R-08-113

Underground design Forsmark, Layout D2

Layout and construction plan

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May 2009

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

Abstract

The Swedish Nuclear Fuel and Waste Management Company (SKB) has the responsibility for the final repository of radioactive waste from Swedish nuclear power plants. SKB plans to design, construct and operate a final repository for spent nuclear fuel in a system where copper canisters, containing the spent radioactive fuel, are deposited at a depth of c. 500 m in crystalline bedrock.

Controlling documents describe prerequisites for the underground facility, concerning, for example, the boundaries of the target volume, geological aspects, the construction work and the final deposition resources. The repository is to have a capacity of 6,000 deposited canisters, which is a net sum. Geological features, such as deformation zones, have large impact on the deposition capacity as deposition cannot occur in deformation zones, or even within a certain distance of major deformation zones > 3,000 m trace length at ground surface. Thus, the calculated capacity of the repository needs to include a percentage of loss of deposition positions dimensioned with input from Site Engineering Report Forsmark /SKB 2008a/.

The layout of the underground facility, which includes the access ramp, shafts, rock caverns in a central area, transport tunnels, main tunnels, deposition tunnels and deposition holes, was achieved through an iterative process between a proposed layout from an earlier design phase /Brantberger et al. 2006/, a functionality study and the prerequisites for the underground facility. The result from the generic functionality study showed that a construction strategy where deposition- and construction activities were separated by using the Linear Development Method, with separating doors/walls between activities in the same main tunnel, is to prefer rather than a side-change construction strategy, which was the idea prior to the functionality study.

The presented layout and the following construction plan is the direct result of the functionality study. With help from that study, and with the prerequisites in mind, certain strategies for the construction plan could be pointed out, for example how to shorten the transportation distances in the underground facility and how to optimize the amount of deposition positions by placing transportation tunnels outside the boundaries for deposition.

This report shows that the requested amount of deposition positions is fulfilled, and loss of depositions are within the assigned limits. Two reserve areas are presented, which together can offer another c. 1,000 deposition positions. The proposed overall construction of the underground facility is made in such way that the requests of robustness, efficiency and flexibility are satisfied.

Sammanfattning

Svensk kärnbränslehantering AB (SKB) ansvarar för att ett slutförvar för radioaktivt avfall från de svenska kärnkraftverken tas fram. SKB planerar att designa, bygga och driva ett slutförvar för använt kärnbränsle i ett system där kopparkapslar, innehållande det uttjänta kärnbränslet, förvaras på ett djup av 500 m i kristallin berggrund.

Styrande dokument innehåller riktlinjer för utformningen av undermarksanläggningen. Dokumenten behandlar olika områden, till exempel gränser för området där möjligheterna för slutförvar undersöks, geologiska aspekter inom undersökningsområdet, utbyggnadsarbetet och resurserna för den slutliga deponeringen. Förvaret ska ha plats för 6 000 deponeringskapslar, netto. Geologiska förhållanden, såsom förekomst av deformationszoner, har stort inflytande på deponeringskapaciteten eftersom deponering inte är tillåten i deformationszoner, eller ens inom ett visst avstånd från större deformationszoner. Detta medför att den beräknade kapaciteten måste ge utrymme för en viss procent bortfall av kapselpositioner beräknat med hjälp av geo-DFN /SKB 2008a/.

Layouten av undermarksanläggningen, vilken inkluderar tillfartsramper, schakt, bergrum i ett centralområde, transporttunnlar, huvudtunnlar, depositionstunnlar och deponeringshål, arbetades fram genom en iterativ process mellan en föreslagen layout från ett tidigare designsteg /Brantberger et al. 2006/, en funktionalitetsstudie och förbehållen för undermarksanläggningen. Resultaten från den generella funktionalitetsstudien visade att en utbyggnadsordning med separering av deponerings- och bergbyggnadsverksamheterna via användning av den linjära utbyggnadsmetoden, med separerande dörrar/väggar mellan aktiviteterna i samma stamtunnel, är att föredra framför en sidbytesstrategi vilket var tanken före funktionalitetsstudien.

Den presenterade layouten, tillsammans med föreslagen utbyggnadsordning, är således ett direkt resultat av funktionalitetsstudien. Med hjälp av den studien och med förutsättningarna i åtanke, kunde vissa strategier för utbyggnadsordningen arbetas fram, till exempel hur transportvägar kunde kortas och att optimering av deponeringsposition kunde ske genom att lägga vissa transporttunnlar utanför deponeringsområdet.

Föreliggande rapport visar att kravet på antal deponeringspositioner kan uppnås, och att andelen bortfall av kapselpositioner hålls inom angivna gränser. Två reservområden presenteras, vilka tillsammans utgör ytterliggare cirka 1 000 kapselpositioner. Den föreslagna utbyggnaden av undermarksanläggningen kan utföras så att kraven på robusthet, effektivitet och flexibilitet uppnås.

Contents

1 Introduction

The Swedish Nuclear Fuel and Waste Management Company (SKB) has the responsibility for the final repository of radioactive waste from Swedish nuclear power plants. Spent nuclear fuel is presently transferred successively from the Swedish nuclear power plants to a central interim storage facility for spent fuel (Clab). SKB plans to design, construct and operate a final repository for spent nuclear fuel in accordance with the KBS-3 method, which provides three protective barriers. This means that the spent nuclear fuel is encapsulated in watertight and load-resistant copper canisters. The canisters are deposited in crystalline rock at a depth of about 500 m and enclosed by a buffer of bentonite clay to prevent inflow of water and to protect the canisters. Tunnels and rock caverns are to be sealed when the disposal is completed.

To carry out disposal according to the KBS-3 method a corresponding comprehensive system is required. The KBS-3 *system* covers transport systems, intermediate storage facilities, encapsulation plant, canister factory and final repository. SKB plans to locate the encapsulation plant close to the interim storage Clab on the Simpevarp peninsula outside Oskarshamn. Two places are currently of interest for location of the final repository; Forsmark in Östhammar municipality and Laxemar in Oskarshamn municipality.

To enable SKB to build and operate the facilities it is required that they are subjected to licensing application in accordance with both the Swedish Environmental Code and the Nuclear Activities Act.

The site investigations at Forsmark ended during 2007, and the design work is planed to continue until 2009, when licensing applications will be submitted. The next phase, i.e. the construction phase, will begin when SKB receives the necessary permits. The objective is to have a system for final storage of spent nuclear fuel ready for taking into operation after an initial construction period of about seven years.

This report presents suggestions for location and layout of a final repository facility at Forsmark, Östhammar municipality.

1.1 Objectives

The main objective of the present layout work in design phase D2 was to investigate the functionality of the underground facility. Other objectives included are:

- Drafting a description of a facility for the selected site with a layout proposal for the surface and underground facilities of the final repository as part of the supporting documents for an application. The description shall account for constructability, technical risks, costs, environmental impact and robustness/effectiveness. The underground layout is to be based on information from the site investigation and constitute the basis for the safety evaluation.
- Ensuring that the requirement of a net deposition capacity of 6,000 canisters can be fulfilled.
- Proposing a possible site adaptation of the repository with respect to the overall requirements of functionality, robustness and long-term safety.
- Demonstrating constructability and effectiveness for a proposed stepwise extension of the underground parts of the repository.
- Ensuring that different phases of the rock excavation do not come into conflict with any deposition activity. The framework of this target includes a number of issues such as: separation of the two main activities, construction and operation of the repository, health and safety, geological aspects, transport efficiency, ventilation, conservation of environmental values.

The layout also provides advising material in accordance with Chapter 6 of the Swedish Environmental Code concerning:

- localization of the surface facility
- localization and extension of the underground facility
- technical description and functionality description of possible layout

1.2 Strategy

The overall strategy with regard to the layout for the underground facility of the final repository is to optimize the number of deposition holes with respect to available facility volume, also considering geographical limitations, condition of the bedrock such as rock domains, fracture domains, abundance/type of fracture/fracture zones, water conditions, thermal and mechanical conditions and financial prerequisites. To optimize the layout the strategy has also included performance of a generic functionality study followed by presentation of a construction plan for the proposed layout at Forsmark.

1.3 Design methodology

The design methodology for design phase D2 is described in Chapter 5.4 in /SKB 2007/ and is divided into five main activities:

1. An initial study based on results from the design phase D1 /Chapter 6 in SKB 2007/ with regard to new information that can influence the layout work.
2. A functionality study of the repository and its function. This main activity has been carried out as a separate item and is presented in Chapter 3.1 of this report.
3. Compilation of layout alternatives, with regard to the premises noted in /SKB 2008a/, that have adequate deposition capacity. Evaluate which alternative(s) that is/are the most favourable with regard to prescribed requirements and objectives.
4. Evaluation of constructability for proposed layouts from the perspective of rock reinforcement and grouting is presented in two separate reports /Eriksson et al. 2008/ and /Brantberger and Janson 2008/, respectively.
5. Risk evaluation of proposed layout, which is presented in /SKB 2008b/.

The achieved output from these studies will serve as input to other separately performed detailed studies for the design of drainage and ventilation systems (including fire ventilation), fire protection plans and rescue arrangements, transport systems, detailed planning of investigation and construction works, etc.

1.4 Organisation

The organisation for the entire "spent fuel" project is presented in /SKB 2007/. The design organisation is to cooperate and coordinate its work with site investigation/modelling, environmental impact assessment report, and safety analysis. For a more detailed description of the organisation please refer to /SKB 2007/.

1.5 Nomenclature

This chapter provides definitions of terms that are of basic importance for the layout modelling and description of the Forsmark site. Many geological terms relate to the geometrical framework of the modelling and thus are common to all disciplines within the design work.

Table 1-1. Designations and explanations.

Terms referring to the investigation site	Explanation
Candidate area	The candidate area refers to the area at the ground surface that has been recognised as suitable for a site investigation, following the feasibility study work /SKB 2000/. Its extension at depth is referred to as candidate volume.
Target area/volume	The target area refers to the northwest part of the candidate area and the rock volume beneath that was selected during the site investigation process as potentially suitable for hosting a final repository for spent nuclear fuel.

Terms referring to geology	Explanation
Deformation zone	Deformation zone is a general term that refers to an essentially 2D structure associated with brittle, ductile or combined brittle and ductile deformation. Deformation zones at Forsmark are denoted by two to eight letters or digits depending on dip and strike. Terminology and geometrical description of brittle structures in the bedrock are based on /SKB 2008a/. The differentiation between the different structures is approximate.

Deformation zone	Length	Width
Regional	> 10 km	> 100 m
Local major	1 km–10 km	5 m–100 m
Local minor	10 m–1 km	0.1–5 m
Fracture	< 10 m	< 0.1 m

Terms referring to geology	Explanation
	The regional and local major deformation zones are deterministically modelled, the local minor deformation zones are deterministically modelled, if possible, but in general stochastic, and finally the fractures are stochastic.
Discrete fracture network (geological DFN)	A discrete fracture network model involves a description of the fracturing in the bedrock on the basis of a statistical model, which provides geometries, directions and spatial distributions for the fractures and the local minor deformation zones within defined *fracture domains*.
Fracture domain	A fracture domain is a rock volume outside *deformation zones* in which rock units show similar fracture frequency characteristics. The respective fracture domains are often linked to a specific *rock domain*. Fracture domain at Forsmark are denoted FFMxx, *where xx refers to a sequential numbering of the fracture domains in the area.
Fracture zone	Fracture zone is a term used to denote a brittle deformation zone without any specification whether there has or has not been a shear sense of movement along the zone.
Model volume	**Regional deterministic model**. The volume for the regional model extends over a large area of the surface at the Forsmark site (Figure 2-1). In total height the extension is 2,200 m whereof 2,100 m is the extension at depth. *Rock domains* and *deformation zones* longer than 3,000 m are included in the regional model. **Local deterministic model.** The volume for the local model extends over 1,200 m in height, of which 1,100 m is the extension at depth. The extension on the surface is shown in Figure 2-1. *Rock domains*, *fracture domains* and *deformation zones* longer than 1,000 m (and some that are < 1,000 m) are included in the local model.
Rock domain	A rock domain refers to a rock volume in which rock units that show specifically similar composition, grain size, degree of bedrock homogeneity, and degree and style of ductile deformation have been combined and distinguished from each other. Different rock domains at Forsmark are referred to as RFMxxx, where x refers to numbers of the specific rock domain.
Tectonic lens	The Forsmark site lies within a regional ductile deformation belt made up of rocks with high ductile strain that anastomose around tectonic lenses. Within the lenses the bedrock is folded and generally affected by lower ductile strain. The candidate area at Forsmark is situated inside one of these tectonic lenses and is simply referred to as the tectonic lens in this report. Within the target volume the tectonic lens is constituted by two *rock domains*, RFM029 and RFM045.

Terms referring to the work with the underground facility and the underground facility itself	Explanation
Central area	Part of facility for rock caverns, tunnels, etc, for personnel, operation and maintenance
Deposition area	Part of facility for disposal in deposition tunnels, main tunnels and deposition holes
Deposition work	Installation of buffer (bentonite), deposition of canister, backfilling and pouring (casting) of concrete plug.
Excavation work	Excavation by drilling and blasting of main-, transport- and deposition tunnels, drilling of deposition holes and preparation for deposition.
Main activities	Excavation work and deposition work.
Respect distance	Deformation zones that are longer than 3 km have a respect distance of 100 m, which means that deposition of canisters is not allowed within this distance.
Underground facility	Space in the rock that is required to operate the final repository

Terms in italic denote that they are explained elsewhere in the table.

2 Design premises and site conditions

Premises for the work are described in control documents, such as /SKB 2007/ and /SKB 2008a/. The following chapter presents a summary of these premises.

