R-08-31

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May 2008

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ISSN 1402-3091
SKB Rapport R-08-31

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Keywords: KBS-3H, Nuclear waste repository, Layout, Olkiluoto

This report is a result of a joint project between SKB and Posiva. This report is also printed as a Posiva WR report, Posiva WR 2007-77.

Preface

The work described in this report is part of the KBS-3H sub-project Design, which is a joint project between Swedish Nuclear Fuel and Waste Management Co (SKB) and Posiva Oy. The report was written by Erik Johansson, Annika Hagros, Jorma Autio and Timo Kirkkomäki at Saanio & Riekkola Oy. Valuable comments have been provided by Margit Snellman (Saanio & Riekkola Oy), Erik Thurner (SKB) and Paul Smith (SAM Ltd).

Abstract

As part of the KBS-3H design an Olkiluoto-specific layout of a KBS-3H repository has been produced based on the latest Olkiluoto data and the bedrock model. One of the main goals of this work was to support the evaluation of the feasibility of the one layer KBS-3H concept and to compare the layouts based on the KBS-3H and KBS-3V disposal concepts.

The layout presented in this work can be considered only preliminary and involves a number of uncertainties. The percentage of unusable host rock was assumed to be 25% in this work but can change due to the further design of the different components of the KBS-3H disposal system and further development of the host rock criteria. The layout is also significantly affected by the layout-determining fracture zones. In this work 11 major (highly transmissive) fracture zones interpreted to intersect the −420 m level were considered deterministically.

The KBS-3H layout requires a larger area than the KBS-3V repository and takes up most of the available area between the major fracture zones HZ20 and HZ21. This is mainly due to the long drift sections occupied by the compartment plugs (30 m) and the bentonite blocks in the blank zones (10 m), which reduces the usability of the host rock and results in larger canister spacings than in the KBS-3V concept, where the positioning of the deposition holes is very flexible and narrow zones with a moderate transmissivity usually have only a minor effect on the locations of the canisters.

According to the results, there is enough bedrock in the current investigation area at central Olkiluoto for KBS-3H layout in one layer. However the layout takes up nearly all of the potential bedrock resource and therefore the result is quite sensitive to possible changes in the design bases.

Contents

1 Introduction

1.1 Background and goals

SKB and Posiva are performing an R&D programme over the period of 2002−2007 with the overall aim to find out whether the KBS-3H concept can be regarded as an alternative to the KBS-3V concept for disposal of spent nuclear fuel. In the KBS-3H repository concept canisters with spent nuclear fuel are deposited horizontally in 100−300 m long deposition drifts.

A design for an Olkiluoto-specific KBS-3H layout is a significant input to the feasibility study of the KBS-3H concept. In particular, the sufficiency of the bedrock resource (i.e. whether the available bedrock resource is large enough for the layout) is of interest for the feasibility study. The layout adaptation is also an important input to the KBS-3H Safety Case.

The KBS-3H layout shall be compared to the KBS-3V alternative and, therefore, it is to be based on the same principles and design bases, when applicable.

1.2 Differences compared to previous layout adaptation

The previous reported work on KBS-3H layout adaptation to the Olkiluoto site was carried out in 2002 /Johansson et al. 2002/. The latest update of the KBS-3H layout adaptation was made in early 2006 in a memorandum (see Appendix 1). Figure 1-1 shows the result of this previous update of layout adaptation. After this latest version, there have been some significant changes in the input data to be used in the layout work. The main differences with respect to the last layout work in early 2006 are the following:

- the consideration of the new Olkiluoto site model /Paulamäki et al. 2006, Ahokas and Vaittinen 2007/,
- the principle of not using imaginary fracture zones,
- the revised respect distances to fracture zones,
- results from a DFN modelling study /Lanyon and Marschall 2006/,
- an update of the canister spacings (different spacings for different canister types),
- respect distances to investigation boreholes.

The new layout will be based mainly on the aforementioned new models for Olkiluoto, respect distances, other design premises, distribution of water inflow, and design specifications.

The layout adaptation also uses the results of the DFN (Discrete Fracture Network) modellings of groundwater flow around a KBS-3H repository situated at Olkiluoto /Lanyon and Marschall 2006/. The results of the modellings are discussed in Chapter 3.2.4, where they are used to estimate the effect of the rock's hydraulic properties on the usability of the bedrock resource at Olkiluoto.

The total amount of spent fuel assumed in this work is based on an estimate of the quantities produced by the five nuclear reactors currently in operation or under construction in Finland. The number of canisters and other technical input data used in this work are presented in Table 1-1. The respect distances to fracture zones and the available bedrock resource are defined later in Chapter 3.2. Canister lengths, canister spacings and other details related to Posiva's three canister types are given below in Table 1-2.

Otherwise the design bases used in this work follow the previous design update in early 2006 (Appendix 1).

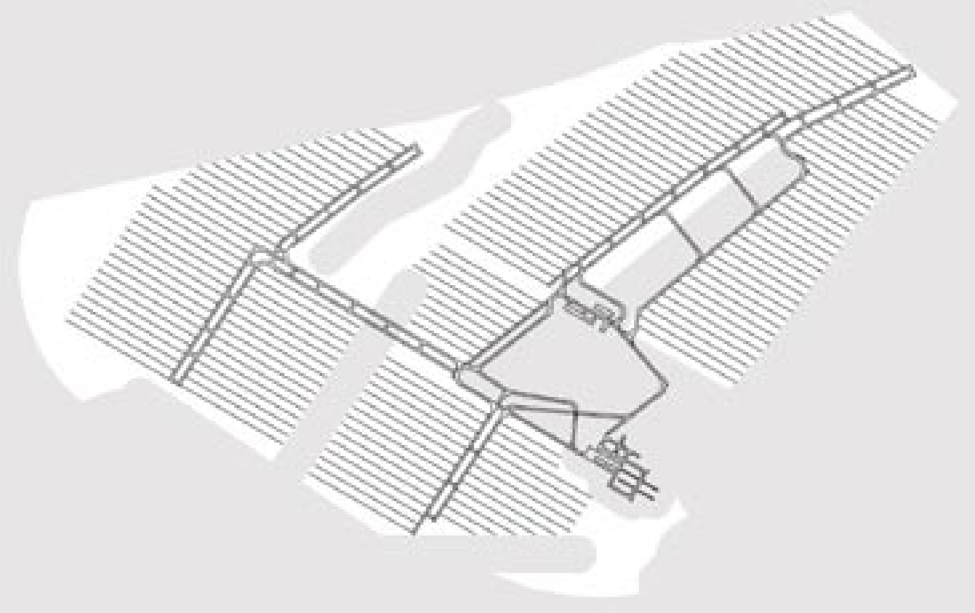

Figure 1-1. Previous KBS-3H layout adaptation to the Olkiluoto site, depth level 400 m. White areas indicate the usable bedrock resource. The full work is presented in Appendix 1.

Table 1-1. Technical input data for the KBS-3H layout adaptation at Olkiluoto.

Parameter	Value/criterion
Number of canisters	2,840
Repository concept	KBS-3H, one layer, no side tunnels – other parts than length of central tunnels, deposition drifts and related niches are similar to present KBS-3V design
Fracture zone model	Layout model /Ahokas and Vaittinen 2007/ with minor modifications; no imaginary fracture zones
Depth level	420 m (400–420 m)*
Spacing between deposition drifts	25 m
Length of deposition drift	100–300 m
Orientation of deposition drift	120 ± 10° (parallel to main principal stress)**
Filling block length (blank zone)	10 m
Compartment plug unit length	30 m
Other space requirements	First canister 25 m from the central tunnel

* For drainage purposes, the deposition drifts are not exactly horizontal; deepest point is 420 m and uppermost point 400 m. The level 420 m is used in the report.

** As assumed in the report by /Malmlund and Johansson 2002/ and supported by /Posiva 2005/.

Table 1-2. Details on Posiva's three canister types and on their positioning in a KBS-3H repository.

Parameter/Canister	BWR 1700 W	VVER 1370 W	EPR 1830 W
Canister length [m]	4.8	3.6	5.25
Canister spacing (center to center distance) [m]*	11.0	9.1	10.6
Supercontainer length [m]	5.53	4.33	5.98
Distance block length [m]	5.475	4.775	4.625
Distance block length with 5 mm gaps [m]	5.465	4.765	4.615

* Based on /Ikonen 2003/.

2 Characteristics of the KBS-3H concept

2.1 General design

In the KBS-3H repository concept, multiple canisters containing spent fuel are emplaced in long deposition drifts, slightly inclined towards the central tunnel (1:50). Each canister, with its surrounding bentonite buffer and a perforated steel shell, called supercontainer, is assembled in a handling cell in a cavern in the central area at the repository level prior to its emplacement in the drift. Each supercontainer is placed between two compacted bentonite distance blocks. In addition to providing the appropriate spacing to meet thermal loading requirements, the other main purpose of the distance blocks in the KBS-3H system is to separate the supercontainers from each other hydraulically, thus preventing the possibility of pathways for flow and advective transport along the drift /Thurner et al. 2006/.

The spent fuel canisters and the buffer material are identical in both KBS-3V and KBS-3H, but the introduction of the steel supercontainer and also the serial emplacement of supercontainers in a drift are new features compared to the KBS-3V concept. Therefore the function and behaviour of the Engineered Barrier System (EBS) after emplacement is different, and thus the long-term performance (safety case) for the two concepts will differ in some aspects /Thurner et al. 2006/.

At present, there are two different variations (called candidate designs) of KBS-3H design: a) Basic Design (BD) and b) design based on Drainage, Artificial Watering and air Evacuation (DAWE). BD alternative is based on the assumption that the distance blocks will seal the supercontainer units in wet sections independently of each other. In DAWE design the drift can be artificially filled with water after plugging one compartment by a steel plug and sealing the compartment. The distance blocks will then also swell and isolate the supercontainer units simultaneously. These two KBS-3H candidate designs are at the moment being developed to proper level of detail based on bedrock data from Olkiluoto in order to evaluate the feasibility of the KBS-3H concept in 2007.

Both designs are based on the principle of dividing the deposition drift into compartments (Figure 2-1). The number of compartments depends on the water inflows and the site-specific bedrock structure. The compartmentalisation is implemented by using a novel steel plug capable of taking the full hydrostatic pressure at the 400−500 m depth level.

The inflow requirements for the positioning of the supercontainer units are discussed in Chapter 2.2. One important design factor, which has significant impact on the usability of the bedrock resource, is the groundwater control, which will affect the site utilisation degree significantly.

