technical feasibility of emplacement and the means of handling water inflow. KBS-3 with horizontal deposition holes should not be studied further.

The results of JADE are now presented, much later than initially planned, which means that some of the results have already been adopted and applied in SKB:s work. This report has due to this a tendency of already being part of the past.

Stockholm, December 2001

Håkan Sandstedt

Project Leader

Abstract

A comparison of the KBS-3 V, KBS-3 H and MLH repository systems with regard to the long-term repository performance and the radionuclide migration is presented in the report.

Several differences between the repository systems have been identified. The differences are mainly related to the:

- distance between canister and backfilled tunnels,
- excavated rock volumes,
- deposition hole direction.

The overall conclusion is that the differences are in general quite small with regard to the repository function and safety. None of the differences are of such importance for the long-term repository performance and radionuclide migration that they discriminate any of the repository systems.

The differences between the two KBS-3 systems are small. Based on this study, there is no reason to change from the reference system KBS-3 V to KBS-3 H.

MLH has the potential to be a very robust system, especially in a long-term perspective. However, the MLH system will require extensive research, development, and analysis before it will be as confident as the reference repository system, KBS-3 V.

Although the MLH and KBS-3 H systems are in some ways favourable compared to the reference system KBS-3 V, the overall conclusion is that the KBS-3 V system is still a very attractive system. A major advantage with KBS-3 V is that it is by far the most investigated and developed system.

The JADE-project was initiated in 1996, and the main part of the study was carried out during 1997 and 1998. This report is published in 2001. The JADE study is consequently based on presumptions that were valid a few years ago. Some of these presumptions have been modified since then. The new presumptions are however not judged change the overall conclusions, see discussion in Appendix E.

Sammanfattning

Denna rapport ger en jämförelse av olika förvarskoncept för använt kärnbränsle med avseende på förvarens långsiktiga funkton och säkerhet. De tre koncepten är KBS-3 V, KBS-3 H och MLH.

Ett flertal skillnader har identifierats. Skillnaderna beror i huvudsak på:

- avståndet mellan kapslarna och återfyllda tunnlar,
- volymen av uttaget berg,
- depositionshålens riktning.

Skillnaderna är generellt sett relativt små och definitivt inte av sådan betydelse för förvarets långsiktiga egenskaper eller radionuklidtransporten att de bedöms diskriminera något av förvarskoncepten.

Skillnaderna mellan de två KBS-3 koncepten är små. Det har i denna studie inte framkommit något som skulle motivera att referenskonceptet KBS-3 V ersätts med KBS-3 H. MLH konceptet har potentialen att vara ett mycket robust förvarssystem, speciellt vad avser den långsiktiga funktionen. MLH kräver dock stora forsknings- och utvecklings insatser liksom grundlig analys, innan detta förvarskoncept kan tillmätas samma tillförlitlighet som referenskonceptet, KBS-3 V.

Trots att MLH och KBS-3 H i vissa avseenden är att föredra framför referenskonceptet KBS-3 V är den sammanfattande slutsatsen dock att KBS-3 V konceptet är ett bra och attraktivt förvarskoncept som står sig väl jämfört med de övriga koncepten. En stor fördel med KBS-3 V är att det är det i särklass mest studerade och utvecklade förvarskonceptet.

JADE-projektet påbörjades 1996 och huvuddelen av studien genomfördes under 1997 och 1998. Denna rapport publiceras 2001. JADE studien bygger följaktligen på förutsättningar som gällde för ett antal år sedan. Vissa av dessa har förändrats. De nya förutsättningarna bedöms dock inte påverka de övergipande slutsatserna, detta diskuteras i Appendix E.

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1 Background

The KBS-3 method, based on deposition of canisters in vertical deposition holes, is since 1984 the reference system for deposition of Swedish spent nuclear fuel. The repository principle is based on a multi-barrier system in the bedrock at 400-700 metres depth below the ground surface, with the spent fuel encapsulated in copper canisters with a cast iron insert, which are surrounded by a bentonite buffer.

SKB has also developed and evaluated other repository systems. During a period between 1986 and 1989, the WP-Cave system was evaluated and compared with KBS-3. The result of the evaluation showed that WP-Cave was judged to fulfil high demands on long-term performance and safety but that the advantages of KBS-3 outweighed the advantages of WP-Cave.

Three other systems; Very deep holes (VDH), Very long holes (VLH), Medium long holes (MLH) have also been developed and analysed. These were evaluated and compared with KBS-3 in a Project on Alternative Systems Study (PASS) /SKB, 1992/.

The comparisons in the PASS-study include comparisons of long-term performance and safety, technology and costs. All compared concepts were judged to fulfil the demands on performance and safety. The conclusion was however that two concepts, KBS-3 and MLH, were valued to be the best although the comparison was not completely unambiguous. Concerning the technology, the deposition process in KBS-3 was judged to be more robust concerning the technical feasibility and more flexible concerning the deposition process. There was a considerable advantage for MLH in the comparison of the costs. In a final judgement, where the advantages in the deposition process in KBS-3 were included, KBS-3 was ranked ahead of MLH.

The possibility in the KBS-3 method to dispose the canisters in horizontal deposition holes in the walls on both sides of the deposition tunnel has been studied. This method (KBS-3 H) is judged to be attractive from an economical point of view since the total length of deposition tunnels can be reduced compared to KBS-3 with vertical deposition holes (KBS-3 V).

In 1996, SKB initiated project JADE. The aim with the project is to enter deeply into the technology key issues concerning horizontal deposition systems. The study comprise a detailed comparison of the alternatives KBS-3 H (horizontal deposition) and MLH (deposition in medium long horizontal deposition holes) with the reference system KBS-3 V (vertical deposition) /SKB, 2001/.

2 Introduction

In the JADE-project, three repository systems (KBS-3 V, KBS-3 H and MLH) are compared with regard to techniques, cost and long-term safety. The systems KBS-3 V and KBS-3 H are based on the same system, with the difference that the deposition holes are placed vertically in KBS-3 V and horizontally in KBS-3 H. In the MLH system (Medium Long Holes), the deposition holes are placed horizontally and are 150-500 m long.

The purpose with the work described in this report has been to identify and rank differences between the three repository systems that can be of importance for the long-term function and safety.

The study is focused on the expected long-term development of the repositories. This implies deposition of intact canisters, slow degradation of the canister and other barriers. In addition, deposition of canisters with initial defects has been considered. Differences between the repository systems with regard to scenarios such as glaciation, earthquakes and human activities are briefly discussed.

Several differences between the repository systems are discussed in this report. Going through the interaction matrices developed during the safety study SR 97 has identified these differences.

Based on the identified differences, the repository systems are ranked with regard to long-term repository performance, radionuclide migration from a degraded canister as well as radionuclide migration from a canister with an initial defect.

The *long-term repository performance* represents the estimated possibility for the repository systems to maintain the function of the canister, bentonite buffer and tunnel backfill in a long-term perspective.

The *radionuclide migration* from a degraded canister depends on the properties of the surrounding barriers. The canister is designed to maintain its function during at least 100 000 years.

The ranking also include radionuclide migration from a canister with an *initial defect*. At this time, the properties of the other barriers are expected to be in accordance with the design criteria.

In addition to the ranking, the possibility to take planned complementary *technical measures* to influence the repository function is considered. The differences related to different repository layouts are not considered to be possible to influence. Whereas, a difference related to technical differences between the repository systems might be possible to influence by technical development or modifications.

Retrievability of the canisters is not considered in this study.

Structure of the report

Background information and basic presumptions for the three repository systems concerning; the repository layout, the fuel and canister, the bentonite barriers, tunnel backfill, engineering and stray materials are given in Chapter 3. Presumptions concerning the near-field and far-field rock are also included in this chapter.

Qualitative comparisons of the three repository systems are given in Chapter 4 in the form of short descriptions of the identified differences.

The ranking of the identified differences has been carried out in a step-wise manner and is given in Chapter 5.

The influence of other scenarios e.g. glaciation, seismic events and human activities is discussed in Chapter 6. The differences between the repository systems with respect to these scenarios have not been included in the ranking given in Chapter 5, but have affected the overall conclusions given in Chapter 8.

The comparison of the repository systems is based on bored deposition tunnels in the KBS-3 repository systems. An alternative is to blast these tunnels. The differences in repository performance between KBS-3 repositories with bored and blasted deposition tunnels are discussed in Chapter 7.

3 Information and presumptions

3.1 Compared repository systems

Within the JADE-project, three repository systems for deposition of spent fuel are compared with regard to techniques /Sandstedt and Munier, 2001/, cost /Ageskog, 2001/, long-term safety etc. The three systems are:

- KBS-3 V (vertical deposition of the canisters with a surrounding bentonite barrier according to the KBS-3 system) /KBS, 1983/,
- KBS-3 H (horizontal deposition of the canisters with dimensions and bentonite barrier according to the KBS-3 system),
- MLH (horizontal deposition of the canisters with a surrounding bentonite barrier in medium long holes).

The KBS-3 V system is the reference alternative.

3.2 Repository layout

The following terminology is used in this report:

- The canisters will be disposed in deposition holes.
- The deposition holes will be bored from deposition tunnels in KBS-3 and from transport tunnels in MLH.
- The deposition tunnels in KBS-3 will be accessed from the transport tunnels.
- An access tunnel and shafts will be excavated from the surface to the central repository area. The transport tunnels will connect the central area with the deposition area.

Figures 3-1, 3-2 and 3-3 illustrate the layout of the repository.

The deposition holes in MLH and KBS-3 will be drilled. The deposition tunnels in KBS-3 may either be blasted or bored. This report is based on the assumption that the deposition tunnels will be bored. Differences between bored and blasted tunnels, with respect to the long-term repository function, are discussed in Chapter 7. The overall layouts are similar for the three compared repository systems. The deposition tunnels in KBS-3 are replaced by bored deposition holes in MLH. The transport tunnels and access tunnels will be blasted in all three repository systems.

The area required for a repository is exemplified for KBS-3 V type repositories in Table 3-1. The repositories are situated in three hypothetical sites (Aberg, Beberg and Ceberg) used in the safety study SR-97. An option is that another repository aimed for disposal of other long-lived waste (SFL 3-5) may be built in connection to the repository for spent fuel. The repository areas in Table 3-1 were chosen to enclose:

- deposition tunnels,
- deposition tunnels, transport tunnels and central area,
- entire repository including SFL 3-5.

The entire repository area including SFL 3-5 was found to range from 2.8 to 3.5 km^2.

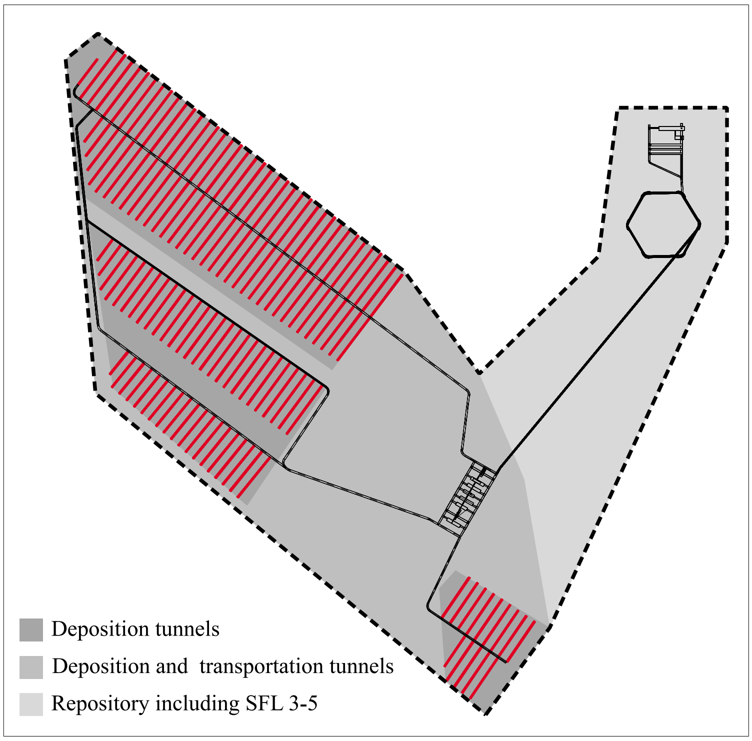

Figure 3-1 Tentative layout for a KBS-3 V repository constructed in Beberg /Munier et al, 1997/.

Table 3-1 The table summarises approximate repository areas for a KBS-3 V type of repository at three hypothetical sites.

Hypothetical repository site	Deposition tunnels (km^2)	Deposition tunnels Transport tunnels Central area (km^2)	Entire repository including SFL 3-5 (km^2)
Aberg	0.8	2.3	3.1
Beberg	1.4	2.5	3.5
Ceberg	1.7	2.1	2.8

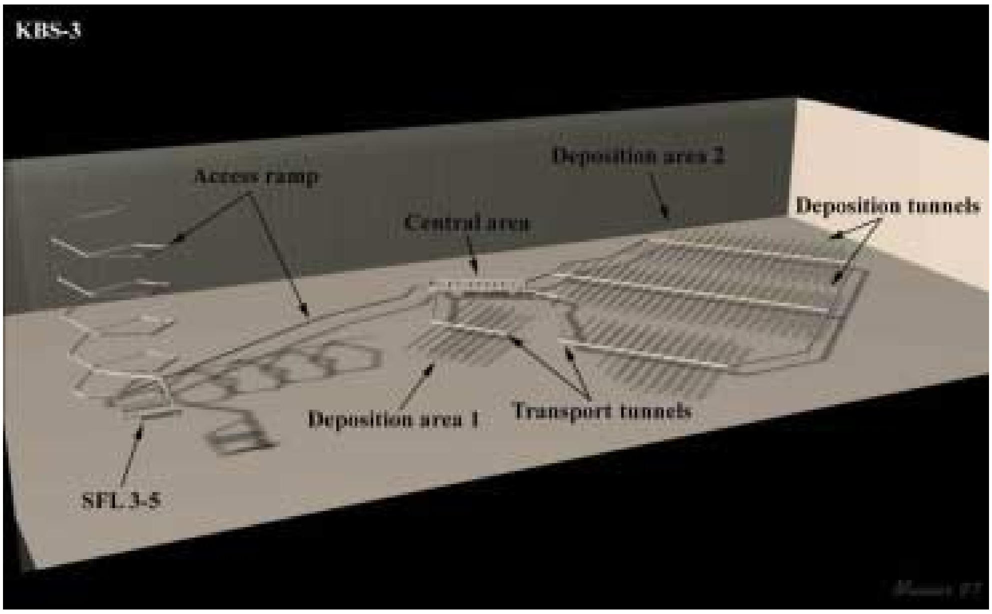

Figure 3-2   Schematic illustration of a tentative KBS-3 repository.

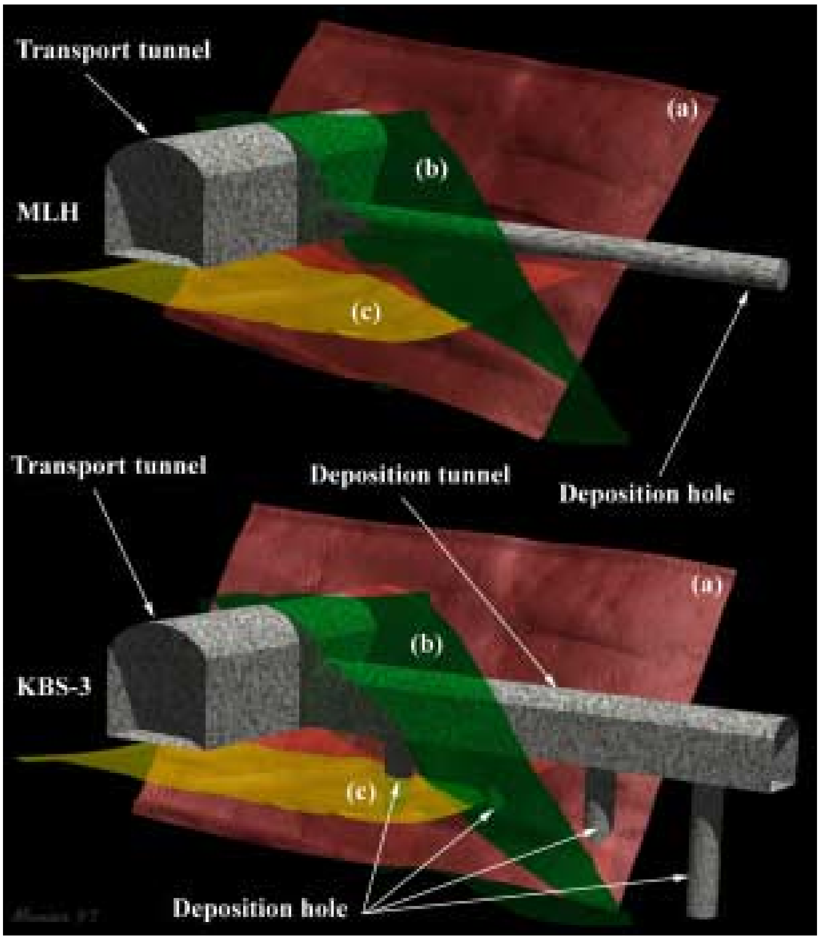

Figure 3-3   KBS-3 V and MLH. Schematic illustration of deposition holes, deposition tunnel and transport tunnel. The figure illustrates the case with blasted deposition tunnels. This study has however been based on bored deposition tunnels.

3.2.1 KBS-3 V and KBS-3 H

The arrangement with deposition hole, deposition tunnel and transport tunnel for KBS-3 V is illustrated in Figure 3-4. The arrangement will be similar for KBS-3 H, with the exception for the horizontal deposition holes drilled in the rock wall on both sides of the tunnel, see Figure 2-5.

The canisters are disposed in 7.83 m deep bored deposition holes with a diameter of 1.75 m. Vertical deposition holes are bored in the floor of the deposition tunnels in KBS-3 V and horizontal holes are bored in the walls on both sides of the deposition tunnels in KBS-3 H. The spacing between the individual deposition holes is in average 6 m in both repository systems. The deposition holes in KBS-3 H have an inclination of 2 degrees to avoid groundwater accumulation. The spacing between the deposition tunnels are 40 m in KBS-3 V and 60 m in KBS-3 H. The exact dimensions of the repositories will be optimised at a later stage with regard to the heat generation from the fuel and properties of the bedrock at the selected site.

The methods used for boring of the deposition tunnels and deposition holes have not yet been decided. However, for the purpose of this study it has been assumed that the choice of methods will not influence the long-term function and safety of the repository.

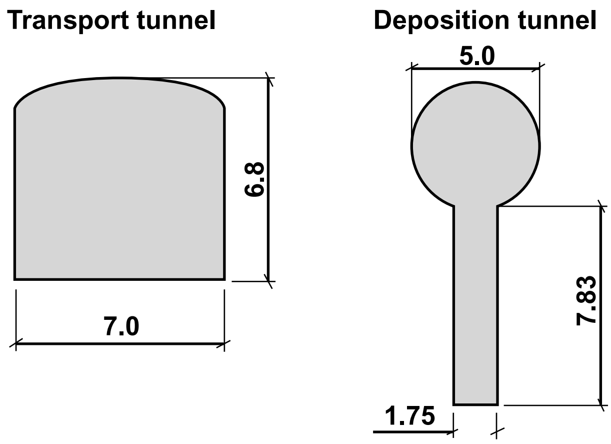

Figure 3-4 KBS-3 V. Dimensions (in metres) of deposition hole, deposition tunnel and transport tunnel in the deposition area.

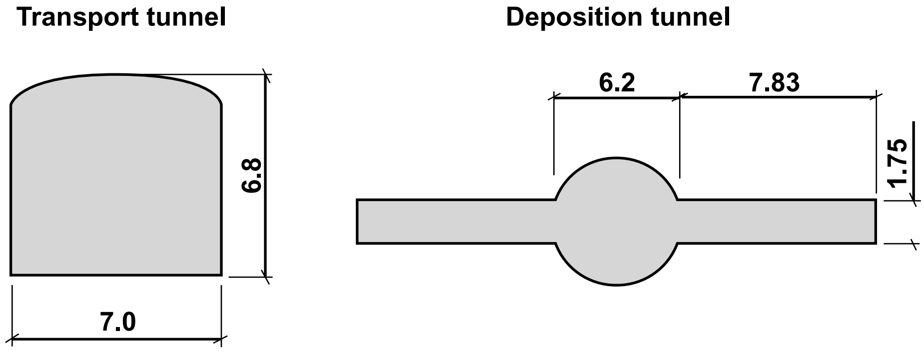

Figure 3-5 KBS-3 H. Dimensions (in metres) of deposition hole, deposition tunnel and transport tunnel in the deposition area.

The dimensions of the deposition tunnels are determined by the size of the equipment that is used during deposition of the canister in the deposition holes. The bored deposition tunnel is assumed to be 5 m in diameter in the KBS-3 V system and 6.2 m in KBS-3 H. An alternative is that the deposition tunnel will be blasted. A blasted deposition tunnel would be 4.2 m wide and 5 m high in KBS-3 V and 6.2 m wide and 5 m high in KBS-3 H. The total length of deposition tunnels required to host the canisters is in the order of 28 km in KBS-3 V and 16 km in KBS-3 H /Ageskog, 2001/. The deposition tunnels are assumed to be backfilled with a mixture of bentonite and crushed rock. The composition is 15 weight % bentonite and 85 weight % crushed rock /SKB, 2001/. The tunnels will eventually be sealed with a plug consisting of concrete and/or highly compacted bentonite blocks.

The transport tunnels are blasted. The transport tunnels in the deposition area is 7 m wide and 6.8 m high. The total length of these tunnels is about 2200 m in KBS-3 V and 1900 m KBS-3 H. The tunnels are backfilled with the same type of bentonite and crushed rock mixture (15/85) as the deposition tunnels.

In addition, there will be about 2000 m of transport tunnels outside the deposition area. These tunnels are 7 m wide and 6 m high.

The lengths of access tunnels and shafts are dependent on the repository layout and site location. The sealing of access tunnels and shafts are also assumed to be carried out using a bentonite and crushed rock mixture (15/85).

3.2.2 MLH

In the MLH repository system, the canisters are disposed, one after the other, in horizontally bored deposition holes with a length of 150-500 m. A typical length of 250 m is used in this study. The diameter of the deposition holes is 1.75 m (see Figure 3-6). The deposition hole is, in contrast to the deposition holes in the KBS-3 systems, also used for transportation of e.g. excavated rock.

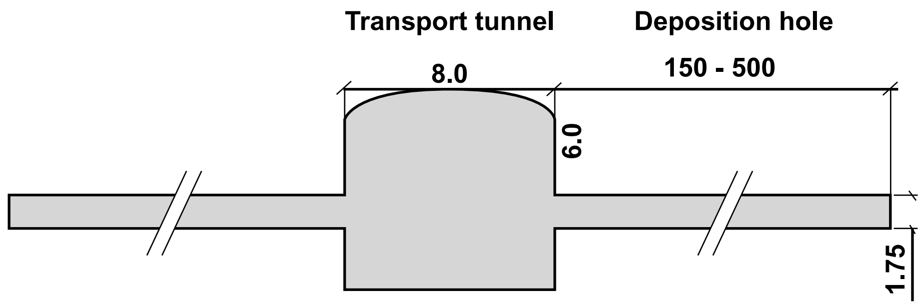

Figure 3-6 MLH. Dimensions (in metres) of deposition hole, deposition tunnel and transport tunnel in the deposition area.

The centre to centre distance between the deposition holes is about 40 m and the holes have an inclination of 2 degrees to avoid groundwater accumulation /Sandstedt and Munier, 2001/. The deposition holes will be plugged with concrete at the interface to the transport tunnel.