2.1 Underground Design Premises/D2

The Underground Design Premises/D2 (UDP/D2) /SKB 2007/ is a document that presents crucial conditions that needs to be taken care of in every included study of design phase D2. It is covering the prerequisites for both Forsmark and Laxemar sites and includes for example the requirement that handling of radioactive material (i.e. deposition work) shall be kept separate from excavation work in all phases of the progressive construction. /SKB 2007/ provides an overall description of the premises for the work and includes references to other controlling documents.

In accordance with /SKB 2007/ the underground work shall be conducted with regard to the geological conditions as described in /SKB 2008a/, which in itself is a controlling document in the form of an engineering geologic description. The total deposition capacity of the deposition area is to be assessed to enable an estimate of the reserve capacity in the area.

The distance between the main tunnel and the first deposition hole is 17.6 m. From the last deposition position to the end of the tunnel the distance is 10.0 m.

All of the tunnels are to be constructed at a suitable inclination to facilitate drainage. The inclination is to be 1:100 for a maximum of 500 m, after which a break is to be made. Accordingly, a 5 m difference in level between tunnel bottoms of the deposition area can be anticipated.

/SKB 2007/ also describes how the final repository is to be extended stepwise and begins with an initial 3-year period for 300 canisters. Normal operation will then commence in steps of 150–200 canisters per year until 6,000 canisters have been deposited.

Rather than listing all specific conditions in /SKB 2007/, the document will be referred to whenever needed in the following text.

2.1.1 Deviations from design premises

As given in /SKB 2007/ Section 7.3.3, no investigation drillhole can be closer than one tunnel diameter from a tunnel in the repository. However, during the final QA-control of the prepared layout it was disclosed that this requirement was not met at four deposition tunnels (DB24, DB52, DC18 & DC22), rendering a total of 27 deposition positions to be discarded unless all deposition tunnels were slightly realigned into new positions. It was at that point considered an unjustified amount of work input to prepare a new layout to rectify this mistake, and instead it was decided by the design coordinator to postpone the adjustment until next phase of the design. It was considered that with only small correction of all deposition tunnels that most, if not all, of the lost 27 positions are possible to retrieve by a modified layout. The drillhole KFM07A passing slightly too close to main tunnel B will also render a small adjustment of the main tunnel in next phase of design.

The main tunnel (B) passing south of the central area is located closer than the minimum distance of 120 m given in appendices of /SKB 2007/. The minimum distance is established with the objective to provide the necessary minimum distance between rock excavation works and already deposited canisters if a new ramp for an extended two-level repository was to be constructed. The deviation is justified by not allowing any deposition holes in these deposition drifts closer than the required minimum distance of 120 m from the central area, and accordingly these deposition holes have been deleted in the proposed layout.

2.2 Site Engineering Report

The Site Engineering Report (SER) /SKB 2008a/ is an engineering geologic description of the site model and provides design prerequisites for long term safety and constructability of the underground facilities. The report describes the geological prerequisites of Forsmark, which for example include an introduction to rock and fracture domains, respect distance to deformation zones which have a trace length greater than 3,000 m at ground surface, and estimated degree of utilization due to long fractures dimensioned with the help of geo-DFN models, required distance between deposition holes due to thermal and mechanical rock conditions and direction of deposition tunnels. Consideration is also to be taken to the distance between existing investigation boreholes and tunnels, access ramp and shafts.

Three specific examples are presented here whereas others will described whenever such condition delimits specific layout decisions in the following report, which will then be marked with a reference to /SKB 2008a/.

- To cover the loss of deposition positions, the gross capacity for deposition must be increased by a maximum of 30%.
- Deformation zones that exceed 3,000 m trace length at ground surface require respect distance of 100 m, which means that depositing is not allowed within this distance.
- The distance between deposition holes in rock domain RFM029 is 6.0 m and in rock domain RFM045 6.8 m. The distance between the deposition tunnels is to be 40 m.

2.3 Input from design coordinator

There are both general and site-specific objectives for each environmental aspect. Every activity controlled by SKB is to follow their environmental programme, which has the purpose to ensure, already from an initial stage of the design phase, that the facilities and operations are adapted so that consequences with regard to health and the environment are as favourable as possible. Within the layout work, special concerns need to be taken when placing the ventilations shafts.

The area southeast of zone A2, (Figure 2-3 and 2-4) is not available for depositing waste, mainly because it is located in fracture domain FFM03 where the bedrock is characterized by open fracture conditions.

The area between the zones ENE0062A and F1 is available for deposition but shall, if possible, be regarded as reserve capacity only.

The area underneath the nuclear power plant at Forsmark (Forsmark Kraft AB = FKA) can be considered as a reserve area but may only be made use of after decommissioning the nuclear power plant (Figure 2-1).

A fire protection evaluation with regard to the fire risks related to the presented sequence of construction of the proposed layout will be made separately and is not included in this report.

The ventilation of the underground facility during excavation and deposition work is to be investigated by SKB.

2.4 Site specific conditions

The geographical area of the underground facility is limited to the northwest and southeast by administrative boundaries (Figure 2-1). In the northwest lies the FKA power plant, underneath which no activity is allowed as long as it is in operation. This is limiting the expansion of the underground facility in the northwest direction. To the southeast the boundary of the available underground area, regardless of depth, is regulated by a conservation area. In addition, landowners delimit the expansion to the south.

The boundaries to the northeast and southwest of the underground facility are constituted by the boundaries of a tectonic lens.

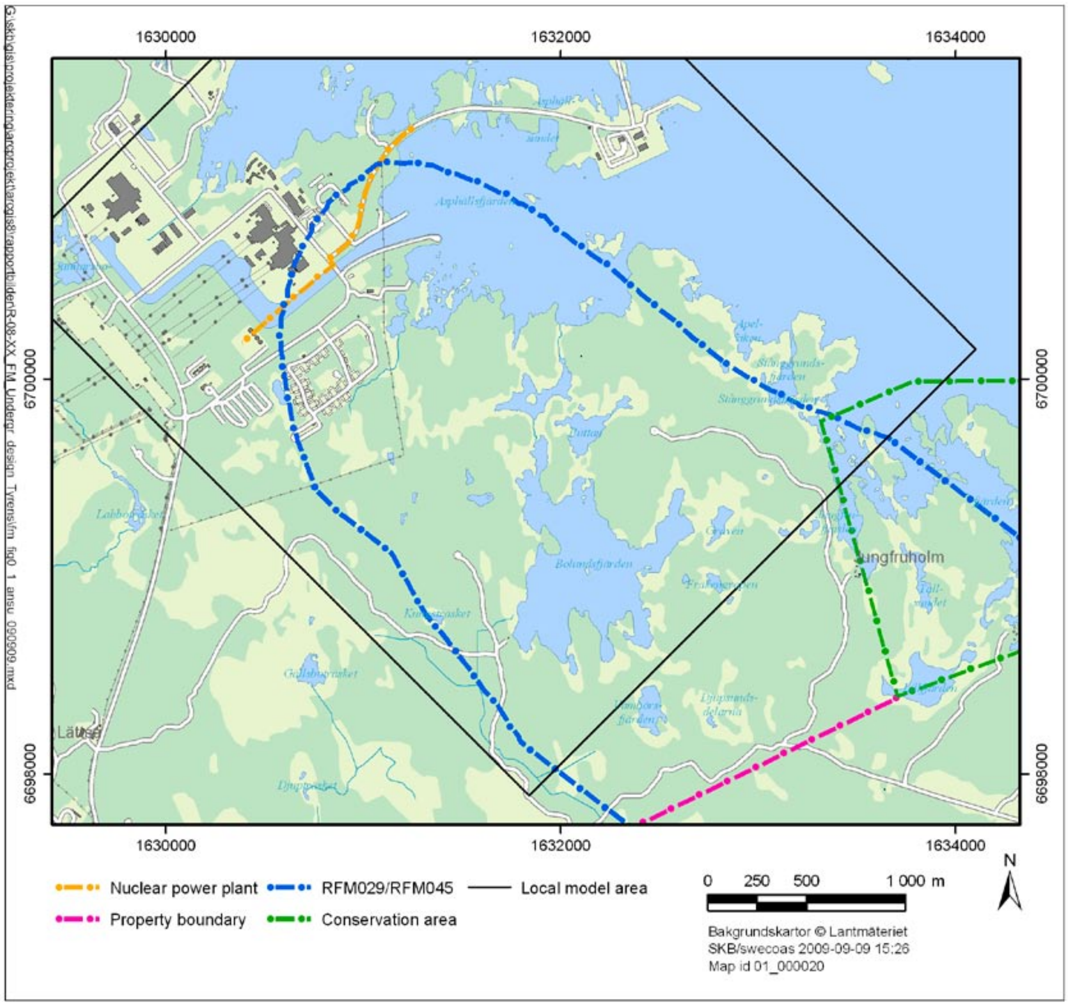


Figure 2-1. *Available underground area and administrative limits, projected on the surface.*

2.4.1 Geological description

The bedrock properties and the deformation zones are major steering conditions for the layout of the potential underground facility. The following text is an overall geological description of the target volume whereas a more thorough description is given in /SKB 2008a/.

The target volume for a potential underground facility lies in the northernmost part of a relatively homogenous tectonic lens. Inside the lens the rocks generally have a lower degree of ductile strain in contrast to the surrounding rocks, which are affected by a higher degree of ductile strain and a noticeable WNW to NW structural trend.

Division into rock domains

Within the target volume the tectonic lens is divided into two rock domains, RFM029 and RFM045 (Figure 2-2). These two rock domains show similar rock composition, but they differ in the degree of early stage alteration referred to as albitization.

Rock domain RFM029 is the volumetrically most significant domain (Figure 2-2). The dominant rock type in domain RFM029 is medium-grained metagranite to granodiorite, which comprises c. 74% of that domain. Subordinate rock types are pegmatite and pegmatitic granite (c. 13%), fine- to medium-grained metagranitoid (c. 5%), and amphibolite and other minor mafic to intermediate rocks (c. 5%). The subordinate rocks are forming isolated minor bodies or lenses and dyke-like sheets.

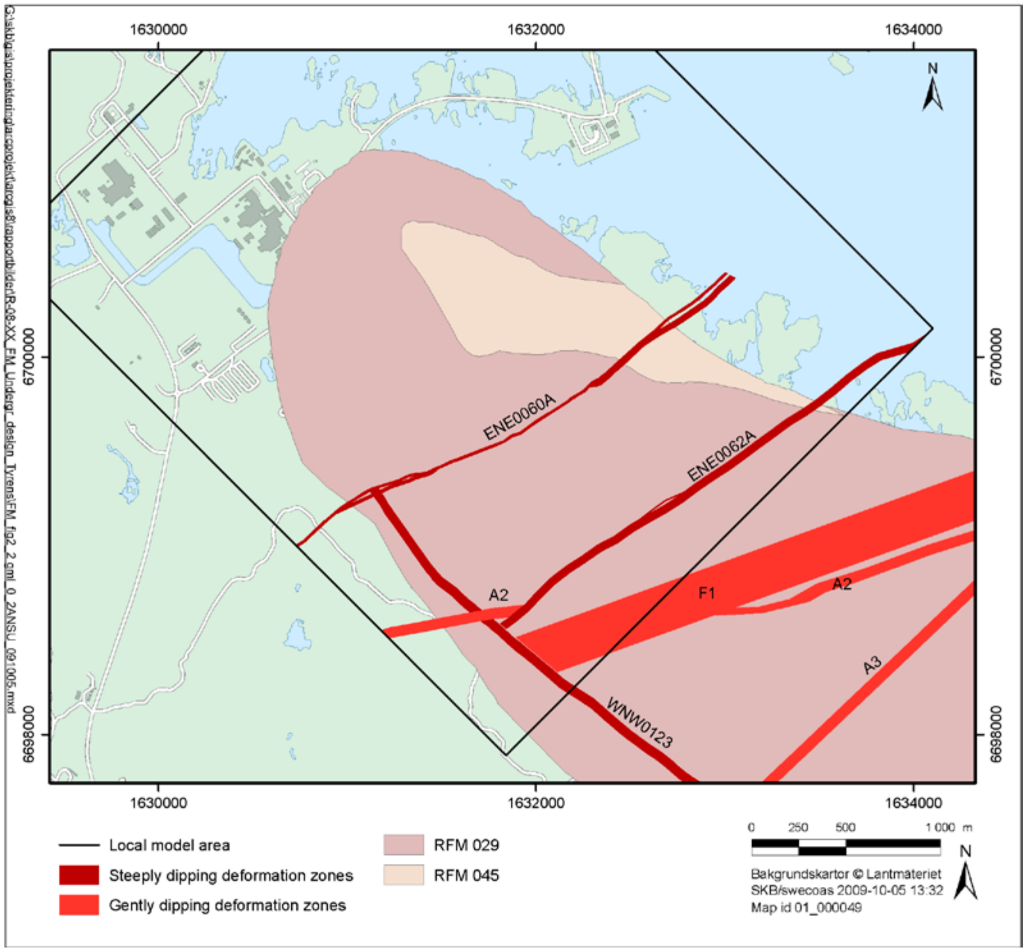


Figure 2-2. *The map is showing the extent of the rock domains RFM029 and RFM045 and also the most important deformation zones in the area. The figure shows the position of zones and rock domains at 470 m depth (RHB 70).*

Rock domain RFM045 forms a subordinate part inside the target volume and is located north-east of rock domain RFM029 (Figure 2-2). The domain has a conspicuous occurrence of albitized and metamorphosed granitic rocks, and a generally finer grain size than rock domain RFM029. The dominant rock types in this domain are aplitic metagranite and medium-grained metagranite, which constitute approximately c. 49% and c. 18%, respectively, of the rock domain volume. Both these rock types are commonly affected by Na-K alteration (albitization). It is also indicated from modal analyses that the quartz content is markedly increased and the K-feldspar content decreased, compared with unaltered rocks. Subordinate rock types in rock domain RFM045 are essentially the same as in rock domain RFM029 and include pegmatite and pegmatitic granite (14%), medium-grained metagranitoid (9%), amphibolite and other minor mafic to intermediate rocks (7%). Rock domain RFM045 has been modelled as a constricted rod-shaped geometry that plunges moderately to steeply to the southeast, more or less parallel to the mineral stretching lineation in the north-western part of the tectonic lens.