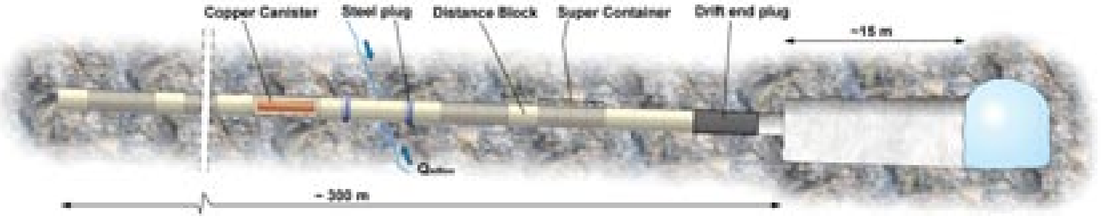

Figure 2-1. *General design of a KBS-3H drift. A significant water leaking section is isolated by a compartment plug including two steel plugs. The length of the distance blocks is about the same as the length of supercontainers in Posiva's design.*

The dimensions and other specifications of the different components of the KBS-3H disposal system are given in Tables 1-1 and 1-2 above. The thermal dimensioning of the repository is based on /Ikonen 2003/.

In this work it will be assumed that the repository is constructed in one layer at the −420 m level.

2.2 KBS-3H specific host rock requirements

The general requirements of the host rock related to the KBS-3H disposal concept are largely similar to those of the KBS-3V disposal concept. Accordingly, the requirements listed by /Andersson et al. 2000/ and /SKB 2002/ are, therefore, assumed to be valid also for KBS-3H. This is mainly due to the fact that in KBS-3V and 3H, large parts of the repository are similar (access ramp, shafts, technical rooms etc), and the processes and events leading to eventual failure of the system are to a large extent similar, for example, the canister failure modes (corrosion, isostatic overpressure and rock shear movements), the possible internal evolutions of the canister and the expected radionuclide pathways and release rates /Gribi et al. 2007/. There are, however, significant differences in the early evolution of the system. Some requirements and aspects that are specific to the KBS-3H system have been studied in the KBS-3H sub-project Safety Case. The discussion below is based on the preliminary results of these studies, which are still ongoing.

The deposition drift positions in the KBS-3H concept cannot be selected in the same manner as in KBS-3V, i.e. based on detailed geological information. It will also be impossible to characterise the position of deposition drift in the same level of detail. Also the KBS-3H concept is more sensitive to some bedrock features than the KBS-3V concept in the operation phase and saturation phase, related both to the layout and to the degree of the bedrock utilisation.

For KBS-3H there is a need for a more thorough investigation of the fracture density and location of these at the planned deposition drift depth, and for detailed investigation of smooth surfaced rock fractures parallel or nearly parallel to the deposition drift. Also, the variation in the possible water inflows, fractures and fracture zones and the in situ stresses is more important in the case of KBS-3H than KBS-3V.

Quantitative criteria for the host rock that have been defined for KBS-3H are very similar to those defined for KBS-3V. They include criteria on the chemical properties of the groundwater and one criterion on mechanical conditions, i.e. that rock shear in deposition drift should be < 0.1 m /Smith et al. 2007/. Other criteria, for example those regarding the hydraulic properties of the rock mass, are still under consideration.

Generally, the KBS-3H system may, in principle, be assumed to tolerate slightly more unfavourable hydraulic properties of the rock mass than the KBS-3V system, because the repository system itself is less conductive in KBS-3H than in 3V. This is apparent based on flow rate calculations showing that in similar flow and fracturing conditions, long-term release rates from a KBS-3H deposition drift are lower than those from a KBS-3V deposition hole, where the upper part of the deposition hole backfilled with the tunnel backfill as well as the tunnel may become important release routes for long-lived radionuclides, if significant flow of groundwater takes place through these parts of the near-field /Nordman and Vieno 2004/. Regarding the hydraulic properties of the rock mass, the adaptation principles assumed in the KBS-3V specific layout adaptation /Malmlund et al. 2004/ may, therefore, be assumed generally applicable, even conservative, for the KBS-3H. There are, however, some specific aspects that need to be considered separately. Groundwater inflows have significant impact on the KBS-3H drift utilisation degree and less favourable hydraulic conditions may, therefore, reduce the feasibility of the KBS-3H alternative significantly more than in case of KBS-3V. The hydraulic processes that require special attention in a KBS-3H repository include:

- the possible piping and erosion of bentonite,
- the consequences of completely dry drift sections (may promote thermal spalling),

- gas transport and possible gas-induced porewater displacement,
- build-up of gas pressure in dry drift sections (may reactivate fractures),
- smooth-surfaced rock fractures near the deposition drift and parallel or nearly parallel to it (these might open by stress release and form a fast transport path, which could connect several canister positions),
- the loss of the transfer resistance boundary at the buffer-rock interface due to iron-bentonite interaction of supercontainer and other steel components present in the deposition drift /Gribi et al. 2007, Smith et al. 2007/.

Accordingly, the KBS-3H concept can be rather sensitive to the local hydraulic properties of the near-field rock. The extent of any such problems depends on the details of the disposal concept – for example, the design of the buffer components and the selection of either the Basic Design or the DAWE design. At present, it will be assumed that the acceptability of different drift sections depends on their inflow rates and transmissivities according to Table 2-1, which has been used as input also in the latest DFN modelling of Olkiluoto /Lanyon and Marschall 2006/. The limit value of 0.1 litres per minute has been used in most of the analyses of KBS-3H carried out to date, as a reference inflow rate to a supercontainer unit (some 10 m long), comprising one supercontainer and one distance block /Smith et al. 2007/, however, this value is a rough estimate to be considered later when a proper design has been produced and tested.

Table 2-1. Inflow classes for KBS-3H deposition drifts /Lanyon and Marschall 2006/.

Inflow Q* (l/min)	Transmissivity T** (m^2/s)	Hydraulic aperture e*** (µm)	Compartment/ Isolated	Treatment of inflow in deposition drift
$Q < 0.004$	$T < 1.0 \cdot 10^{-10}$	$e < 5$	Super-container Compartment	Tight section where gas build-up possible.
$0.004 \leq Q < 0.1$	$1.0 \cdot 10^{-10} \leq T < 2.65 \cdot 10^{-9}$	$5 \leq e < 15$	Super-container Compartment	Acceptable.
$0.1 \leq Q < 1$	$2.65 \cdot 10^{-9} \leq T < 2.65 \cdot 10^{-8}$	$15 \leq e < 32$	Compartment or isolation (in compartment but no super-container, only filling)	Sealing by using extra fine low pH grout. Limit for sealing by cementitious grout is likely at the level of $1.0 \cdot 10^{-8}$ (the same limit is probably also applicable for non-cementitious grout, /Ahokas et al. 2006/).
$1 \leq Q < 10$	$2.65 \cdot 10^{-8} \leq T < 2.65 \cdot 10^{-7}$	$32 \leq e < 69$	Isolated	Defines compartment – inflow reduced by grouting or optional structural sealing.
$10 \leq Q < 30$	$2.65 \cdot 10^{-7} \leq T$	$69 \leq e$	Isolated	As above, optional structural sealing, abandon drift if flow after sealing above 30 l/min. (Note: 30 l/min is a first estimate and may be revised in the future).

* Into one supercontainer section from fractures without sealing.

** Assuming one inflowing fracture.

*** Hydraulic apertures have been calculated assuming a water density ρ of 1,000 kg/m^3 and viscosity μ of $1 \cdot 10^{-3}$ Pa·s using the cubic law

$$T = \frac{\rho g e^3}{12\mu} \tag{1}$$

where T is the transmissivity in m^2/s and e the hydraulic aperture in m.

According to the laboratory tests reported by /Börgesson et al. 2005/, very little water flow is sufficient to cause piping through a distance block and erosion at constant water flow (less than 0.001 l/min). If the pressure increases at rates above 0.1 MPa/h and the total applied pressure difference between wet and dry units is above 2 MPa, piping along the bentonite/rock interface may occur when the inflow rate from the rock exceeds 0.1 l/min /Gribi et al. 2007/. These results are based on tests made by using small samples and contain, therefore, significant uncertainties.

Regarding hydrochemistry, the requirements are very similar in both 3H and 3V /Smith et al. 2007/, however some attention needs to be paid to the amount of iron present in the KBS-3H near-field, as the gradual degradation of the supercontainer is expected to produce significant amounts of corrosion products of iron and corrosion gas (H_2) during a long period of time. Iron-bentonite interaction may, by various mechanisms, lead to alteration of physical properties, e.g. swelling pressure, swelling capacity, hydraulic conductivity and rheology of bentonite. This issue has been discussed in more detail by /Johnson et al. 2005, Smith et al. 2007 and Gribi et al. 2007/.

One specific aspect of the KBS-3H deposition drift is the likelihood of need for grouting along the drift, and also the use of cement as sealing material for fixing rings and compartment plugs, and also possibly as a drift end plug (see /Autio 2007/ for a description of these KBS-3H specific components). This means that in the KBS-3H concept there will be cement (low-pH grout) in the near-field in contact with the buffer, and the implications of this for the long-term safety of the concept need to be evaluated.

The KBS-3H concept may also set different requirements on the avoidance of fracture zones and on the size of the respect distances to these fracture zones, as compared to the KBS-3V system. Fracture zones and respect distances are discussed in more detail in Chapters 3.2.2 and 3.2.3. The related issue of avoiding long fractures at canister locations due to earthquake risks is discussed in Chapter 3.2.4.

The rock mechanical stability appears to be, in principle, better in a KBS-3H repository than in a KBS-3V repository, because in the latter the highest induced stresses are expected to be found near the intersection of the deposition hole and the tunnel. Such intersections are not present in a KBS-3H repository, and the KBS-3H deposition drifts can generally be oriented parallel or sub-parallel to the maximum horizontal stress, which contributes to stable conditions. However, the stability of KBS-3H drifts is dependent on the proper swelling of the bentonite buffer. There are indications that during the heating period, after the sealing and plugging of the deposition drift, the bentonite may not swell properly in very dry KBS-3H drift sections. This may result in a situation where the bentonite does not swell and support the rock surface and, as a consequence, the rock will damage in form of spalling /Lönnqvist and Hökmark 2007/. This thermal spalling may cause a difference between the KBS-3V and 3H alternatives, however these indications, especially with respect to the bentonite behaviour, are not fully understood and need more research before final conclusions can be drawn.

There are strict requirements on the shape of the KBS-3H deposition drift, and for this reason the present KBS-3H design is sensitive to rock failures during operation (whereas in KBS-3V deposition holes, any spalling during the operation phase may be irrelevant in terms of long-term safety, see /SKB 2006/). Because of the drift size and geometry, the technical means to cope with any stability problems are also more limited in KBS-3H than in KBS-3V. In KBS-3V, anomalous areas of rock stress or sections of low strength can be passed and a failed deposition hole can be abandoned. In case of KBS-3H, this might not be so feasible.

2.3 Layout-related differences between KBS-3H and KBS-3V

Even if the requirements of the host rock, which were discussed above, were the same for KBS-3H and 3V, it may be assumed that the sections of unusable host rock have a stronger effect on the usability of the deposition area in KBS-3H than in 3V. This is because the KBS-3V system is more flexible regarding the locations of the deposition holes, which can be selected initially based on the conditions observed in the tunnel. In KBS-3H, any unusable sections would probably require some sealing structures (plugs, additional bentonite blocks) that have some specified minimum length (Table 1-1). In general it appears, therefore, that similar unfavourable sections of the rock mass result in a lower usability of bedrock resource in KBS-3H than in 3V. The usability of the bedrock resource is discussed in more detail in Chapter 3.2.4.