The transport tunnels are blasted and the dimensions are 8 m wide and 6 m high. The total length of the tunnel is about 2200 m. The transport tunnel is backfilled with a mixture of bentonite and crushed rock (15/85) and eventually the tunnel will be sealed with a plug consisting of concrete and/or highly compacted bentonite blocks.

In addition there are about 2000 m of transport tunnels outside the deposition area, these tunnels will be 7 m wide and 6 m high.

The lengths of access tunnels and shafts are dependent on the repository layout and selected site. The sealing of access tunnels and shafts has also been assumed to be carried out using a bentonite and crushed rock mixture (15/85). An alternative is to only use crushed rock.

3.3 Canister

The reference canister selected for this study holds 12 BWR assemblies with boxes. The canister design is independent of the choice of repository system.

The canister is 4.83 m long and 1.05 m in diameter with a 50 mm thick outer shell of copper that will provide corrosion protection. The cast insert of steel provides mechanical strength.

The 12 BWR assemblies are placed in prefabricated positions in the cast insert. The gap between the copper shell and the insert is 1 mm. The copper canister has four welds. The two longitudinal welds and the weld at the bottom are made first, before emplacement of the insert. These welds can be fully inspected. The lid is welded after emplacement of the insert and consequently this weld can only be inspected from the outside. One alternative is to fill the void in the canister with inert gas. The total weight of the canister loaded with fuel is about 25 tonnes.

The total number of canisters is 3 800.

3.4 Bentonite buffer in the deposition holes

A bentonite buffer will surround the canisters in all three repository systems. The emplacement method varies between the repository systems, but a prerequisite in the study is that the buffer properties (density, permeability etc) are the same in all compared repository systems after closure and resaturation. The risk for and the effects of a buffer that will obtain inferior quality are however discussed in the report. The canister is centred in the deposition holes due to the swelling and homogenisation of the buffer material. The emplacement methods and the possibility to add bentonite pellets in order to obtain prescribed properties differ between the repository systems. Furthermore, some of the emplacement methods are not yet fully developed and evaluated.

The homogenised bentonite barrier surrounding the canister has a bulk density of about 2000 kg/m^3. The corresponding hydraulic conductivity is $< 10^{-12}$ m/s. The thermal conductivity of the homogenised barrier is approximately 1.3 W/m,K. The thermal conductivity for unsaturated bentonite is lower, 1.2 W/m,K /SKB, 2001/.

3.4.1 KBS-3 V and KBS-3 H

The bentonite blocks placed in the deposition holes are made of compacted sodium bentonite (MX-80) with high water content.

The deposition of the canisters in KBS-3 V will take place in two steps, starting with placing bentonite blocks in the hole and finally inserting the canister /Jansson et al, 2001/. The canister is placed on a bottom base pad of bentonite with a height of 0.5 m, see Figure 3-7. The bentonite blocks, 0.29 m thick /SKB, 2001/, are surrounded by air filled gaps, theoretically 10 mm between canister and bentonite and 50 mm between bentonite and bedrock. The gap between bentonite and bedrock can be filled with bentonite pellets and water with a suitable chemical composition. Blocks of compacted bentonite are placed in a 1.5 m section above the canister. The distance between the top of the canister and the deposition drift is 2.5 m. The 1 meter long *plugging zone* is filled with tunnel backfill (15/85, bentonite/crushed rock mixture) in KBS-3 V and with bentonite blocks in KBS-3 H, see Figure 3-7.

The deposition of the canisters in KBS-3 H take place either as one unit or in two steps in a similar way as in KBS-3 V, where the bentonite blocks are placed first in the deposition hole /Kalbantner, 2001a/. The geometry and the dimensions of the buffer and canister are similar to KBS-3 V, with a few exceptions. Due to the horizontal deposition, it is possible to decrease the volume of gaps since the bentonite blocks will be in contact with the rock at the lower part of the deposition hole. This implies that the bentonite blocks surrounding the canister can be 0.31 m thick at emplacement, which is thicker than in KBS-3 V. Gaps between the canister-buffer-rock is located in the upper part of the horizontal deposition holes.

It is assumed that the canisters in both KBS-3 systems are centred in the deposition hole and surrounded by a 0.35 m thick saturated bentonite buffer with equal properties. This is obtained by filling the gaps with pellets in KBS-3 V and using slightly thicker bentonite blocks in KBS-3 H.

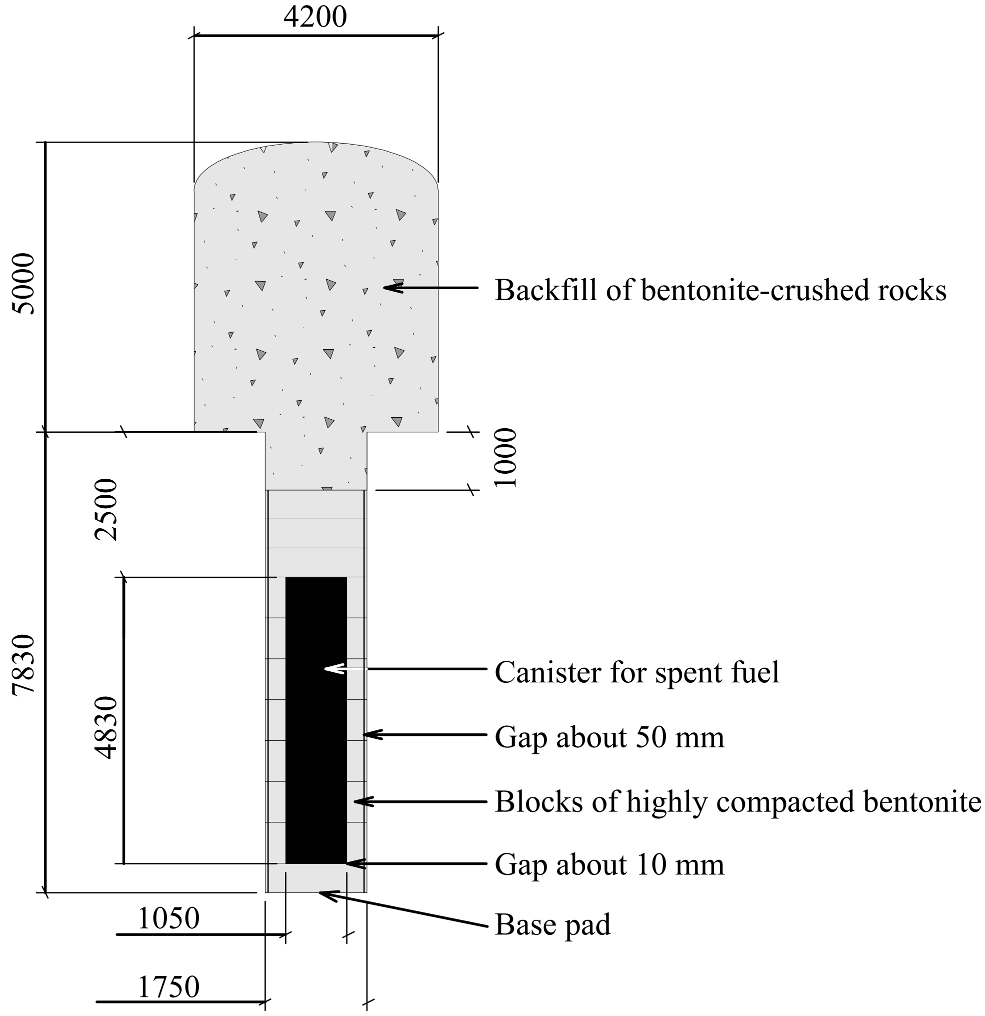

Figure 3-7 Deposition hole with canister, buffer and backfill in KBS-3 V. (The measures are theoretical and given in mm). The figure illustrates the case with blasted deposition tunnels. This study is however based on bored deposition tunnels.

3.4.2 MLH

The deposition method to be used in MLH has not yet been developed, but the canister and the bentonite buffer has been suggested to be disposed as one unit. One alternative is to use a copper mesh that surrounds the canister and bentonite during deposition. The mesh is left in the deposition hole. Other alternatives are deposition of the whole unit without any mesh /Kalbantner, 2001b/.

One difference between these alternative deposition methods from a long-term perspective is the introduction of the copper mesh. This has been considered in the study. It is uncertain whether or not it is possible to add bentonite in the form of pellets during the deposition process in MLH. Consequently, it is assumed that pellets can not be added. The bentonite blocks are 0.31 m thick since the gaps can be reduced if the bentonite is in contact with the rock at the lower part of the deposition holes and the bentonite and buffer are disposed as one unit.

After saturation of the bentonite a 0.35 m thick barrier surrounds the canister, which is assumed to be centred in the deposition hole. The distance between the canister ends, which is about 1.2 m, is filled with bentonite.

3.5 Backfill, engineering and stray materials

The transport tunnels in KBS-3 and MLH and the deposition tunnels in KBS-3 will be backfilled with a mixture of bentonite and crushed rock (15/85). In addition, engineering materials such as cement, concrete and rock bolts will be introduced in the tunnels and in the surrounding bedrock in order to stabilise the rock and reduce the water inflow into the tunnels during the construction and operational phases. Stray materials will be brought into the repository area during these phases.

Stray and engineering materials can influence the long-term properties in the repository by affecting the buffer and/or the canisters. These materials will originate from:

- engineering materials (grouting, shotcrete, plugs, rock bolts and steel fabrics),
- transportation (rubber from tires, oil leakage, battery acid, diesel fumes),
- human activities (microbes, urine, snuff),
- ventilation (organic material),
- groundwater (microbes, chemical species),
- impurities in bentonite and crushed rock,
- blasting (nitrogen oxides etc.).

3.5.1 Tunnel backfill

Transport tunnels and deposition tunnels in KBS-3 will be backfilled with a mixture of bentonite and crushed rock (15/85). The total amount of backfill differ very much between the three repository systems, see Figure 3-8. It should be noted that the volume of the backfill of access tunnels and shafts has not been included in the comparison. The volume of these tunnels is dependent on the repository layout and selected site. The volume is however expected to be comparable to the volume of transport tunnels and considerably less than the volume of the deposition tunnels in KBS-3. It should be noted that these tunnels are located relatively far away from the canister positions.

The bored deposition tunnels have a cross-section of 20 m^2 in KBS-3 V and 30 m^2 in KBS-3 H, a total length of 28 km in KBS-3 V and 16 km in KBS-3 H. This result in large volumes that have to be backfilled, 550 000 m^3 in KBS-3 V and 483 000 m^3 in KBS-3 H. These volumes have no equivalence in MLH.

The length of the transport tunnels in the deposition area is 2200 m in KBS-3 V, 1900 m in KBS-3 H and 2200 m in MLH. The length of the transport tunnels outside the deposition area is about 2000 m in all three repository systems. The total volume of backfill in the transport tunnels are 172 000 m^3 in KBS-3 V, 158 000 m^3 in KBS-3 H and 169 000 m^3 in MLH.

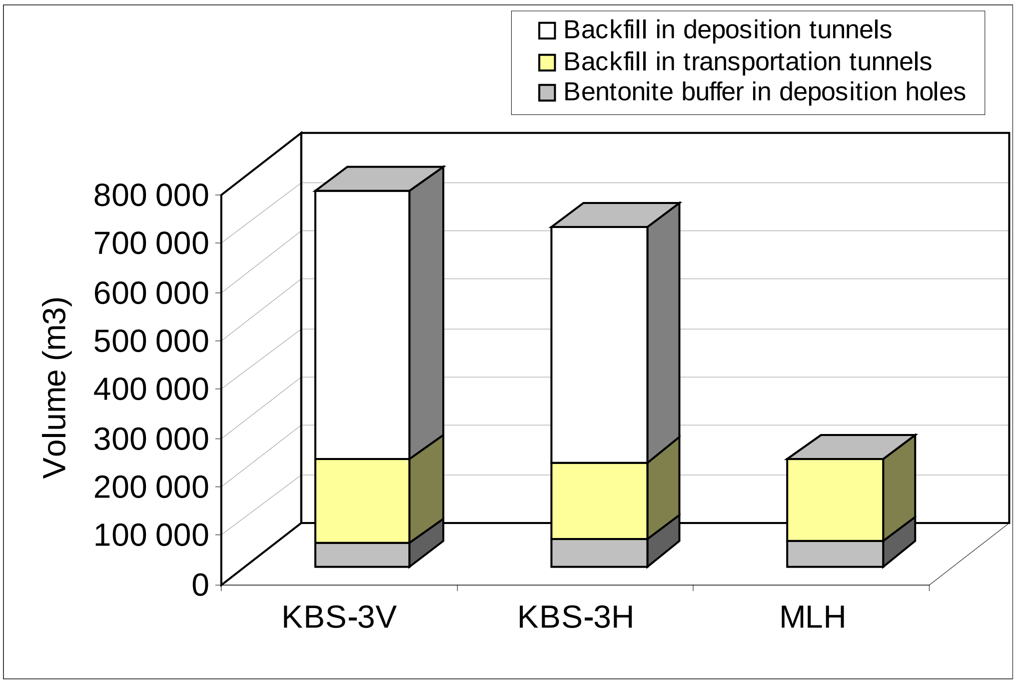

Figure 3-8 Volume of tunnel backfill and bentonite buffer in KBS-3 V, KBS-3 H and MLH. Based on bored deposition tunnels and deposition of 3800 canisters.

The estimated quantities of backfill and bentonite blocks loaded into the deposition holes and tunnels per canister are given in Table 3-2.

Table 3-2 Estimated quantities of bentonite buffer and backfill in deposition tunnels. The values in the table are given per canister and are based on deposition of 3 800 canisters.

Barrier material	Quantity per canister (kg/canister)		
	KBS-3 V	*KBS-3 H*	*MLH*
Buffer			
Bentonite	24 000	29 000	26 000
Backfill in deposition tunnels			
Bentonite	41 000	36 000	0
Crushed rock	230 000	210 000	0

The amounts of impurities and chemical species that enter the repository with buffer, backfill and groundwater are being estimated in other SKB Projects. The analysis carried out so far indicate that the amounts are considerable compared to the other stray materials that enter the repository during the construction and operation phases. The crushed rock in the backfill provides rock surfaces, which have been weathered. This can lead to considerable leaching of ions from the crushed rock.

3.5.2 Engineering materials

The engineering materials will mainly consist of:

- grouting,
- shotcrete,
- concrete plugs,
- rock bolts and steel fabrics.

Grouting

Grouting is an effective method for reducing water inflow during the operational phase. Cement slurry will be injected into fracture zones and larger fractures during the boring/excavation of the deposition tunnels and the boring of the deposition holes.

Shotcrete

Shotcrete will be used as reinforcement in the ceiling in the KBS-3 deposition tunnels. The amounts of shotcrete that will be used depend on the bedrock properties. The shotcrete will be in direct contact with the backfill in the deposition tunnels. Shotcrete may also be used in the deposition holes in MLH but only at locations where no canisters will be disposed.

Concrete plugs

Concrete plugs may be used to plug off MLH deposition holes that extend into fracture zones that are found to be so wide that further boring is excluded.

Rock bolts and steel fabrics

Rock bolts and steel fabrics, consisting of iron, is used in the deposition tunnels in order to stabilise the rock and prevent stones to fall during the construction and operational phases. Rock bolts and possibly steel fabrics is as well used in the deposition holes in MLH.

Estimated amounts of engineering materials

The estimated amounts of engineering materials are summarised in Table 3-3.

Table 3-3 Estimated amounts of engineering materials per canister /Sandstedt, 1999/.

Repository system	Amount of shotcrete per disposed canister (kg/canister)		Amount of injected cement per disposed canister (kg/canister)	
	Deposition hole	Deposition tunnel	Deposition hole	Deposition tunnel
KBS-3 V, bored dep. tunnel	0	336	31	339
KBS-3 H, bored dep. tunnel	0	236	31	238
MLH	[a]	-	62	-
KBS-3 V, blasted dep. tunnel	0	363	31	361
KBS-3 H, blasted dep. tunnel	0	254	31	257

[a] *Shotcrete may be used at sections intersected by fracture zones of class D3, see Appendix A.*

The amount of engineering materials is somewhat smaller in KBS-3 H compared to KBS-3 V as a result of less excavated volumes and shorter deposition tunnels. The total amount of engineering materials is smaller in the MLH system compared to the KBS-3 systems. The amount of engineering materials is larger in the MLH deposition holes compared to the deposition holes in KBS-3. Sections of the deposition holes in MLH that need reinforcement will be rejected for canister deposition.

Amount of engineering materials in SFL 2

The amount of engineering materials in SFL 2 (KBS-3 V type of repository with blasted deposition tunnels) are reported in Jones et al /1999/. The average and maximum amounts are given in Table 3-4. The amounts given in Table 3-4 correspond well to those given in Table 3-3.

Table 3-4 Average and maximum amounts of engineering materials per canister in SFL 2 (a KBS-3 V type of repository) with blasted deposition tunnels /Jones et al, 1999/.

Engineering materials	Amounts in SFL 2 (kg/canister) with blasted deposition tunnel	
	Average	Maximum
Grouting	250	1 500
Shotcrete	250	1 250
Rock bolts	70	200

3.5.3 Stray materials

The human activities during construction and operation of the repository introduce stray materials in the form of microbes, urine, tobacco, snuff etc. Stray materials from transportation include rubber from tires, spill of oil, battery acids and diesel fumes. The alternative with blasted deposition tunnels in KBS-3 introduces nitrogen oxides etc.

Estimated amounts of stray materials

The average and maximum amount of stray materials that remain in a KBS-3 V repository with blasted deposition tunnels has been reported in Jones et al /1999/. These amounts can however be reduced by using other types of explosives or boring of the tunnels, even more careful cleaning of the deposition holes and deposition tunnels etc. The amounts of stray materials in KBS-3 with bored deposition tunnels and MLH are expected to be smaller compared to the numbers given in Table 3-5, since no explosives are used and cleaning of bored tunnels or holes is easier than cleaning of blasted tunnels. Furthermore, the amount of stray materials left from transportation of excavated rock are less in MLH and in KBS-3 H compared to KBS-3 V since the excavated rock volumes are smaller and consequently less transportation will take place. A qualitative comparison of the amount of stray materials in KBS-3 V, KBS-3 H and MLH is given in Appendix C.

Table 3-5 Average and maximum amounts of stray materials in SFL 2 (a KBS-3 V type of repository) with blasted deposition tunnels /Jones et al, 1999/.

Stray material	**Amounts in SFL 2 (kg/canister)** with blasted deposition tunnel	
	Average	**Maximum**
Oil products	2	27
Battery acid	0.01	0.3
Rubber from tires	0.2	1
Organic materials from human activities [1)]	1	21
Other organic materials	0.5	2
Nitrogen oxides	0.2	0.5

[1)] *including water in urine*

The total amounts of stray materials are judged to be largest is KBS-3 V mainly due to the large volume of excavated rock, which e.g. result in more transportation. Another difference between the three repository systems is that the major part of stray material in the two KBS-3 systems is left in the deposition tunnel whereas the stray material in MLH is left in the deposition holes.

The amount of stray materials is larger in blasted deposition tunnels compared to bored tunnels. Additional stray materials will be introduced due to the blasting e.g. in the form of nitrogen oxides. In addition, a bored tunnel has smoother walls and is therefore easier to clean.

Microbial activity

Microorganisms will be brought into the repository by man, ventilation or may occur naturally in the groundwater. Microbial activity requires access to water and nutrients. In addition, the chemical environment will be important, however, microbes can adapt to quite extreme conditions what regards pH, redox conditions, temperature etc. The risk that microbial activity should affect the repository performance increase with rock surface area, the time the tunnels and holes are kept open and the access to nutrients.

Microbes will influence the redox condition by taking part in redox reactions /West and Arme, 1985/. Microbial activity may lead to the formation of corrosive agents such as sulphide and organic acids. The microbes or organic acids and other substances produced by the microbes may take up radionuclides by sorption or complex formation. Chemical and physical degradation of bentonite has been demonstrated to be caused by microorganisms /Pedersen and Karlsson, 1995; McKinley et al, 1985/.

3.6 Near-field rock

The hydraulic properties in the near-field rock will have large impact on pathways and travel times for escaping radionuclides. The extent and properties of the excavation disturbed zone will to some extent determine the hydraulic properties in the near-field rock. This is discussed below.

Excavation disturbed zone

The rock close to a tunnel or a deposition hole will be disturbed due to the excavation. Several experiments aiming to study the magnitude and extension of this disturbance have been carried out. One of the more ambitious experiments is the ZEDEX experiment carried out in the Äspö underground rock laboratory. The results from the ZEDEX experiments are illustrated in Figure 3-9.

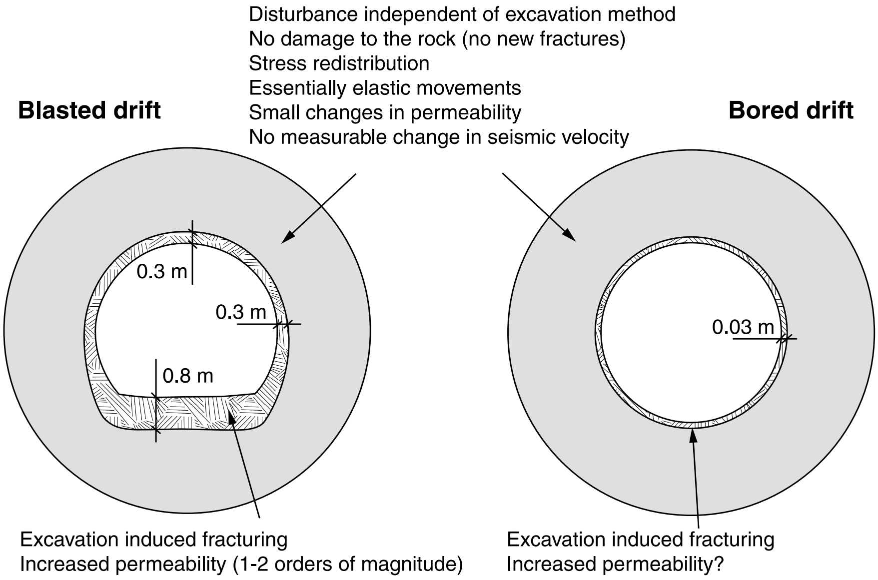

Figure 3-9 Summary of the results from the ZEDEX experiments performed at Äspö.

It can be seen in Figure 3-9 that the excavation disturbed zone (EDZ) with increased fracturing and increased permeability is significantly larger around blasted tunnels (0.3 - 0.8 m) compared to bored tunnels (< 0.03 m) /Olsson, 1997; Emsley et al, 1997/. Furthermore, a stress redistribution zone will be formed. This zone will extend further out, about one tunnel diameter, and will be independent of excavation method. This zone show no new fractures and only small changes in permeability, which is expected, since there will mainly be elastic movements in this zone /Olsson, 1997/.

Earlier experiments carried out in the Stripa mine indicated that the extension and hydraulic impact of the EDZ is larger compared to the findings from the ZEDEX experiments. The following analysis has however been based on the results from the ZEDEX experiments as illustrated in Figure 3-9.

Deposition holes will be bored from the deposition tunnel (KBS-3) or transport tunnel (MLH). The upper part of these holes will be located in the excavation disturbed zone around deposition/transport tunnel. The fracturing and hydraulic conductivity may be increased in this section. The effect on the canister of the excavation disturbed zone around the tunnel can be decreased if the canister is disposed further away from this zone, i.e. in a deeper deposition hole.