Division into fracture domains

The upper part of the bedrock inside the tectonic lens at Forsmark contains an increased frequency of sub-horizontal and gently dipping fractures with apertures, referred to as open and partly open fractures. A systematic assessment of the variation in the frequency of particularly open and partly open fractures with depth along investigation boreholes led to the division of the bedrock between deformation zones into fracture domains. On the basis of the borehole data, a 3D geometric model for four of the six fracture domains (FFM01, FFM02, FFM03 and FFM06), inside the target volume, was constructed (Figure 2-3).

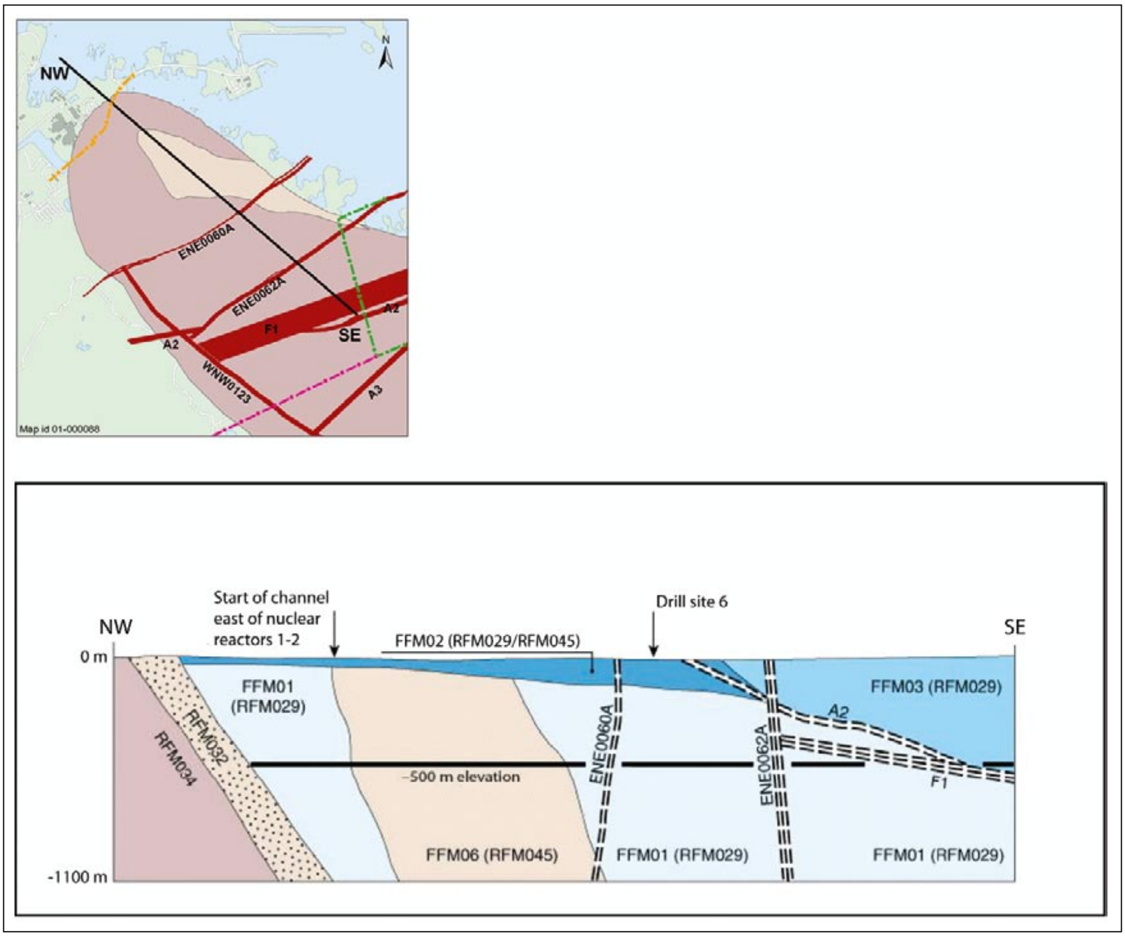


Figure 2-3. *Top view, orientation map of the Forsmark area. Bottom view, NW-SE cross-section showing rock domains and the division of the rock domains RFM029 and RFM045 in fracture domains. The position of the cross-section is shown on the orientation map. The steeply dipping deformation zones ENE0060A and ENE0062A together with the relationship between the gently dipping zones A2 and F1 are also shown. Modified from /SKB 2008a/.*

The rock domains RFM029 and RFM045 inside the local model volume consequently have been divided into separate fracture domains (FFM01, FFM02, FFM03 and FFM06) (Figure 2-3).

Fracture domain FFM01

Fracture domain FFM01 is situated beneath the gently dipping or sub-horizontal zones A2 and F1, and below a depth that varies from c. 40 m in north-eastern part of the rock domain RFM029 to c. 200 m close to zone A2 (Figure 2-3). The bedrock in this fracture domain shows a lower frequency of fractures with apertures compared to the overlying fracture domain FFM02.

Mainly mineral sealed, vertical or steeply dipping fractures that strike ENE to NNE and NNW, as well as gently dipping to sub-horizontal fractures are noticeable in fracture domain FFM01 /SKB 2008/. Calcite, chlorite, laumontite, adularia, hematite and quartz are present along the different sets of fractures.

The rock mass at depth beneath deformation zone A2, i.e. in fracture domain FFM01, has a low frequency of transmissive fractures. Between levels 200–400 m the linear frequency of flowing fractures is about 0.05 m^{-1} in FFM01 and the rock mass has an "average conductivity" in the order of $5.2 \cdot 10^{-10}$ m/s. Below approximately 400 m depth, the frequency of flowing fractures is even lower. Investigation boreholes drilled in FFM01 indicate that there are very few measurable water flows below approximately 360 m depth /SKB 2008/.

The major part of the layout for the potential underground facility is located in fracture domain FFM01 at 470 m depth (RHB 70).

Fracture domain FFM02

Fracture domain FFM02 is situated close to the surface inside the target volume, directly above fracture domains FFM01 and FFM06 (Figure 2-3). The fracture domain is characterised by a complex network of gently dipping and sub-horizontal highly fractures transmissive fractures which are open or partly open.

Gently dipping to sub-horizontal fractures and vertical to steeply dipping fractures that strike ENE or NNW are most noticeable in this domain. As in fracture domain FFM01 calcite, chlorite, laumontite, adularia, hematite and quartz are present along the different sets of fractures. However, clay minerals, pyrite, asphaltite and goethite, which all belong to the younger generations of minerals, are more prominent in fracture domain FFM02 relative to all the other fracture domains. Furthermore, fractures without any mineral coating or filling are also conspicuous in FFM02.

The fracture domain FFM02 is not at the level of the potential underground facility, but the access ramp and shafts is designed to pass through this fracture domain.

Fracture domain FFM03

Fracture domain FFM03 (Figure 2-3) is situated within rock domains RFM029, in the south-east part of and outside the target volume /SKB 2008/. Fracture domain FFM03 is to be found above zone A2. The rock domains in this volume are characterised by a high frequency of gently dipping fracture zones, containing both open and sealed fractures. The rock mass between the fracture zones, i.e. fracture domain FFM03, is dominated by mineral sealed, vertical or steeply dipping fractures that strike ENE to N-S and NW, as well as gently dipping to sub-horizontal fractures.

Not any part of the potential underground facility layout is designed within fracture domain FFM03.

Fracture domain FFM06

Fracture domain FFM06 is situated within rock domain RFM045, inside the target volume. It lies beneath both zone A2 and fracture domain FFM02 (Figure 2-3). According to /SKB 2008a/ this fracture domain can be anticipated as having the same characteristics as FFM01, beside that there is a widespread occurrence of fine-grained, altered (albitized) granitic rock, with slightly higher contents of quartz compared with unaltered granitic rock, i.e. on the basis of lithological characteristics.

Deformation zones

Within the tectonic lens there are deformation zones of different length and thickness and with various mechanic and hydraulic significance. Four major sets of deformation zones > 1,000 m trace length at ground surface has been deterministically modelled within the target volume. These zones are predominantly vertical or steeply dipping, with WNW, NW, ENE (NE) and NNE sub-sets, or gently dipping with dips to the south and SE. A few deformation zones that are vertical or steeply dipping and oriented NNW or E-W are also present (Figure 2-4).

Both deformation zones and minor deformation zones are identified in boreholes by a population of fractures distinct from the background fractures in fracture domains and by the significant occurrence of hydrothermal alteration. All fractures belonging to deformation zones are excluded from the statistical modelling of fractures and minor deformation zones in the geological discrete fracture network model (DFN). However, some minor deformation zones, with a trace length < 1,000 m, have also been modelled deterministically. These zones are vertical or steeply dipping and belong predominantly to the ENE to NNE set; some minor zones that are oriented NNW, WNW and E-W are also present (Figure 2-4). Such zones have thus been treated twice; both in the DFN and in the deterministic modelling work.

Only two deformation zones which belong to the WNW-NW set (WNW0123 and WNW2225), with a trace length at the ground surface greater than 1,000 m, are present inside the target volume between 400–600 m depth. Both these zones are present in the margins of this volume. One of them, WNW0123 is longer than 5,000 m and forms part of the boundary southwest of the area for the potential underground facility (Figure 2-4), whereas zone WNW2225 has a trace length which is less than 3,000 m in and occur mainly within rock domain RFM045 in the north-eastern part of the target volume.The zones in the WNW-NW set are dominated by sealed fractures and sealed fracture networks. However, an increased frequency of open fractures and non-cohesive crush rock is also present at different intervals inside several of these zones.

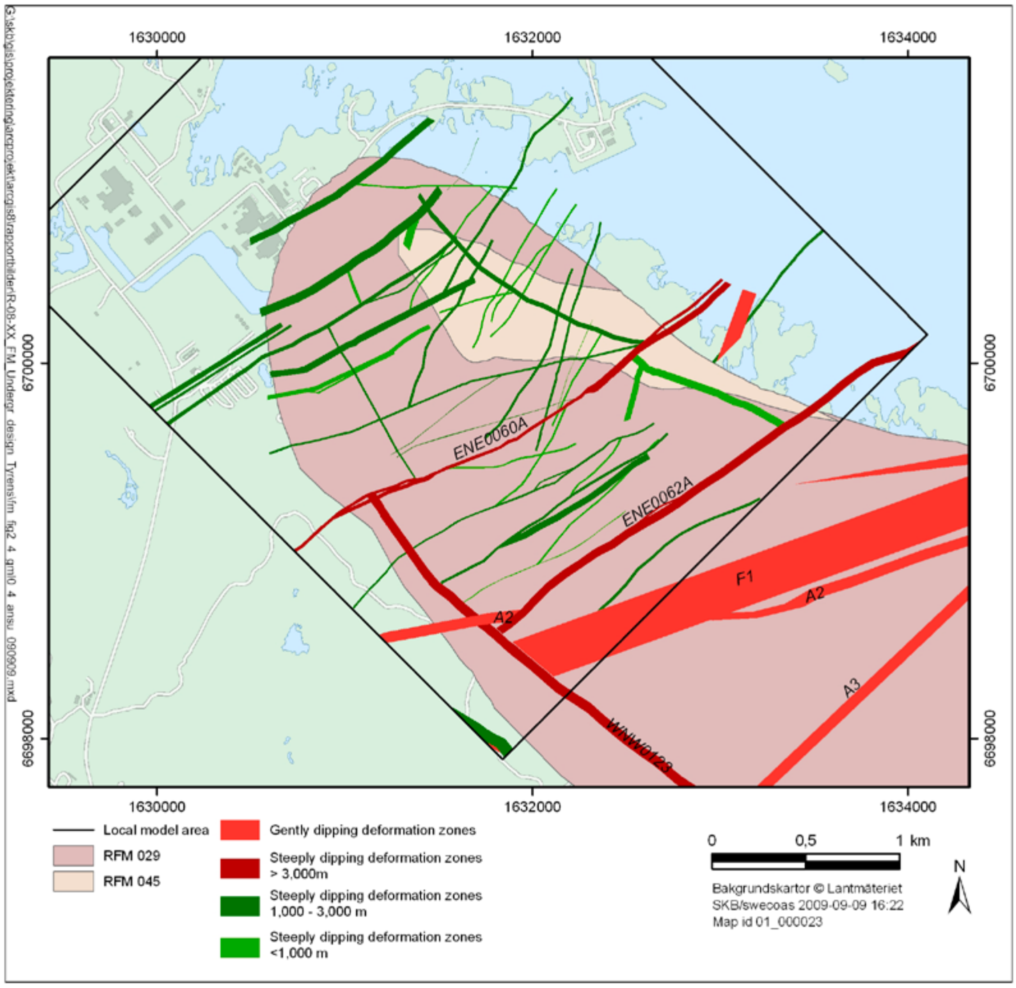


Figure 2-4. *Deformation zones at the depth of 470 m (RHB 70).*

The trace length at the surface of the deformation zones which belong to the ENE to NNE set in the target volume varies from c. 1,000 m to 3,500 m, and most are less than 2,000 m. Only two zones with a surface trace length greater than 3,000 m intersect the target volume, ENE0060A and ENE0062A, with their attached branches (Figure 2-4). Twenty-three deformation zones with trace length at the ground surface ≥ 1,000 m and splays of such zones, are present at 400 to 600 m depth inside the potential repository volume. The zones in the ENE to NNE set show only brittle deformation and are fracture zones. Fault core intervals consist of a highly elevated fracture frequency, commonly with sealed fracture networks. Locally, cohesive breccia and cataclasite are also present.