3 Adaptation principles

3.1 General

3.1.1 Location on ground surface

The KBS-3H disposal concept does not entail any specific requirements on the location of the repository with respect to ground surface. The principles presented in the KBS-3V layout adaptation reports /Malmlund et al. 2004, Kirkkomäki 2006/ therefore apply.

3.1.2 Disposal depth

The disposal depth to be used in this work has been set to about 420 m. In the following, it will be briefly discussed, whether this disposal depth appears feasible – considering the KBS-3H system and in light of any new developments – and whether it sets some requirements on other aspects of layout design.

Strength/stress ratio

Based on the discussion in Chapter 2.2, it may be assumed that KBS-3H deposition drifts are stable, during construction and operation, in rock mass with a lower strength/stress ratio than what would be required for stable KBS-3V deposition tunnels and holes. On the other hand, there is a need for a KBS-3H deposition drift to be stable throughout the entire drift, whereas in KBS-3V tunnels it is probably rather easy to overcome moderate stability problems and the locations of the deposition holes can be selected so that the most unstable sections are avoided. These two aspects may compensate for each other, and while no quantitative analyses have been made to compare the strength/stress requirements of the two disposal concepts, it will be simply assumed here that the depth of 420 m, which is suitable for a KBS-3V repository in terms of strength/stress ratio /Johansson and Rautakorpi 2000, Hagros 2006/, is suitable also for a KBS-3H type repository. This should be verified by quantitative analyses that also consider the risk of thermal spalling, which may be more important in KBS-3H than in 3V (see Chapter 2.2 above) and which is assumed to increase with increasing rock stresses /SKB 2006/. Thermo-mechanical analyses and possible thermal spalling at Olkiluoto are discussed in more detail in /Lönnqvist and Hökmark 2007/.

In this work, the layout will be designed so that the deposition drifts are as parallel as possible to the maximum horizontal stress, in order to improve the stability situation of the drifts (Chapter 3.3.1).

Groundwater chemistry

The hydrochemical criteria are similar for KBS-3H and 3V (Chapter 2.2) and the disposal depth of 420 m can be assumed to be equally acceptable for both KBS-3H and 3V /e.g. Malmlund et al. 2004, Pastina and Hellä 2006/. For example, the concentration of dissolved salts in the Olkiluoto groundwater is such that chemical erosion of bentonite gel is not expected under unperturbed conditions.

Actually the salinity of the groundwater is not as important for KBS-3H as for KBS-3V, which needs to consider the performance of the tunnel backfill and the related salinity limit (TDS < 35 g/l). For the KBS-3H concept, a salinity (TDS) criterion such as [NaCl] < 100 g/l has been assumed to be adequate /Gribi et al. 2007/. The salinity of the groundwater at Olkiluoto should, therefore, not present any limitations on the usability of the −420 m level. It is also reasonable to assume that KBS-3H is less problematic than 3V regarding the chemical disturbances and interactions due to smaller excavated volume. In this work it is also assumed unnecessary to define any specific respect distances to highly saline groundwater, as such groundwater has not been observed in the vicinity of the planned disposal depth (420 m).

In addition to the effects of salinity on tunnel backfill, the most significant chemical difference between KBS-3H and 3V is the effect of the iron (steel) produced by the degradation of the supercontainer. However, this does not result in any specific requirements on groundwater chemistry that would render the −420 m level unacceptable for a KBS-3H repository. The change from oxic to anoxic conditions is actually expected to be faster in the 3H due to the large amount of steel present.

Hydraulic conductivity

As was discussed in Chapter 2.2, the requirements set by the KBS-3H system on the hydraulic properties of the rock mass are generally similar or less strict than those of the KBS-3V system, but the local hydraulic conditions may be very significant at the scale of the deposition drifts. Accordingly, it can be concluded that the −420 m level, which appears suitable for the KBS-3V system /Malmlund et al. 2004, Hagros 2006/ is also generally suitable for KBS-3H, but the local hydraulic properties need to be considered when estimating the usability of the bedrock resource, which will be discussed in Chapter 3.2.4.

3.1.3 Technical factors affecting layout

The stepwise construction of a KBS-3H repository and the related constraints on the layout are basically similar to those of the KBS-3V system /Kirkkomäki 2006/. Factors with layout implications that are specific to the KBS-3H system include the following:

- minimum length of deposition drifts (assumed to be 100 m),
- position of the first canister in a drift,
- filling components in water leaking canister positions.

In the entrance to the drift there is a section where plugs and adjacent buffer components are installed. The first canister can, therefore, be positioned at a distance of 25 m from the drift entrance in the KBS-3H alternative.

New issues that were not considered in the previous KBS-3H layout adaptation (Appendix 1) include the following:

- a respect distance of 10 m+1.25%*Z (Z=vertical depth in m) to surface investigation drill holes will be used in this work,
- canister spacings of 11 m, 10.6 m and 9.1 m for different canister types (see Table 1-2) will be used.

3.2 Horizontal location

3.2.1 Groundwater flow

The repository will be located according to the same principles assumed in the KBS-3V layout adaptation work /Kirkkomäki 2006/, since in both concepts it is favourable to minimise the groundwater flow through the repository and to increase the length of possible release routes from the repository.

As compared to the previous layout adaptations /Johansson et al. 2002/ and Appendix 1, new data on hydraulic conductivity of fractures and fracture zones have been acquired and these were used in this work. The avoidance of transmissive fracture zones is discussed in the following.

3.2.2 Fracture zones

The fracture zones to be taken into account in the layout adaptation work in 2007 have been defined and classified by /Ahokas and Vaittinen 2007/ and are presented in Table 3-1 and Figures 3-1 and 3-2. Accordingly, no classification of fracture zones is performed in this work. Furthermore, imaginary fracture zones will not be used in this work. The classification by /Ahokas and Vaittinen 2007/ was based on an assumption that the zone RH21[1] and all large scale zones with a transmissivity of 10^{-5} m^2/s or higher should be avoided when locating the deposition tunnels, and these are so-called “class A” zones, and that zones with a transmissivity between $10^{-5}...10^{-7}$ m^2/s can be intersected by deposition tunnels but should not be intersected by canister positions, and these are so-called “class B” zones. The selection of these particular limit values was not explained. The latter class also includes fracture zones that can form a hydraulic connection from the sea to the repository area. It was also checked that in addition to these zones there are no zones that would need to be avoided due to very unfavourable geotechnical properties. The classification was originally made for the KBS-3V layout adaptation work /Kirkkomäki 2006/, and the same classification is also used here for the KBS-3H system, so that the two concepts can be compared.

Table 3-1. The classification of fracture zones that are assumed to affect the layout adaptation of a repository at Olkiluoto /Ahokas and Vaittinen 2007/. The modifications made during the layout adaptation exercise are also shown. The modified fracture zones were used in this work. The respect distances are those defined in the ONKALO project.

Fracture zone	Alternative code	Transmissivity (m^2/s)	Class 1)	Layout adaptation related modifications	Respect distance (m)
HZ20A	RH20A	$> 10^{-5}$	A	–	30
HZ20B_ALT	RH20B_ALT	$> 10^{-5}$	A	extended	30
HZ21	RH21	$> 10^{-5}$	A	extended	30
HZ21B	RH21B	$> 10^{-5}$	A	extended	30
HZ008	RH8	$10^{-5} – 10^{-7}$	A	–	30
BZF028		$10^{-5} – 10^{-7}$	B	–	5
BFZ053 2)		$10^{-5} – 10^{-7}$	B	–	5
BFZ055 2)		$10^{-5} – 10^{-7}$	B	–	5
BFZ042		$10^{-5} – 10^{-7}$	B		5
BFZ076		$10^{-5} – 10^{-7}$	B	–	5
BFZ005		$< 10^{-7}$	B	–	5
BFZ099		$< 10^{-7}$	B	extended	5

1) These classes are based on /Ahokas and Vaittinen 2007/.

2) Close to HZ20A (not shown in Figure 3-1).

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[1] In the model by /Ahokas and Vaittinen 2007/, fracture zones from both the new model /Paulamäki et al. 2006/ and the bedrock model 2003/1 /Vaittinen et al. 2003/ have been used. The zones with RH-codes are from the 2003/1 model, although they have been renamed as HZ-zones.

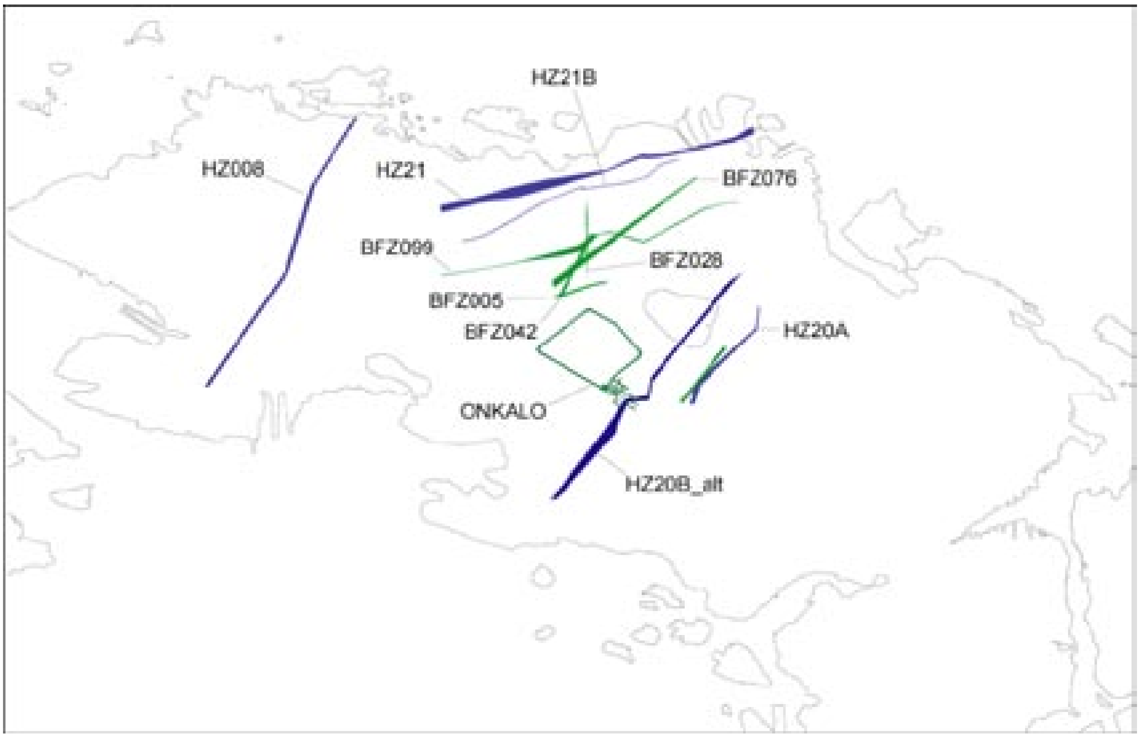

Figure 3-1. *The layout-determining fracture zones (see also Table 3-1) at level –420 m at Olkiluoto showing also the location of ONKALO and the shoreline of the Olkiluoto island /Kirkkomäki 2006/, based on /Ahokas and Vaittinen 2007/.*