3.7 Far-field rock

No specific repository site was selected for this study. The repository has been assumed to be located in "typical" Swedish bedrock at a depth of about 500 m. The bedrock is intersected by fractures and fracture zones classified in Appendix A. The temperature at 500 m depth is expected to be in the range of 10-15 °C /SKB, 1999/.

The far-field rock is defined as the undisturbed bedrock surrounding the repository. The three repository systems studied will have similar extensions and will therefore be intersected by similar discontinuities. The overall conclusion is that the differences connected to the far-field rock are in general very small.

3.8 Biosphere

The repository area in all three systems is assumed to be about 3 km^2. The compared repositories have been assumed to be located in the same rock volume. The overlying recipients are therefore expected to be similar.

3.9 Radionuclide migration pathways

Migration in the near-field barriers includes migration through the bentonite buffer and in the disturbed zone surrounding deposition holes and tunnels. After water-saturation, the low hydraulic conductivity in the bentonite buffer will restrict the groundwater flow, and diffusion will constitute the dominating transport mechanism. Examples of processes that may alter the buffer and increase the hydraulic conductivity are:

- chemical alteration due to ion-exchange with calcium,
- transformation of montmorillonite to hydrous mica (illite).

Radionuclides escaping from a canister will be diluted in the pore water and delayed due to sorption on the bentonite surfaces. This retardation will significantly reduce the amount of released short-lived radionuclides. The escaping radionuclides must in all cases migrate a distance through the bentonite buffer in order to emerge in the disturbed zone or a fracture zone in the vicinity of the deposition hole.

The radionuclide migration in the disturbed zone surrounding the deposition holes and the tunnels is dependent on parameters like the Darcy velocity, the area available for sorption and matrix diffusion.

The excavation disturbed zone around a blasted tunnel is larger than around a bored tunnel. This zone may provide a pathway for the escaping radionuclides. If the distance between the canister and this disturbed zone is found to be of large importance for the safety of a repository, than it is possible to modify the layout, e.g. deeper deposition holes.

Radionuclides migrating in the disturbed zone may be significantly retarded compared to the water velocity because of sorption on available fracture surfaces and diffusion into the rock matrix followed by sorption on the inner surfaces of the rock. The magnitude of these retardation mechanisms will to a large extent be determined by the flow-wetted surface per volume of flowing water. A larger flow wetted surface increase the retardation. Blasted tunnels will obtain a larger disturbed zone and thereby get a larger flow wetted surface compared to bored tunnels.

The fuel in the canisters generates heat. The obtained thermal gradient may affect the water flow and the migration of radionuclides in the bentonite buffer as well as in the disturbed zones. The effect of this thermal gradient is, however, largest during a relatively short initial time period extending some hundreds of years. Therefore, the impact, of the thermal gradient on the migration of radionuclides from canisters without initial defects, is considered to be insignificant in a long-term perspective.

The radionuclide migration in the near-field will as well be dependent on the direction of the hydraulic gradient compared to the direction of tunnels and holes.

3.9.1 KBS-3

The migration of escaping radionuclides in the bentonite buffer is controlled by diffusion. However, high gas pressure induced by corrosion within the canister might induce displacement of contaminated water and piping in the buffer. These pipes can act as release paths for radionuclides.

The flow-paths of main interest in the near field for escaping radionuclides are the disturbed zones that will surround all drifts, fractures and the fracture zones close to the deposition hole. Radionuclides escaping from a defect in the canister must, however, migrate from the canister to one of the larger flow-paths, see Figure 3-10.

The identified migration paths for the radionuclides escaping a KBS-3 V repository are:

1. Diffusion through the bentonite buffer to fractures intersecting the deposition holes.

2. Diffusion upward in the bentonite buffer in the deposition hole to the deposition tunnel and further diffusion into intersecting fractures or fracture zones. The radionuclides will be retarded in the backfill in the deposition tunnel due to sorption.

3. Diffusion through the bentonite buffer to the disturbed zone surrounding the deposition hole and subsequent migration in the disturbed zone surrounding the deposition hole, or through a fracture intersecting the deposition hole, to the disturbed zone around the drift. If the extension of the EDZ is as small as assumed in this study (3 cm), this pathway is of secondary importance. If the extension of this zone is larger than assumed here, this zone will constitute an important migration pathway for radionuclides to the deposition tunnel.

4. Diffusion through the bentonite buffer and migration through the rock to a fracture zone located close to a deposition hole.

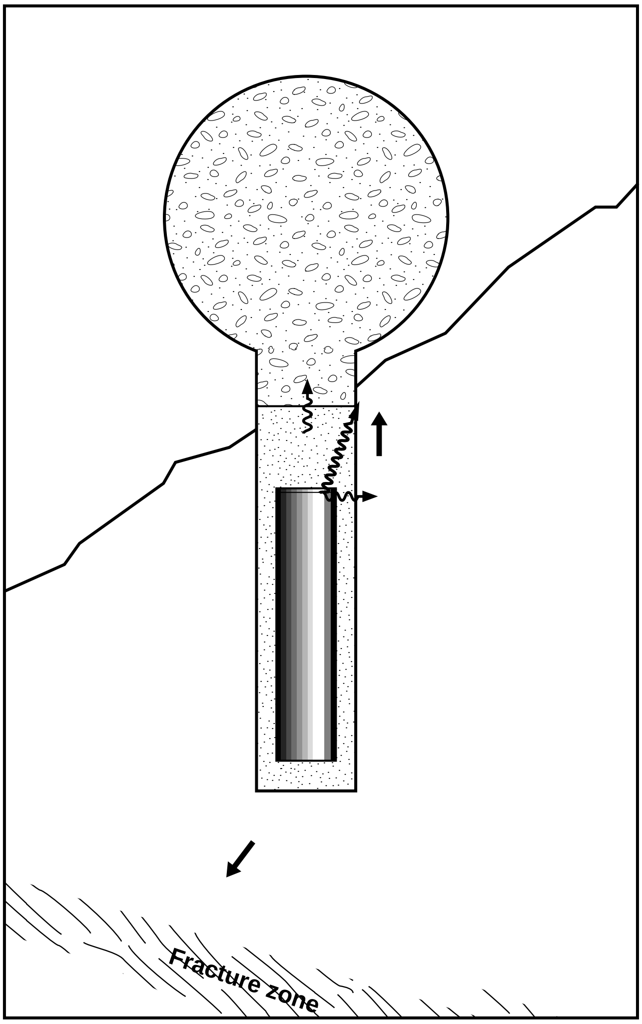

Figure 3-10 Migration pathways for radionuclides in the near-field (KBS-3 V).

In case 1, the radionuclides have to migrate at least about 0.35 m in the bentonite surrounding the canister before entering a fracture intersecting the deposition hole.

In case 2, the migration distance for the radionuclides in the bentonite is dependent on the location of the defect in the canister, but will be considerably longer than the 0.35 m mentioned for case 1. A probable location for a failure in the canister is in the weld at the lid. Migration through the backfill in the tunnel will further retard and delay the radionuclides before entering a fracture or fracture zone intersecting the deposition tunnel.

In case 3, the radionuclides have to migrate at least about 0.35 m in the bentonite surrounding the canister before entering the disturbed zone around the deposition hole. The radionuclides can then migrate either in the disturbed zone around the deposition hole or within a fracture intersecting the deposition hole and connecting to the disturbed zone around the tunnel. The distance between the bentonite/deposition hole interface and the disturbed zone around the tunnel is in the order of meter(s) dependent on the location of the canister failure. A fracture located in rock where the stresses are altered due to the presence of the deposition hole as well as the drift might have a significantly increased hydraulic conductivity.

In case 4, a fracture zone is located close to the canister and can therefore act as important pathways for escaping radionuclides. The radionuclides have to migrate through at least 0.35 m bentonite first and than either diffuse through the rock or migrate in a fracture zone.

The migration pathways for radionuclides in the near-field from a KBS-3 H repository are analogous to those from the KBS-3 V repository described above.

3.9.2 MLH

The migration of escaping radionuclides in the bentonite buffer is controlled by diffusion. However, high gas pressure induced by corrosion within the canister might induce displacement of contaminated water and piping in the buffer. These pipes can act as release paths for radionuclides.

The flow-paths of main interest in the near-field for escaping radionuclides are the disturbed zone surrounding holes and tunnels, fractures and fracture zones intersecting the deposition holes. If a disturbed zone larger than assumed (3 cm) is developed, this zone will form a migration pathway for radionuclides along the deposition hole to intersecting fractures or fracture zones or to the transport tunnel. Possible migration pathways from a defect in a canister are illustrated in Figure 3-11.

The identified migration paths for the radionuclides escaping a MLH repository are:

1. Diffusion through the bentonite into the disturbed zone around the deposition hole or directly into fractures in the deposition hole and transport away from the deposition tunnel in this fracture.

2. Diffusion through the bentonite buffer and migration from the disturbed zone through the rock to a fracture or a fracture zone intersecting or located close to the deposition hole.

3. Diffusion through the bentonite buffer and migration in the disturbed zone around the deposition hole to the disturbed zone around the transport tunnel. This is a pathway mainly for radionuclides escaping from canisters disposed close to the transport tunnel.

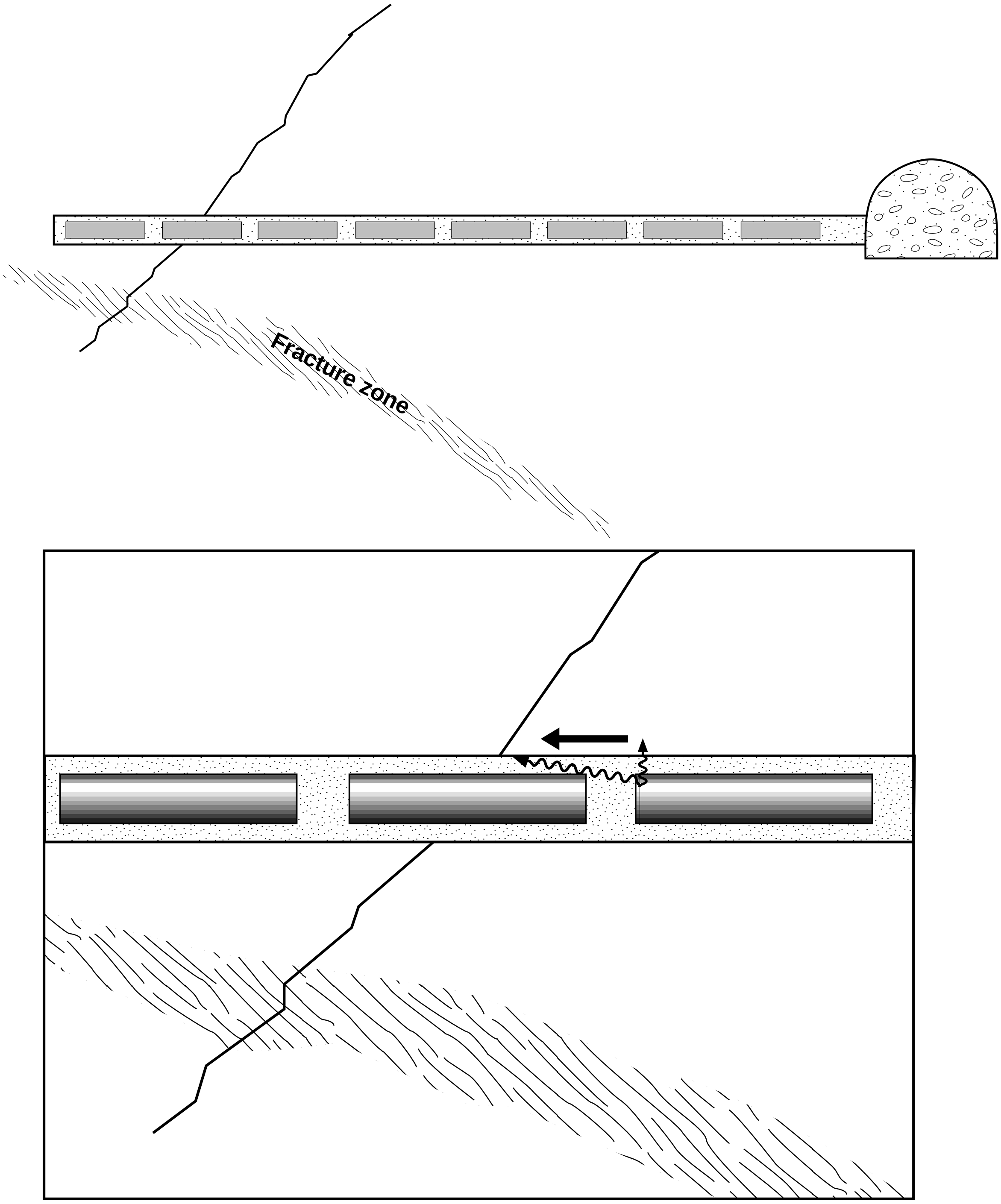

Figure 3-11. Migration pathway for radionuclides in the near-field (MLH).

Differences between the repository systems

An example of a difference between the repository systems is the distance between the canisters and the backfilled tunnels. This distance is considerably shorter for the KBS-3 systems. This difference and other differences between the repository systems that have implications on the radionuclide migration are discussed in Chapter 4.

3.10 Summary of background information and presumptions

The background information and presumptions concerning the three repository systems described in the previous sections (3.1 - 3.9) are summarised in Table 3-6.

Table 3-6 Summary of background information and presumptions.

	KBS-3 V (reference system)	**KBS-3 H**	**MLH**
Fuel			
BWR element/canister	12	12	12
Canister			
Number of canisters	3 800	3 800	3 800
Deposition position	Vertical	Horizontal	Horizontal
Dimensions, length/diameter (m)	4.83 / 1.05	4.83 / 1.05	4.83 / 1.05
Deposition hole			
Technique	Bored	Bored	Bored
Diameter (m)	1.750	1.750	1.750
Length per canister (m)	7.83	7.83	7.70 [a)]
Total length (m)	29 754	29 754	29 252
Bentonite thickness (m) (sides/top/ bottom)	0.35 / 1.5 / 0.5	0.35 / 2.5 / 0.5	0.35 / 0.6 / 0.6
Shortest distance between canisters (m)	~6	~6	1.2
Inclination	Vertical	2 degrees	2 degrees
Plug to tunnel (weight %)	1m thick bentonite/crushed rock (15/85)	1m thick bentonite/crushed rock (15/85)	Cement plug
Deposition tunnel			
Excavation technique	Bored [b)]	Bored [c)]	
Dimension, diameter (m) [d)]	5	6.2	
Total length (m)	28 015 [e)]	15 847 [f)]	
Length per canister (m/canister)	7.37	4.17	
Tunnel backfill (weight %)	Bentonite/crushed rock (15/85)	Bentonite/crushed rock (15/85)	
Plug to transport tunnel	Concrete	Concrete	
Transport tunnel			
Technique	Blasted	Blasted	Blasted
Dimension (width×height) (m)	7×6.8 [g)] / 7×6 [h)]	7×6.8 [g)] / 7×6 [h)]	8×6 [g)] / 7×6 [h)]
Length (m)	2200 [g)] / 2000 [h)]	1900 [g)] / 2000 [h)]	2200 [g)] / 2000 [h)]
Backfill (weight %)	Bentonite/crushed rock (15/85)	Bentonite/crushed rock (15/85)	Bentonite/crushed rock (15/85)
Access tunnel			
Backfill (weight %)	Bentonite/crushed rock (15/85)	Bentonite/crushed rock (15/85)	Bentonite/crushed rock (15/85)

a) including 20 length% bad rock.
b) an alternative in KBS-3 V is blasted tunnels, 4.2 m wide and 5 m high
c) an alternative in KBS-3 H is blasted tunnels, 6.2 m wide and 5 m high
d) assumed from Ageskog /2001/. The widest measure from blasted tunnels has been selected
e) including 10 length% bad rock
f) including 12 length% bad rock
g) transport tunnels in deposition area
h) transport tunnels outside the deposition area

4 Qualitative comparison of the repository systems with respect to the long-term function and safety

Differences in the expected function of the repository systems that may influence the long-term function and safety have been identified. The identification of the differences has been based on going through the interaction matrices developed for the KBS-3 V repository system for the SR 97 safety study. Within SR 97, all interactions were classified based on their importance for the long-term safety. The following classes were used:

- *important* interaction that should be part of the safety analyses,
- interaction with *limited or uncertain* influence,
- interaction with *negligible* influence.

The *important* interactions in the interaction matrices for the near-field /Pers et al, 1999/, the buffer* /Pers et al, 1999/, and the far-field /Skagius et al, 1995; Pers et al, 1999/ have been considered in the comparison. Identified differences between the repository systems have been documented in three JADE databases (near-field, buffer and far-field). The databases are available on Compact Disc, see Appendix D.

The identification of differences between the repository systems was carried out in two steps. Firstly, the important interactions including differences were identified. The documentation alternatives were; "Include difference (Yes)", "Include no difference (No)" or "Uncertain". In the second step the differences marked with "Yes" or "Uncertain" in step 1 were judged either to have "Influence", "Uncertain influence", or "No influence" the repository long-term function and safety.

The identification of differences between the repository systems is documented in a database. The database, which is available on Compact Disc in FileMaker Pro format, is described in Appendix D.

A compilation of the number of important interactions and the number of interactions identified to include differences of potential importance for the long-term repository function and safety is given in Table 4-1.

* Some interactions are important only during the water saturation phase (pink interactions in the buffer matrix), these interactions have not been considered for the repository long-term function and safety.

Table 4-1 Number of interactions in the matrices.

Interaction matrices	Important interactions	Step 1		Step 2	
		Include differences	Uncertain	Differences that influence safety	Differences with uncertain influence
Near-field	103	70	1	32	30
Buffer	63	30	2	13	11
Far-field	61	19	3	8	9
Total	227	119	6	53	50

Short descriptions of the identified differences that are expected to influence the repository performance are given below.

4.1 Canister position

One basic difference between the three repository systems is that the canisters will be disposed either in a vertical position (KBS-3 V) or in a horizontal position (KBS-3 H and MLH). This will induce differences in the repository performances, which are discussed below.

The cast steel insert in the canister is neglected as a barrier for the radionuclide migration.

Filling the deposition holes with water

Subsequent to the deposition, the gaps between rock-bentonite and between bentonite-canister are filled with air. The air will however be replaced with water due to the natural water inflow, if man does not fill the gaps with water. An advantage with KBS-3 V, compared to both MLH and KBS-3 H, is that it is possible to replace the air with water. This will reduce the risk to get air trapped in the deposition hole (see section "*Heat conduction*") and will as well reduce the risk for very uneven swelling of the bentonite during the resaturation. Uneven swelling may increase the risk for mechanical deterioration of the canister (see section "*Water uptake in the bentonite surrounding the canister during the transient phase*"). Adding of water is expected to have a positive effect mainly for deposition holes with low groundwater inflow (see Appendix B).

The gaps between rock-bentonite and between bentonite-canister is theoretically 50 and 10 mm respectively in KBS-3 V. The total volume of the gaps in one deposition hole, if no pellets are added, is estimated to 2 m^3 for KBS-3 V. This volume is roughly equal to the water volume needed to saturate the bentonite (see Appendix B). If the groundwater flow into the hole is low (1 l per hour and hole) it takes more than 3 month for 2 m^2 of groundwater to enter the hole.

There might be a negative effect of filling the deposition holes with water if the canister has an initial defect. The release of radionuclides from the defect canister presumes that water enters the canister, the radionuclides dissolve in the water and migrate away from the canister. This process is initiated earlier if water is added to the deposition hole.

There is a risk that air is trapped in the long inclined (2 degrees) deposition holes in MLH. If the air is trapped outside the bentonite buffer it is most likely that the air will dissolve in the ground water or migrate through fractures in the bedrock. On the other hand, gas remaining in the gap between canister and bentonite may be trapped.

Initial defect in the welds

One or a few of the disposed canisters might have an initial defect that has not been observed during the quality controls. The copper canister has two longitudinal welds in addition to the welds at the bottom and at the lid, see Figure 4-1. The first three welds can be carefully inspected from the outside as well as from the inside. The weld around the lid is made after fuel emplacement and can consequently only be inspected from the outside. The risk is largest that an initial defect occurs in this weld. The size of the defect is assumed to be restricted to a few mm^2.

Radionuclides may be released from this initial defect in the canister by diffusion, by advection, or with water displaced by gas. The position of the defect influences the release of radionuclides. The most unfavourable location of a defect is in the lowest part of the canister as positioned in the deposition hole. The reason is that this would allow the total amount of water inside the canister to be expelled by gas. In this respect, the vertical position of the canister in the deposition hole as in the KBS-3 V system is more favourable than the horizontal in the KBS-3 H and MLH systems. The weld at the lid in a KBS-3 V canister is always located in the highest positioned part of the canister while this weld is partly located in the lowest part in a horizontal canister.

Figure 4-1 illustrates possible positions of an initial defect in the canister lid weld.

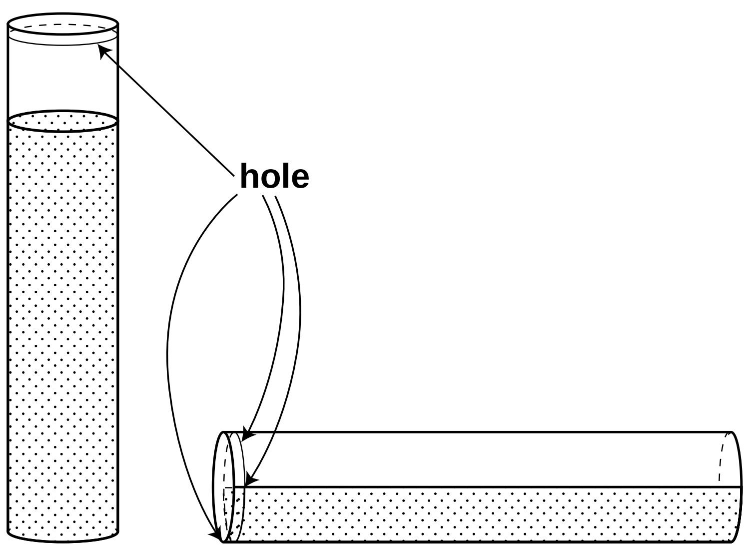

Figure 4-1 Possible positions of an initial defect in the canister.

Position of initially intact welds

All welds might be initially intact, but the welds are still expected to constitute the part of the canister where corrosion is most likely to occur. The most unfavourable location of a defect is still in the lowest part of the canister. Both horizontal and vertical canisters have long welded sections located in a low position.

Surface area within the canister available for reactions

Water penetrating a defect canister may initiate a number of reactions e.g. fuel alteration, fuel dissolution/precipitation, radiolysis, sorption/desorption, instant release of soluble elements in gaps and cracks, and corrosion of metals (copper, steel and zircaloy). These processes depend, at least to some extent, on the contact surface area between the penetrated water and the reacting material. A horizontal position of the canister will result in larger contact surfaces until the canister is half-filled with water. Production of gases due to corrosion will probably lead to that the canister will mainly be less than half-filled with water, which implies that a vertical position of the canister (KBS-3 V) is preferable. However, the first water entering the canister may evaporate if the fuel is still hot. In this case, there is no difference between a vertical and a horizontal canister with respect to the contact surfaces for reaction within the canister.

Heat conduction

Air trapped in the gap between the canister and bentonite will reduce the heat transfer somewhat. This might increase the temperature inside the canister and thereby lead to increased canister surface temperatures. Consequently, there is a risk that bentonite in contact with these canister surfaces may obtain a too high temperature. The risks for limited heat transfer is probably largest in horizontal deposition holes, see section "*Filling the deposition holes with water*" above.