Five gently dipping zones have been deterministically modelled within the target volume. Only three gently dipping zones A2, A8 and B7 enter the target volume between 400 and 600 m depth, north-west of zone ENE0062A (Figure 2-4). The zones B4 and F1 have been modelled to terminate to the north-west against the steeply dipping zone ENE0062A. Zone B4 is situated below the proposed depth of the underground facility. The two zones, A2 and A8, belong to a family of gently dipping structures that occur along or close to the roof of the volume of the potential repository. Fault core intervals, if present in the gently dipping zones, consist of a highly elevated fracture frequency of mainly open fractures, or hydraulically conductive non-cohesive crush rock. Locally sealed fracture networks, cohesive breccias and cataclasite are present. A passage with a ventilation shaft through zone B7 will occur.

The fourth sub-set of deformation zones are vertical and steeply-dipping, NNW oriented and are dominated by sealed fractures. Due to their rare occurrence they are considered to be of less significance with regard to the potential underground facility than the other sub-sets.

2.5 Key issues and site adaptation

Adaptation of the underground facility to the existing conditions with regard, for example, to passage through different types of fracture domains; the placement of facility parts in relation to deformation zones and their respect distance; etc, has been made during an iterative process between the various investigation and design phases. Relevant adaptations are presented below.

2.5.1 Optimization of available deposition area

All underground facilities are to be located within rock domains RFM029 and RFM045 /SKB 2008a/. Figure 2-5 shows the available deposition area and the central area. Only part of the area south-east of zone ENE0062A lies within the local model volume. The knowledge of occurrence of deformation zones shorter than 3,000 m is therefore poorer for this area than for other parts of the investigated area /SKB 2008a/. Furthermore, this area is relatively small in relation to possible issues that may arise when passing through zone ENE0062A with excavation work. Thus, the area has not been included as available deposition area in the account of the gross capacity.

2.5.2 Deformation zones

Deformation zones with trace length at ground surface longer than 3,000 m within the deposition area, i.e. ENE0060A, ENE0062A, A2 and WNW0123, require respect distances that preclude deposition within that distance (Figure 2-5). A respect distance is required due to the risk of seismic activity caused by post-glacial rebound /SKB 2008a/. Deformation zones with trace length less than 3,000 m do not require respect distance, but deposition is not allowed within the boundaries of these zones. Volumes that are penetrated by investigation boreholes are rejected (Figure 2-6). A minimum distance from a tunnel to an investigation borehole shall be set to one tunnel diameter /SKB 2007/.

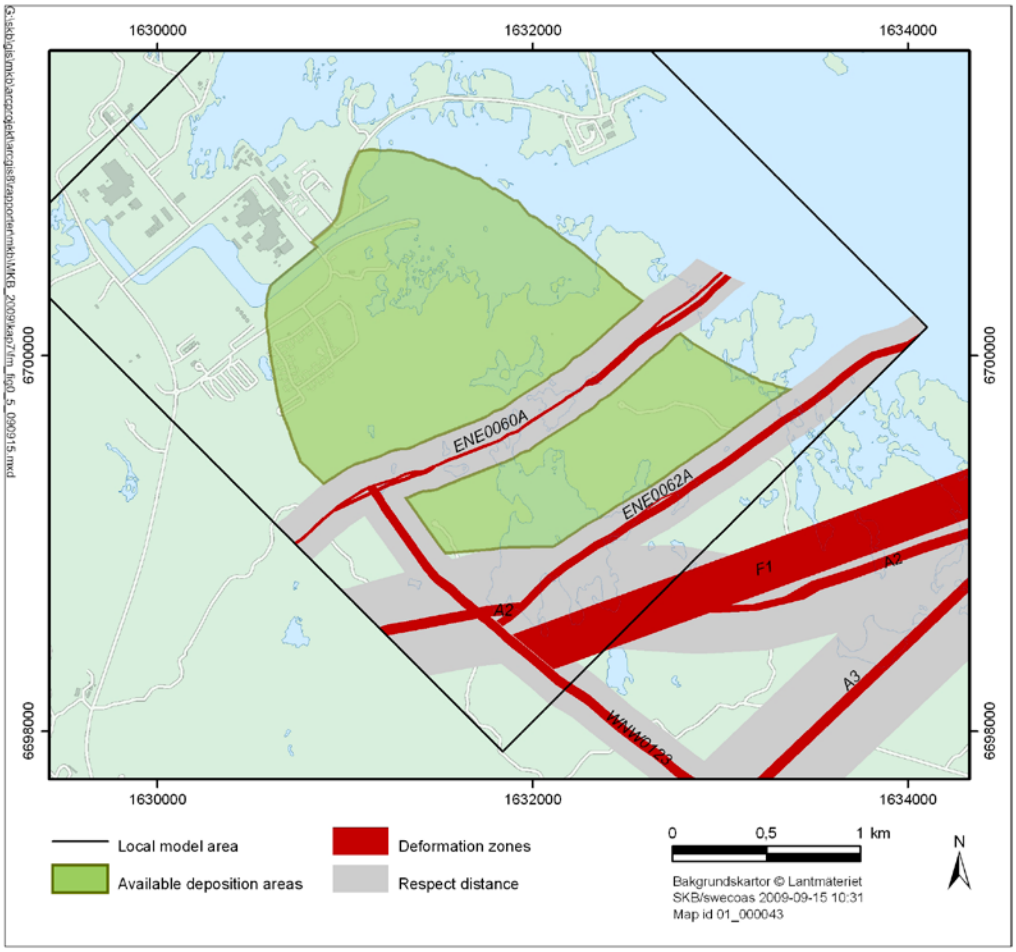


Figure 2-5. Available deposition area when consideration is taken to respect distance for relevant deformation zones. The section refers to 470 m depth (RHB 70).

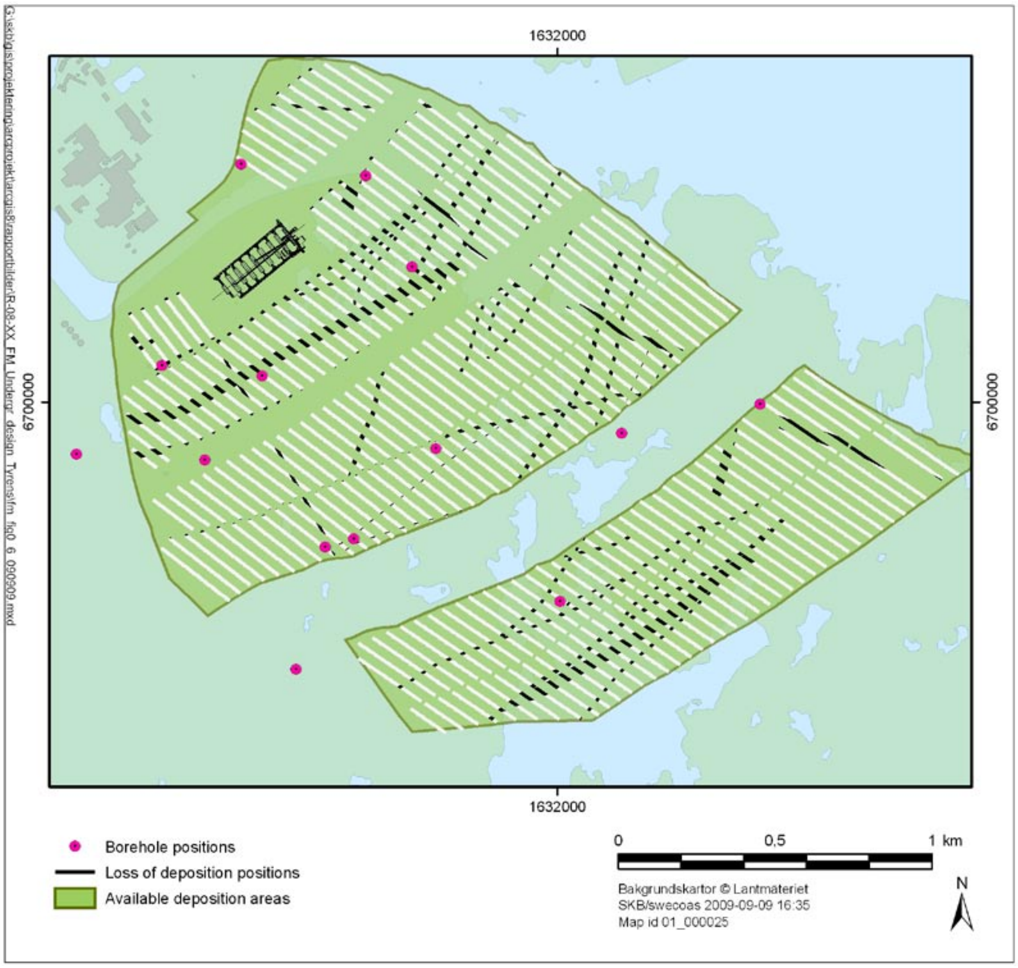


Figure 2-6. *Loss of deposition positions due to intersecting deformation zones and respect distances to investigation boreholes drilled from the surface. The section refers to 470 m depth (RHB 70).*

2.5.3 Fracture domains

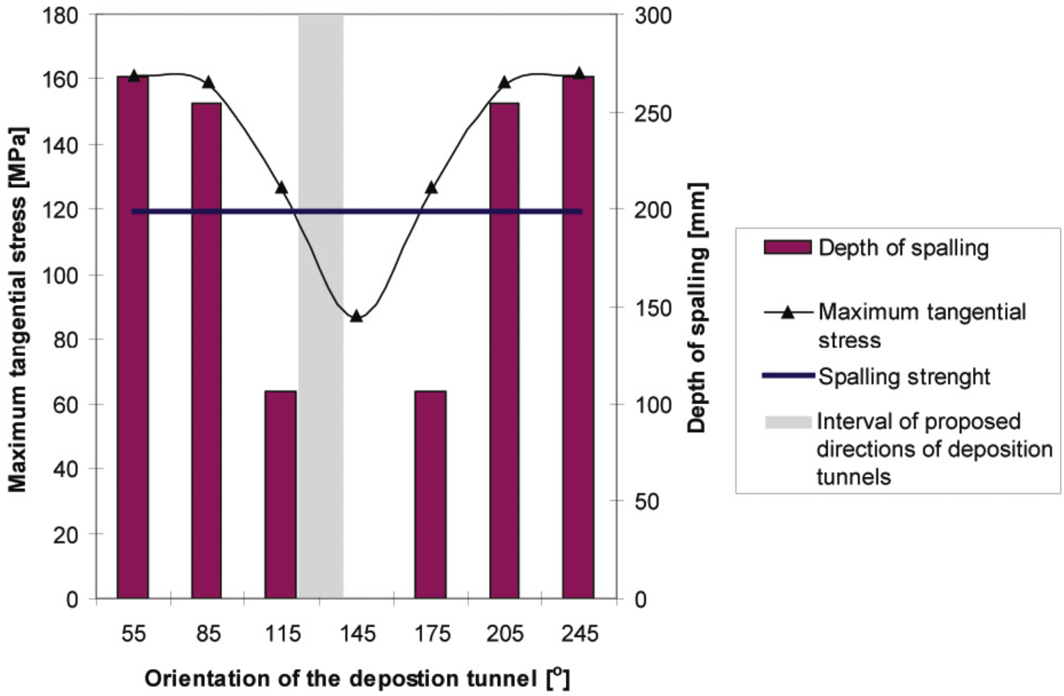
Consideration must be taken to the heterogeneous hydraulic conditions in fracture domain FFM02 (Figure 2-3). The layout of the access ramp should intersect these transmissive features at as large angle as possible to facilitate appropriate sealing by grouting measures /SKB 2008a/.

2.5.4 Repository depth

According to /SKB 2008a/ the total volume of the final repository facility should be situated between a depth of 450 and 500 m (RHB 70). To minimize length of the access to the underground facility and also to minimize the risk of increased water pressure and increased risk of spalling, the highest point (tunnel roof) in the deposition area has been placed at –457 m. The depth of the facility at 470 m coincides with the bottom of the transport tunnels out from the central area, which leaves about 20 m margin for tunnel height and tunnel slope.

2.5.5 Mechanical properties – spalling

Description of the strategy and methodology with regard to rock reinforcement is given by /Eriksson et al. 2008/. The results in that report show that the direction of the maximum horizontal principal stress at the facility depth (–470 m) is 145 ± 15°. /SKB 2008a/ postulates that the deposition tunnels are to be located in a direction that coincides with, or do not deviate more than 30° from the direction of the maximum horizontal stress at the depth of the facility in order to minimize the risk of spalling. The report concerning rock reinforcement /Eriksson et al. 2008/ indicates, however, that the deviation should probably be somewhat smaller (Figure 2-7).