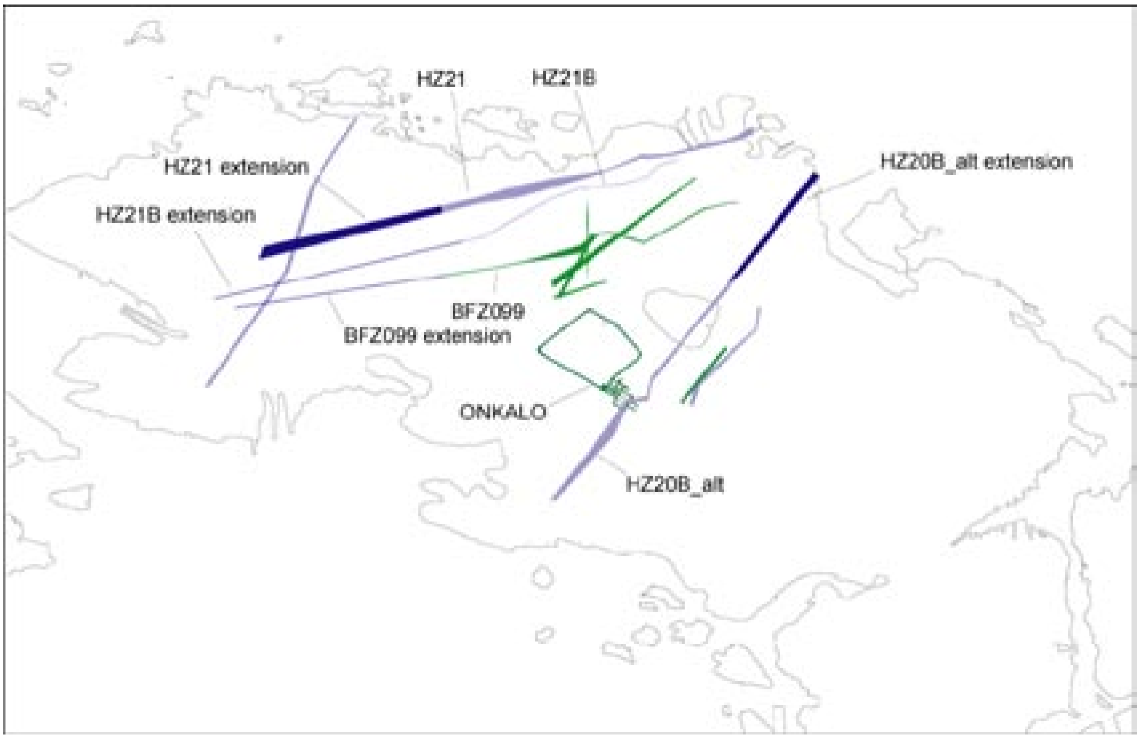

Figure 3-2. *The layout-determining fracture zones at the level –420 m at Olkiluoto showing the extensions of certain fracture zones /Kirkkomäki 2006/ which were considered in this work.*

The preliminary respect distances have been defined in the ONKALO project and they have been used in the latest KBS-3V layout adaptation work /Kirkkomäki 2006/. The respect distance to class A zones (Table 3-1) is 30 m and the respect distance to class B zones is 5 m. The same respect distances were used in both KBS-3H and KBS-3V layout work, so that the two concepts could be compared.

3.2.3 Notes on respect distances in KBS-3V and KBS-3H

The respect distance issue has been studied to some extent in the earlier phases of the KBS-3H project and it has been suggested that from the point of view of long-term safety, similar respect distances may be sufficient for the KBS-3H and 3V, but horizontal fracture zones immediately above or below the deposition drifts require special attention in KBS-3H. The reasons for this include the following:

- There is a more efficient transport pathway for radionuclides along the drift, since radionuclides from several canisters can more easily enter this pathway in KBS-3H than KBS-3V.
- In KBS-3H, the canisters are several times longer in horizontal direction than in KBS-3V, which is why it is more likely that a vertical fracture can connect a canister directly with a horizontal fracture zone below or above the repository. Also, there probably are more fractures (providing potential transport "channels") intersecting a 3H deposition drift than 3V deposition holes.

Accordingly, the release of radionuclides from the canisters to a nearby horizontal fracture zone may be more pronounced in the 3H concept than in 3V. Class A fracture zones have a respect distance of 30 m, so they cannot be located immediately above or below the deposition drifts. Class B zones have a respect distance of only 5 m, so it needs to be checked separately that they do not lie directly above or below any canisters. However, none of the class B zones are horizontal (their dip varies between some 30°...85°), so this requirement does not need to be considered further in this work. It should be noted that this conclusion is valid for the 11 hydraulically conductive fracture zones (Table 3-1) that are taken into account in this work, but not necessarily to other fracture zones at Olkiluoto. Later it should be studied whether some of the zones not considered here (i.e. zones with a transmissivity lower than 10^{-7} m^2/s) would require a respect distance if located immediately above or below the deposition level (drifts).

No other KBS-3H specific requirements on the respect distances were identified. It is, thereby, concluded that the same respect distances as those used in the KBS-3V project can also be used in this work, resulting in fairly similar effects on the performance of both types of repositories. Whether these effects are within acceptable limits, should be studied later in much more detail than what was possible here, and this is relevant for both concepts (KBS-3H and 3V). In particular, the possible seismic effects related to the presence of major fracture zones in the vicinity of the repository should be considered. It has been suggested that this concerns fracture zones more than 3 km long and should result in respect distances in the order of 100 m /Munier and Hökmark 2004, Munier 2006/. However, none of the fracture zones considered in this work are more than 3 km long (based on their currently modelled lengths), so they do not give rise to respect distances in the order of 100 m. It should be noted that for the purposes of flow modelling, the fracture zones were extended by /Ahokas and Vaittinen 2007/, and their extended lengths may exceed 3 km. The real length of the zones is not known. Furthermore, the possibility of other, yet undetected fractures zones > 3 km long cannot be completely ruled out. Accordingly, it should be taken into account in this work that some criteria on allowable fracture intersections at the locations of the supercontainers may be necessary to minimise the risk of displacements of > 0.1 m /see Munier and Hökmark 2004/. This will be discussed in Chapter 3.2.4 below.

In addition to applying respect distances between fracture zones and supercontainers, it is also important to ensure that there are no connective flowpaths between the drifts and those parts of the repository, which remain open for a long period. Such flowpaths could shortcircuit the end-plug of the drift. The effect of the flowpaths can evidently be reduced during the time when parts of the repository are open also by engineering actions (sealing, plugging, filling).

3.2.4 Available bedrock resource

Bedrock resource at Olkiluoto

According to the principles presented in this Chapter, it is possible to define the locations of potential bedrock resource at the level –420 m at Olkiluoto. The area separated by fracture zones HZ20 and HZ21 (Figure 3-2) is the area generally suitable for deposition drifts (i.e. it does not include the class A fracture zones discussed above), although it does contain minor fracture zones and other sections of the rock mass where supercontainers cannot be emplaced. Class B fracture zones are not actual resource (they require a respect distance to supercontainers) but they can be intersected by deposition drifts. Furthermore, in the actual bedrock resource there are unusable sections, the locations of which are currently unknown. The effect of these on the required drift lengths is discussed separately below. In addition to the major fracture zones, the bedrock resource was defined considering the respect distances to the boreholes and the shoreline of the Olkiluoto island. Except for the shoreline, it is not possible to define any exact lateral boundaries for the resource area, as the areas outside the current investigation area may also be suitable for disposal, although this should be confirmed with further studies. It was also taken into account that no deposition drifts should be located immediately below the access tunnel to the ONKALO.

Percentage of unusable host rock

The total length of deposition drifts assumed in layout adaptation needs to include the sections of rock mass unsuitable for deposition. The technical factors that affect the emplacement of canisters (e.g. the position of the first canister in a drift) were discussed in Chapter 3.1.3 and the following discussion refers only to the deposition area in the drift (the section of the deposition drift that could be used for disposal if allowed by the host rock properties, i.e. not including the first 25 m of the drift). The main factors related to host rock that are assumed here to prevent the emplacement of a canister in a KBS-3H deposition drift include the following:

- Supercontainers and canisters cannot be emplaced in positions where water leakage is before grouting over 0.1 l/min. Instead a filling component (with an assumed length of 10 m) is installed.
- If inflow exceeds 1 l/min, the leaking fracture is isolated by using a compartment plug, which takes about 30 m of the length of the drift.
- Sections of rock which do not fulfil other requirements (e.g. “dry” fracture intersections, rock failures, cavities etc).

These factors reduce the number of canisters that can be emplaced in one drift and lower the usability of bedrock. The values presented above (and discussed previously in Chapter 2.2) are rough estimates and will be specified in more detail later after the design of buffer components and related testing has been finished.

To take these constraints on canister emplacement into account when determining the total tunnel lengths, the proportion of unusable rock mass in the bedrock resource needs to be calculated. The following discussion relates only to the actual bedrock resource not including class B fracture zones, since the locations of the class B respect zones are taken into account separately (it is assumed that they and their respect zones are not usable for disposal).

The percentage of unusable host rock is evaluated here based on the KBS-3H specific DFN modelling work carried out for the Olkiluoto site. The DFN model /Lanyon and Marschall 2006/ considers only the hydraulic properties of the rock mass i.e. fractures and major fracture zones, which is why some additional factors (minor fracture zones etc) will also be considered when determining the eventual percentage of unusable rock. The effect of the hydraulic properties are discussed first and other aspects of host rock that may hinder the emplacement of a supercontainer are discussed subsequently.

Hydraulic properties

The inflow classes assumed in the DFN model /Lanyon and Marschall 2006/ were given in Table 2-1 above. The definition of the unusable sections is based on these classes, i.e. on the assumption that sections where the transmissivity is higher than $2.65 \cdot 10^{-9}$ m^2/s are unusable for disposal and require isolation (plugs) or filling ("blank zones"). The DFN model is based on /Hellä et al. 2006/ and /Vaittinen et al. 2003/ (bedrock model 2003/1) and does not consider the new geological model of Olkiluoto. However, in the DFN work a total of eight fracture zones were considered separately (assuming that they would not be included in the bedrock resource) and the actual number of such fracture zones is 11 in this work. Accordingly, the results of /Lanyon and Marschall 2006/ are probably applicable in this work, although they may be slightly conservative due to the smaller number of fracture zones excluded from the hydraulic data that were used to describe the host rock. It is also assumed that the components of the repository (e.g. the dimensions of the compartment plugs) and the respect distances used here are not significantly different from those assumed in the DFN model.