4.2 Emplacement of bentonite and canister

The emplacement methods differ between the repository systems. In KBS-3 V, the canisters are disposed in a vertical position and in KBS-3 H and MLH the canisters are disposed in a horizontal position. The length of the deposition holes differs from 7.8 m in KBS-3 to 250 m in MLH. In KBS-3, the deposition holes are bored from a deposition tunnel and the buffer surrounding each canister interact with the backfill in this tunnel. In addition to the differences mentioned above, there are some planned complementary technical measures that can be taken to increase the barrier performance. The consequences of identified differences and the possibility to take planned complementary technical measures are discussed below.

Deterioration of bentonite during emplacement

The length of the deposition holes is about 7.8 m in the KBS-3 systems and in average 250 m in MLH. Assuming the same water inflow per meter deposition hole will give a larger total water flow in the MLH deposition hole due to the length. In MLH, the canister/bentonite package will be placed in the inner part of the hole. However, a large amount of water will flow in the bottom of the deposition hole. This water will thereby pass the bentonite during the saturation phase since it will take some time for the previously installed canister/bentonite packages to swell and prevent the water flow. This water might carry out some of the bentonite. This scenario imply that the bentonite surrounding the canisters in MLH might get lower density, and thereby higher hydraulic conductivity, compared to the bentonite surrounding the canisters in KBS-3 V. The problems will probably be smaller for KBS-3 H than for MLH due to the shorter deposition holes. The application method can probably be developed in order to avoid a decreased bentonite density.

An alternative for MLH would be to install a few canister/bentonite packages and then prevent the water out-flow by installing a temporary plug which will be removed when the buffer has expanded. This would certainly reduce the risk for groundwater to carry out bentonite and make adding of water possible. A permanent concrete plug would bring engineering materials in contact with the bentonite. Possible negative effects of engineering materials are discussed in section 4.4.

Filling gaps and rock fall-outs with bentonite pellets

The density of the bentonite buffer surrounding the canisters can be increased if the gaps between the rock-bentonite are filled with bentonite pellets. This is judged to be possible only in vertical deposition holes, i.e. KBS-3 V. It might, however, be possible to add bentonite pellets at the upper interface between buffer and rock also in MLH and KBS-3 H. This will require some technical development.

Added pellets might lead to uneven bentonite densities in the deposition hole. A possible effect of this is uneven stresses on the canister, which may increase the risk for mechanical deterioration.

The gaps might occur anywhere around the rock-bentonite interface. Filling these gaps might result in an eccentrically position of the canister after saturation. The deviation from a centric position is estimated to be in the order of a few centimetres /Börgesson, 1997/. The impact of an eccentrically position is that radionuclides escaping the canister may get a slightly shorter migration length through the bentonite. The consequence of this, with regard to the release to the biosphere, is however mainly restricted to short-lived radionuclides (e.g. Sr-90, Cs-137) from an initially defect canister via a fast pathway through the bedrock.

Irregularities in the deposition holes might lead to uneven densities of the bentonite buffer, which may lead to an eccentric canister position as well as uneven stresses on the canister. One way to compensate for this in vertical deposition holes (KBS-3 V) is to add bentonite pellets in the voids.

It should however be noted that addition of pellets to a deposition hole would increase the total stress on the canister. This negative effect is judged to be less significant than the positive effects related to adding pellets.

Although the canister is heavy and has a high density it is assumed for all three repository systems that the canister will stay in place and not sink through the bentonite.

Water uptake in the bentonite surrounding the canister during the saturation phase

The water uptake in the bentonite will probably be very uneven during the saturation phase since the emerging water mainly originate from a small number of water conductive fractures. Uneven uptake of water in the bentonite can cause sheer stresses that might affect the integrity of the canister.

The magnitude of the forces that might be introduced by the bentonite is well above the force introduced by the weight of the canister. This implies that there is no significant difference between a canister disposed horizontally or vertically if the geometric pattern of the intersecting water conductive fractures is the same. Uneven swelling is not judged to cause cracking of the canisters in any of the deposition systems /Börjesson, 1997/.

The gaps between rock-bentonite and between bentonite-canister can be filled with water subsequent to deposition in vertical holes (see "*Filling the deposition holes with water*" above). This will reduce the risk for uneven swelling. It might also be possible to fill the gaps in horizontal deposition holes by installing temporary constructions.

4.3 Deposition Tunnel

Properties at the interface between the deposition holes and the deposition tunnels

All canisters disposed in the KBS-3 H and KBS-3 V systems are, in contrast to the canisters in MLH, located close to a tunnel (the deposition tunnel). The properties in the bentonite surrounding the canisters in KBS-3 H and KBS-3 V is therefore to some extent dependent on the properties of the tunnel backfill.

The density of the backfill in the deposition tunnel is highest in the bottom of the tunnel. The materials in the deposition holes in KBS-3 V is therefore in contact with backfill having a relatively high density whereas the materials in the deposition holes in KBS-3 H will be in contact with backfill having lower density. The KBS-3 V system will probably be preferential even though the swelling forces from the bentonite buffer partly has to be taken up by the low density backfill at the ceiling of the deposition tunnel straight above the deposition hole.

Rock slabs adjacent to the deposition holes can be developed during the repository construction or after repository sealing due to heat generation from the canisters or due to rock movements. Expansion of the buffer into the deposition tunnel (KBS-3) or transport tunnel (MLH) may move the rock slabs, see Figure 4-2. This can result in degenerated properties of the buffer. This risk is larger in KBS-3, compared to, MLH due to a larger number of deposition holes. Furthermore, there is a concrete plug between the deposition holes and transport tunnels in MLH.

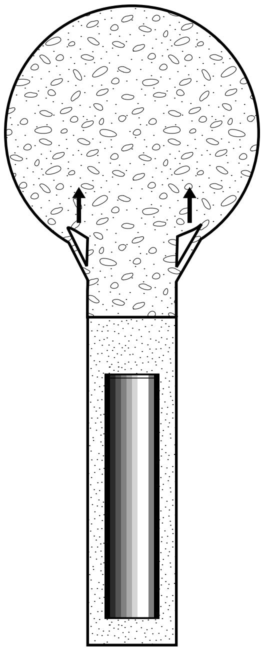

Figure 4-2 Possible motion of rock slabs at the interface between deposition holes and deposition tunnels in KBS-3 V.

Backfill in deposition tunnels

The deposition tunnels will be backfilled with bentonite/crushed rock (15/85). The hydraulic properties in the backfilled deposition tunnels will therefore be inferior compared to the properties in the bentonite buffer surrounding the canisters.

All canisters disposed in accordance with the KBS-3 repository systems is located just a few meters from the backfilled deposition tunnels. The canisters disposed in MLH are, in average, located in the order of one hundred meter from the backfilled tunnels. The properties of the backfill in the tunnels will therefore have larger impact on the bentonite properties close to the canisters in the KBS-3 systems compared to MLH. Unexpected events such as rapid degradation of the bentonite in the tunnel, rock movements, and backfill settlement will therefore have larger impact on the KBS-3 systems. Furthermore, the amount of backfill is significantly larger in KBS-3.

Another difference is related to possible changes in the groundwater composition due to the introduction of backfill. Since the amount of backfill is larger in KBS-3, the impact on the water chemistry is larger.

Heat is generated in the canisters due to radioactive decay. This will increase the temperature in the buffer and tunnel backfill. The temperature increase in the backfill is expected to be relatively limited for all three repository systems. The difference between the deposition tunnels and transport tunnels is only a few degrees. The limited temperature increase is not judged to significantly increase the degradation of the backfill.

4.4 Engineering and stray materials

Corrosion and degradation of engineering materials will result in formation of corrosion/degradation products. These chemical species might influence the water chemistry (pH, redox conditions, concentrations of ions and organics) which might have impact on the repository performance and the properties of the buffer, backfill and the canister. Engineering material introduced in the vicinity of the bentonite surrounding the canister will have larger impact.

A fundamental difference between the KBS-3 and the MLH systems is that people will work in the MLH deposition holes during construction and that operation and transportation takes place in those holes. This puts high demands on the rock stability in the MLH holes. Therefore, engineering materials are used to reduce water inflow and increase the rock stability in the MLH deposition holes. The human activities in the KBS-3 deposition holes are mainly restricted to the mapping of the holes. The amount of engineering materials in contact with and in the vicinity of the bentonite buffer will therefore be larger in MLH compared to the KBS-3 systems although the canisters will be disposed in sections with good rock where the use of engineering materials can be limited.

Grouting

Hydroxide ions leached from the cement may interact with smectite forming zeolites and hydrosilicates, which will reduce the elastic properties of the buffer.

Cement injected during the boring of the *deposition holes* is located close to the buffer/canister and will therefore have potential to affect the long-term properties. Cement is injected into the rock before the boring of the deposition holes in all three repository systems.

Cement will also be injected into fracture zones and larger fractures during the boring and construction of the *deposition tunnels* in the KBS-3 systems. The cement injected in the bedrock around the deposition tunnel will be fairly close to the bentonite buffer and canister in KBS-3. The cement injected around the transport tunnels in MLH will have less impact on the buffer/canister due to the long distance between the canisters and the transport tunnel.

Shotcrete

Shotcrete will mainly be used as mechanical support to the ceiling and the upper part of the walls in the deposition and transport tunnels. The shotcrete will be in direct contact with the backfill in the deposition and transport tunnels. Degradation of the backfill in the deposition tunnel might affect the properties of the bentonite buffer surrounding the canister.

The potential impact of buffer degradation due to reaction with the degradation products from the shotcrete in the KBS deposition tunnel and the MLH transport tunnel is different for the repository systems due to different average distances between the deposition tunnel and the canisters. Shotcrete is applied closer to the canister in the KBS-3 systems.

Considerable amounts of shotcrete might be used in the MLH deposition holes where fracture zones intersect. These sections will not be used for canister disposal.

Concrete plugs

Concrete plugs are used only at the interface between MLH deposition holes and transport tunnels and if a deposition hole has to be plugged off when intersecting a fracture zone. Concrete plugs will not be used in the KBS-3 deposition holes.

The potential impact of the concrete in the deposition holes in MLH is degradation of the buffer due to reaction with the concrete degradation products. However, the canister and the concrete plug are separated with a bentonite plug, at least one meter thick.

Rock bolts and steel fabrics

Rock bolts and steel fabrics, consisting of iron, will be used in the tunnels in all three repository systems, in order to stabilise the rock and prevent stones from falling. Rock bolts and possibly also steel fabrics will be used in the deposition holes in MLH. These reinforcements will corrode and thereby release corrosion products that might affect the repository performance and radionuclide migration.

Dissolved Fe(II) may interact with the bentonite in the buffer by ion-exchange where sodium will be replaced. This process occurs in competition with the sodium-calcium exchange and is expected to have a similar effect on the physical properties of the bentonite buffer. Iron may also precipitate in the buffer and reduce the porosity, but also reduce the elastic properties of the buffer.

Stray materials

Stray materials include organic materials, oil spill, acids from batteries etc. The organics might form complexes and colloids. Inorganic materials, such as nitrogen oxides from blasting and acids from batteries, might for example influence the chemical composition and the pH in the near-field groundwater.

A difference between the KBS-3 and the MLH systems is that people will work more in the deposition holes in MLH than in the KBS-3 holes and that the holes in MLH will be used for transportation. The human activities in KBS-3 deposition holes are mainly restricted to the mapping of the holes. Furthermore, it is easier to clean horizontal holes (KBS-3 H and MLH).

Copper mesh

One of the deposition methods that could be used in MLH, is deposition of the canister and bentonite as one unit kept together by a copper mesh. The mesh will be left in the deposition hole. When the bentonite is saturated, this mesh will be situated a few centimetres from the rock-bentonite interface. Dissolved copper may interact with the bentonite in the buffer by ion-exchange where sodium will be replaced by copper. This process occurs in competition with the sodium-calcium exchange and is expected to have a similar effect on the physical properties of the bentonite buffer. Copper may also precipitate in the buffer and reduced the porosity and the elastic properties of the buffer. The amount of copper in the mesh is small compared to the amount in the canister, but the surface area of the mesh will be considerable. Furthermore, the bentonite buffer separates the mesh and the radionuclides. The long-term repository performance of the repository as well as the radionuclide migration is judged to be less influenced by the copper mesh compared to the copper in the canister.

Comparison of engineering and stray materials in the different repository systems

The amounts of engineering and stray materials as well as their potential impact on the repository performance differ between the different repository systems. The main reasons are:

- Most stray materials are expected to be located in the deposition tunnel or transport tunnel. The distance from these drifts to the canister positions is larger in MLH compared to the KBS-3 systems.
- The total amount of engineering and stray materials will be largest in KBS-3 V due to the larger excavated rock volume.
- More human activities takes place in the deposition holes in MLH. This increases the amount of engineering and stray materials in the deposition holes.
- It will be easier to clean horizontal holes (KBS-3 H and MLH).
- Transportation will take place in the MLH deposition holes.
- A mesh of copper may be left in the deposition holes of MLH.

Engineering and stray materials in or in the vicinity of the deposition holes will probably have the largest impact on the long-term repository performance and the radionuclide migration. The differences between the repository systems can be summarised as:

- KBS-3 H will have the smallest amounts of engineering and other stray materials in the deposition holes.
- The difference between KBS-3 V and MLH is that more human activities take place in the MLH deposition holes. This will probably result in larger amounts of engineering and stray materials close to the canisters in MLH even though it is easier to clean horizontal holes.

4.5 Microbial activity

The risk for microbial activity in a repository increases with available rock surface area but also with the time the tunnels and holes are kept open. The deposition holes in KBS-3 has an estimated total rock surface area of 160 000 m^2 and the total rock surface area in MLH deposition holes is estimated to 150 000 m^2. The deposition tunnel in KBS-3 has the largest surface area 440 000 m^2 in KBS-3 V and 310 000 m^2 in KBS-3 H. The transport tunnels have an estimated total rock surface area of about 100 000 m^2. The time the tunnels and deposition holes will be kept open is dependent on the time needed for boring and deposition as well as for quality and safety control. The time period the holes and tunnels are open has not been quantified.

The microbiological activity in the deposition holes of MLH is expected to be larger than in the deposition holes of KBS-3 due to more human activities and transportation. The total microbial activity is however expected to be largest in KBS-3 V due to the large rock wall surfaces in the deposition tunnels.

4.6 Near-field rock

The behaviour of the rock close to the repository, the near-field rock, is dependent on factors such as:

- local geology,
- stress field,
- repository layout,
- excavated rock volume,
- excavation method.

These factors will influence the stress situation in the rock adjacent to tunnels, extension of excavation disturbed zones, fracturing, near-field water flow and the possibility to characterise the rock volume at repository depth.

Rock stress situation

The stress situation in the rock mass influences the stability of excavated tunnels and deposition holes. The impact depends on the excavation method as well as the layout and the orientation of tunnels and holes. The stress situation also influences the conductivity and the potential for propagation and sealing of the near-field fractures. A comparison between the three repository systems (see Table 4-2) can be summarised as:

- MLH is the most robust deposition method because the stability of the rock surrounding the deposition holes is less influenced by the stress orientation.
- KBS-3 (H and V) with bored deposition tunnels is the best alternative if the orientation of the tunnels can be optimised in the rock stress field. On the other hand, the stability of the rock in the KBS-3 systems with blasted tunnels (especially KBS-3 H) is dependent ono variations in the stress field orientation.

It is however important to note that most of the rock mechanical properties can be handled during the construction and operation of the repository. Rock stability can be increased with rock bolts and shotcrete, water leakage can be decreased with grouting etc. Effects that are difficult to handle in a long-term safety perspective are related to fracture movements and water flow in the near-field /Munier, 1997/. From this perspective it can be concluded that:

- KBS-3 (H and V) with bored deposition tunnels are the best alternatives if the orientation can be optimised.
- MLH is somewhat less favourable.
- KBS-3 with bored deposition tunnels are favourable compared to blasted tunnels.

Table 4-2 Relative stability in rock with simplified structures. The orientation of the deposition holes studied are perpendicular (⊥) and parallel (||) to the principal rock stress orientation. (1= small importance, 4= large influence and high frequency) **/Munier et al, 2001/.**

Repository system	Orientation	Block loss	Overload	Fracture movements	Influence on water flow	∑
KBS 3-V, bored tunnel	⊥	2	4	3	2	11
KBS 3-V, blasted tunnel	⊥	3	3	3	4	13
KBS 3-H, bored tunnel	⊥	2	4	3	2	11
KBS 3-H, blasted tunnel	⊥	2	3	4	4	13
MLH	⊥	2	2	2	2	8
KBS 3-V, bored tunnel	||	2	2	2	1	7
KBS 3-V, blasted tunnel	||	3	2	2	4	11
KBS 3-H, bored tunnel	||	2	2	1	1	6
KBS 3-H, blasted tunnel	||	2	1	1	4	8
MLH	||	2	1	1	4	8

Discrimination of canister positions

Discrimination of deposition holes/positions influences the extension of the repository. The difference in number of discriminated canister positions between the three repository systems is judged to be small, based on a study of an Aberg type of rock /Munier et al, 2001/. The number of discriminated canister positions have been considered in the estimations of the bentonite buffer and backfill volumes given in Chapter 3.

Rock characterisation

Discontinuities can, very simplified, be divided into four classes D1, D2, D3 and D4. Class D1 represents the largest discontinuities and should not intersect the repository. Further information can be found in Appendix A. The possibility to locate and characterise fractures classified as D2, D3 and D4 will differ between the repository systems. The possibility to characterise the rock is in general better in KBS-3 V compared to KBS-3 H and MLH due to the following factors /Sandstedt et al, 2001/:

- The excavated volume of rock is larger in KBS-3 compared to MLH.
- KBS-3 V provides a three-dimensional random sample domain (with respect to D3-D4) since the excavation takes place in three perpendicular directions.
- MLH will give information within a two-dimensional domain (D3-D4).
- The amount of information in KBS-3 H is equal to KBS-3 V, but the domain is two-dimensional (with respect to D3). Furthermore, characterisation of subhorizontal fractures is more difficult in KBS-3 H compared to KBS-3 V.

The influence on the long-term function and safety of the repository, due to the different possibilities to characterise the rock, is that the distance from a disposed canister to an unidentified fracture or fracture zone can be shorter in KBS-3 H and MLH compared to KBS-3 V. This might decrease the travel times of radionuclides from the repository to the biosphere.

Drilling of investigation boreholes in the vicinity of the repository would add valuable information that could be used in the evaluation of the hydrological and geological properties of the host rock. A few boreholes drilled in suitable directions would significantly reduce the difference in information between the repository systems regarding the knowledge of fracture zones. These boreholes will be plugged after the characterisation programme and will therefore constitute a relatively limited disturbance.

Designing a repository where the deposition takes place at several levels would give a better possibility to characterise the rock in three dimensions independent of repository system. This would therefore reduce the differences between the repository systems identified above. It should however be noted that deposition at several levels might have negative influences on the heat propagation as well as on other factors.

Excavation disturbed zone

The extension of excavation disturbed zones (EDZ) around the tunnels and deposition holes is influenced by the orientation of tunnels in the rock stress field, the excavation method etc.

In MLH, the deposition holes are bored and the transport tunnels are blasted. The extension of the disturbed zone around the deposition holes will therefore be limited to a few centimetres, see Figure 3-9. The disturbed zone around the blasted transport tunnels is larger than around the bored deposition holes. The impact of the disturbed zone around the transport tunnel will probably be very small due to the long distance to the canisters. The permeability in the disturbed zone around the deposition hole will probably be increased compared to the adjacent rock, but the impact of the zone will be quite small because of the limited extension.

In KBS-3, the deposition holes are bored and the deposition tunnel either bored or blasted. This study is based on bored deposition tunnels. This would, as in MLH, result in quite small effects due to the disturbed zone.

The extension of the EDZ around bored holes and tunnels has been assumed to be 0.03 m based on the ZEDEX experiments. The hydraulic conductivity in the EDZ is expected to be somewhat increased compared to the surrounding rock. The disturbed zone can act as a short and fast pathway for radionuclides escaping from a defect canister. Since the water flow rates are increased in the EDZ, the radionuclides diffusing through the bentonite buffer will be diluted in a large water volume. Furthermore, the induced fracturing in the EDZ will give additional surfaces available for matrix diffusion and sorption of radionuclides. The overall conclusion is that the disturbed zone has negative (pathway) as well as positive effects (sorption, matrix diffusion, dilution) with respect to radionuclide migration. The net effect is however judged to be negative.

It is assumed that the EDZ around deposition tunnels and deposition holes have the same extension and hydraulic properties in all three repository systems. The distance between a canister and the closest EDZ is equal. Since the distance between the canister and the deposition tunnel is relatively short in the KBS-3 systems, the positive effects due to a larger water volumes and surface areas makes the KBS-3 systems favourable.

If the extension of the EDZ is larger than expected and dependent on the diameter of the tunnel/hole, this would increase the importance of the EDZ, especially for tunnels with large diameters. The hydraulic conductivity might as well be considerably higher in the EDZ compared to the undisturbed rock. The impact of a larger EDZ with respect to radionuclide migration is judged to be the same for the two KBS-3 systems. However, there would be a significant difference between the KBS-3 systems and MLH. The deposition holes in KBS-3 and MLH have the same diameter and therefore the same extension and properties of the EDZ. The EDZ around the deposition tunnel in KBS-3 would be larger and have a higher conductivity compared to the EDZ around the deposition holes. The canisters in KBS-3 would in this case be located close to the large EDZ around the deposition tunnel, which can constitute a fast pathway for escaping radionuclides. In this case, the MLH repository system is judged to be favourable.

The hydraulic situation in and around the deposition tunnel is dependent on the hydraulic properties of the degraded backfill and of the EDZ. In a short-term perspective, when the hydraulic properties of the backfilled tunnel are according to the design specifications, the properties and extension of the EDZ might determine the hydraulic situation. In a long-term perspective, when the backfill in the tunnel has degraded, the importance of the EDZ will be less, especially for the KBS-3 systems.

4.7 Far-field rock

Many of the basic far-field rock properties are quite similar for the three repository systems. The different repositories are supposed to be located in the same rock, at the same depth and they all have similar extension. However, the total volume of excavated rock differs between the KBS-3 systems and MLH. A larger excavated volume, with backfill having hydraulic properties inferior to the bedrock, may increase the water flow in the far-field rock.

Length of deposition hole

The deposition holes might be intersected by several discontinuities classified as class D3. These discontinuities can constitute pathways for radionuclides if the hydraulic properties in the bentonite are deteriorated or if the hydraulic conductivity in the disturbed zone is larger than assumed. The difference in the length of deposition holes has no influence, since the shorter deposition holes in KBS-3 are, however, connected by the deposition tunnel.

Volume of excavated rock

The total volume of excavated rock differs between the KBS-3 systems and MLH. A larger excavated rock volume increase the water flow in the far-field rock if and when the hydraulic properties in the backfilled deposition tunnels are inferior compared to the surrounding rock. A larger excavated volume (KBS-3) may therefore induce a faster radionuclide migration in the far-field rock.

Tunnels and drifts introduce disturbances in the stresses in the adjacent rock. Therefore, a larger excavated volume (KBS-3) cause a larger stress disturbance.

5 Ranking of identified differences

The repository systems have been ranked based on the identified differences. The ranking has not been based on a safety analysis, but on qualified objective judgements carried out in a stepwise manner. Even though the ranking is based on qualified judgements, the judgements are to some extent subjective. Safety analysis for the different repository systems may lead to partly other conclusions than presented in this report. The aim is that the argumentation behind the ranking in the report should be traceable and easy to follow.