Figur 2-7. *Presentation regarding significance of deposition tunnel orientation in relation to when spalling strength is exceeded in a deposition hole. From /Eriksson et al. 2008/.*

2.5.6 Hydrogeological properties – grouting

Grouting strategy and methodology is described in an individual report /Brantberger and Janson 2008/. In brief, the need of grouting varies depending on the fracture domain concerned. At the facility depth in fracture domain FFM01 and FFM06 it is anticipated that systematic grouting will not be needed, but fracture zones at repository level will require systematic grouting. However, a considerable variation of hydrogeological conditions is expected close to the ground surface in fracture domain FFM02. There, the need of grouting can locally be substantial and the requirements on leakage of water for the upper (1^{st} km) part of the ramp difficult to fulfil /Brantberger and Janson 2008/. However, leakage into the upper parts of the ramp is considered having small impact on repository functionality.

3 Final repository layout

The design process described in this report is the result of an iterative process starting with design phase D1 /Brantberger et al. 2006/, followed by a generic functionality study presented in Chapter 3.1 below. The process also involved updated site descriptions from corresponding phases in the site investigations. In the following chapters the functionality studies and the derived proposed layout and construction plan will be presented.

3.1 Functional studies

The working mode in the functional studies has been somewhat different to that described in /SKB 2007/. In these studies no optimization or any extensive adaptation to the site has been made. Rather, the investigation was carried out as a conceptual plan based on the D1 layout with the objective of compiling the most effective strategy for the construction plan and layout. The D1 layout is further described in Underground design Forsmark, Layout D1 /Brantberger et al. 2006/ but the basic outline is shown in Figure 3-1.

To handle the complexity of the process of building the repository parallel to the deposition and back-filling, a model was used to simulate the working process instead of a more conventional approach. The use of a model provides a flexible and time-efficient way to analyze different approaches and alternatives to run the process.

Within SKB the classical way of describing the construction of the repository alongside the deposition of spent fuel has been based on the idea where separation of the two main activities (rock excavation and deposition) is done by the use of two main tunnels and side changes /SKB 2006/. This concept was also used initially for the simulations during these functionality studies. The results of these simulations showed that several problems arose as a direct consequence of the side changes. As a response to this a somewhat different method was developed, the Linear development method, where no side changes between main tunnels exist and problems related to side changes thus practically were eliminated. After consent from SKB this method was used for the following simulations and subsequently for the layout work.

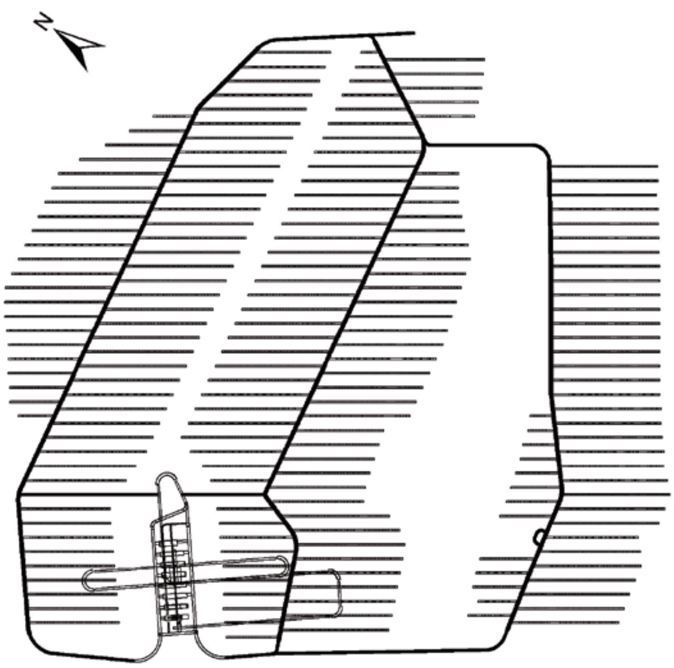


Figure 3-1. *The D1 Layout as presented in Underground design Forsmark, Layout D1 /Brantberger et al. 2006/.*

The two methods are described and compared under heading 3.1.2 to 3.1.4 below.

The basic outlines for the processes involved in the construction of the repository as well as depositing canisters and backfilling were given by SKB. The outlines include the different processes, and provides estimated times for each process. The input data is presented in short in the following text.

The input data from SKB was used after minor changes by the designer. Primarily the structure was altered to enable model simulations.

In table 3-1 the column "Critical resource" holds the resource that is critical to the activity. Personnel and simpler equipment were not regarded as critical.

Table 3-1 gives a total time of 90 weeks for the excavation of one deposition tunnel.

Table 3-2 state the input data for modelling deposition and backfilling. The estimated time for deposition and backfilling of one deposition tunnel is 32 weeks.

3.1.1 Separation of main activities using two main tunnels and side changes

The side-change concept was used as premises for the first model simulations. Figure 3-2 shows an example for how a stepwise construction of the repository could be planned using the D1 layout /Brantberger et al. 2006/ and side changes between two main tunnels.

Table 3-1. Restructured data concerning excavation work that was the input to the model.

Activity and subactivities	Time per reference tunnel (weeks)	Critical resource
Gallery excavation	12.6	Drill rig
• Core drilling for deposition tunnels. Detailed investigation of location and approval.		One rig provides for driving of three tunnels
• Probing holes and grouting. To be performed in 10% of the cases, only.		
• Gallery drilling		
• Charging		
• Blasting and ventilation		
• Mucking		
• Scaling and rock support		
Diamond wire cutting of floor level	8.5	Wire saw
• Drilling of benches.		One saw provides for one tunnel
• Blasting of benches		
• Mucking		
Location survey, deposition holes	16	
• Installations		
• Location survey for deposition holes		
• Core drilling and display		
TBM	36+17	TBM
TBM	36 weeks for TBM drilling and 17 weeks for after work	One TBM provides for one tunnel
• TBM-drilling		
After work TBM		
• Cutting of deposition hole contour		
• Geological mapping of the deposition holes and covering with protection caps		
• Contour boring for concrete sealing		
• Scaling and cleaning of tunnel roof and tunnel walls		

Table 3-2. Restructured data concerning deposition and backfilling that was the input to the model.

Activity and subactivities	Time per reference tunnel (weeks)	Critical resource
Deposition • Final inspection of the deposition holes and overhaul of installations • Lowering and mounting of bentonite blocks • Deposition	12	Deposition never becomes critical to the operation
Backfilling • Preparations for backfilling • Backfilling • Installation of filter and Construction of concrete sealing	20	Backfilling machine One machine provides for one tunnel

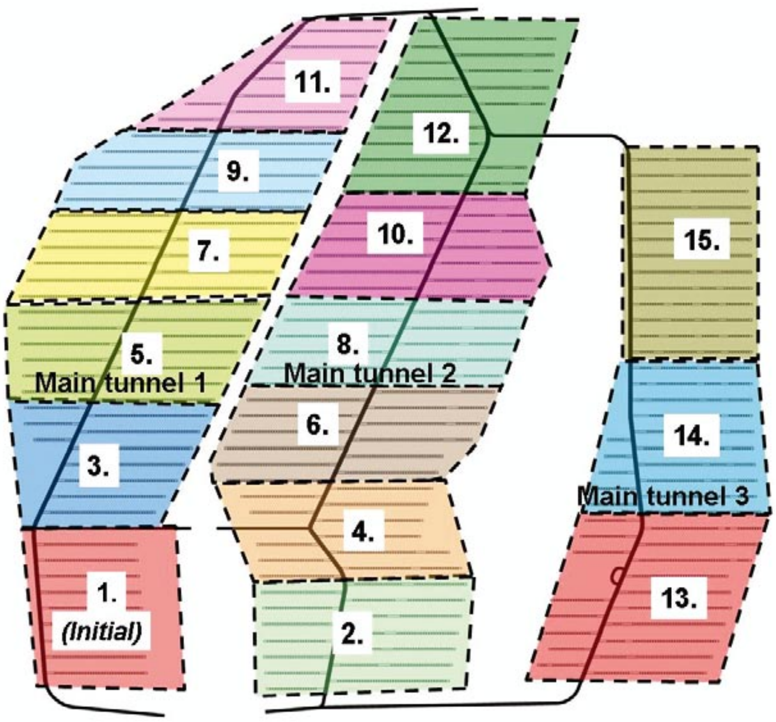


Figure 3-2. *Example of how construction steps could be planned for D1 Layout. This could for instance be three-year steps. The numbers indicate in which order the steps are constructed.*

As deposition is finished in one step, it will move to the other main tunnel and in the same manner excavation will move from one main tunnel to another as shown in Figure 3-2. A security zone that is at least two tunnels wide (which means a total of four tunnels for the side-change concept) is created in the excavation step as seen in Figure 3-3 to ensure that the required distance of 80 m between blasting and deposition is kept.

As these simulations were analyzed some problems became evident, which are described below.

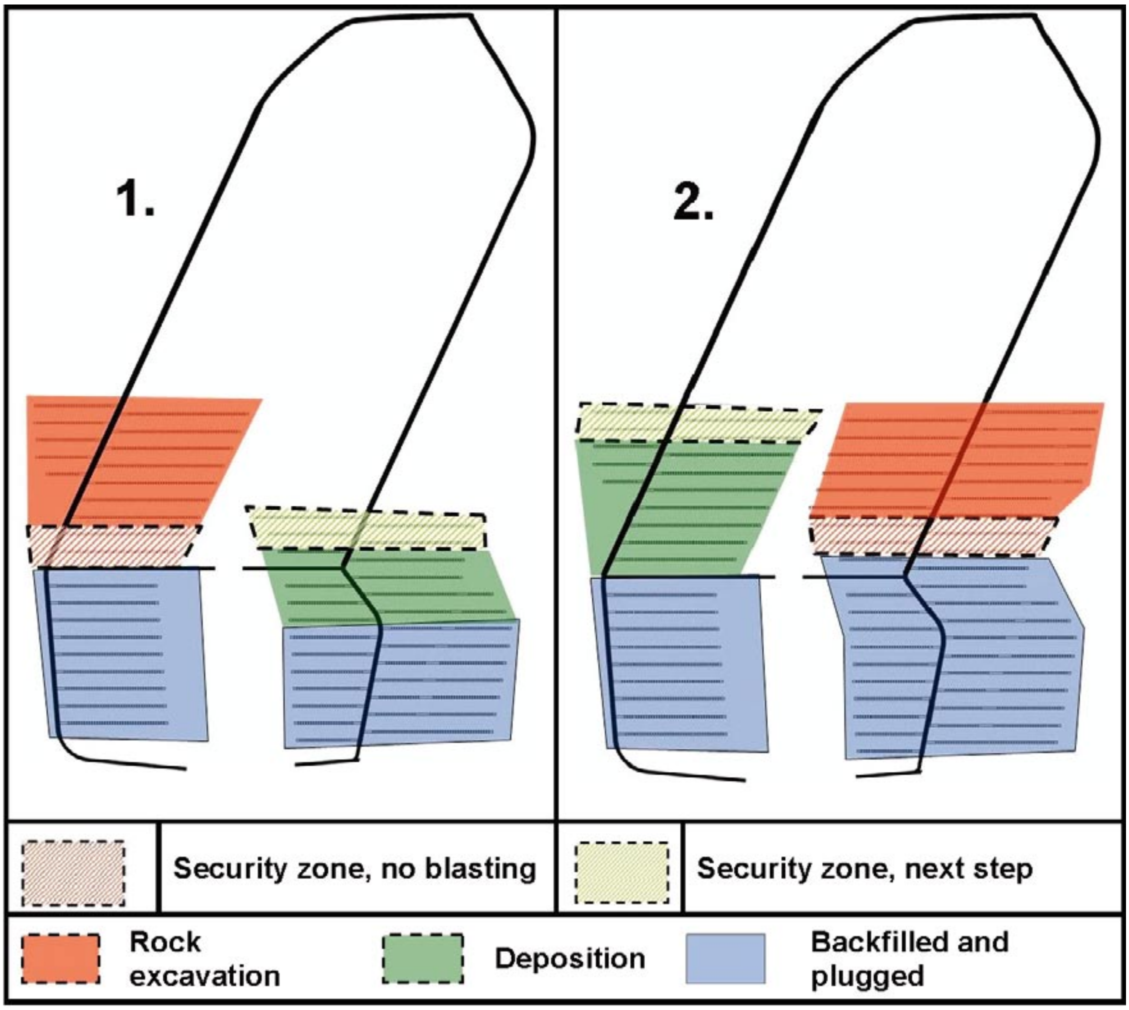


Figure 3-3. *Example of how the side changes could be done. To keep the 80 m distance between blasting and deposited tunnels, the width of two tunnels will not be deposited at the end of each construction step. These tunnels will then work as a security zone where no blasting is allowed when excavation moves to this side (picture 2).*

3.1.1.1 Loss in capacity as a consequences of side changes

With the side-change concept there would be trouble producing the required deposition holes to meet the demand of 150–200 deposited canisters per year. This problem would be a continuous problem, i.e. several times during the operation due to side changes. The reason for this is loss in excavation capacity at each side change, which is due to the following:
When the last canister has been deposited in one deposition tunnel a side change has to follow since no more deposition holes are available (picture 1, Figure 3-4). Deposition is moved to the other main tunnel where excavation occurs. To allow deposition the excavation has to stop and move out from the main tunnel where it was working. At this point, it would be preferable to move excavation to the other main tunnel and start excavation work there, but this is not easily done. As deposition moved out of the last tunnel and started on the other side there will still be some backfilling left to do (picture 2, Figure 3-4). This backfilling will take some time during which rock excavation cannot be executed anywhere, thus the rock excavation resource has to stand and wait until backfilling is finished.

This loss in capacity is especially problematic for the TBM resource because it is the most time-critical part of the excavation work (see Table 3-1).