According to the DFN work, the deposition area of a 300 m long deposition drift includes, on average, one compartment plug (30 m), 3 to 4 blank sections (10 m each) and 22.5 supercontainers /Lanyon and Marschall 2006/. As the theoretical maximum number of supercontainers in a 300 m long drift is 27 in the modellings of /Lanyon and Marschall 2006/, it is possible to calculate that the percentage of rock mass unusable due to hydraulic properties is, on average, 17% of the rock mass.

Minor fracture zones

It has been assumed that it is unacceptable to locate supercontainers at fracture zone intersections because of possible risk for shearing. As only eleven major fracture zones are included in the layout model, there is a number of smaller fracture zones that will be encountered in the repository. Many of them will have a transmissivity higher than $2.65 \cdot 10^{-9}$ m^2/s, in which case they would be avoided anyway due to their hydraulic properties (see above). Some fracture zones will, however, be relatively dry, but need to be avoided because of poor rock quality or the possibility of becoming significant transport routes later, after changes in transmissivity (e.g. during a glacial cycle). The eleven fracture zones that are considered deterministically in this work (Table 3-1) cover less than 3% of the borehole length at Olkiluoto, whereas it has been estimated that a total of 10% of the rock mass at Olkiluoto belongs to fracture zones /Vaittinen et al. 2001/. Some of the smaller fracture zones are likely to be located near the major fracture zones (in their respect zones), and the frequency of fracture zones may be generally higher near the surface than near the level −420 m, so it will be tentatively assumed here that 5% of the rock mass within the actual bedrock resource discussed above belongs to fracture zones.

According to /Vaittinen et al. 2003/, only some 25% of the fracture zones at Olkiluoto have a transmissivity less than $1 \cdot 10^{-8}$ m^2/s, so it will be assumed in this work that some 1% of the rock mass is unusable due to minor, dry fracture zones. It should be noted that the sections that were estimated to be unusable due to their hydraulic properties, do not include only those sections where $T > 2.65 \cdot 10^{-9}$ m^2/s, but also some rock mass immediately adjacent to these sections, since the required plugs and blank zones have minimum dimensions that probably are quite often greater than the thickness of the transmissive sections.

Fracture displacement

A similar criterion on rock shear is valid for both KBS-3V and 3H. According to this criterion, fracture displacement in a deposition drift should be < 0.1 m. This criterion causes a need to avoid placing canisters in drift sections intersected by fractures that could potentially undergo shear movements in excess of 0.1 m /Gribi et al. 2007/. It is probably sufficient to avoid long fractures[2] at the positions of the supercontainers, as no significant bentonite erosion should

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[2] Fractures in the length scale of tens of metres or hundreds of metres are probably relevant here /cf. La Pointe and Hermanson 2002, Munier and Hökmark 2004/.

probably occur due to shear movements (> 0.1 m) at the locations of distance blocks or sealed and backfilled sections /Gribi et al. 2007/.

Due to the higher stiffness of canisters in the longitudinal direction, shear movements on reactivated flat (sub-horizontal) fractures across the deposition holes are most relevant for KBS-3V, whereas in the KBS-3H concept canisters are likely to be more vulnerable to shear movements on steep (sub-vertical) fractures perpendicular to the axis of the deposition drift /Gribi et al. 2007/. Accordingly, it could be argued that the issue of rock shear is more problematic in the case of KBS-3V, because a horizontal fracture would intersect several canisters (and such a fracture may be difficult to identify as long), whereas in the KBS-3H concept a vertical fracture would probably intersect only one or few canisters, depending on its orientation, and whenever several canisters were intersected by a single long fracture, it should be rather easily observable in the deposition drift. If such a long fracture is observed, it may result in a rejection of a long drift section. On the other hand, bedrock deformations caused by earthquakes appear normally in vertical fractures and fracture zones. Therefore, the deformation is more likely to deform the horizontal long holes than shorter vertical holes, which can be positioned with more flexibility /Thorsager and Lindgren 2004/.

It has not yet been decided, what will be the avoidance criteria for potentially damaging fractures in the deposition drift. The risk of rock shear of > 0.1 m relates only to fractures that are several tens or hundreds of metres long /Munier and Hökmark 2004/, but the full length of a fracture is usually not observable in a tunnel. If potentially long fractures are not avoided at all, it has been calculated that approximately 1 in every 190 horizontally emplaced canisters will be affected by a potentially damaging fracture, the corresponding values for KBS-3V being 1 in 150 /Smith et al. 2007/. The difference is largely due a lower sensitivity of KBS-3H to sub-horizontal fractures. It has not yet been studied, how many potentially significant fractures would have to be avoided at Olkiluoto to reduce the risk to an acceptable level. If the avoidance criterion will be formulated so that all fractures cutting the whole drift perimeter will be avoided (as suggested by /Munier 2006/ for KBS-3V), this is likely to result in a significant increase in the proportion of unusable rock mass. Since the diameter of a KBS-3H deposition drift is smaller than that of a KBS-3V deposition tunnel, a KBS-3H drift will probably include more full-perimeter fractures than a KBS-3V tunnel. An example of how many full-perimeter fractures there may be in a KBS-3H drift is illustrated by the mapping results from good quality rock at Äspö /Bäckblom and Lindgren 2005/.

In conclusion, it could be estimated that the identification of potentially damaging fractures is slightly easier in 3H and more efficient identification can, therefore, be assumed, but the total number of fractures to be avoided – particularly the total length of canister positions (drift sections) to be avoided – is greater in 3H than in 3V (this is a general conclusion not considering the different avoidance criteria related to transmissive drift sections, which were discussed separately above – their effect on the actual avoidance criteria for long fractures is discussed below). Less strict criteria on potentially damaging fractures could, therefore, be used, to arrive at a similar result in terms of long-term safety. On the other hand, the failure criterion of 0.1 m may not be strict enough for KBS-3H in the very long term (> 10^5 years), because the corrosion of the supercontainer may result in a reduction of buffer plasticity /Gribi et al. 2007/.

It is currently assumed that avoidance criteria for long fractures are dependent on the distance to major (> 3 km long) fracture zones /Munier and Hökmark 2004/. If the distance to such fracture zones is > 200 m, only those fractures that are more than 200 m long (in diameter) need to be avoided at canister locations due to the risk of displacement /SKB 2004/. Fractures this long are likely to be minor fracture zones instead of individual fractures, in which case they would be taken into account in any case (see above) and no separate avoidance criteria on individual long fractures would be required. It is possible that > 3 km long fracture zones are not present in the proximity of the planned repository area at Olkiluoto (Chapter 3.2.2), but this is currently unknown and it will never be completely certain that such fracture zones do not exist in or near the repository area.

While the issue of rock shear is still being studied, it is tentatively assumed here that the avoidance criterion for potentially damaging fractures is not as strict in the KBS-3H system as in KBS-3V – where it may be necessary to avoid all full-perimeter fractures – but it requires the rejection of significantly more canister locations than 1/190 ≈ 0.5% (see above), since the real length of fractures is almost impossible to measure in a repository and extra conservativeness is, thereby, needed (see, e.g. /Hagros 2006/). It will be assumed here that some 5% of the deposition drift length is unusable due to identified potentially damaging fractures. As fracture length has been observed to correlate with fracture transmissivity /e.g. Follin et al. 2005/, it is likely that most of this 5% will coincide with the drift sections that are anyway unusable due to too high inflows (see above). Accordingly, the additional effect of rock shear associated with dry fractures on the required drift length is estimated to be only some 1–2%. It is considered appropriate to assume this percentage to be 2% in this work.

Conclusions

Based on the discussion above, some 17% of the available bedrock resource in the deposition area is estimated to be unusable due to hydraulic properties and an additional 1% is unusable due to minor (dry) fracture zones. In addition, some 2% is estimated to be unusable due to potentially long (dry) fractures. There may also be other reasons that prevent the use of particular drift sections for disposal (for example, weathered and altered sections), but as most of such sections are assumed to be located mainly in or near the intersections of fracture zones or drift sections where $T > 2.65 \cdot 10^{-9}$ m^2/s, their effect is thought to be rather small. However, the percentages related to minor fracture zones and potentially long fractures (1% and 2%, respectively) should be increased, because the actual effect of such sections on the required drift lengths is likely to be greater than 1 and 2 percent. This is because a KBS-3H supercontainer (length 5.56 m) will often have to be moved by several metres to avoid an unusable section, no matter how narrow the section is. It will, therefore, be assumed in the KBS-3H layout adaptation that a total of 25% of the host rock is unusable for disposal within the actual used bedrock resource at Olkiluoto. This will require an increase in the total drift length of 25/(100-25) ≈ 33% in the deposition area (drift sections where supercontainers can be emplaced). In the layout adaptation, this can be taken into account by increasing the number of canister locations by 33%, i.e. from 2,840 to some 3,780.

As a comparison it could be mentioned that in the KBS-3V layout work the number of canister locations was increased by 20% to 3,408 locations /Kirkkomäki 2006/. The corresponding percentage of unusable host rock would be some 17%.

3.3 Orientation of canister drifts

3.3.1 In situ stresses

Only few stress measurement results have been received after the previous study /Johansson et al. 2002/. Some reinterpretation (statistical analyses) of the results has also been made. The data indicate, that the maximum horizontal stress is oriented in the E-W to ENE-WSW direction but the variation is still quite large. The scatter in orientation data (for 90% confidence intervals) is typically ±10−30° (occasionally larger). The scatter in magnitudes (for 90% confidence intervals) is around ±5 MPa for each measurement level. The site data support the notion of a thrust faulting stress regime at Olkiluoto, i.e. $\sigma_H > \sigma_h > \sigma_v$. The major principal stress (σ_1) is subhorizontally oriented, thus being slightly larger in magnitude than the maximum horizontal stress.

The effect of the orientation of the stress field on the mechanical stability of the canister drifts has been clearly demonstrated by /Johansson et al. 2002/ and /Lönnqvist and Hökmark 2007/. To minimise the risks for rock spalling the KBS-3H canister drifts are located so that their longitudinal axis will be close to the direction of the maximum principal stress, which is taken to be 120°. This is the same as used in the KBS-3V layout adaptation /Kirkkomäki 2006/.

3.3.2 Foliation and fractures

According to /Paulamäki et al. 2006/ the mean orientation of the foliation is dipping gently to SE (Figure 3-3) and fractures are assigned to three sets based on their orientation: a sub-horizontal set dipping towards the southeast, and two vertical sets with N-S and E-W strike. Mean orientations of sets are 139/18° (close to foliation), 089/89° and 177/86°, the first of which has clearly the smallest dispersion.

Taking the direction of the foliation and the main fracture sets into account, a favourable orientation for the KBS-3H canister drift supports the drift orientation of 120° that was already specified based on the major stress field.