5.1 Methodology

The long-term function and safety of three repository systems have been ranked based on prevailing geological and hydrological conditions at an assumed typical repository site in typical Swedish bedrock. Impact of other scenarios such as glaciation, seismic events and human activities have not been included in the ranking, but are discussed in Chapter 6.

The repository systems have been ranked with regard to:

- *Long-term repository performance* of the repository system.
- *Radionuclide migration* from a degraded canister.
- Radionuclide migration from a canister with an *initial defect*.

The *long-term repository performance* represents the estimated possibility for the repository systems to maintain the function of the canister, bentonite buffer and tunnel backfill in a long-term perspective.

The *radionuclide migration* from a degraded canister will depend on the properties of the surrounding barriers at the time for the radionuclide release. The canister is designed to maintain its function during at least 100 000 years.

Ranking has also been performed for radionuclide migration from a canister with an *initial defect*. In this case, the properties of the other barriers are expected to be in accordance with the design criteria.

Possibility to take planned complementary technical measures

In addition to the ranking, the possibility to take planned complementary *technical measures* to influence the repository function has been considered. The differences related to different repository layouts are not possible to influence. Whereas, a difference related to technical differences between the repository systems might be possible to influence by technical development or modifications.

Ranking

The ranking between the repository systems is based on qualified judgements. The KBS-3 V system is the reference repository system to which the other systems, KBS-3 H and MLH, have been compared and summarised in Tables 5-1, 5-2 and 5-3. If the compared repository system was judged to be better than KBS-3 V, the system was assigned a " + ". A " - " indicates that KBS-3 V was considered to be better. A small difference is indicated as "(+)" or "(-)". If the expected difference between the repository systems is judged to be non-existent or insignificant it is indicated with a " = ". In addition, the notation " NA " is used for non applicable comparisons.

The ranking procedure

The identified differences were used for ranking between the repository systems. The ranking was carried out in three steps:

1. Compilation of identified differences that are judged to be of any importance (section 5.2.1 and Table 5-1) extracted from the interaction matrices and the descriptions given in Chapter 4.

2. Comparison of the repository systems with respect to function of each barrier (section 5.2.2 and Table 5-2).

3. Identification of differences that are of such importance for the long-term repository performance and radionuclide migration that they influence the choice of repository system (section 5.2.3 and Table 5-3).

5.2 Ranking

5.2.1 Compilation of identified differences

Identified differences between the three repository systems are compiled in Table 5-1. The compilation is based on differences identified and documented in the JADE databases (see Appendix D) and the descriptions given in Chapter 4. The databases contain more than one hundred identified differences between the repository systems. Many of these differences are related. Each item in Table 5-1 can therefore be based on several of the identified differences. For each item in the table, the function in KBS-3 H and MLH is compared to the reference repository system, KBS-3 V. It is also stated in Table 5-1 whether it would be possible to take planned complementary technical measures to decrease the differences.

The ranking procedure used in Table 5-1 is exemplified below.

The item *"Canister. Initially defect, location of lid weld"* will affect the radionuclide migration from a canister with an initial defect. The differences between the three repository systems are described in Chapter 4.1, where it was concluded that a vertical canister position is preferred with regard to this item. An initially defect canister will lead to corrosion of the canister and release of radionuclides and corrosion products.

These ions may affect the properties in the surrounding bentonite. This will possibly have minor effect on the long-term performance of the repository system as well as on the long-term radionuclide migration through the bentonite buffer.

The item *"Canister. Position of initially intact welds*" is based on deposition of an intact canister. The canister will degrade with time. It has been assumed that corrosion is most likely to occur in the welds. Independent on canister position, there is a risk that the degraded weld will be in an unfavourable location with regard to radionuclide release. This risk has been judged to be the same, independent on canister position. The canister will be subjected to degradation independent on canister position. Therefore, the long-term performance of the three repository systems is judged to be similar. This item is not applicable for radionuclide migration from an initially defect canister.

The item *"Possible procedures. Resaturation of the buffer by adding water in KBS-3 V deposition holes. Stresses on canister"* will decrease the risk for uneven swelling of the bentonite and the risk for uneven stresses on the canister. These are not judged to break the canister but might enhance the corrosion of the canister and thereby influence the long-term performance of the repository system. Uneven stresses on the canister are not expected to influence the radionuclide migration of escaping radionuclides through the barriers.

Table 5-1 Compilation of identified differences between the three repository systems. Comparison to KBS-3 V. The used notations are: + better than KBS-3 V, - worse than KBS-3 V, = no difference compared to KBS-3 V, NA not applicable. ( ) indicate a small difference.

Identified differences	Possible to effect by technical measures		Long-term performance		Radionuclide migration, degraded canister		Radionuclide migration, initial defect	
	Yes	No	KBS-3 H	MLH	KBS-3 H	MLH	KBS-3 H	MLH
Canister								
Horizontal or vertical canister position:								
- Initially defect, location of lid weld		X	(-)	(-)	(-)	(-)	-	-
- Position of initially intact weld		X	=	=	=	=	NA	NA
- Contact surfaces for reactions within the canister		X	(-)	(-)	-	-	-	-
Buffer								
Bentonite properties (density, temperature):								
- bentonite block thickness		X	(+)	(+)	(+)	(+)	(+)	(+)
- emplacement, risk for water to carry out bentonite	X		(-)	-	(-)	-	(-)	-
- resaturation		X	=	=	=	=	=	=
- degradation due to the EDZ		X	=	=	=	=	=	=
Engineering and stray materials in deposition holes (amount and distance to canister):								
- Grouting	X (partly)		=	-	=	(-)	=	-
- Rock bolts (only in MLH)	X (partly)		NA	-	NA	(-)	NA	-
- Copper mesh (only in MLH)	X		NA	(-)	NA	(-)	NA	(-)
- Shotcrete at fracture zone intersections (only in MLH)	X (partly)		NA	-	NA	(-)	NA	-
- Other stray materials left after cleaning	X (partly)		(+)	-	(+)	(-)	(+)	-
Biological activity in deposition holes:								
- Excavated volume (surface of rock walls)		X	=	=	=	=	=	=
- Groundwater (temperature, pH, biological activity/m)	X		=	=	=	=	=	=
- Human activity	X		(+)	(-)	(+)	(-)	(+)	-
Possible procedures (impact on canister and buffer)								
Resaturation of the buffer by adding water in KBS-3 V deposition holes:								
- Stresses on canister	X		(-)	(-)	NA	NA	NA	NA
- Locally decreased heat conduction	X		(-)	(-)	(-)	(-)	=	=
- Radionuclide dissolution	X		NA	NA	=	=	(+)	(+)
Filling gaps with bentonite pellets (in KBS-3 V):								
- bentonite density	X		-	-	-	-	-	-
- centering of the canister	X		NA	NA	=	=	(+)	(+)
- stresses on canister	X		(+)	(+)	NA	NA	NA	NA
Filling irregularities in deposition holes with bentonite pellets (in KBS-3 V):								
- bentonite density	X		(-)	(-)	(-)	(-)	(-)	(-)
- centering of the canister	X		NA	NA	=	=	(-)	(-)
- stresses on canister	X		(-)	(-)	NA	NA	NA	NA

Table 5-1 (cont.) Compilation of identified differences between the three repository systems. Comparison to KBS-3 V. The used notations are: + better than KBS-3 V, - worse than KBS-3 V, = no difference compared to KBS-3 V, NA not applicable. ( ) indicate a small difference.

Identified differences	Possible to effect by technical measures		Long-term performance		Radionuclide migration, degraded canister		Radionuclide migration, initial defect	
	Yes	No	KBS-3 H	MLH	KBS-3 H	MLH	KBS-3 H	MLH
Backfill								
Interface between deposition hole and tunnel:								
- Risk for movement of buffer into backfill		X	(-)	+	(-)	+	(-)	(+)
- Risk for rock slabs at interface to bored deposition tunnel		X	=	+	=	+	=	(+)
Backfill in tunnels (amount and distance to canister):								
- Chemical and physical degradation		X	(+)	+	=	+	=	=
- Degradation due to the EDZ		X	=	+	=	+	=	=
- Sorption of radionuclides		X	NA	NA	=	(-)	=	=
Engineering and stray materials in tunnels (amount and distance to canister):								
- Grouting	X (partly)		=	+	=	(+)	=	(+)
- Shotcrete (ceiling and walls)	X (partly)		(-)	+	=	(+)	(-)	(+)
- Rock bolts and steel fabrics (ceiling)	X (partly)		(-)	+	=	(+)	(-)	(+)
- Other stray materials left after cleaning	X (partly)		(+)	+	=	(+)	(+)	(+)
Biological activity in tunnels:								
- Surfaces (amount and distance to canister)		X	=	+	=	(+)	=	(+)
- Groundwater (temperature, pH, biological activity/m)	X		=	=	=	=	=	=
- Human activity	X		(+)	+	=	(+)	(+)	(+)
Near-field rock								
Impact of the EDZ on radionuclide migration:								
- Sorption and matrix diffusion		X	NA	NA	=	(-)	=	(-)
- Dilution		X	NA	NA	=	(-)	=	(-)
- Fast pathways (distance to)		X	NA	NA	=	=	=	=
Far-field rock								
Radionuclide migration		X	NA	NA	(+)	+	=	=
Rock characterisation								
- Detection of vertical fractures	X		NA	NA	=	=	=	=
- Detection of horizontal fractures	X		NA	NA	(-)	(-)	(-)	(-)
Intersecting fractures (deposition holes and deposition tunnels):								
- Migration pathways	X		NA	NA	=	=	=	=

It is obvious from Table 5-1 that most of the differences between the repository systems are related to "Buffer", "Backfill" and "Possible procedures". It can also be seen that just a few differences are related to "Canister", "Near-field rock" and "Far-field rock". This seems reasonable since the same canister will be used and the repository systems are quite equal if viewed from a distance.

Comments to and motivations for the ranking are given below. The differences between the repository systems that are listed under the heading "Possible procedures" in Table 5-1 are discussed in connection to the relevant barrier.

Canister

The canister position (horizontal or vertical) is determined by the repository layout. It is judged that a vertical position of the canister is preferential if the lid weld has an initial defect. The reason is that displacement of contaminated water will be delayed compared to if the defect is in the lower part of the canister.

A defect in the canister due to the long-term degradation can occur in a high or low position independent of canister position. It is however likely that the welds will constitute weak sections of the canisters. Both horizontal and vertical canisters have long welded sections located in a low position. A failure in a high position is preferential.

A horizontal position of the canister (MLH and KBS-3 H) will result in larger contact surfaces until the canister is half-filled with water. Production of gases due to corrosion will probably lead to that the canister will mainly be less than half-filled with water, which implies that a vertical position of the canister (KBS-3 V) is preferable.

The heat conduction between the canister and bentonite decrease if air is trapped in the gap. The air will eventually obtain a high water content. The thermal conductivity of air, independent of water saturation degree, is considerably lower than in water. A vertical canister is preferential since the air filled gaps can be filled with water at canister emplacement. This will decrease the risk for limited heat conduction.

A drawback with filling the gaps with water is that this will give quicker saturation of the buffer and therefore be disadvantageous for the radionuclide migration if the canister has an initial defect.

Buffer

The short as well as the long-term properties of the bentonite buffer is dependent on the emplacement of the bentonite blocks. It is probably considerably harder to avoid that some of the bentonite will be carried out with the water that will emerge into the deposition hole if the hole is horizontal (KBS-3 H and MLH). This effect would decrease the bentonite density and thereby deteriorate the bentonite properties such as the hydraulic conductivity. The problems will probably be smaller for KBS-3 H than for MLH due to the shorter deposition holes. It should however be noted that this is a technical problem that probably could be solved. If it is possible to add pellets, that would to some extent compensate for the bentonite that has been carried out by the groundwater.

The water in the EDZ around the deposition holes will cause degradation of the buffer. The importance of this effect is expected to be the same for all repository systems since the extent and the hydraulic importance of the EDZ depend on the diameter of the deposition holes, which are identical.

Engineering and stray materials might influence the properties of the bentonite and/or the canister. The amount of stray and engineering materials in the deposition holes are judged to be largest for MLH since more human activities takes place in these deposition holes. Grouting and shotcrete may be used to decrease the water flow and to stabilise the rock walls in sections of the deposition holes, which are unsuitable for canister deposition due to intersecting fracture zones. Similar sections will be avoided for canister deposition also in the KBS-3 systems. Furthermore, the fact that people will work more in the MLH deposition holes will put demands on more grouting and reinforcements in and in the vicinity of the deposition holes (safety reasons for workers). The difference between KBS-3 V and KBS-3 H is not expected to be large, with the exception that a horizontal deposition hole (KBS-3 H) is be easier to keep clean with regard to stray materials.

One of the deposition methods that could be used in MLH implies the introduction of a copper mesh that is left in the deposition hole. The long-term repository performance of the repository as well as the radionuclide migration is judged to be less influenced by the copper mesh compared to the copper in the canister.

The extent of the biological activity in the deposition holes depend on the time the hole will be kept open, the amount of water that emerge into the hole, the extent of different human activities in the holes etc. It is advantageous to keep the holes open for as short time as possible and to avoid human activities in the holes. This extent of human activities will be largest in MLH.

Uneven stresses on the canister and uneven heat conduction between the canister and bentonite should if possible be avoided. One way can be to fill the deposition holes with water in order to have a more controlled resaturation of the buffer. It is easier to add water to a vertical hole. The differences between the repository systems are mainly restricted to early times.

The negative effects are judged to be less significant compared to the positive effects related to adding pellets. Adding bentonite pellets to the deposition hole increase the bentonite density and thereby improve bentonite properties such as the hydraulic conductivity. It is possible to add bentonite pellets to a vertical deposition hole. However, this might lead to an eccentric position of the canister if the entire gap between rock, canister and bentonite occur at one side of the hole. It is an advantage if the canister is centred in the deposition hole since that ensures a long diffusion path through the bentonite buffer.

Addition of pellets might also lead to uneven bentonite densities in the deposition hole. A possible effect of this is uneven stresses on the canister, which may increase the risk for mechanical deterioration.

Irregularities in the deposition holes might cause uneven bentonite densities and thereby uneven stresses on the canister and an eccentric canister position. These negative effects can to some extent be compensated for in KBS-3 V by adding pellets to the local irregularities.

Addition of bentonite pellets to a horizontal deposition hole has not been considered but might be possible. This will certainly be significantly more difficult to perform and will lead to an eccentric position of the canister. Using slightly thicker bentonite blocks around the canisters may compensate for the fact that pellets probably cannot be used in horizontal deposition holes.

Backfill

The volume of backfilled tunnels will differ significantly between the repository systems. The volume for the MLH system is by far the smallest. The volume for a KBS-3 H repository is slightly smaller compared to KBS-3 V.

The properties of the tunnel backfill will influence the repository performance and the radionuclide migration, in a short-term as well as in a long-term perspective. Tunnels with backfill may constitute flow-paths for escaping radionuclides if the backfill settle with time, degrade or if the design criteria cannot be achieved. It is therefore an advantage to have few and short tunnels that preferably also should be located far away from the canisters. A possible positive effect of backfill is that it has a large surface area available for sorption of radionuclides.

The degradation of the backfill depends for example on the water flow through the backfill, which is dependent on the hydraulic properties in the near-field rock. An important factor for the water flow through the backfill is the extension and the hydraulic properties of the EDZ. The extension of the EDZ around bored tunnels has for all repository systems been assumed to be 0.03 m and this zone might have a somewhat increased hydraulic conductivity compared to the undisturbed rock. Degradation of the backfill may also occur due to chemical interactions between the bentonite and the crushed rock. The degradation of the backfill due to water flow in the EDZ and chemical interactions is expected to be the same for all repository systems. However, the distance between the backfill and the canisters is shorter in the KBS-3 systems.

The interface between deposition hole and tunnel may constitute a weak part of the repository system since highly compacted bentonite is in contact with a backfill having lower density and higher conductivity. These inferior properties in the tunnel backfill might to some extent influence the properties of the bentonite in the deposition hole. One way to avoid this problem could be to install a plug between the bentonite buffer and the tunnel backfill. Regarding this aspect, it is an advantage if the canister is disposed far away from the tunnel backfill. Each canister disposed in KBS-3 will be located fairly close to the backfill, whereas, the canisters in MLH will be disposed far away from the tunnel backfill.

The density of the backfill in the deposition tunnel will be largest in the bottom of the tunnel and decrease with increasing height. The deposition holes in KBS-3 V will therefore be in contact with backfill having a high density and the deposition holes in KBS-3 H will be in contact with backfill having lower density. The KBS-3 V system will probably be preferential even though the swelling forces from the bentonite buffer partly has to be taken up by the low density backfill at the ceiling of the deposition tunnel straight above the deposition hole.

The weakest section, considering the rock mechanic situation, is probably the deposition tunnel - deposition hole interface. It can not be ruled out that the rock will break after repository sealing due to rock movements caused by e.g. heat generation from the canisters or swelling of the bentonite. These rock blocks might influence the properties of the bentonite in the deposition hole. The number of deposition holes, and thereby the risk for rock slabs, is significantly larger for the KBS-3 systems compared to MLH.

Engineering and stray materials in the tunnels may affect both the short- and long-term properties of the backfill. In a short-term perspective, engineering and stray materials may influence the water chemistry in the backfill, e.g. pH, complexing agents, organic compounds. This could have negative effects on the radionuclide migration. In a long-term perspective, engineering and stray materials may influence the hydraulic properties of the backfill. Fairly large amounts of stray and engineering material will remain in the tunnels in all three repository systems. However, the distance from a canister to the tunnel is significantly larger in MLH, compared to the KBS-3 systems, which means that the potential impact of stray and engineering materials in the tunnels on the long-term function and safety is significantly smaller.

Biological activities in the tunnels may have negative effects on the long-term performance of the repository. The amount of biological activity in the tunnel is about the same for all three repository systems. The difference that can be identified is related to a significantly smaller excavated volume in MLH and a somewhat smaller volume in KBS-3 H, compared to KBS-3 V. Furthermore, the human activities in the KBS-3 repository systems will be carried out in the deposition tunnels in contrast to MLH where corresponding activities to a large extent be carried out in the deposition holes.

Near-field rock

The radionuclide migration in the near-field rock is very similar in the repository systems. One difference is related to retardation. Radionuclides escaping a KBS-3 repository might to some extent be retarded in the backfill and in the EDZ around the tunnel due to sorption and matrix diffusion. This effect will not be as important in MLH due to the long distance between the canisters and the tunnel.

Another difference is related to dilution. A consequence of a short distance to the EDZ around the tunnel is that escaping radionuclides will be more diluted due to the increased water flow. The EDZ might however be a pathway for escaping radionuclides.

The positive effects with an excavation disturbed zone are increased rock surface area available for sorption and matrix diffusion as well as increased dilution due to higher water flow. The negative effect is that the excavation disturbed zone may constitute a pathway for escaping radionuclides. The net effect with regard to radionuclide migration is judged to be negative. The evaluation of the ZEDEX-experiments at Äspö has however not indicated any significant increase of the hydraulic conductivity in the EDZ.

Far-field rock

The migration in the far-field rock will be almost identical for the three studied repository systems. One potential difference is that it might be more difficult to detect subhorizontal fracture zones near a MLH or KBS-3 H repository compared to KBS-3 V since all holes and tunnel will be located in one plane which might give less information regarding the geological situation at the site. The lack of knowledge might lead to a shorter distance to undetected subhorizontal fracture zones. On the other hand, it is easier to detect vertical fractures in KBS-3 H due to the large number of horizontal deposition holes. The larger volume of excavated rock in KBS-3 gives more information regarding the rock characteristics.

A planned complementary technical measure that is possible to take to decrease the difference between the repository systems is to drill a few boreholes from the deposition holes in MLH to get further information about fractures. The holes are thereafter plugged. The disturbance of the bedrock is insignificant compared to the large excavated volume in KBS-3.

The total volume of excavated rock differs between the KBS-3 systems and MLH. A larger excavated rock volume will increase the water flow in the far-field rock if and when the hydraulic properties in the backfilled deposition tunnels are inferior compared to the surrounding rock. A larger excavated volume (KBS-3) may therefore induce a faster radionuclide migration in the far-field rock.

5.2.2 Function of each barrier

The compilation in Table 5-1 is very extensive and includes inevitable and potential differences as well as differences of varying importance. It is therefore difficult to use Table 5-1 to get an overview of whether or not a repository system is preferable to another. The information in Table 5-1 has therefore been compiled in Table 5-2.

Each barrier in the repository systems has been compared in Table 5-2. The integrated rating for the barrier is based on a qualified weighted compilation of all differences identified in Table 5-1. The items included in Table 5-1 under the heading "*Possible procedures*" has been considered in the evaluation of the canister as well as the buffer**.**

Table 5-2 Function of each barrier. Comparison to KBS-3 V. The used notation is: + better than KBS-3 V, - worse than KBS-3 V, = no difference compared to KBS-3 V, NA not applicable. ( ) indicate a small difference.

Barrier	Long-term performance				Radionuclide migration, degraded canister				Radionuclide migration, initial defect			
			Possible to effect by technical measures				Possible to effect by technical measures				Possible to effect by technical measures	
	KBS-3 H	MLH	Yes	No	KBS-3 H	MLH	Yes	No	KBS-3 H	MLH	Yes	No
Canister	(-)	(-)		X	(-)	(-)		X	-	-		X
Buffer	(-)	-	X		(-)	-	X		(-)	-	X	
Backfill	=	+	(X)	X	=	+	(X)	X	=	(+)	(X)	X
Near-field rock	NA	NA			=	=		X	=	=		X
Far-field rock	NA	NA			(+)	(+)	(X)	X	=	=	X	

Canister

The main difference between the repository systems is related to the radionuclide migration from an initially defect canister. In this aspect, a vertical canister is to be preferred.

Buffer

The main difference between the repository systems is related to the emplacement of the compacted bentonite blocks and the subsequent risk for water to carry out bentonite from horizontal deposition holes, which will result in a reduced density of the bentonite buffer. A reduced density of the bentonite will influence the long-term properties of the repository as well as the radionuclide migration.

The emplacement is judged to be easier in a vertical hole. Furthermore, it is probably easier to avoid that large quantities of bentonite are carried out in KBS-3 H compared to MLH.

On the other hand, the design criteria for the bentonite buffer is assumed to be achieved for all repository systems even though the systems that are based on horizontal deposition holes might require extensive technical developments.

Another negative effect for the MLH repository system is the larger amounts of engineering and stray materials in the deposition holes.

The differences of importance between the systems regarding the buffer are possible to affect by planned complementary technical measures.

__Backfill__

Tunnels with backfill may constitute flow paths for escaping radionuclides if the backfill properties are degraded or if the design criteria cannot be achieved.

The main differences between the repository systems are related to the excavated rock volume, the canister - tunnel distance and the number of tunnel - deposition hole interfaces. A considerable larger rock volume will be excavated in the KBS-3 systems, especially the KBS-3 V, compared to MLH. The average distance between canister and tunnels is significantly larger in the MLH compared to the KBS-3 systems. The number of intersections between deposition holes and tunnels are significantly lower for MLH compared to the KBS-3 systems.

__Near-field rock__

No important differences with regard to the near-field rock properties have been identified between the repository systems. This is mainly due to the results from the ZEDEX experiment, which indicate that the EDZ has a small extension and is of minor hydraulic importance.

Other experiments indicate that the extension and the hydraulic conductivity of the EDZ may be larger than assumed. If this is the case, then the MLH repository system is preferential compared to the KBS-3 systems.