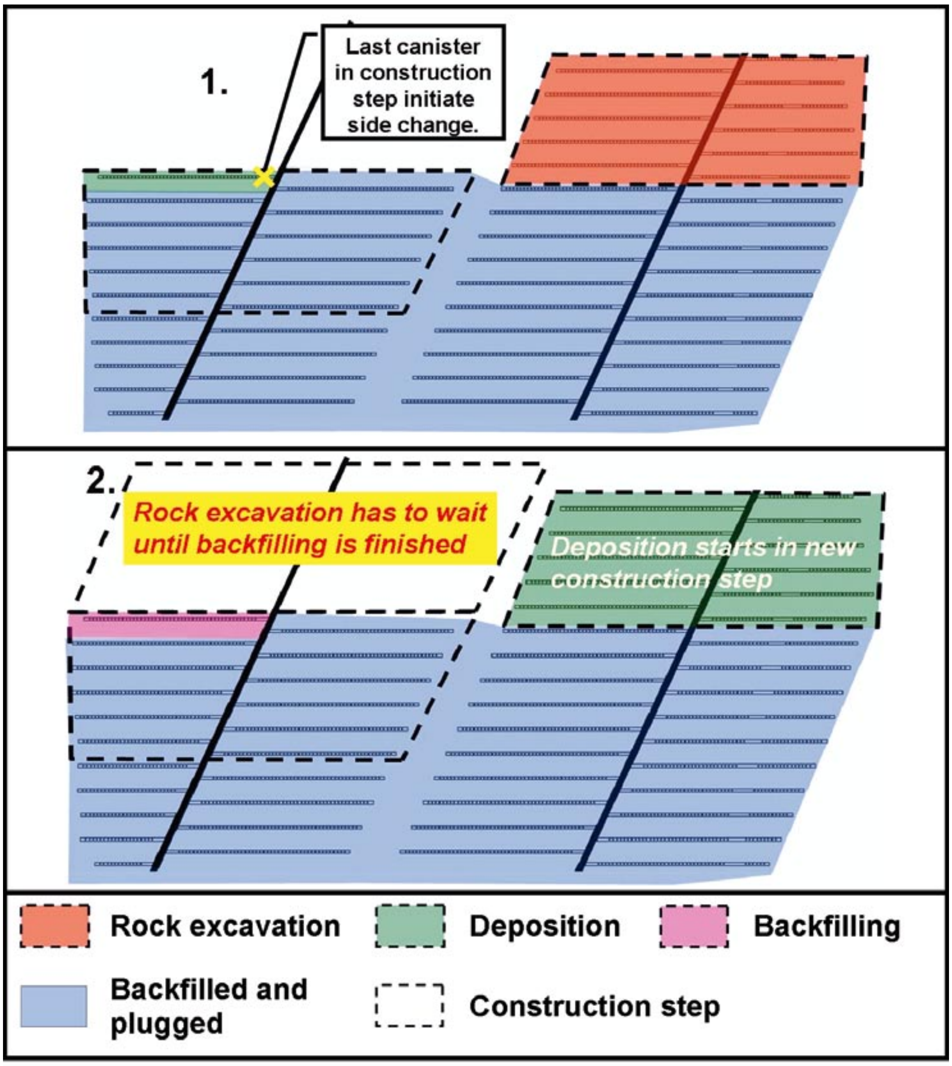


Figure 3-4. *Simplified example of loss in excavation capacity due to the side change.*

3.1.1.2 Deposition holes kept open for long time as a consequence of side changes and main tunnel configuration

Another problem in meeting the 150–200 canister per year demand relates to the number of main tunnels and how the number of deposition positions varies from one tunnel to another. This occurs at the end of the operation when excavation and deposition starts in main tunnel 3. Figure 3-5 shows an example of the problem. When the last construction step in main tunnel 2 has been excavated and deposition starts in this tunnel excavation will move on to main tunnel 3 (picture 1, Figure 3-5). When deposition has been completed in main tunnel 2 the deposition work has to move to main tunnel 3. At this point a delicate situation occurs. Excavation work is not allowed either next to deposition or in the same main tunnel as deposition work occurs, but the excavation work cannot move elsewhere (picture 2, Figure 3-5).

The only way to get around this is by excavating the entire main tunnel 3 before deposition starts in this tunnel (Figure 3-6). The implications of this are first that a considerable overcapacity in rock excavation resources is needed to be able to finish main tunnel 3 before deposition starts. Again, the main problem will be the critical TBM resources. Secondly, excavation of whole main tunnel 3 means that the deposition holes will be kept open for a very long period of time before any deposition will be done. In this case it is possible that some holes will be open for up to twelve years.

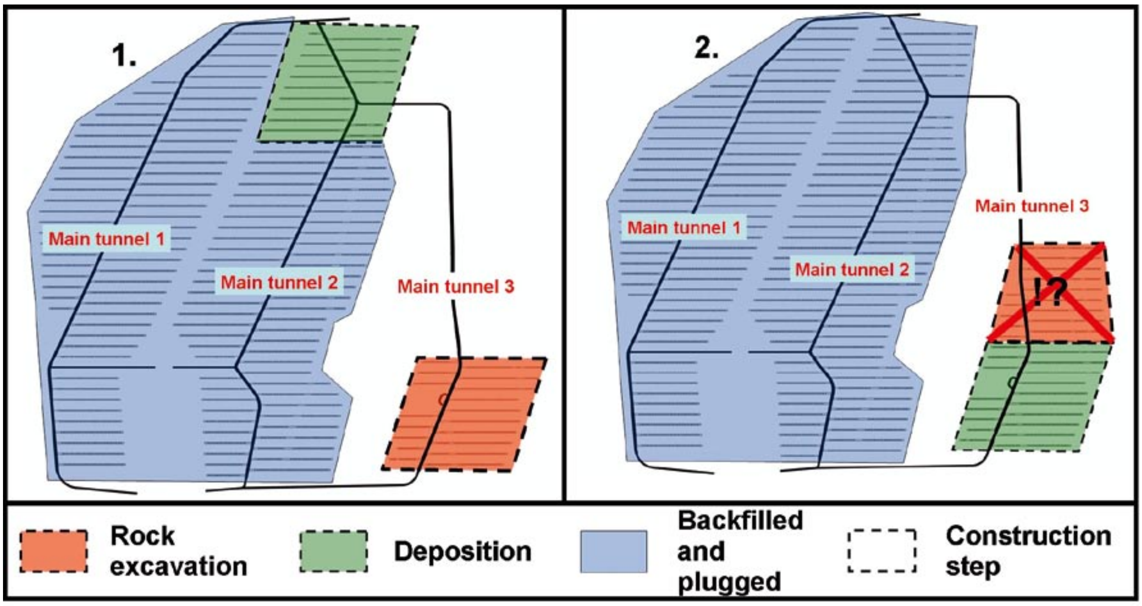


Figure 3-5. *As the first construction step in main tunnel 3 is excavated and deposition is started, there is nowhere to go for excavation.*

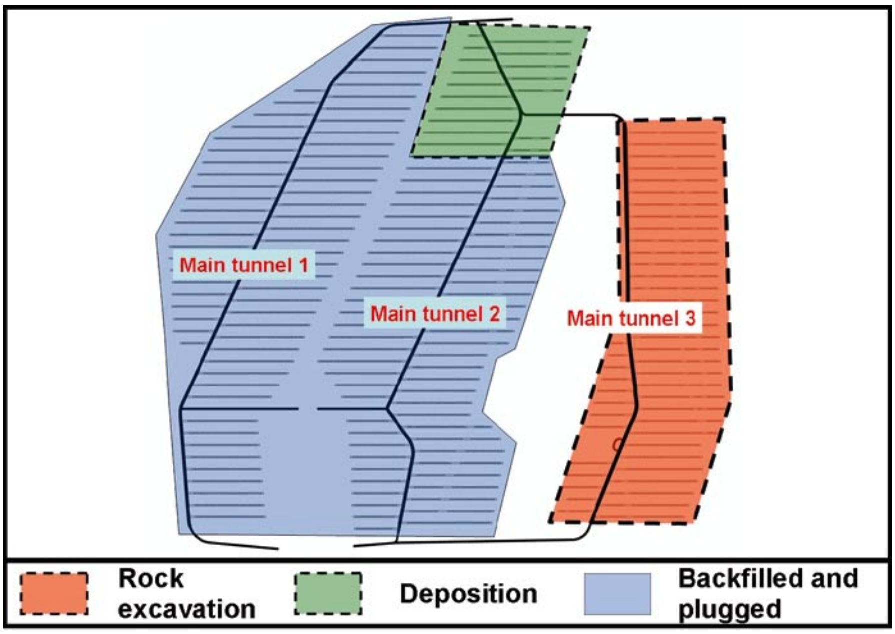


Figure 3-6. *All of main tunnel 3 has to be excavated before deposition can start. The deposition tunnels have to be held open for a long time.*

It is possible to plan the construction steps so that the time is somewhat shortened. This can be done by making sure that two construction steps are left in main tunnel 2 as work starts in main tunnel 3 allowing for one side change between tunnel 2 and 3 before the rest of the holes needs to be prepared. But even in this case some deposition holes will stay open for eight to nine years before deposition reaches them. Shorter steps also mean more side changes, which means greater loss in TBM-capacity.

3.1.1.3 Complications due to side changes

The conclusion of the model simulations using the concept of side changes between main tunnels was that even though it is theoretically possible to make the operation work, and meet the demand of 150–200 canisters per year, it is obvious that the operation as a whole will suffer from a number of complications. These are listed below:

- Increased need of TBM resources
- Loss of excavation capacity
- Deposition tunnels and deposition holes need to be held opened during a relatively long period of time
- The process will be very sensitive to disturbances
- The process will be complicated to plan and in need of advanced control systems during operation
- Change of sides generates movements of equipment, personnel and media
- Long-term consequences of decisions and incidents are hard to foresee
- The operations are highly dependent on the layout
- Deposition tunnels and deposition holes might need to be held opened during a long period of time
- The planning and controlling of the process will be comprehensive and complex
- A complete overview of the whole situation will require special knowledge and tools
- The two main activities will be heavily dependent on each other
- The operation will be highly dependent on layout, tunnel configuration and resources per activity
- Decisions and events in the early stages, will affect the entire period of operation
- The operation will be sensitive to disturbances

The reasons for these complications and compromises are, to a great extent, due to the change of sides and movement of equipment between the main tunnels. Therefore, a construction method without side changes was developed.

3.1.2 Separation of main activities by using the Linear Development Method without side changes

To avoid the side changes it was necessary to find a way to separate excavation and deposition within a main tunnel. The simplest way to do this would be to install doors/walls in the tunnel and have excavation on one side and deposition on the other. If possible, the excavation and deposition could be run like a train through the whole repository, excavation being the engine followed by deposition and backfilling, and thus, side changes, and the problems associated to it, could be completely eliminated. Security zones with the width of two deposition tunnels would be used in the same manner as when side changes are used. How the construction of the repository could be done is shown conceptually in Figure 3-7, and the construction strategy was denominated as the Linear Development Method. The figure also shows that two escape routes will always be available as the doors/walls between the main activities may work as escape routes both ways.

This approach may seem radically different than the method of working in separate main tunnels. It could, however, be debated how two main tunnels should be defined. When looking at the situation that occurs in the side-change concept at the end of two main tunnels and comparing it with the concept without side-changes (Figure 3-8) it can be seen that it is virtually the same scenario.

Thus, the difference in separating the main activities between the two concepts is only a matter of definition. Consequently, if separation of main activities can be defined by using the linear development method the construction plan using side-changes can be discarded and other methods presented. This matter was presented to SKB who gave their consent to the further studies of another method to arrange the construction plan.

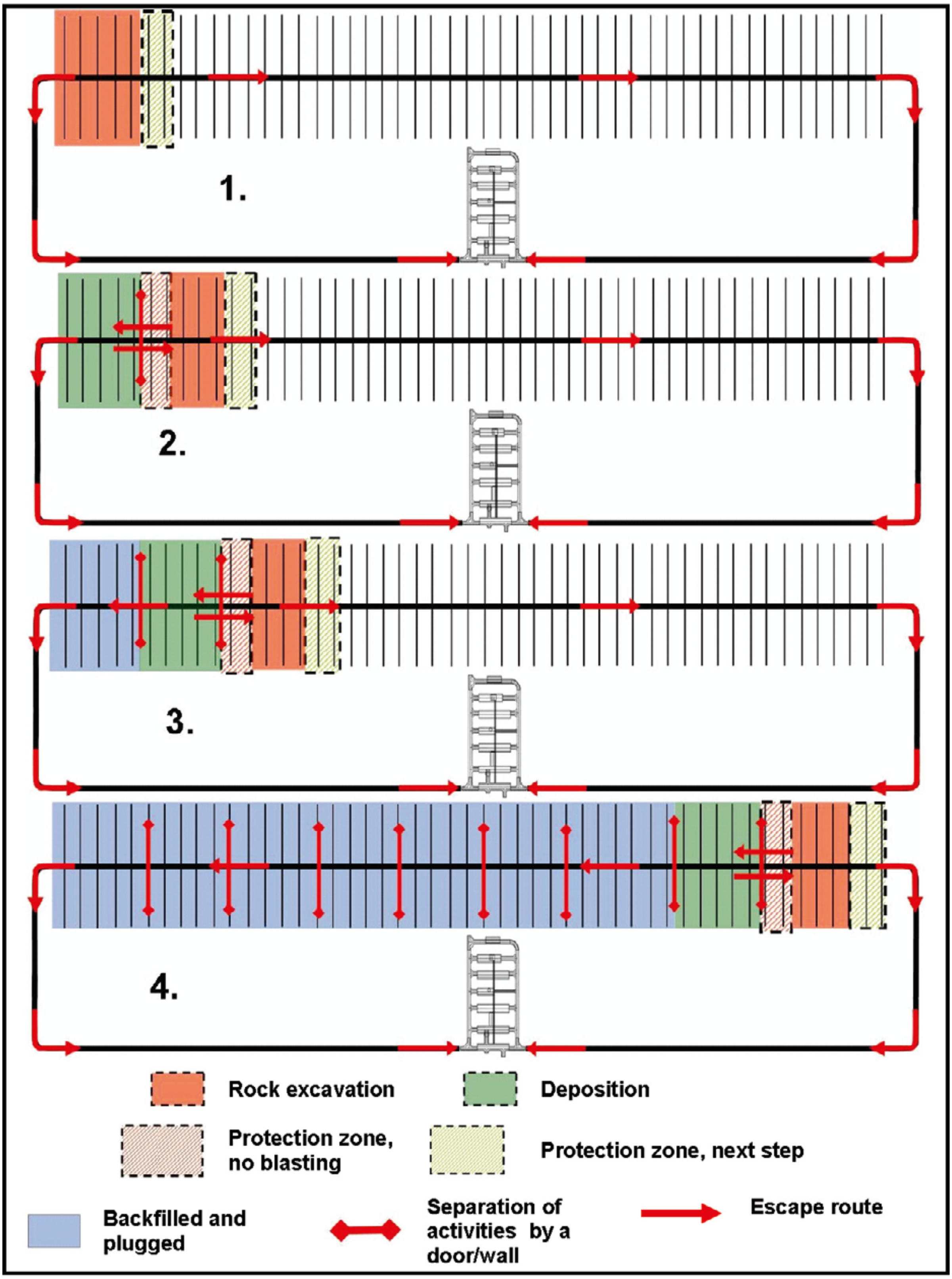


Figure 3-7. *Example on using the Linear Development Method and of how deposition and excavation could be carried out simultaneously in the same main tunnel. This way the side changes can be avoided completely.*