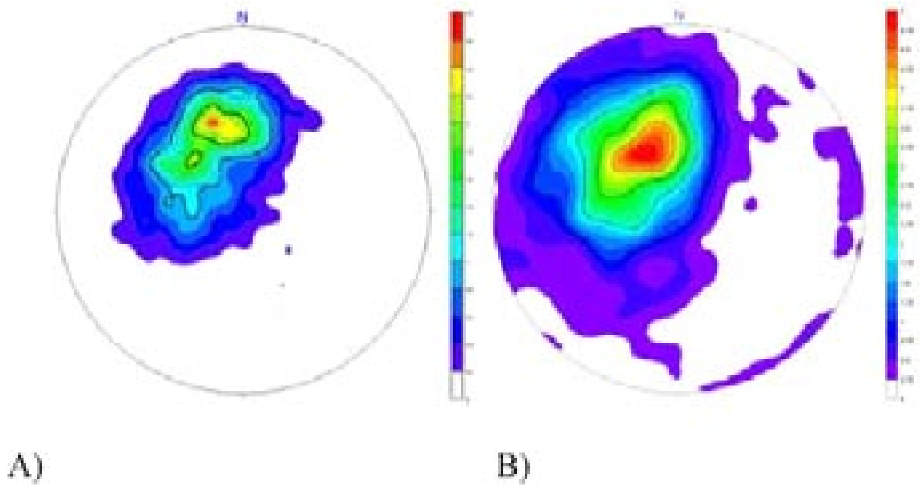

Figure 3-3. *A. Stereogram showing foliation plane orientations (dip direction/dip) measured from drillholes/core samples OL-KR1–OL-KR33, Olkiluoto (N = 9,500, lower hemisphere equal area projection). B. Fault plane orientations (dip direction/dip) measured from the same samples/holes (N = 1,655). Schmidt lower hemisphere, equal area projection. Concentrations % of total per 1% area /Paulamäki et al. 2006/.*

4 KBS-3H layout adaptation

The input data shown in Tables 1-1 and 1-2 were used to adapt the KBS-3H layout to the Olkiluoto site at the −420 m level. The realisation, which is comparable with the KBS-3V concept, is shown in Figure 4-1. In this example there are 171 deposition drifts, the average deposition drift length is 272 m and the total canister drift length is some 46,400 m. In the actual repository, the total length of central tunnels is 8,400 m (this total length includes both adjacent central tunnels and the connecting tunnels between them), and the ONKALO facility includes additional 1,700 m of central tunnels. There are 3,779 canister locations in the layout example, which corresponds to the required number (see Chapter 3.2.4).

The layout takes up most of the area between the major fracture zones HZ20 and HZ21 (Figure 3-2), as can be seen in Figure 4-1. Table 4-1 shows a comparison between the KBS-3H and 3V concepts based on the latest layouts. The total length of the KBS-3H deposition drifts is larger than that of the KBS-3V deposition tunnels, and accordingly the KBS-3H repository requires a larger area than the KBS-3V repository.

Due to the unusable sections of the host rock, the actual canister spacing is some 15 m on average in the deposition drifts (excluding the first 25 m where the drift end plug is installed), based on the layout shown in Figure 4-1. In a 300 m long drift with average properties, there is one drift end plug (25 m) and 18.5 canisters occupying a total length of some 193 m (assuming average thermal canister spacings), and the total length of unusable host rock is, thereby, 82 m. This can be assumed to contain one compartment plug (30 m) and 5.2 blank zones (10 m each) on average. The blank zones are not necessarily always exactly 10 m long, as the previous canister is not always located precisely where the blank zone should start, in which case it would have to be longer. Also some shorter blank zones may be used if a canister location should be moved by only a little to avoid intersecting some potentially long, dry fracture.

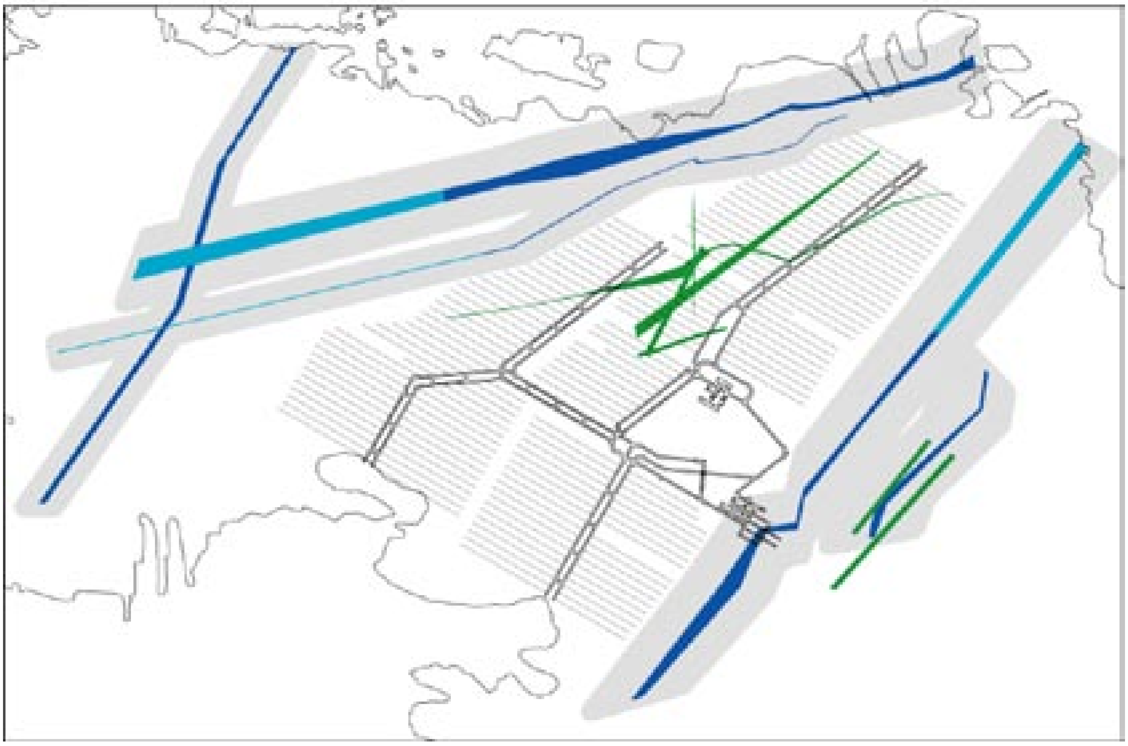

Figure 4-1. KBS-3H layout with canister drift orientation of 120°, level –420 m at Olkiluoto. Grey areas indicate the respect distances to the fracture zones (fracture zones codes are given in Figure 3-2).

Table 4-1. Comparison between KBS-3V (based on /Kirkkomäki 2006/) and KBS-3H concepts. The volumes and lengths are approximate values.

Parameter/Disposal concept	KBS-3H	KBS-3V
Number of deposition drifts/tunnels	171	137
Average length of the deposition drifts/tunnels	272 m	300 m
Total length of deposition drifts/tunnels	46.4 km	41.1 km
Total number of canister positions*	3,779	3,408
Total number of OL1-2 canister positions	1,610	1,452
Total number of OL3 canister positions	1,240	1,118
Total number of LO1-2 canister positions	929	838
Number of deposition drifts/tunnels with OL1-2 canisters	75	58
Number of deposition drifts/tunnels with OL3 canisters	61	48
Number of deposition drifts/tunnels with LO1-2 canisters	35	31
Total volume of the repository	894,000 m^3	1,360,000 m^3
Total volume of the access tunnel	229,000 m^3	229,000 m^3
Total volume of the shafts and shaft connections	83,900 m^3	83,900 m^3
Total volume of the technical rooms	82,600 m^3	82,600 m^3
Total volume of the central tunnels (incl. those in the ONKALO)	380,000 m^3	333,000 m^3
Total volume of the deposition drifts/tunnels (excl. 3V deposition holes)	125,000 m^3 **	580,000 m^3

* The number of canisters in 2,840 in both concepts but the required number of canister positions is different mainly because in KBS-3H the compartment plug sections and blank zones take up long sections in the drifts (see Chapter 3.4.2).

** This value assumes that the whole length of the deposition drifts is circular with a constant diameter of 1.85 m. It has, however, been planned that the first 10−15 m of the drift would have a large horseshoe-shaped profile /e.g. Thorsager and Lindgren 2004/, the cross-sectional area of which has not been finally decided yet.

5 Discussion and conclusions

In this work an Olkiluoto-specific layout of a KBS-3H repository has been produced based on the latest data and bedrock model. One of the main goals of this work was to support the evaluation of the feasibility of the KBS-3H concept and to compare the layouts based on the KBS-3H and KBS-3V concepts. The relevant data are also presented in Table 4-1.

The study shows that the KBS-3H layout requires a larger area than the KBS-3V repository and takes up most of the available area between the major fracture zones HZ20 and HZ21. This is mainly due to the long drift sections occupied by the compartment plugs (30 m) and the bentonite blocks in the blank zones (10 m), which reduces the usability of the host rock and results in larger canister spacings than in the KBS-3V concept, where the positioning of the deposition holes is very flexible and narrow zones with a moderate transmissivity usually have only a minor effect on the locations of the canisters. The criteria for the host rock are, however, not yet decided on, and the percentage of unusable host rock may be smaller or greater than what has been assumed here (25%). This percentage, which results in an increase of drift lengths of some 33%, may also change due to changes in the design of the different components of the KBS-3H disposal system (e.g. the compartment plugs).

The layout presented here is, therefore, only preliminary and involves a number of uncertainties. In addition to the uncertainties related to the host rock criteria and the details of the design (see above and also Chapter 2), the layout is also significantly affected by the assumed model of layout-determining fracture zones. In this work 11 major (highly transmissive) fracture zones interpreted to intersect the −420 m level were considered deterministically. The respect distances to fracture zones were, on general, significantly smaller than those used previously /e.g. Äikäs and Riekkola 2000, Malmlund et al. 2004/. For example, the layout would have been different, if the respect distance to class B zones were increased from 5 m to several tens of metres, as many class B zones intersect a large number of deposition drifts in the layout (Figure 4-1). Also, it would be important to study in future whether the same respect distances result in equally acceptable performance of both concepts. It may be that one concept is more sensitive to the proximity of fracture zones than the other. In order to produce layouts that are comparable in terms of long-term safety and technical feasibility and are based on similar criteria on repository performance, it may be necessary to use slightly different respect distances in KBS-3H, as compared with those used in 3V. Also, to be conservative the extension of some zones, which are located near the boundaries of the repository area, has been increased in this work as it was done in the KBS-3V work, as well. This has had only a minor effect on the layout, but the effect is perhaps little greater for the KBS-3H than for 3V, since 3H has more need for space.

As the KBS-3H layout takes up nearly all of the potential bedrock resource in the current investigation area at central Olkiluoto based on the results of this work, the margin for uncertainties is very small. It may be worthwhile to consider to extend the investigation area, if the repository is intended to be constructed in one layer only.