__Far-field rock__

The total volume of excavated rock differs between the KBS-3 systems and MLH. A larger excavated rock volume will increase the water flow in the far-field rock if and when the hydraulic properties in the backfilled deposition tunnels are inferior compared to the surrounding rock. A larger excavated volume (KBS-3) may therefore induce faster radionuclide migration in the far-field rock.

The tunnels and deposition holes will be located in two directions in KBS-3 H and MLH, but in three directions in KBS-3 V. This three-dimensional sampling of the rock at tunnel scale at repository depth in KBS-3 V might increase the knowledge regarding subhorizontal fracture zones etc. The larger excavated volumes in the KBS-3 systems will give more knowledge regarding the host rock compared to the small excavated volume in MLH. This additional information that will be obtained especially for KBS-3 V, is however judged to be of minor importance for the knowledge of the site. The knowledge about the host rock in the KBS-3 H and MLH systems could be increased by additional geophysical measurements or by drilling a few vertical boreholes and carry out a suitable characterisation programme.

5.2.3 Differences that influence the choice of repository system

The differences that are compiled in Table 5-2 include minor as well as major differences between the repository systems. These differences have been further compiled in Table 5-3, which illustrate differences of such importance for the long-term repository performance and radionuclide migration that they determine the choice of repository system.

The ranking of "radionuclide migration" is mainly performed for the expected performance of the repository, which implies release from a degraded canister. Early release from a canister has also been considered in the compilation in Table 5-3. Its importance, is however, judged to be limited, since the number of disposed canisters having an initial defect is expected to be very low and since the barrier properties are in accordance with the design criteria at the time for the release.

Table 5-3 Differences of such importance for the long-term repository performance and radionuclide migration that they influence the choice of repository system. Comparison to KBS-3 V. The used notations are: + better than KBS-3 V, - worse than KBS-3 V, = no difference compared to KBS-3 V, NA not applicable. ( ) indicate a small difference.

Barrier	Long-term performance and radionuclide migration		Possible to effect by technical measures	
	KBS-3 H	MLH	Yes	No
Canister	=	=		X
Buffer	(-)	-	X	
Backfill	(+)	+	(X)	X
Near-field rock	=	=		X
Far-field rock	=	(+)		X

Canister

No difference related to the canister has been identified that determine the choice of repository system with respect to the long-term repository performance and radionuclide migration.

The identified differences related to radionuclide migration from an initially defect canister are not judged to be of such importance that they determine the choice of repository system.

Buffer

Horizontal emplacement of the buffer (KBS-3 H and MLH) could result in less favourable buffer density, uneven swelling etc. These problems are possibly larger for long deposition holes, i.e. MLH. Development of proper techniques could eliminate this difference between the repository systems.

It is foreseen that the amount of engineering and stray materials will be larger in the MLH deposition holes compared to the KBS-3 deposition holes. This can be unfavourable for the long-term properties of the buffer and the canister. Controlling the amount of stray material and avoiding rock that would require extensive grouting could eliminate this difference.

Backfill

Tunnels with backfill may constitute flow paths for escaping radionuclides if the backfill properties are degraded or if the design criteria cannot be achieved. The tunnel volume that will be backfilled is significantly smaller in MLH compared to the KBS-3 systems. The distance between a canister and the tunnel is, on average, significantly longer in MLH compared to KBS-3. These differences between the repository systems are dependent on the different layouts and are hence not possible to influence.

The addition of engineering and stray materials as well as the occurrence of biological activity in the tunnels can affect the short-term as well as the long-term properties of the backfill. The amount of engineering and stray materials as well as the biological activity can to some extent be adjusted by technical measures.

Near-field and far-field rock

The larger excavated volumes in the KBS-3 may enhance the radionuclide migration through the near-field rock if and when the hydraulic properties in the backfilled deposition tunnels are inferior compared to the surrounding rock.

No other important difference related to the near-field and far-field rock has been identified that determine the choice of repository system with respect to the long-term repository performance and radionuclide migration.

The EDZ might have a larger extension and higher hydraulic conductivity than assumed based on results from the ZEDEX experiments. This would be a disadvantage for all three repository systems, especially KBS-3.

6 Other scenarios

Introduction

The ranking between the repository systems is focused on the expected behaviour for the repositories. This implies deposition of intact canisters, slow degradation of the canister and other barriers. Scenarios that are discussed in this chapter are related to:

- glaciation,
- seismic events,
- human activities.

Main differences between the repository systems

The main differences between the three repository systems that will influence the repository performance due to glaciation, seismic events and human activities are related to the:

- volume of excavated rock,
- repository layout.

The amounts of excavated rock will be considerably larger in KBS-3 (especially KBS-3 V) compared to MLH. Large amounts of excavated rock will decrease the resistance to external disturbances.

The deposition layout will be quite different in the repository systems. The canisters will be more or less individually disposed in KBS-3, while MLH is based on disposing a large number of canisters after each other in one deposition hole.

The overall conclusion is that an external disturbance that will affect the repository performance is less probable in MLH due to the smaller excavated rock volume, but might have larger impact since several canisters are disposed in each deposition hole.

Glaciation

The coming glaciations may influence water flow rates, water pressure, redox conditions and stresses at repository depth.

Possible rock movements due to the pressure from the ice load will probably occur in major fault zones. The location of the repositories will be such as to avoid these major zones. The risk that new fault zones that will jeopardise the repository performance are formed as a consequence of glaciation is therefore judged to be minor. The risk that the changed conditions will cause rock movements is judged to be minor in all three repository systems. The risk is presumably larger in KBS-3 (especially KBS-3 V) due to a larger excavated rock volume. Small rock movements (5-10 cm) can induce deformations of the canisters, but is not expected to cause rupture /Birgersson et al, 1992/. However, the consequence of rock movements might be larger for MLH due to the large number of canisters in each deposition hole. Fractures and fracture zones formed as a consequence of glaciation influence the hydraulic situation in the vicinity of the repository.

High hydraulic gradient over the repository area will occur during the glaciation cycle. The gradient will increase the water flow through the repository and surrounding rock. The increased water flow will lead to a faster degradation of the barriers. This is a disadvantage for all repository systems, especially for the KBS-3 systems due to the larger volumes of backfilled tunnels.

Increased water flow rates and changed water flow directions during the glaciation cycle might cause oxidised water to reach repository depth. The risk for this effect is judged to be somewhat larger for the KBS-3 systems in accordance to the discussion in the previous paragraph.

Seismic events

Rock displacement in the repository area may occur due to earthquakes or fracture movements associated with post-glacial periods. A literature review and a preliminary modelling study based on a hypothetical KBS-3 V repository /La Pointe, 1997/ has been carried out to demonstrate a method for estimating displacements on fractures close to or intersecting canister deposition holes. The study indicates that the maximum shear displacement along secondary fractures is expected to be about one millimetre if the earthquake magnitude is 6.1 along a strike-slip fault 2 km from the repository. Additional simulations /La Pointe, 1997/ of earthquakes as a result of reverse-slip or strike-slip on a steeply dipping fault indicate maximum displacements that varies from millimetres to tenths of meters depending on the magnitude (6 to 8.2) and distance to the repository edge (50 m to 20 km). The expected displacements at repository depth (500 m) are expected to be in the order of millimetres. The difference between the repository systems depends on the intersecting fractures rather than on the orientation of the canisters (horizontal or vertical). Individual canister deposition (KBS-3) may have some advantage although the displacement is localised to the fractures and is therefore assumed to influence only single canisters in all three repository systems.

Human activities

Human activities, intentional as well as unintentional, can effect the repository performance. Examples of activities are:

- Mining in the vicinity of the repository.
- Retrieval of the waste and/or the copper canisters.
- Drilling of deep boreholes.

The risk for these activities are judged to be the same for the different repository systems, since the same location will be chosen and the same amounts of waste and canisters will be disposed.

A borehole drilled through the repository could be bored between the canisters or through a canister. The impact of the borehole is judged to be the same for all repository systems. However, the possibility to intersect a canister is considerably larger if the canisters are disposed in a horizontal position (MLH and KBS-3 H) since this will increase the exposed surface area (about 6 times) for a hole bored straight downward from the surface. The probability for drilling boreholes as deep as the depth of the repository is judged to be small.

7 Tunnel excavation method

The deposition tunnels in KBS-3 may either be blasted or bored. This report has been based on the assumption that the deposition tunnels will be bored. The choice of excavation method will influence the repository performance and radionuclide migration even in a long-term perspective.

7.1 Identified differences between bored and blasted deposition tunnels in KBS-3

The main differences between bored and blasted deposition tunnels in KBS-3 are related to:

- extension of excavation disturbed zone (EDZ),
- radionuclide migration pathways,
- dilution in water flowing in the EDZ,
- sorption and matrix diffusion in the EDZ,
- rock stress situation,
- rock mechanic stability,
- engineering and stray materials,
- cleaning of blasted tunnels.

These items have been identified and discussed in the previous sections and are summarised below.

The excavation disturbed zone (EDZ) around blasted tunnels is significantly larger (0.3 - 0.8 m) and has increased fracturing and increased permeability compared to bored tunnels (< 0.03 m) /Olsson, 1997; Emsley et al, 1997/. Furthermore, a stress re-distribution zone will be formed. This zone will extend about one tunnel diameter outward, and will be independent of excavation method. This zone show no new fractures and only small changes in permeability since the movements will be mainly elastic /Olsson, 1997/. If the distance between canister and this disturbed zone is found to be of large importance for the safety of a repository it is possible to modify the layout, e.g. deeper deposition holes.

The disturbed zone can effect the radionuclide release from a defect canister. If this is the case, then a large disturbed zone with increased hydraulic conductivity will induce a larger release of radionuclides. The disturbed zone might constitute fast pathways for water and radionuclides. However, a large water flow in the disturbed zone might reduce the water flow through the backfilled tunnels and deposition holes. The disturbed zone would in this case act as a "hydraulic cage". This can result in an increased dilution of escaping radionuclides. Furthermore, the induced fracturing give additional surfaces that are available for matrix diffusion and sorption of radionuclides. The conclusion is that the disturbed zone will have negative as well as positive effects with respect to radionuclide migration. The net effect is however judged to be negative.

The rock stress situation in the undisturbed rock mass will influence the stability of excavated tunnels and deposition holes. The impact depends on the excavation method as well as the repository layout and orientation of tunnels and holes. The local stress situation is very site specific and will influence the conductivity of the near-field fractures as well as their potential for propagation and sealing. Most of the rock mechanical consequences can be handled during the construction and operation of the repository. Rock stability can be increased with rock bolts and shotcrete, water leakage can be decreased with grouting etc. Effects that are difficult to handle in a long-term safety perspective are related to fracture movements and water flow in the near-field /Munier, 1997/. From this perspective, it can be concluded that the KBS-3 systems with blasted deposition tunnels are less favourable compared to bored tunnels.

The deposition holes will be bored perpendicular to the tunnels. The rock stresses at the interface will be significantly changed. These sections will be mechanically weak and the risk for block fall-outs is increased. The risk for block fall-outs will be larger for blasted tunnels.

The amount of engineering and stray material that will remain in a KBS-3 V repository with blasted deposition tunnels has been reported /Jones et al, 1999/. The differences compared to a bored tunnel are the materials related to the blasting and need of reinforcement. Nitrogenoxides and ignition caps will remain in the tunnels after blasting. The amount of these and other stray materials can be reduced by using other types of explosives and even more careful cleaning of deposition holes. The cleaning of blasted tunnels with rough rock surfaces is more difficult than the cleaning of bored tunnels. It is also believed that a blasted tunnel needs more reinforcements (rock bolts, steel fabrics and shotcrete) than a bored tunnel.

The overall conclusion is that bored deposition tunnels are preferred with respect to both the long-term repository performance and the radionuclide migration.

8 Conclusions

A comparison of the KBS-3 V, KBS-3 H and MLH repository systems has been carried out with regard to:

- Long-term repository performance.
- Radionuclide migration from a degraded canister.
- Radionuclide migration from a canister with an initial defect.

Several differences between the repository systems have been identified. The differences are mainly related to the:

- distance between canister and backfilled tunnels,
- excavated rock volumes,
- deposition hole direction.

Some of these differences are possible to influence by planned complementary technical measures.

The overall conclusion from this study is that the differences are in general quite small with regard to the repository function and safety. None of the differences are of such importance for the long-term repository performance and radionuclide migration that they discriminate any of the repository systems.

MLH has the potential to be a very robust repository system, especially in a long-term perspective. However, the MLH system will require extensive research, development, and analysis before it will be as confident as the reference repository system, KBS-3 V.

The difference between the two KBS-3 systems is small. The main advantages with KBS-3 H are related to the smaller excavated volume. The main disadvantages are related to the horizontal emplacement of the bentonite buffer and the horizontal canister position. There is no reason related to the long-term repository performance and radionuclide migration to abandon KBS-3 V for KBS-3 H.

Expected behaviour of the repositories

Horizontal emplacement of the buffer (KBS-3 H and MLH) can lead to practical problems resulting in less favourable buffer density, uneven swelling etc. These problems are possibly larger for long deposition holes, i.e. MLH. Development of proper techniques could eliminate this difference between the repository systems.

The large volumes of excavated rock in KBS-3 are mainly unfavourable since these volumes can constitute flow paths for escaping radionuclides if the backfill is degraded. Furthermore, the backfilled tunnels are located close to the deposition holes in the KBS-3 systems, which further put demands on the long-term properties of the backfill. This difference is dependent on the different layouts for the repository systems.

It is foreseen that the amount of engineering and stray materials will be larger in the MLH deposition holes compared to the KBS-3 deposition holes. This can be unfavourable for the long-term properties of the buffer and the canister. Controlling the amount of stray material and avoiding rock that would require extensive grouting could eliminate this difference.

In MLH and KBS-3 H, the canisters are disposed in a horizontal position. This is unfavourable if the canister has an initial defect in the lid weld.

Modified presumptions

The JADE-project was initiated in 1996, and the main part of the study was carried out during 1997 and 1998. This report is published in 2001. Some of the presumptions that the study was based on have been modified. The new presumptions are however not judged to change the major conclusions.

Scenarios (glaciation, seismic events and human activities)

The report has been focused on the expected behaviour of the repository barriers. Scenarios related to glaciation, seismic events and human activities have been discussed briefly. The main differences between the repository systems that will influence the repository performance and radionuclide migration due to these scenarios are related to the volume of excavated rock and the repository layouts. The volume of excavated rock is considerably larger in KBS-3 (especially KBS-3 V) compared to MLH. Large amounts of excavated rock will increase the consequence of external disturbances.

The deposition layout will be quite different in the repository systems. The canisters will be more or l Swedish Nuclear Fuel and Waste Management Co.ess individually disposed in KBS-3, while MLH is based on disposing a large number of canisters after each other in one deposition hole.

The overall conclusion is that an external disturbance that will affect the repository performance is less probable in MLH due to the smaller excavated rock volume, but might have larger impact since several canisters are disposed in each deposition hole.

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APPENDIX A

Classification of discontinuities

A comparison between the three repository systems regarding the importance of discontinuities in the host rock is found in /Munier et al, 2001/. The function of the discontinuities were classified into four classes /SKB, 1999/:

D1: These discontinuities are not allowed to intersect the repository rock volume *(regional discontinuity).*

D2: These discontinuities are not allowed to intersect the deposition tunnels or the deposition holes *(local discontinuity).*

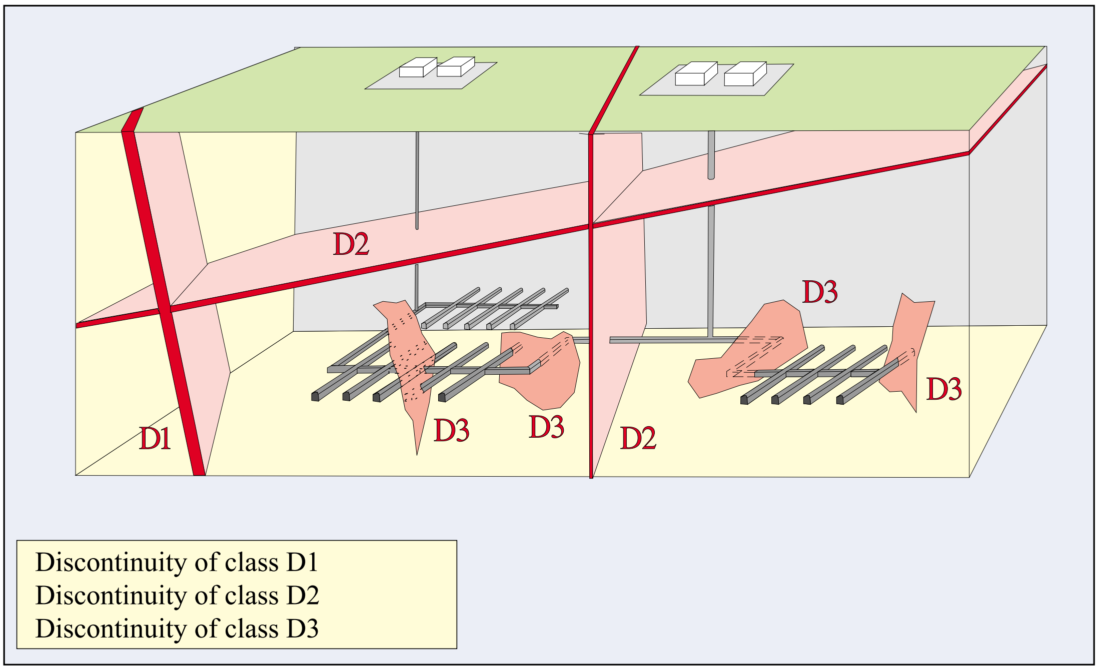
D3: These discontinuities may intersect the transport and deposition tunnels *(local minor discontinuity).*

D4: These discontinuities may intersect the deposition positions *(single fractures).*

A safety distance will be required between discontinuities classified as D1, D2 or D3 and the closest canister position.

Discontinuities type "D3" /SKB, 1999/ or larger will discriminate canister deposition at the intersection with the deposition hole regardless of deposition method. In MLH, grouting and shotcrete may be used to decrease the water flow and to stabilise the rock walls in such sections. This section of the deposition hole will be backfilled with e.g. bentonite. In KBS-3, the deposition tunnel at the intersection with the discontinuity will be backfilled.

A schematic illustration of the classification of discontinuities as used in JADE is given in Figure A1. Properties and examples of classified discontinuities (D1 and D2) in Äspö are given in Table A1.



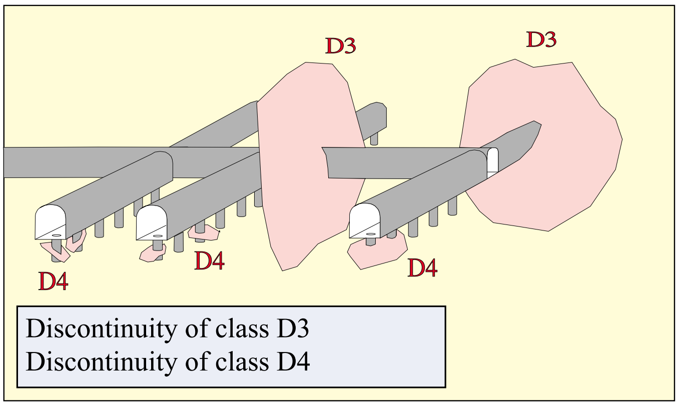


Figure A1 Schematic illustration of discontinuities as used in JADE.

The *hydraulic anisotropy* within the rock mass, i.e. the direction of conductivity in the rock in three dimensions, will influence the water flow in tunnels and deposition holes differently depending on their layout and orientation.

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APPENDIX B

Water in deposition holes

In this appendix the volume of water that can be added to the vertical KBS-3 V deposition holes is estimated from the empty spaces (gaps) left in the deposition holes after emplacement of canister and bentonite blocks. The theoretical gap between the bentonite blocks and canister is 0.01 m and the gap between the bentonite blocks and the rock is 0.05 m. Addition of pellets is not foreseen in this calculation. The amount of water needed to saturate the bentonite blocks is also estimated as well as the groundwater flow into the deposition holes.

Volume of water added

The volume of water that could be added to the gaps between canister and bentonite blocks and between bentonite blocks and rock in a KBS-3 V deposition hole has been estimated to 2 m^3 from the dimensions given in Chapter 2 in the report.

Deposition hole		
Depth	7.83	m
Diameter	1.75	m
Volume	18.8	m^3
Canister		
Length	4.83	m
Diameter	1.05	m
Volume	4.2	m^3
Bentonite block (pellets not included), total		
Volume	10.3	m^3
Backfill (crushed rock and bentonite)		
Volume	2.4	m^3
Gaps		
Volume of gap between canister and bentonite	0.2	m^3
Volume of gap between bentonite and rock	1.8	m^3

Adding of water to horizontal deposition holes (KBS-3 H and MLH) is technically more difficult and the water volumes needed has not been estimated here.

Inflow of groundwater to the deposition holes

The groundwater inflow to a KBS-3 V deposition hole has been assumed to be 1 litre per deposition hole and hour in a "good" rock and 10 litres per deposition hole and hour in a "bad" rock. The volume of the gaps in KBS-3 V is 2 m^3 and consequently it would take 3 month to fill this space with groundwater if the saturation of the blocks is neglected in a "good rock" and 0.3 month in a "bad" rock. Adding of water may therefore enhance the saturation of the bentonite-blocks only if the groundwater inflow to the deposition holes is low (< 1 l per hour). The influence of the added water is judged to be small if the groundwater inflow to the deposition holes is high (>10 litres per hour).

Amount of water needed to saturate the bentonite blocks

The amount of water needed to saturate the bentonite blocks is estimated to 0.18 m^3/m^3 block. The water volume needed to saturate the bentonite blocks in a KBS-3 V deposition hole (10.3 m^3 bentonite blocks) is estimated to 1.8 m^3. The time it would take to saturate the bentonite blocks has not been estimated here. Background information is given in Table B1.

Table B1 Information about the bentonite blocks and the bentonite buffer /Bäckblom, 1996/.

Parameter	Block	Buffer	Definition
Water saturation (Sr)	0.85	1	volume of pore water/pore volume
Water content (w)	0.175	0.28	mass of water/mass of solid
Bulk dry density (ρ_d)	1.74	1.59	mass of solid/volume (g/cm^3)

The mass of solid matter ($m_s = \rho_d \cdot V$) in the bentonite blocks in one deposition hole is calculated to about 17 900 kg and the mass of water ($m_w = w \cdot m_s$) is calculated to about 3 100 kg. After saturation of the bentonite blocks the mass of water is estimated to about 5 000 kg in one deposition hole in KBS-3 V. The amount of water needed to saturate the blocks in one deposition hole is hence 1 900 kg or 1.9 m^3.

Reference

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APPENDIX C

Quantities of buffer, backfill, engineering and stray materials

The quantities of buffer and backfill in the repository systems are estimated in this Appendix. The backfill is a mixture of 85 weight% crushed rock and weight% bentonite. The quantities of engineering and stray materials in SFL 2, a KBS-3 V type of repository with blasted deposition tunnels, have been reported in Jones et al. /1999/. Based on this study the quantities of these materials in KBS-3 V and KBS-3 H, with bored deposition tunnels, and in MLH are discussed.

Bentonite buffer

The volume of the bentonite buffer are estimated to 12.2 m^3 per canister in KBS-3 V, to 14.7 m^3 per canister in KBS-3 H and 13.1 m^3 per canister in MLH. The differences between the repository systems are related to the total length of deposition holes filled with bentonite in the repository systems, where the length is compensated for bad rock etc.