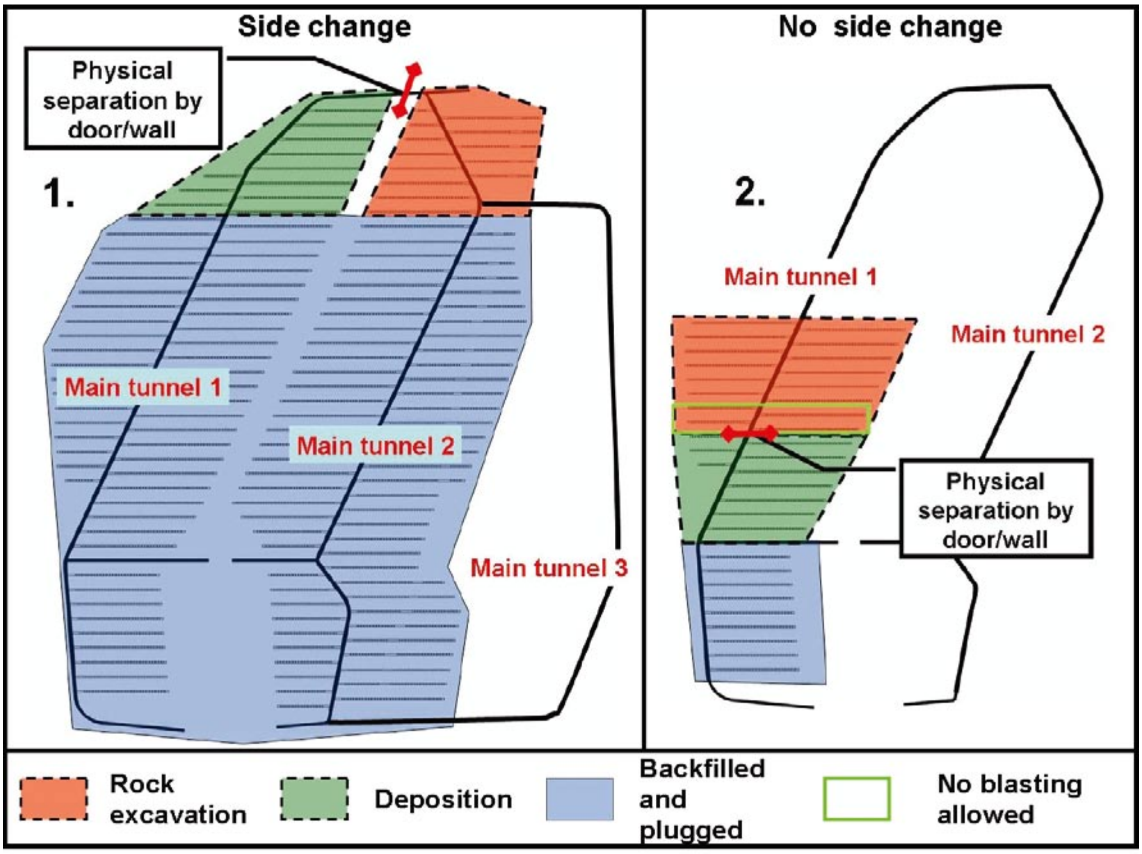


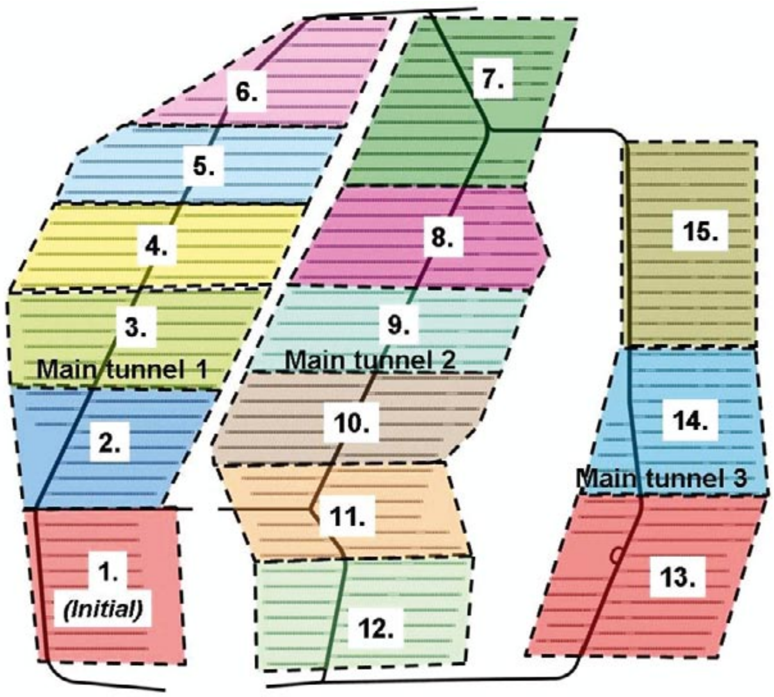
Figure 3-8. *The difference between separation by side changes and by using the linear development method with a door/wall is merely a matter of definition as shown here.*

The construction of the underground facilities will differ a lot when this new approach is used compared to the case shown earlier in Figure 3-2. As described the construction will be more like a train running through the repository. No specific steps need to be planned ahead. When deposition comes close to the next separating door/wall in a main tunnel, a new one is installed where excavation is finished and the excavation continues on the other side of the wall (in reality the walls will already be in place, as they are also required for fire security reasons). This will give a construction plan looking something like Figure 3-9 for the D1 layout. The construction plan could, for example, represent four year intervals. The whole process could just as well be described as one single step that starts in one end and stops in the other.

3.1.2.1 Advantages using the linear development method instead of side changes

There are a number of advantages using this method:

- The rock excavation and the deposition work do not depend on each other because no changes of side are needed
- There are no losses of either capacity or deposition positions (no compromises)
- All available capacity for rock excavation can be used for production or as reserve capacity, in case of unforeseen incidents, as there is no need for the pre-advance in excavation required using the other strategies
- The operation is easy to plan, runs rationally and can be easily controlled as there are no complex relationships between the activities
- The period of time that tunnels and deposition holes need to be opened can be minimized or they can be continually regulated
- Productivity, resource requirements and planning will not be layout dependent



***Figur 3-9.** Construction plan using the linear development method without side changes.*

3.1.2.2 Disadvantages using the linear development method instead of side changes

The only real drawback to this method is an increase in transportation distance (which also means an increased risk for accidents related to traffic). The increase depends on the need to get access at both ends of a main tunnel during work. This will be further discussed in Section 3.1.4.

There are also some issues that need to be studied further to be able to use this strategy:

- Sufficient ventilation must be provided and additional combined separation/fire cell doors/walls might be needed
- Fire, escape routes and other security issues need to be resolved in an acceptable way

3.1.3 Transport work

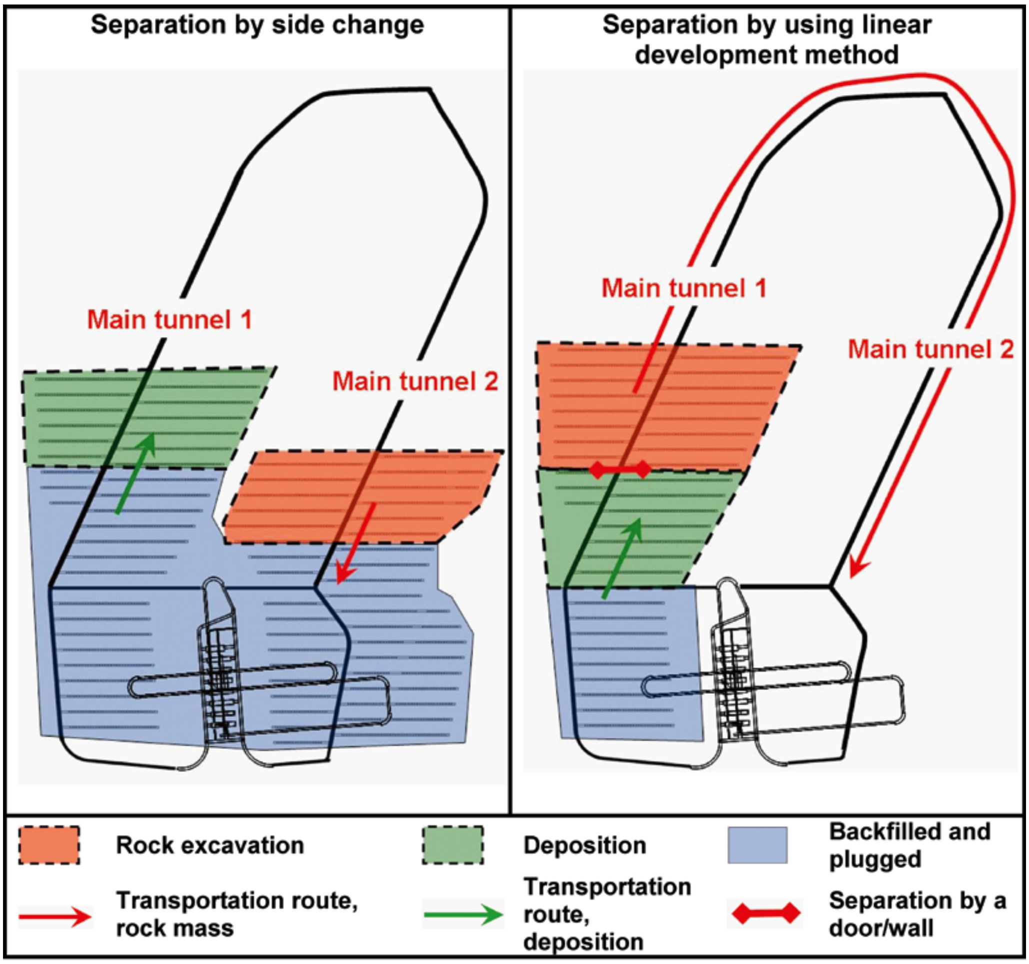
The reason that there will be an increase in transportation work when the linear development method is used for separation compared to side changes is that there will be a need to get access at both ends of a main tunnel during work (Figure 3-10) as the only alternative would be to transport the excavated rock mass through the deposition area which is unacceptable.

3.1.3.1 Use of "shortcuts" to decrease transportation for the linear development method

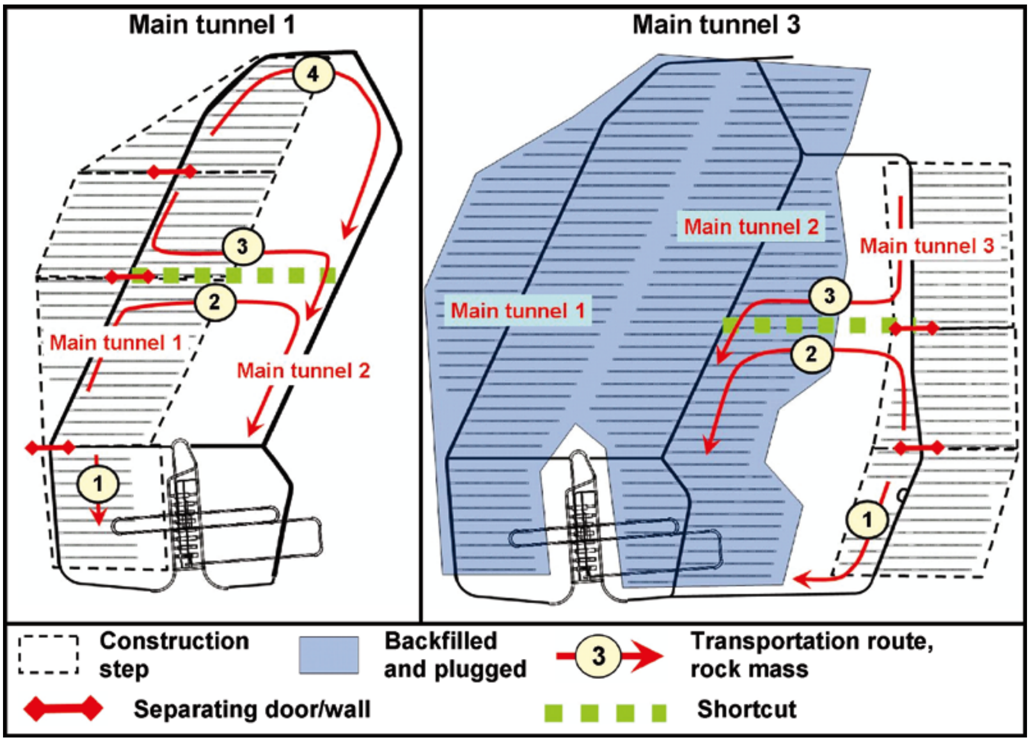
It would be possible to limit the increase in transportation by some changes in the layout. If one or several "shortcuts" were built between the main tunnels these could be used to shorten the transportation routes as shown in Figure 3-11.