The final amount of canisters may differ from the assumption used here and therefore the adequacy of the present available bedrock may change. The bedrock, which is now available, may, however, also change in future.

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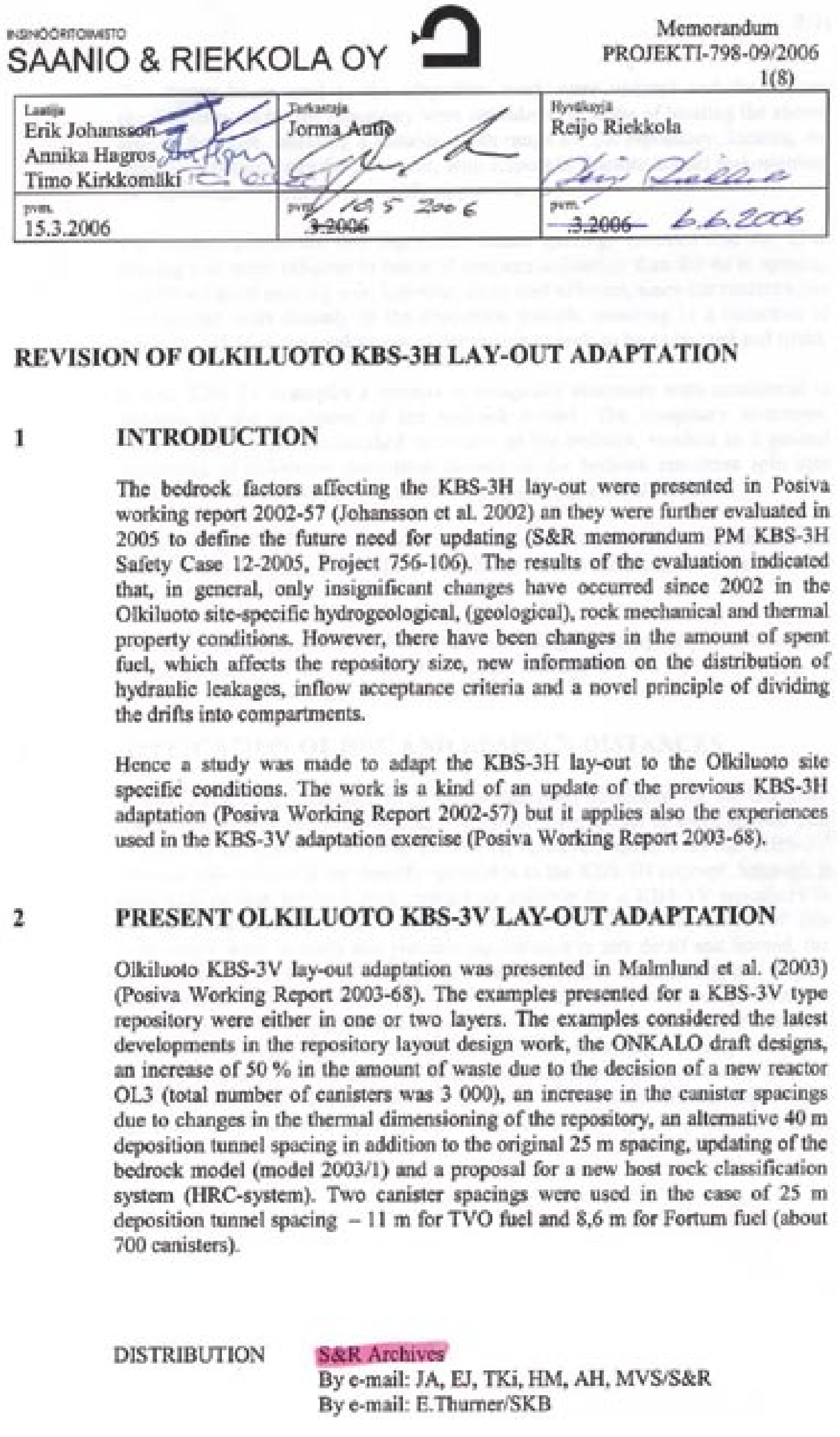
Appendix 1

Previous layout adaptation



INSINÖÖRITOIMISTO
SAANIO & RIEKKOLA OY

Memorandum
PROJEKTI-798-09/2006
1(8)

Laatija Erik Johansson Annika Hagros Timo Kirkkomiki	Tarkastaja Jorma Autio	Hyväksyjä Reijo Riekkola
pvm. 15.3.2006	pvm. 18.5 2006 ~~.3.2006~~	pvm. ~~.3.2006~~ 6.6.2006

REVISION OF OLKILUOTO KBS-3H LAY-OUT ADAPTATION

1 INTRODUCTION

The bedrock factors affecting the KBS-3H lay-out were presented in Posiva working report 2002-57 (Johansson et al. 2002) an they were further evaluated in 2005 to define the future need for updating (S&R memorandum PM KBS-3H Safety Case 12-2005, Project 756-106). The results of the evaluation indicated that, in general, only insignificant changes have occurred since 2002 in the Olkiluoto site-specific hydrogeological, (geological), rock mechanical and thermal property conditions. However, there have been changes in the amount of spent fuel, which affects the repository size, new information on the distribution of hydraulic leakages, inflow acceptance criteria and a novel principle of dividing the drifts into compartments.

Hence a study was made to adapt the KBS-3H lay-out to the Olkiluoto site specific conditions. The work is a kind of an update of the previous KBS-3H adaptation (Posiva Working Report 2002-57) but it applies also the experiences used in the KBS-3V adaptation exercise (Posiva Working Report 2003-68).

2 PRESENT OLKILUOTO KBS-3V LAY-OUT ADAPTATION

Olkiluoto KBS-3V lay-out adaptation was presented in Malmlund et al. (2003) (Posiva Working Report 2003-68). The examples presented for a KBS-3V type repository were either in one or two layers. The examples considered the latest developments in the repository layout design work, the ONKALO draft designs, an increase of 50 % in the amount of waste due to the decision of a new reactor OL3 (total number of canisters was 3 000), an increase in the canister spacings due to changes in the thermal dimensioning of the repository, an alternative 40 m deposition tunnel spacing in addition to the original 25 m spacing, updating of the bedrock model (model 2003/1) and a proposal for a new host rock classification system (HRC-system). Two canister spacings were used in the case of 25 m deposition tunnel spacing – 11 m for TVO fuel and 8,6 m for Fortum fuel (about 700 canisters).

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The design bases used in the adaptation work were updated and the various requirements set for the repository were considered in terms of locating the above-ground facilities, selecting a suitable depth range for the repository, locating the repository horizontally (in particular, with respect to fracture zones) and orienting the deposition tunnels as favourably as possible.

The comparison of the two deposition tunnel spacings revealed that the 25 m spacing was more efficient in terms of resource utilisation than the 40 m spacing. The 40 m tunnel spacing was, however, more cost efficient, since the canisters can be disposed more densely in the deposition tunnels, resulting in a reduction of some 20 - 25 % in the total length of deposition tunnels to be excavated and filled.

In four KBS-3V examples a number of imaginary structures were considered in addition to the structures of the bedrock model. The imaginary structures, representing the yet unidentified structures of the bedrock, resulted in a general shortening of individual deposition tunnels as the bedrock resources split into smaller bedrock blocks, as well as an extending of the central tunnels.

Malmlund et al. (2003) evaluated that 17 % of the canister locations within the disposal area at Olkiluoto would be unsuitable (due to the conductive sections and poor rock quality) based on the HRC-system.

In one storey concept, level –420 m and including the imaginary structures, the utilization degree of the site was 79% (1,5 km^2/1,9 km^2).

3 APPLICATION OF HRC AND RESPECT DISTANCES

A Host Rock Classification (HRC) system has been developed for the Olkiluoto site for identifying suitable volumes of rock for the disposal of spent nuclear fuel (Hagros et al. 2005). The HRC-system is, however, specific to the KBS-3V disposal concept and is not directly applicable to the KBS-3H concept, although it may well be that the host rock defined as suitable for a KBS-3V repository is equally suitable for a KBS-3H repository. It is outside the scope of this preliminary work to study this possible equivalence in any detail and instead, the HRC-system will be used only where necessary, i.e. in defining the respect distances to layout-determining fracture zones, and with only minimal modifications. The respect distances to Class A and B fracture zones are shown in Table 1, where the horizontal deposition drifts are assumed to correspond to the deposition tunnels of the KBS-3V system and similar respect distances will be used. The same classification of fracture zones at Olkiluoto will be used as was presented in the layout adaptation work for the KBS-3V system (Malmlund et al. 2003).

Table 1. Layout-determining fracture zones (Class A and B) and the related respect distances (modified from WR 2005-07 (Hagros et al. 2005)). In the KBS-3H design it is assumed that the deposition drift corresponds to the deposition tunnel in the KBS-3V concept.

Class	Fracture zones in the class	Basis for the definition of fracture zone class		Respect distance
A	Fracture zones that cannot be intersected by any part of the repository below a depth of 300 m.	A1	Length ≥ 5000 m	1 % of the length, 100 m at most
		A2	T400m ≥ 1E-05 m2/s	50 m
B	Fracture zones that cannot be intersected by deposition drifts but can be intersected by other parts of the repository.	B1	1E-06 ≤ T400m < 1E-05 m2/s	40 m
		B2	1E-07 ≤ T400m < 1E-06 m2/s	30 m
		B3	Q' < 0.5 and thickness > 5 m	15 m

Other parameters of the HRC-system will not be considered directly in this preliminary work. Indirectly it will, however, be assumed that a portion of the rock mass would be unsuitable due to some criteria on rock mass quality (in addition to certain criteria on transmissivity which are discussed below).

4 EFFECT OF GEOHYDROLOGICAL CONDITIONS

Transmissive sections and the corresponding inflow classes were estimated based on the table by Lanyon 2005. Three inflow classes as shown in Table 2 were used. The calculation of the transmissive sections in the repository that require compartment plugs or bentonite blocks is presented in Table 3. Data from the hydraulic measurements carried out in boreholes KR1...KR23 (depth interval 350 - 570 m) were used, whenever available (these boreholes were chosen because they were considered in the bedrock model 2003/1 that was used here). The calculations indicate that 21 % of the bedrock resource is unusable due to too high transmissivities (> 2.65E-09 m^2/s) and the related need of compartment plugs and bentonite blocks. This value was decided to be tentatively rounded up to 30 % to include the probable effect of other factors (e.g. low rock quality and non-transmissive Class C fracture zones, see Hagros et al. 2005).

Table 2. Inflow classes (related to transmissivity) of rock mass within the bedrock resource and their effects on the locating of canisters in KBS-3H deposition drifts.