The total volume of bentonite is estimated from the diameter of the deposition hole (1.75 m), the total length of bentonite (KBS-3 V: 25 954 m, KBS-2 H: 29 754 m and MLH: 27 302 m) /Ageskog, 2001/, see Table C1.

Table C1 Quantities of bentonite buffer in the repository systems.

Bentonite buffer	KBS-3 V	KBS-3 H	MLH	Unit
Total length	25 954	29 754	27 302	m
Total volume	46 534	55 674	49 776	m^3
Volume per canister	12.2	14.7	13.1	m^3/canister
Weight per canister	24 000	29 400	26 200	kg/canister

Backfill in deposition and transport tunnels

The deposition tunnels in KBS-3 and the transport tunnels in KBS-3 and MLH will be backfilled with a mixture of bentonite (15 weight%) and crushed rock (85 weight%). The total quantities of backfill loaded into the repository systems have been estimated.

The volume of backfill needed in the *deposition tunnels* has been estimated to be 550 000 m^3 in KBS-3 V and 483 000 m^3 in KBS-3 V. The used data are given in Table C2.

Table C2 Dimensions and volume of the deposition tunnels.

	KBS-3 V	KBS-3 H	Unit
Deposition tunnel			
Total length	28 000	16 000	m
Diameter	5	6.2	m
Cross-section	20	30	m^2
Volume per canister	145	127	m^3
Total volume (3 800 canisters)	550 000	483 000	m^3

The transport tunnels are blasted. The transport tunnels in the KBS-3 deposition area will be 7 m wide and 6.8 m high. The total length of these tunnels is about 2200 m in KBS-3 V and 1900 m KBS-3 H. The transport tunnel in the MLH deposition area is 8 m wide and 6 m high and the total length of the tunnel is about 2200 m. The tunnels are assumed to be backfilled with bentonite and crushed rock mixture (15/85).

In addition there are about 2000 m of transport tunnels outside the deposition area in all three repository systems, these tunnels will be 7 m wide and 6 m high.

The volume of backfill needed in the *transport tunnels* has been estimated to be 172 000 m^3 in KBS-3 V, 158 000 m^3 in KBS-3 V and 169 000 m^3 in MLH. The used data are given in Table C3.

Table C3 Dimensions and volume of the transport tunnels.

	KBS-3 V	KBS-3 H	MLH	Unit
Transport tunnels in deposition area				
Total length	2200	1900	2200	m
Height	7	7	8	m
Width	6.8	6.8	6	m
Cross-section	43	43	43	m^2
Total volume (3 800 canisters)	96 400	81 700	93 100	m^3
Volume per canister	25	22	25	m^3
Transport tunnels outside deposition area				
Total length	2000	2000	2000	m
Height	7	7	7	m
Width	6	6	6	m
Cross-section	43	43	43	m^2
Total volume (3 800 canisters)	76 000	76 000	76 000	m^3
Volume per canister	20	20	20	m^3
Summary, transport tunnels				
Total volume (3 800 canisters)	172 000	158 000	169 000	m^3
Volume per canister	45	42	45	m^3

The backfill of bentonite and crushed rock loaded into the tunnels has roughly been estimated to contain: 1615 kg crushed rock and 259 kg bentonite, and 26 kg pore water per m^3 backfill. The volume of groundwater needed to saturate the bentonite in the backfill is estimated to be 145 kg/m^3 backfill.

The total quantities of bentonite, crushed rock and groundwater needed to saturate the bentonite are given in Table C4.

Table C4 Quantities of bentonite, crushed rock and groundwater needed to saturate the bentonite.

	Quantities (kg/canister)					
	KBS-3 V		KBS-3 H		MLH	
	Deposition tunnels	Transport tunnels	Deposition tunnels	Transport tunnels	Deposition tunnels	Transport tunnels
Bentonite	41 000	13 000	36 000	12 000	0	13 000
Crushed rock	230 000	73 000	210 000	67 000	0	72 000
Groundwater	21 000	6 600	18 000	6 000	0	6 500

Engineering and stray materials

The quantity of engineering and stray materials has been reported for SFL 2, a KBS-3 V type of repository with blasted deposition tunnels, by Jones et al./1999/. The reported average and maximum quantities are given in Table C5 below.

Quantities in KBS-3 H and MLH

The quantities in a KBS-3 V repository with drilled tunnels and the KBS-3 H with drilled tunnels and in MLH have not been estimated here. However, in Table C6 it is indicated if the quantities of the materials given in Table C5 is expected to increase " + ", decrease " - ", be equal " = ", or not occur " 0 " in KBS-3 V and KBS-3 H with bored tunnels and in MLH. A small difference is indicated with " ( ) ". Bored tunnels results in less stray materials compared to blasted tunnels. The total quantities of engineering and stray materials are judged to be largest in KBS-3 V and smallest in MLH. The main reason is the volume of excavated rock. However, the quantities of engineering and stray materials in the deposition holes are judged to be largest in MLH due to more transport, reinforcements and human activities in these deposition holes compared to the deposition holes in KBS-3.

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Table C5 Quantities of engineering and stray materials in SFL 2 (a KBS-3 V type of repository with blasted deposition tunnels) /from Jones et al., 1999/.

Pos	Material	Chemical content	Canister position [1)]		Deposition hole
			Average	Max	Max
1	Ignition caps	Aluminium Plastic	0.3 2.5	0.6 5.0	0.1 1.0
2	Explosives	Nitrogen oxides	0.01	<0.1	<0.1
3	Bolts (reinforcement)	Steel	60.0	180.0	0.0
4	Bolts (anchor)	Steel	10.0	20.0	15.0
5	Cement around bolts	Cement	40.0	120.0	12.0
6	Shotcrete Reinforcement Accelerator	Cement Steel Calcium chloride	250.0 25.0 2.5	1 250.0 175.0 12.0	20.0 4.0 0.5
7	Grouting	Cement Bentonite	250.0 8.0	1 500.0 50.0	300.0 10.0
8	Asphalt floors	Bitumen	0.15	0.8	0.2
9	Concrete floors	Cement	0.0	0.0	0.0
10	Concrete constructions	Cement Steel	150.0 7.0	750.0 35.0	750.0 35.0
11	Tyre	Rubber	0.2	1.0	0.2
12	Diesel fumes	Nitrogen oxides Soot and ash	0.2 0.05	0.4 0.1	0.1 <0.1
13	Degreasing compound and detergent	Hydrocarbon + other organic material	0.5	2.5	1.0
14	Hydraulic- and lubricating oil	Hydrocarbon	1.0	20.0	10.0
15	Diesel oil	Hydrocarbon	0.2	4.0	2.0
16	Battery acid	Sulphuric acid	0.01	0.3	0.2
17	Metal fragment from metal work	Tungsten, cobalt Steel, welding slags	0.2 1.5	1.0 15.0	0.5 12.0
18	Remainder of wood	Wood	0.2	0.6	0.2
19	Remainder of concrete	Cement	3.0	60.0	30.0
20	Corrosion products	Rust (FeO) Zinc	0.3 0.2	1.5 1.0	1.0 0.7
21	Urine	Urine inc. water	1.0	20.0	10.0
22	Other human waste	Organic	0.2	1.4	0.5
23	Ventilation air	Organic	0.3	1.5	0.5

[1)] Canister position - 6 m deposition tunnel including one deposition hole

- The materials in positions 1, 2, 3, 13, 14 and 17 occur in proportion to the excavated volume of rock.
- The materials in position 7 occur in proportion to the length of deposition tunnels.
- The materials in positions 11,12,15, 16, 18, 20, 21, 22 and 23 occur in proportion to the distance of transport of materials in the repository.
- The materials in position 4 are in the deposition tunnels.
- The materials in position 5 are proportional to the weight of the bolts in position 3 and 4.
- The shotcrete in position 6 is in proportion to rock surfaces. As a maximum 30 % or the roof in the deposition tunnels and 10 % of the walls in the deposition tunnels are covered with shotcrete.
- Material in position 8 and 9 constitute remainders from floors.
- Materials in position 10 are left concrete constructions mainly in connection to the deposition holes.
- Materials in Position 19 are remainders from temporary concrete plugs between the deposition tunnels and transport tunnels.

Table C6 Relative quantities of engineering and stray materials in KBS-3 V, KBS-3 H and MLH compared to SFL 2 (a KBS-3 V type of repository with blasted deposition tunnels). The notation used is: if the quantities of the materials given in Table C5 is expected to increase " + ", decrease " - ", be equal " = " , or not occur " 0 ".

Pos	Material	Chemical content			
			KBS-3 V	KBS-3 H	MLH
1	Ignition caps	Aluminium Plastic	0	0	0
2	Explosives	Nitrogen oxides	0	0	0
3	Bolts (reinforcement)	Steel	=	(-)	-
4	Bolts (anchor)	Steel	-	-	-
5	Cement around bolts	Cement	=	(-)	-
6	Shotcrete Reinforcement Accelerator	Cement Steel Calcium chloride	= = =	(-) (-) (-)	- - -
7	Grouting	Cement Bentonite	= =	(-) (-)	- -
8	Asphalt floors	Bitumen	=	=	0
9	Concrete floors	Cement	=	=	0
10	Concrete constructions	Cement Steel	(-) (-)	(-) (-)	(-) (-)
11	Tyre	Rubber	=	(-)	-
12	Diesel fumes	Nitrogen oxides Soot and ash	=	(-)	-
13	Degreasing compound and detergent	Hydrocarbon and other organic material	=	(-)	-
14	Hydraulic- and lubricating oil	Hydrocarbon	=	(-)	-
15	Diesel oil	Hydrocarbon	=	(-)	-
16	Battery acid	Sulphuric acid	=	(-)	-
17	Metal fragment from metal work	Tungsten, cobalt Steel, welding slags	=	(-)	-
18	Remainder of wood	Wood	=	(-)	-
19	Remainder of concrete	Cement	=	=	0
20	Corrosion products	Rust (FeO) Zinc	=	(-)	-
21	Urine	Urine incl. water	=	(-)	-
22	Other human waste	Organic	=	(-)	-
23	Ventilation air	Organic	=	(-)	-

APPENDIX D

Identification and documentation of differences between three repository systems - KBS-3 V, KBS-3 H and MLH

Differences between the three repository systems (KBS-3 V, KBS-3 H and MLH) have been identified based on the interaction matrices developed during the safety analyse SR 97 /Pers et al, 1999/. Within SR 97, all interactions were classified based on their importance for the long-term safety. The following classes were used:

- *Important* interactions should be part of the safety analyse (**red**[*] colour in the interaction matrix).
- Interactions with limited or uncertain influence (**yellow** colour in the interaction matrix).
- Interactions with *negligible* influence (**green** colour in the interaction matrix).

All the *important* interactions in the interaction matrices for the near-field /Pers et al, 1999/, buffer /Pers et al, 1999/, the far-field /Skagius et al., 1995; Pers et al, 1999/ have been considered to identify important differences between the repository systems. The interaction matrices are illustrated in Figures D1, D2 and D3. Detailed information concerning the interaction matrices is found in /Pers et al, 1999/.

The identification of differences between the repository systems is documented in a database. The database is available on Compact Disc, in FileMaker Pro format, see below "Documentation in a database".

The identification of differences between the repository systems was carried out in two steps:

Step 1 Identification of differences between the repository systems (KBS-3 V, KBS-3 H, MLH).

Step 2 Impact of identified differences on the repository long-term function and safety.

The documentation alternatives in step 1 were; "Include difference (Yes)", "Include no difference (No)" or "Uncertain". In the second step the differences marked with "Yes" or "Uncertain" in step 1 were judged either to have "Influence", "Uncertain influence", or "No influence" the repository long-term function and safety. In addition to the identification steps a description of the expected difference are given in the database (JADE motivation).

[*] Some interactions are important only during the water saturation phase (pink interactions in the buffer matrix), these interactions have not been considered for the repository long-term function and safety.

Important interactions that imply differences between the repository systems ("Yes" or "Uncertain" in the first identification step) and were judged to have potential influence the repository long-term function and safety ("Influence" or "Uncertain influence" in Step 2) are compiled in Tables D1-D3.

Buffer

FUEL	1.2 Radiation	1.3 Radiation	1.4 Radiolysis	1.5 Radiation	1.6 Radiation	1.7 Radioactive decay	1.8	1.9 Radiation/ radiolysis	1.10 Radiation	1.11 Radiation	1.12 Radiation
2.1 Confine-ment	CANISTER	2.3 Pressurizing Expansion	2.4 Ion release	2.5	2.6 Corrosion	2.7 Heat transport	2.8 Flow paths	2.9	2.10	2.11	2.12
3.1	3.2 Canister movement Mech. impact Shearing	SMECTITE/ BUFFER	3.4 Diffusivity Phys. state Diss./prec. Ion exchange Colloid form. Sorption Flow in buffer Suction	3.5 Movement of species	3.6 Gas incl., rel. and transp.	3.7 Heat transp. Buffer temp.	3.8 Flow in nearfield rock	3.9	3.10 Swelling pressure Self-sealing	3.11 Reinforce-ments Buffer exp.	3.12 Buffer swelling
4.1	4.2 Corrosion Pressurizing canister	4.3 Buffer swelling Smectite diss. Prec. of sec. minerals Ion-exch./sorp. Conv. of smectite Microstruc.	BUFFER PORE-WATER	4.5 Dissolution Precipitation	4.6 Vapor press. Diss. of gas Gas in buffer Gas comp./exp. Microbial act.	4.7 Heat conductivity Heat of wetting	4.8 NF hydrology	4.9 Transp. of species	4.10 Mechanical impact on rock	4.11	4.12 Hydr. impact on backfill
5.1	5.2 Corroding contacting canister	5.3 Degrading contacting smectite	5.4 Dissolution Precipitation Formation of colloids	NON-SMECTITE MINERALS/ IMPURITIES	5.6	5.7 Heat conductivity	5.8	5.9	5.10	5.11	5.12
6.1	6.2 Mech. impact on canister Corrosion	6.3 Piping Erosion Buffer dehyd.	6.4 Dissolution Pressurizing	6.5 Chemical reactions	GAS	6.7 Heat transport	6.8 Gas in NF rock	6.9 Dissolution	6.10 Saturation Gas-rock interact.	6.11 Pressurizing	6.12 Backfill sat. Piping
7.1 Fuel alteration	7.2 Therm. exp./contr. Struct. alt. Press. change	7.3 Microstruct. Therm. prop. Swelling Exp./contr. Shear strength Chem. equil. Kinetics	7.4 Vapor./cond. Porewater rheology Kinetics Chem. equil. Therm. induced transp. and press.	7.5 Chem. equil. Kinetics	7.6 Gas compr./exp. Vapor transp. Dissolution	TEMPERA-TURE	7.8 Boyancy eff. Heat-aff. flow	7.9 Chem. equil. Kinetics	7.10 Therm. exp./contr. Shearing Kinetics Chem. equil.	7.11 Therm. exp./contr. Degr. of rein-forcements	7.12 Chem. equil. Kinetics Hydr. cond.
8.1	8.2	8.3 Erosion Water sat. and press.	8.4 Flow in buffer	8.5 Erosion of buffer	8.6 Gas compr./exp. Two-phase flow	8.7 Heat transport through convection	GROUND-WATER HYDRO-LOGY	8.9 Saturation Groundwater composition	8.10 Erosion Particle transport	8.11 Erosion Load on reinforce-ments	8.12 Erosion Saturation
9.1	9.2	9.3	9.4 Exch. of species	9.5	9.6 Dissolution	9.7 Heat transport	9.8 Density grad. Viscosity changes	GROUND-WATER CHEMISTRY	9.10 Dissolution/ precipitation	9.11 Degr. of rein-forcements Cement mat.	9.12 Diss./prec. Ion-exch./sorp.
10.1	10.2	10.3 Confinement Rock displac. Buffer exp. and dim. Rock creep	10.4 Earth currents	10.5	10.6 Gas transp. and inclu.	10.7 Heat transport	10.8 Hydrology	10.9 Diss./prec. Earth currents Colloid transp. Sorption Matrix diff.	NEARFIELD ROCK	10.11 Mech. impact	10.12 Confinement Backfill exp.
11.1	11.2 Being lost in deposi-tion holes	11.3 Confine-ment	11.4	11.5	11.6 Corr. Storing of gas	11.7 Heat transport	11.8 NF hydrology	11.9 Degr. of reinforce-ments	11.10 Mech. support	REINFORCE-MENTS	11.12 Confine-ment
12.1	12.2	12.3 Confine-ment	12.4	12.5	12.6 Gas escape and inclusion	12.7 Heat flow	12.8 NF hydrology	12.9 Diss./prec. Ion-exch./sorp.	12.10 Mech. impact and support Backfill expand.	12.11 Mech. impact	BACKFILL

Figure D1 Graphical presentation of the buffer interaction matrix.

Nearfield

FUEL	1.2 Radiation Neutron activation	1.3 Radiation Neutron activation	1.4 Dissolution/ precipitation Cladding corrosion	1.5 Radiation	1.6 Radiation	1.7 Radiation	1.8 Radiation	1.9 Radiolysis Fuel oxidation Diss./prec., colloid form Cladding corr.	1.10	1.11 Helium production Radiolysis Cladding corrosion Radioactive gas	1.12 Heat generation	1.13	1.14 Diss./prec. Instant release Cladding corr.	1.15
2.1 Confine-ment	STEEL CANISTER	2.3 Yawning	2.4 Corrosion products Void size	2.5	2.6	2.7	2.8	2.9 Corrosion	2.10 Integrity	2.11 Corrosion gas Gas release	2.12 Heat transport	2.13	2.14 Sorp./desorp. Diffusion Colloid filter Dissolution	2.15
3.1	3.2 Confine-ment Galv. corr.	COPPER CANISTER	3.4 Void size	3.5 Mech. load Exp./compr.	3.6	3.7	3.8	3.9 Corrosion	3.10 Integrity Intersects flowpaths	3.11 Gas release	3.12 Heat transport	3.13	3.14 Sorp./desorp. Diffusion Colloid transp. Dissolution	3.15
4.1 Fuel alt. Diss./prec. Cladding corr. Solubility	4.2 Corrosion Solubility	4.3 Canister creep	VOIDS IN CANISTER	4.5 Swelling	4.6	4.7	4.8	4.9 Solubility Extent of reactions	4.10 Internal water pressure	4.11 Gas expansion/ compres-sion	4.12 Heat transport	4.13	4.14 Diss./prec./ vapor. Sorp./desorp. Inst. release of RN	4.15
5.1	5.2	5.3 Canister movement Mech. impact Shear Stress corr. cracking	5.4 Buffer intrusion	BUFFER	5.6 Swelling	5.7 Intrusion	5.8 Mechanical impact	5.9 Colloid gener. Diss./prec. Ion-exch./sorp. Diffusion Colloid transp. Phys. state of water	5.10 Intersects flow paths Flow in buffer Water exch., canister	5.11 Gas flow in buffer	5.12 Heat transport	5.13 Swelling Mech. impact on rock	5.14 Ion-exch., sorp./desorp. Diff. Colloid filter Diss./prec./ vapor.	5.15
6.1	6.2	6.3	6.4	6.5 Confine-ment	BACKFILL	6.7 Intrusion	6.8 Mechanical impact	6.9 Colloid gener. Diss./prec. Ion-exch./sorp. Diffusion Colloid transp.	6.10 Local hydrology	6.11 Gas flow	6.12 Heat transport	6.13 Swelling Tunnel dim.	6.14 Ion-exch./ sorp./desorp. Diffusion Colloid transp. Dissolution	6.15
7.1	7.2	7.3	7.4	7.5 Rock displac. Confinement Buffer exp.	7.6 Rock movements Confinement Backfill exp.	NEAR-FIELD ROCK	7.8 Reinforce-ments	7.9 Sorption Matrix diff. Diss./prec., colloid gener. Earth currents Molecular diff.	7.10 Local hydrology	7.11 Gas flow	7.12 Heat transport	7.13 Stress relaxation	7.14 Sorp./desorp. Matrix diff. Molecular diff. Dissolution	7.15
8.1	8.2	8.3 Mechanical impact	8.4	8.5 Confine-ment	8.6 Confine-ment	8.7 Mechanical support	CONSTRU-CTION MATERIALS	8.9 Alteration Stray materials	8.10 Flow pattern	8.11 Corrosion Gas flow	8.12 Heat transport	8.13	8.14 Sorp./desorp. Diffusion Dissolution	8.15
9.1 Fuel alter., diss./prec. Cladding corr.	9.2 Corrosion	9.3 Corrosion	9.4	9.5 Ion-exch. Diss./prec. Swelling Illitization	9.6 Ion exch./sorp. Diss./prec. Swelling	9.7 Fracture alteration Rock alteration	9.8 Alt. of construct. material Cement matur.	NEAR-FIELD WATER COMPOSI-TION	9.10 Density, viscosity	9.11 Diss. of gas Microb. activity Gas gener.	9.12 Heat transport	9.13	9.14 RN diss./prec., sorp./desorp. Colloid transp. Diss. of radioactive gas	9.15 Exchange
10.1	10.2	10.3	10.4 Water transport	10.5 Pressure Erosion	10.6 Erosion Solubility	10.7 Erosion of rock Diss./prec.	10.8 Erosion Solubility Grouting	10.9 Transport of species Solubility	NEAR-FIELD WATER FLOW	10.11 Gas compr./exp., dissolution Two-phase flow	10.12 Heat convection	10.13 Effective stress	10.14 Transport of dissolved RN and gas Diss./prec./vapor.	10.15 Hydraulic gradient
11.1 Cladding corrosion H2 catalysis	11.2 Corrosion Mech. impact	11.3 Corrosion Internal impact	11.4	11.5 Piping Flotation Porewater press. Dehydration Chem. reactions	11.6 Dehydration Piping	11.7 Dehydration Chemical reactions Fractures	11.8 Mechanical impact	11.9 Gas dissolution Radiolysis	11.10 Displace-ment Two-phase flow	NEAR-FIELD GAS	11.12 Heat transport	11.13	11.14 Colloids on gas bubbles Dissolution of radioactive gas	11.15 Gas flow Rel. of gas
12.1 Struc./chem. alt. Kinetics Equilibria Volatility Therm. exp./contr.	12.2 Exp./contr. Struct. alt. Kinetics Equlibria	12.3 Exp./contr. Struct. alt. Kinetics Equlibria	12.4 Phase changes	12.5 Kinetics Chem. equil. Hydr. cond. Swelling Therm. exp./contr. Porewater press. Therm. prop. Shear	12.6 Kinetics Equilibria Hydraulic conductivity	12.7 Fracturing Fracture aperture Kinetics Equlibria Thermal conductivity	12.8 Expansion/ contraction Kinetics Equilibria	12.9 Kinetics Equilibria Phase ch. Diffusion Therm. grad. transp.	12.10 Convection cells Viscosity	12.11 Expansion/ compression Gas dissolution	NEAR-FIELD TEMPERA-TURE	12.13	12.14 Kinetics Equilibria Diffusion	12.15 Heat transfer
13.1	13.2	13.3	13.4	13.5 Rock displac. and creep	13.6 Rock displac. and creep	13.7 Fracturing Fracture aperture	13.8 Deforma-tions	13.9	13.10	13.11	13.12	NEAR-FIELD ROCK STRESSES	13.14	13.15 Stress
14.1 Dissolution/ precipitation	14.2 Sorption, coprec.	14.3 Sorption, coprec.	14.4	14.5 Sorp., prec. Radiation eff.	14.6 Sorp., prec. Radiation eff.	14.7 Sorp., prec. Radiation eff.	14.8 Sorp., prec. Radiation eff.	14.9 Contamination Redox front Radiolysis	14.10	14.11 Dissolution/ evaporation	14.12 Heat generation	14.13	RADIO-NUCLIDES IN NEAR-FIELD WATER	14.15 RN release
15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9 Earth currents Exchange	15.10 Regional flow	15.11 Gas flow and exch.	15.12 Heat exchange	15.13 Stress	15.14 Exchange	FAR-FIELD

Figure D2 Graphical presentation of the near-field interaction matrix.