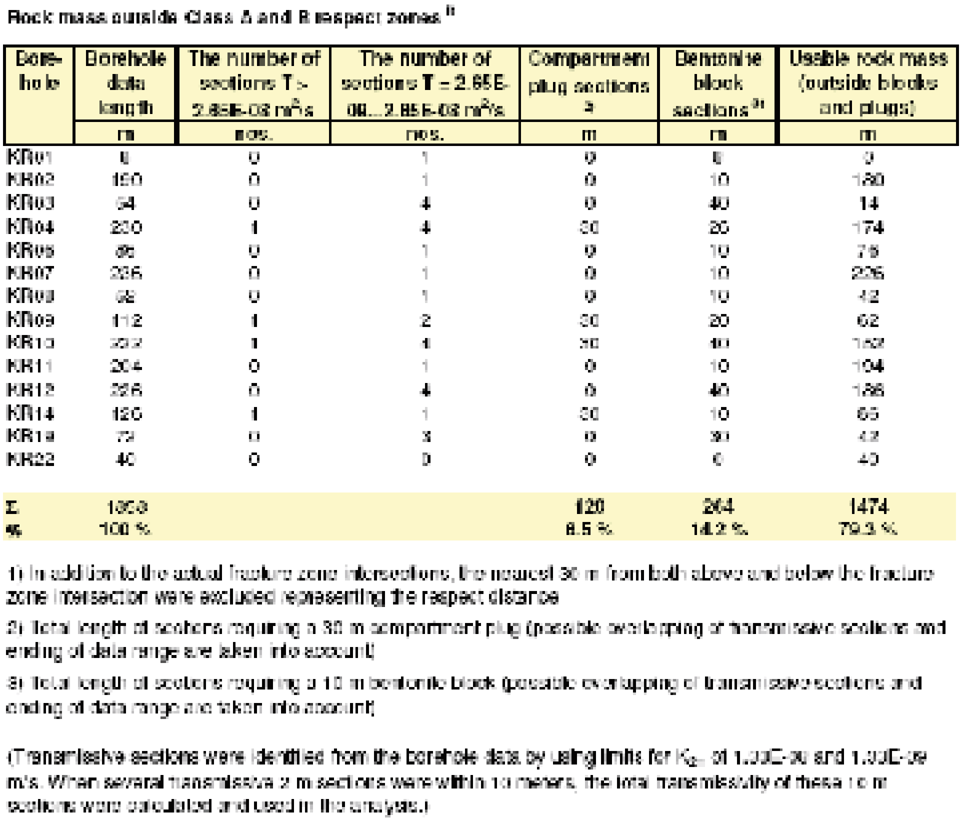
Inflow (l/min) into one supercontainer section from fractures without sealing	Transmissivity (m^2/s) assuming one inflowing fracture [1]	Effect on the locating of canisters (KBS-3H supercontainers) and the need for seals (isolation)
Inflow < 0.1	T < 2.65E-9	No effect (a supercontainer can be located into the section)
0.1 ≤ Inflow < 1	2.65E-9 ≤ T < 2.65E-8	A bentonite block of 10 m shall be located into the section.
Inflow ≥ 1	T ≥ 2.65E-8 [2]	A compartment plug unit of 30 m [3] in total shall be located into the section.

1) Transmissivity calculated from inflow using the Thiem equation and assuming a constant head of 400 m at a radius of 50 m from the tunnel (radius 0.925 m).

2) If T ≥ 1E-7 m^2/s, the section probably belongs to a Class A or B fracture zone (see Table 1) and such sections should, therefore, not occur in the bedrock resource where the deposition drifts are located.

3) 30 m = stabilization zone 10 m + fracture zone (conductive section) 10 m + stabilization zone 10 m.

Table 3. Calculation of the percentage of transmissive sections (that require compartment plugs or bentonite blocks, see Table 2) at Olkiluoto. Borehole data from the depth range 350 - 570 m (vertical depth below sea level) have been used. Transmissitivies were evaluated from the borehole flow measurement data measurements (Pöllänen & Rouhiainen 1996a, 1996b, 1997, 2000, 2002, Rouhiainen 2000, Pöllänen et al. 2005).



Rock mass outside Class A and B respect zones [1]

Bore-hole	Borehole data length	The number of sections T > 2.65E-08 m^2/s	The number of sections T = 2.65E-09...2.65E-08 m^2/s	Compartment plug sections [2]	Bentonite block sections [3]	Usable rock mass (outside blocks and plugs)
	m	nos.	nos.	m	m	m
KR01	6	0	1	0	6	0
KR02	190	0	1	0	10	180
KR03	54	0	4	0	40	14
KR04	230	1	4	30	26	174
KR05	85	0	1	0	10	75
KR07	236	0	1	0	10	226
KR08	52	0	1	0	10	42
KR09	112	1	2	30	20	62
KR10	232	1	4	30	40	162
KR11	204	0	1	0	10	194
KR12	226	0	4	0	40	186
KR14	126	1	1	30	10	86
KR19	72	0	3	0	30	42
KR22	40	0	0	0	0	40
Σ	1858			120	264	1474
%	100 %			6.5 %	14.2 %	79.3 %

1) In addition to the actual fracture zone intersections, the nearest 30 m from both above and below the fracture zone intersection were excluded representing the respect distance

2) Total length of sections requiring a 30 m compartment plug (possible overlapping of transmissive sections and ending of data range are taken into account)

3) Total length of sections requiring a 10 m bentonite block (possible overlapping of transmissive sections and ending of data range are taken into account)

(Transmissive sections were identified from the borehole data by using limits for K_{2m} of 1.00E-09 and 1.00E-08 m/s. When several transmissive 2 m sections were within 10 meters, the total transmissivity of these 10 m sections were calculated and used in the analysis.)

5 INPUT DATA TABLE

It is assumed that the repository will be constructed in one layer at about –400 m depth at Olkiluoto. The total amount of fuel is based on the present estimate, which corresponds to 3 000 canisters. Similar requirements and bases are used as in the present KBS-3V adaptation to produce comparable result. Due to the unusable bedrock resource (30 %) as shown in Table 4, a space for 4 290 canisters would be needed.

Table 4. Input data for Olkiluoto KBS-3H adaptation.

Parameter	**Value/criterion**
Number of canisters	3 000
Repository concept	KBS-3H, one layer, no side tunnels – other parts than deposition drifts and related niches are similar to present KBS-3V design
Bedrock model	Olkiluoto 2003/1 model
Bedrock resource	As in WR 2003-68 + imaginary structures* + 30 % of resource considered unusable**
Respect distances	As in Table 1
Depth level	400 m***
Spacing between deposition drifts	25 m****
(Canister length	4 835 mm)
Canister spacing (center to center distance)	10.9 m ***
(Supercontainer length	5 560 mm***)
(Distance block length	5 350 mm***)
Length of deposition drift	100 – 300 m***
Orientation of deposition drift	120 ± 10° (parallel to the assumed main principal stress)****
Other space requirements	First canister 25 m from the central tunnel

* Taken as in WR 2003-68 (Class B fracture zones, see Table 1)

** 21 % of the bedrock resource is unusable due to too high transmissivities (> 2.65E-09 m^2/s) and the related need of compartment plugs and bentonite blocks (see Tables 2 and 3). This value is tentatively rounded up to 30 % to include the probable effect of other factors (e.g. low rock quality and non-transmissive Class C fracture zones) on the locating of the canisters (cf. WR 2003-68). In the adaptation work, this 30 % unusability of resource is considered by increasing the number of canisters by 43 % (=30/(100-30)) to 4290 canisters.

*** Input parameters for Safety Case (S&R Memo 756-11/2005 PM Input parameters for HMCGB analyses, version 6.12.2005)

**** As in WR-2002-57

6 KBS-3H LAY-OUT ADAPTATION EXAMPLE

The input data shown in Table 4 were used to adapt the KBS-3H lay-out to the Olkiluoto site. The "best" realization is shown in Figure 1. In this example there are 156 canister drifts, the average canister drift length is 264 m and the total canister drift length is 41 167 m. There are 3 419 canister locations in the lay-out example, which is 79.7 % of the target number, i.e. 4 290.

When using the above described input assumptions, the utilization degree of the Olkiluoto site is then about 120 % in the KBS-3H concept, whereas it was about 80 % in the KBS-3V concept. It should be noted that in the KBS-3V adaptation canister spacing 8.6 m was used for Fortum's 700 canisters. This effect is, however, considered to be small.

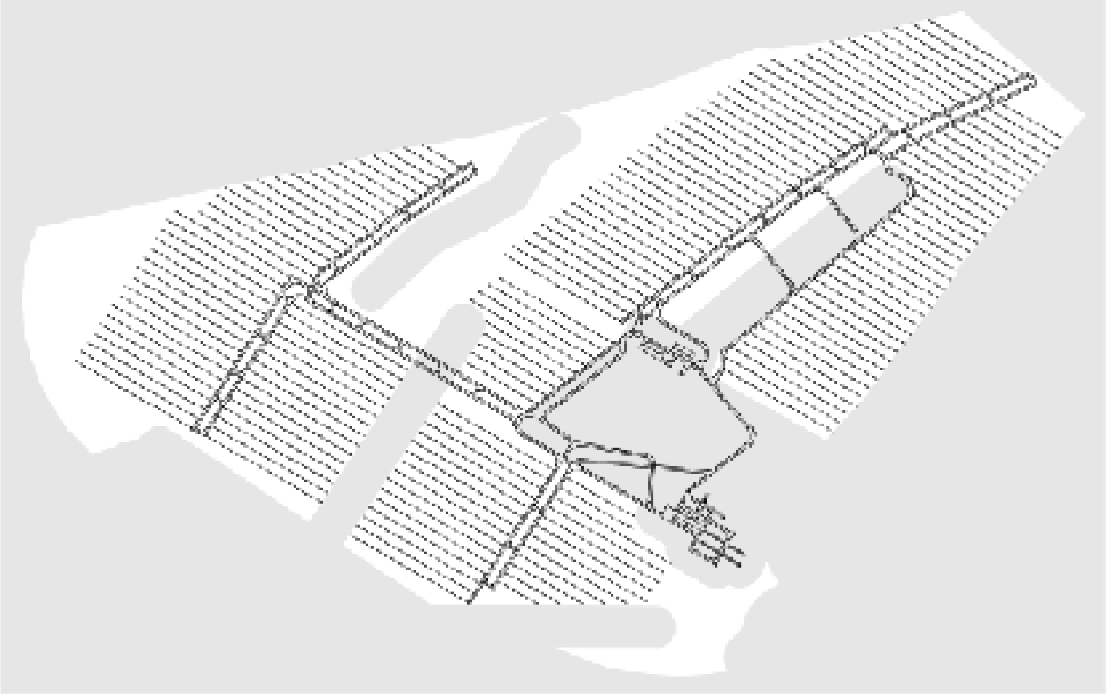


Figure 1. KBS-3H lay-out adaptation to the Olkiluoto site, depth level 400 m. White areas indicate the usable bedrock resource.

7 CONCLUSION

Using the input data described in Table 4 there is not enough available bedrock resource to adapt the KBS-3H concept in one layer. However, keeping in mind the uncertainties related to the input, especially available bedrock resources, the situation can be quite different. Coming updates (next during 2006) of geological and geohydrological site model will in more detail show the usable bedrock resources.

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