Farfield

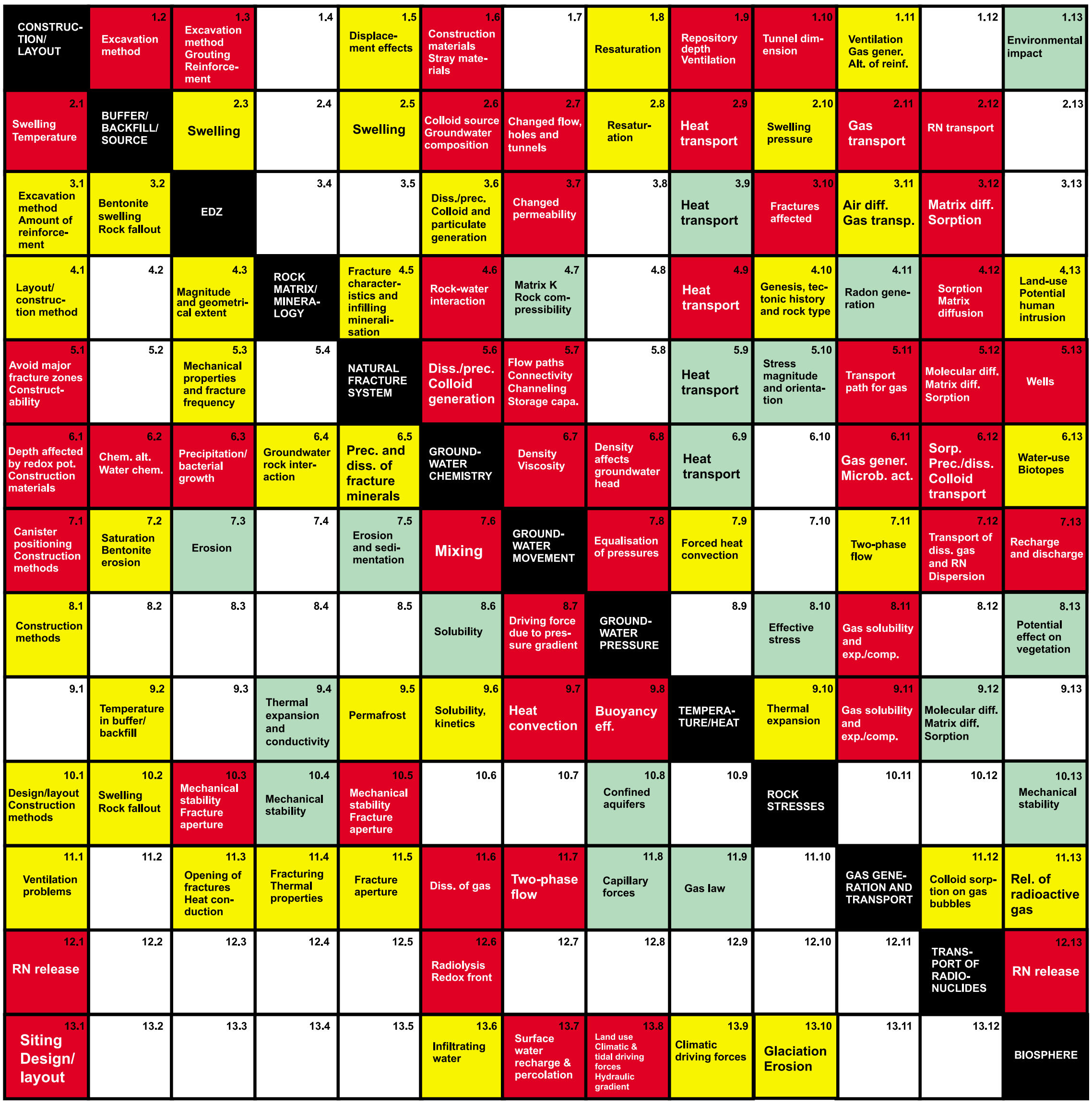

Figure D3 Graphical presentation of the far-field interaction matrix.

Documentation in a database

The interaction matrices developed during the safety assessment SR 97 for the buffer, near-field and far-field were used as basis for the documentation of differences between the three compared repository systems. The documentation in the SR 97 database concerns the reference system KBS-3 V. Differences between KBS-3 H or MLH and the reference system KBS-3 V were documented in a copy of the SR-97 database.

The documentation coupled to the interaction matices and the identification procedure is accessed by pressing the buttons in the "JADE Main menu", se Figure D4. The information that can be accessed from the interaction matrix menus ("JADE Buffer menu", JADE Near-field menu", "JADE Far-field menu"), see Figure D5, is described in Table D4.

The documentation of identified differences between the repository systems as well as the description of the current interactions can be viewed from the interaction lists by pressing the green button "JADE motivation". Pressing "light blue buttons" access the documentation from the safety assessment SR 97.

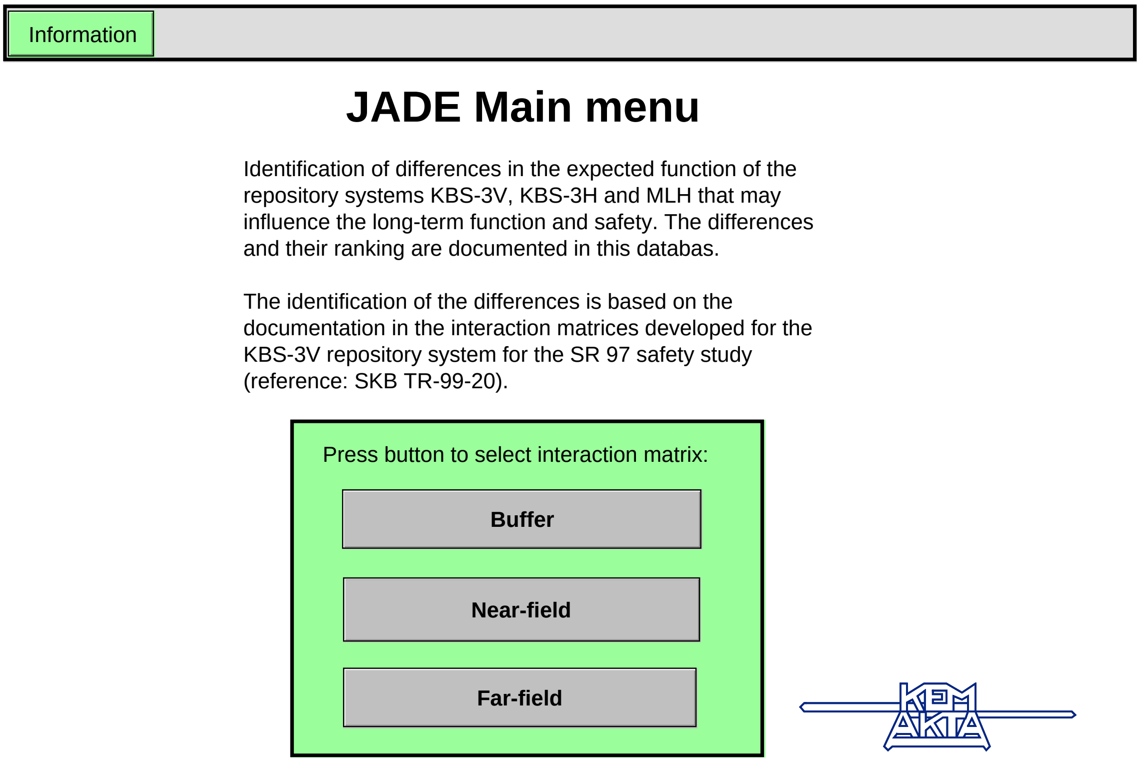

Figure D4 "JADE Main menu" to access the documentation of the identified differences and the ranking.

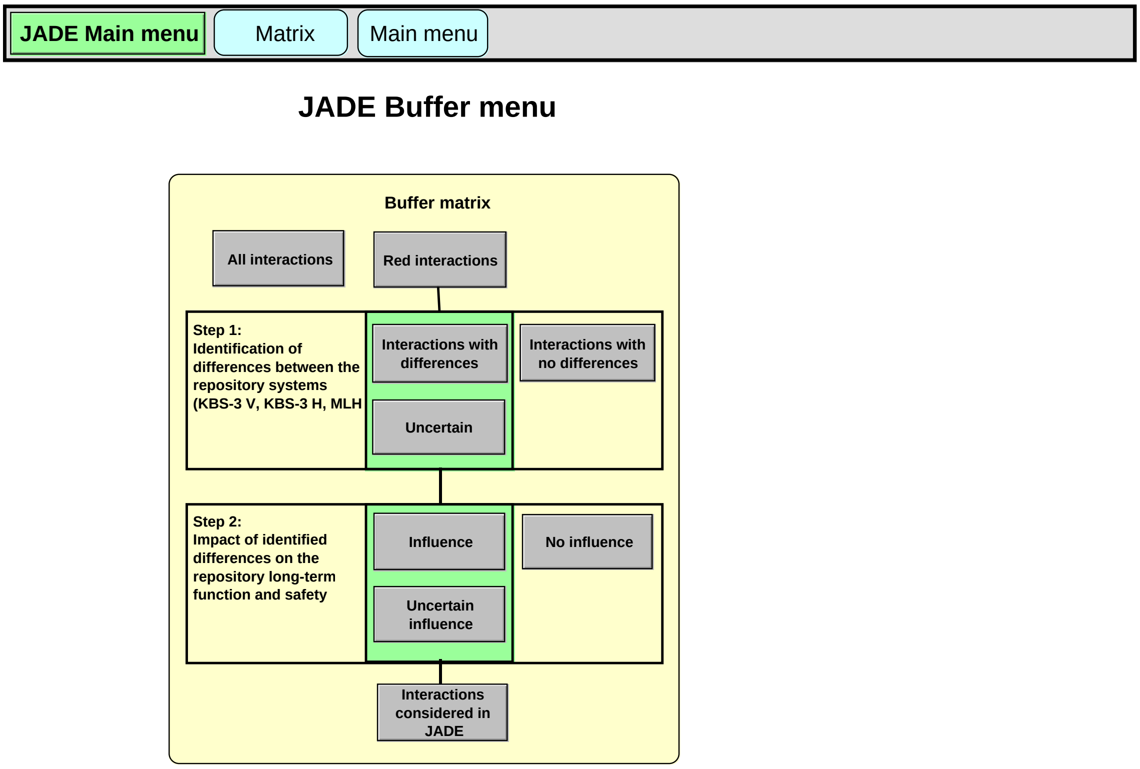

Figure D5 "JADE Buffer menu" to access the identified differences and the ranking. A "JADE Near-field menu" and a "JADE Far-field menu" are also available in the database.

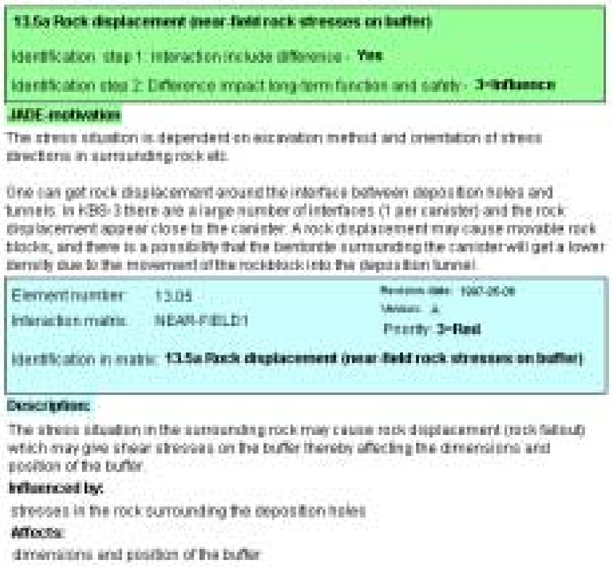

Figure D6 Layout in database showing the two identification steps and the motivation.

References

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SKB TR-99-20, Svensk Kärnbränslehantering AB.

Skagius K, Ström A, Wiborgh M, 1995
The use of interaction matrices for identification, structuring and ranking of FEP's in a repository system. Application on the far-field of a deep geological repository for spent fuel.
SKB TR 95-22. Svensk Kärnbränslehantering AB.

Table D1 Interactions in the buffer interaction matrix including differences between the repository systems KBS-3 V, KBS-3 H and MLH. The differences influence or may influence the long term function and safety.

2.6	Canister on nearfield gas (by corrosion)
3.2a	Buffer on canister (by affecting its position through swelling pressure anomalies)
3.4a	Buffer on buffer pore water (by ion diffusion)
3.4b	Buffer on buffer pore water (by affecting its physical state)
3.8	Buffer on groundwater hydrology (by affecting flow in nearfield rock)
3.10a	Buffer on nearfield rock (by affecting the stability through swelling pressure)
3.10b	Buffer on nearfield rock (by affecting fracture aperture through swelling pressure)
3.10c	Buffer on nearfield rock (by self-sealing)
3.12	Buffer on backfill (by swelling pressure)
4.2a	Buffer porewater on canister (by corrosion)
4.3a	Buffer porewater on buffer (by producing swelling pressure and expandability)
4.3b	Buffer porewater on buffer (by dissolution of the smectite content)
4.3d	Buffer porewater on buffer smectite (by ion-exchange)
4.3e	Buffer porewater on buffer smectite (by degrading and alterating it)
7.12a	Temperature of nearfield on backfill (by affecting chemical equilibria)
7.12b	Temperature of nearfield on backfill (by affecting the rate of chemical changes)
9.4	Groundwater chemistry on buffer porewater (by affecting its chemical composition)
9.12a	Groundwater chemistry on backfill (by affecting chemical equilibria)
9.12b	Groundwater chemistry on backfill (by sorption)
10.8	Nearfield rock on groundwater hydrology (by its structural constitution)
11.9	Reinforcements on groundwater chemistry (by dissol. and influence on chemical equilibria)
12.3	Backfill on buffer (by providing confinement)
12.8	Backfill on groundwater hydrology (by distribution of flow in and through the backfill)
12.9a	Backfill on groundwater chemistry (by diss. of minerals and affecting chemical equilibria)

Table D2 Interactions in the near-field interaction matrix including differences between the repository systems KBS-3 V, KBS-3 H and MLH. The differences influence or may influence the long term function and safety.

1.12	Decay heat (fuel on near-field temperature)
1.14b	Instant release (fuel on radionuclides in water in canister)
1.14c	Cladding corrosion (fuel on water in canister)
2.4b	Void size (steel canister on voids in canister)
2.9	Corrosion (steel canister on water composition in canister)
2.11a	Corrosion gas (steel canister on gas in canister)
3.10a	Integrity (copper canister on water flow through canister)
3.11	Gas release (copper canister on gas inside canister)
4.1a	Fuel alteration (voids in canister on fuel)
4.1b	Fuel dissolution/precipitation (voids in canister on fuel)
4.9b	Extent of reactions (voids in canister on water composition in canister)
4.14b	Extent of reactions (voids in canister on radionuclides in water in canister)
4.14c	Volume effect on IRF (voids in canister on radionuclides in water in canister)
5.3a	Confinement (buffer on copper canister)
5.3c	Shear (buffer on copper canister)
5.3d	SCC (buffer on copper canister)
5.3e	Porewater pressure (hydrostatic pressure) (buffer on copper canister)
5.6	Swelling pressure (buffer on backfill)
5.7	Intrusion (buffer on near-field rock)
5.9a	Colloid source (buffer on water composition in near-field rock)
5.9d	Diffusion (buffer on near-field water composition)
5.9e	Colloid filter (buffer on porewater composition)
5.9f	Water activity (buffer on buffer porewater)
5.10a	Intersects flow paths (buffer on water flow in near-field rock)
5.10b	Flow in buffer (buffer on water flow in buffer)
5.10c	Water exchange, canister (buffer on water flow through canister)
5.11	Gas flow in buffer (buffer properties on gas in buffer)
5.12	Heat transport (buffer on temperature in canister and buffer)
5.13a	Swelling pressure (buffer on near-field rock stresses)
5.14b	Diffusion (buffer on radionuclides in near-field water)
5.14c	Colloid filter (buffer on radionuclides in near-field water outside the buffer)
6.5	Confinement (backfill on buffer)
6.10	Local hydrology (backfill on near-field water flow)
6.13a	Swelling pressure (backfill on near-field rock stresses)
6.13b	Tunnel dimensions (backfill on near-field rock stresses)
6.14a	Ion-exchange, sorption (backfill on radionuclides in near-field water)
6.14b	Diffusion (backfill on radionuclides in near-field water)
7.5a	Rock displacement (near-field rock on buffer)
7.5b	Confinement (near-field rock on buffer)
7.6b	Confinement (near-field rock on backfill)
7.10	Local hydrology (near-field rock on near-field water flow)
7.11	Gas flow (near-field rock on near-field gas)
7.14a	Fracture sorption (near-field rock on radionuclides in near-field water)
7.14b	Matrix diffusion (near-field rock on radionuclides in near-field water)
7.14c	Matrix sorption (near-field rock on radionuclides in near-field water)
8.9a	Alteration (construction materials on near-field water composition)
8.9b	Stray materials (construction materials on near-field water composition)
9.5a	Ion-exchange/sorption (composition of buffer porewater on buffer)

9.5c	Microstructural constitution (composition of buffer porewater on buffer)
9.14a	Dissolution/precipitation (near-field wat. comp on radionucl. in near-field water)
9.14b	Sorption/desorption (near-field water comp. on radionucl. in near-field water)
9.14c	Colloid transport (near-field water comp. on radionucl. in near-field water)
10.4	Intrusion/expulsion
10.9a	Transport of species (near-field water flow on near-field water composition)
10.14a	Transport of dissolved RN (n-f water flow on radionucl. in near-field water)
11.2b	Corrosion by water vapour (gas in canister on steel canister)
11.5a	Piping (gas in buffer on buffer)
13.5a	Rock displacement (near-field rock stresses on buffer)
13.7a	Fracturing (near-field rock stresses on near-field rock)
13.7b	Fracture aperture (near-field rock stresses on near-field rock)
15.10	Regional flow (far-field GW flow on near-field water flow)
15.13	Stress (far-field stress on near-field stress)

Table D3 Interactions in the far-field interaction matrix including differences between the repository systems KBS-3 V, KBS-3 H and MLH. The differences influence or may influence the long term function and safety.

1.3a	Excavation method
1.6a	Construction materials
1.6b	Stray materials
2.6b	Groundwater composition
2.7b	Changed flow in tunnels
2.12	Source term
3.7	Changed permeability
3.1	Fractures affected
3.12a	Changed porosity and surface area
4.12a	Sorption
4.12b	Matrix diffusion
5.1a	Avoid major fracture zones
5.7a	Flow paths
5.7b	Connectivity
5.7c	Fracture aperture
6.3a	Precipitation/bacterial growth operating phase
10.3b	Fracture aperture

Table D4 The information that can be reached from the interaction matrix menus ("JADE Buffer menu", JADE Near-field menu", "JADE Far-field menu").

Button	Description
All interactions	Display all interactions in the interaction matrix
Red interactions	Display important (red) interactions in the matrix. These interactions were considered in the comparison of the repository systems.
Step 1	*Identification of differences between the repository systems (KBS-3 V, KBS-3 H, MLH).*
Yes	Display interactions in the interaction matrix that include differences between the repository systems.
Uncertain	Display interactions in the interaction matrix that may include differences between the repository systems.
No	Display interactions in the interaction matrix that does not include differences between the repository systems.
Step 2	*Impact of identified differences on the repository long-term function and safety.*
Influence	Display interactions in the interaction matrix that include differences between the concepts that influence the repository long-term function and safety.
May influence	Display interactions in the interaction matrix that include differences between the concepts that may influence the repository long-term function and safety.
Not influence	Display interactions in the interaction matrix that include differences between the concepts but the differences do not influence the repository long-term function and safety.
Interactions considered in JADE	Display interactions in the interaction matrix that include differences between the concepts that influence or may influence the repository long-term function and safety, se Table D1-D3.
JADE Main menu	Display "Jade Main menu", se Figure D6.
Matrix	Display the interaction matrix /Pers et al, 1999/
Menu	Display the matrix menu
JADE motivation	Display description of the identified difference between the repository concepts. The layout is shown in Figure D6. This button is accessed from the views displaying the interaction.

APPENDIX E

Presumptions that have been changed

The JADE study was based on presumptions that in some cases have been modified. The changes are for example related to: the tunnel excavation technique, the number of canisters that are assumed to be disposed and the canister construction technique.

Tunnel excavation technique

In the JADE study, the deposition tunnels for the KBS-3 concepts were assumed to be bored whereas the present preference is blasted deposition tunnels. There are no deposition tunnels in the MLH concept.

A blasted tunnel will induce a larger EDZ, which might enhance the transport of radionuclides in the near-field. This is a drawback compared to a bored deposition tunnel. On the other hand, using modern technique based on soft blasting can reduce the extension of the EDZ around a blasted tunnel. One positive aspect with blasted deposition tunnels is that the shape of the tunnel can be adjusted to the deposition equipment, which will result in smaller volumes of excavated rock.

Changes in tunnel excavation technique from bored to excavated will have some minor positive as well as negative effects. The net effect is judged to be very small and do not influence the overall ranking between the concepts.

Number of canisters

At the time for the JADE study it was assumed that the total number of canisters would be about 3800. According to recent estimations about 4500 have to be disposed.

The total number of canisters that are disposed will have impact on several aspects such as; the number of deposition holes, the volume of rock that have to be excavated, the amount of engineering and stray material, the risk for deposition of an initially defect canister.

Even though the amount of canisters will affect several aspects, it will not influence the ranking between the concepts. The difference could be described as a scaling effect that is independent of deposition alternative and will hence not influence the ranking between the concepts.

Canister construction technique

The canister was in the JADE study assumed to have four welds; two longitudinal, one at the bottom and one at the lid. Recently, alternative methods for production of copper tubes in full scale are being developed. It is therefor possible that the canister that will be used will only have two welds; one at the bottom and one at the lid.

Welds might constitute weak sections of the canister. It is therefore an advantage to reduce the number of welds. All welds, except the last at the lid, can be carefully inspected from the outside as well as from the inside. The last weld can only be inspected from the outside.

It is an advantage to have the last weld at the lid at a high position. This can be achieved in KBS-3V independent of the total number of welds in the canister. Reducing the number of welds from 4 to 2 is advantageous independent of deposition direction. A change in canister construction technique as discussed above will not influence the ranking between the concepts.

Method development

When the KBS-3V concept was compared to KBS-3H and MLH in the JADE study, the KBS-3V was considered favourable since it was considerably more developed.

Recent experiments at the Äspö laboratory have mainly been focused on further development of the KBS-3V concept. Therefore, the difference in hands-on experience and development between the concepts is even larger today.

Influence on the ranking

The JADE study was based on presumptions that in some cases have been modified. One main conclusion from the JADE study was that the difference between the concepts was quite small and that KBS-3V was preferred, partly because it was the most investigated and developed system.

The new presumptions do not change this conclusion. The KBS-3V concept is still preferred to KBS-3H and MLH. One reason for this is that recent experience from experiments at Äspö regarding deposition techniques has further developed and strengthens the KBS-3V concept. The difference between the concepts is however still quite small.