3.1.3.2 Comparison of transportation between strategies

An analysis showed that the transportation work would double if the linear development method is used compared to using separation by side changes. If short cuts would be installed the difference is reduced to about 1.4 times higher. It is, however important to consider that this analysis was done for the D1 layout, which was not designed with this method in mind. A design better fitted to this method will decrease the transportation work further, and for actual required transport work for the D2 layout reference is given to Section 4.3.



Figur 3-10. Example of increased transport work when separation by using the linear development method is used.



Figur 3-11. Examples of transportation routes for main tunnels 1 and 3 using shortcuts. The routes for main tunnel 2 will be as for tunnel 1 but reversed.

3.1.4 Comparison between design strategies

The comparison will look at the advantages and disadvantages of the different strategies.

3.1.4.1 Separation using two main tunnels and side changes

Advantages:

- A minimum of transport work can be done

Disadvantages:

- Increased need of TBM resources
- Loss of excavation capacity
- Deposition tunnels and deposition holes need to be held opened during a relatively long period of time
- Very sensitive to disturbances
- Complicated to plan and in need of advanced control systems during operation
- Change of sides generates movements of equipment, personnel and media
- Long-term consequences of decisions and incidents are hard to foresee
- The operations are highly dependent on the layout
- Deposition tunnels and deposition holes need to be held opened during a long period of time

3.1.4.2 Separation by using the linear development method, no side changes

Advantages:

- Optimized use of resources
- Easy to plan and control
- All available capacity for rock excavation can be used for production or as reserve, in case of unforeseen incidents, as there is no need to create the pre-advance required using the other strategies
- Small dependency between rock excavation and deposition work
- Easy to get an overview of the production
- Minimization of movements of equipment, personnel and media
- Much less long-term consequences from decisions and incidents
- Robust solution
- The time that tunnels and holes are kept opened can be regulated

Disadvantages:

- Increase in transport work. (This increase is highly dependent on layout)
- Higher risk for accidents related to the increased transport work
- Some "constraint" of the layout because transportation routes are needed at an early stage.
- Ventilation and fire issues need to be resolved

The overall advantages of constructing the underground facilities with the concept of separating the main activities by using the linear development method rather than working with the side-change concept are obvious. Therefore, this is the concept that was adopted and from which the below presented layout was designed.

3.1.5 Health and safety

An overall risk assessment of the concept of separating the main activities by using the linear development method has been made according to AFS 2003:2 /Arbetsmiljöverket 2003/ (i.e. Swedish Work Environment Authority). The risk assessment is presented in Table 3-3.

Table 3-3. Risk assessment according to AFS 2003:2 /Arbetsmiljöverket 2003/.

§ in AFS 2003:2	Risk	Preventive/damage reducing activity	Comment
2 § General Before underground work can start, sufficient investigations and a risk assessment have to be performed.	Insufficient knowledge of the rock	The purpose of the site investigation as well as parts of design step D2 is to understand the rock behaviour. This is also considered in the technical risk assessment for design step D2.	
3 §–8 § General Relates to working methods, equipment, communication, protective gear, light, warning signs and traffic rules.	Accidents, ill health, work-related injuries	These kinds of risks can not be handled or influenced at this stage of the process but are submitted to separate studies during the next design step or construction. However, the facility layout shall be designed to fully separate the different activities deposotion of canisters and rock construction works. No traffic from neither activity is allowed to pass the other activity. The management system shall include instructions on physical protection and safe handling of nuclear material and nuclear waste.	
9 § General Refer to trafficked areas	Traffic accidents	/SKB 2007/ describes tunnel widths and passage of vehicles. It is, however, uncertain whether or not a pedestrian path has been planned for. This issue should be addressed.	
10 § Ventilation	Air pollutions, bad climate (temperature, moisture, oxygen levels). Spreading of blasting fumes and dust. Spreading of fire fumes. Radon	/SKB 2007/ describes the dimensions for ventilation and exhaust-air shafts. Other dimensions are dealt with in separate ventilation studies.	
11 §–13 § Remote controlling	Accidents	These kinds of risks can not be handled or influenced at this moment but are submitted to separate studies in fututre design step or construction.	
14 §–19 § Vehicles	Air pollution, accidents, light	These kinds of risks cannot be handled in detail at this stage but creating a layout that aims to make transportation efficient should decrease the risks substantially. The details are submitted to separate studies during the next design step or construction.	
20 § Transport roads Regarding the standard of transport roads	Accidents, work-related injuries	/SKB 2007/ describes construction of transport roads.	
21 §–22 § Radon	Ill health	Control of radon during construction, ventilation (§ 10).	
23 § Evacuation, rescue, fire protection Relates to alarm systems	Fire-related accidents	A fire protection evaluation with regard to the fire risks related to the construction strategy based on the linear development method will be made separately and is not included in this report.	
24 § Evacuation, rescue, fire protection Two separate escape routes should be available at all times. If not, rescue chambers should be available.	Fire-related accidents	A fire protection evaluation with regard to the fire risks related to the construction strategy based on using separating the linear development method will be made separately and is not included in this report.	According to instructions from SKB, rescue chambers will not be necessary during excavation and backfill of deposition tunnels even if the length exceeds 150 m.
25 §–28 § Evacuation, rescue, fire protection Consider action plan, minimization of fire stress, installations, fire fighting	Fire-related accidents, accidents	A fire portection evaluation with regard to the fire risks related to the construction strategy based on the linear development method will be made separately and is not included in this report. Other risks can not be handled or influenced at this stage of the process but are submitted to separate studies during the next design step or construction.	
29 §–34 § Rock drilling 35 § Handling of boulders and mechanical demolishing 36 § Handling of rock 37 §–40 § Rock inspection, scaling, rock reinforcements and maintenance of rock chamber § 41 Elevators § 42 Pregnant and breast feeding employees	Ill health, work-related injuries, accidents	These kinds of risks can not be handled or influenced at this stage of the process but are submitted to separate studies during the next design step or construction.	

3.2 Layout strategies

Site-specific strategies have been applied for the different parts of the facility on the grounds of the overall objectives and purposes of the layout work and based on /SKB 2007/ and /SKB 2008a/.

The facilities and operation are also adapted, as previously mentioned in Section 2.3, to avoid unfavourable consequences with regard to the environment.

The following sub-sections describe specific guidelines for the accesses and the central area:

- **Effective access to the deposition area.** The overall objectives include that the proposed solution shall be efficient with regard to transportation and compliant with regard to energy consumption. Accordingly, efforts are to be made to locate the central area as close as possible to the centre of the available deposition area. This criterion is limited however in that location of the central area is closely linked to the design of the industrial area surface facilities.
- **Limit the access length through FFM02 and deformation zones**. The different access structures are configured so that their length is limited through fracture domain FFM02. This strategy has been chosen with regard to both risk and cost, in such way that excavation work and the following construction work may be hazardous as the fracture domain is difficult to work in. Costs are reduced as a shorter passage will need less amount of grouting volume. The direction of the accesses agree with the suggestions in /SKB 2008a/.
- **Avoid passage of deformation zones in the central area**. To minimize the need of grouting and rock reinforcement, the central area is to be located so that passage of deformation zones is avoided. Uncertainty with regard to width and extent of deformation zones, and the possible presence of water-conductive fractures, imply that it can be difficult to assess the need of grouting and/or rock reinforcement. Accordingly, the strategy of avoiding passage of deformation zones as far as possible has been chosen both with regard to risk and cost. To enhance the possibilities to locate the deformation zones that interfere with the layout at an early stage, surface investigations and investigations along with the excavation work are proposed.

The deposition area requires specific strategies. The following sub-sections describe the guidelines for this area:

- **Efficient utilization of available deposition area.**
  - The available deposition area is limited, and as described earlier it is confined by the boundaries of the rock domains RFM0029 and RFM045 (and deformation zone ENE0062A), forming an area similar to a rectangular profile. To achieve efficient utilization of the area, one strategy is to orientate the 100–300 m long deposition tunnels either parallel or at right angles in relation to boundaries of the almost rectangular deposition area. Parallel orientation of the deposition tunnels to the north-west trending boundary of the area almost coincides with the criterion that direction of the deposition tunnels should correspond with the direction of maximum horizontal stress in the bedrock in order to avoid spalling.
  - With consideration taken to rock mechanics and hydrogeological conditions it is considered consistent with the overall purposes of the design work (constructability, technical risks, cost, environmental impact and also robustness/efficiency) to locate main and transport tunnels in smaller deformation zones, wherever possible. This will further optimize the available deposition area. However, tunnels should not run parallel to the NE oriented fracture groups since this could entail "overbreak" of the tunnel contour. Nevertheless, running tunnels parallel to fractures and deformations zones in ENE direction is considered feasible.
  - To optimize the available deposition area, the possibility of locating transport tunnels outside the rock domain RFM029/RFM045 has been considered.
  - According to /SKB 2008a/ the distance between deposition holes in rock domain RFM029 is 6.0 m and 6.8 m in rock domain RFM045. When possible, depositing in rock domain RFM029 should be given priority, because of the shorter distance between deposition holes relative to that in rock domain RFM045.
- **Transport efficiency.** To increase transport efficiency, the deposition positions close to the central area are given priority. It is also there the initial deposition is made in the development strategy. To further increase transport efficiency, as the length of transportation routes is longer in the construction strategy based on using the linear development method (Figure 3-2) than would be required for a side change construction (Figure 3-9), the main tunnels in the deposition area are interconnected by utilising deposition tunnels as temporary transport tunnels.

- **Flexibility.**
  - Planning the main and transport tunnel network in such way that the entire deposition area within the administrative boundaries is accessible, is a basic prerequisite for a construction strategy based on using the linear development method.
  - The main tunnel northwest of zone ENE0060A is located so that the deposition tunnels are slightly shorter than the stipulated length on the north-west side in the western part of the main tunnel. This is done to ensure flexibility if the stated position for zone ENE0060A is modified.
  - Enable a strategy that allows for a flexible and robust construction plan.
- **Optimisation of investigation.** By carrying out surface investigations of layout-controlling deformation zones prior to construction of tunnels the possibilities to increase safety with regard to locations of such structures are enhanced. In connection with tunnel excavation, further investigation drilling is carried out and investigation tunnels are also made to facilitate final confirmation of such deformation zones.

3.2.1 Uncertainties

The uncertainties of the layout and thus the uncertainties in estimating the absolute number of deposition positions are related to 1) the geometric properties of the rock, and 2) the governing conditions for the underground facility. In addition to these two main types of uncertainty, the 30% (maximum) loss of deposition positions according to /SKB 2008a/, is a significant uncertainty in the premises.

Geometric uncertainties.
  - The boundaries of the tectonic lens and between different rock and fracture domains are not clear-cut limits, they consist as a rule of gradual transitions. Similarly, the location and boundaries of deformation zones are difficult to determine unequivocally.
  - Determining the boundary between the rock domains RFM029 and RFM045 is important because they have different thermal characteristics which in turn influence the distance between deposition holes.
  - Determining the boundary between fracture domain FFM02 and FFM01 is important because they have different rock mechanical and hydrogeological characteristics that influence construction methods and building capacity.

- **Uncertainty in governing conditions.**
  - Property values of the rock mechanics, thermal and hydrogeological characteristics influence drafting of the layout.
  - Values of the rock mechanic characteristics influence the layout, for example the risk of spalling in deposition holes is dependent on the orientation of the deposition tunnels with respect to maximum horizontal stress.
  - The thermal characteristics constitute one of the controlling parameters in determining the distance between deposition holes and the distance between deposition tunnels.
  - The different parts of the underground facility have specific requirements with regard to inflow of water. For example there is a requirement that leakage in deposition holes must be less than 0.1 l/min. The hydrogeological characteristics are decisive in grouting operations, which implies that determining these characteristics is essential to enable fulfilment of prescribed requirements.

3.2.2 Monitoring program

The uncertainties that have been identified in the above chapter (Chapter 3.2.1) are to be dealt with as far as possible before tunnel construction is carried out. The purpose of the investigation strategy is to examine the existing geological uncertainties beforehand and to confirm the dimensioning characteristics that form the basis in configuring the repository. Determining the position of deformation zones in detail in the underground facility should be made from the surface or from suitable underground space by drilling and possibly by complementary geophysical investigations. Suggestions concerning which areas are to be investigated from the surface are noted in Figure 3-12. Proposed areas are presented together with the proposed order of extension in Chapter 4. Drilling is to be carried out in such a way that it does not penetrate any part of the underground area where deposition tunnels or deposition holes are to be located.

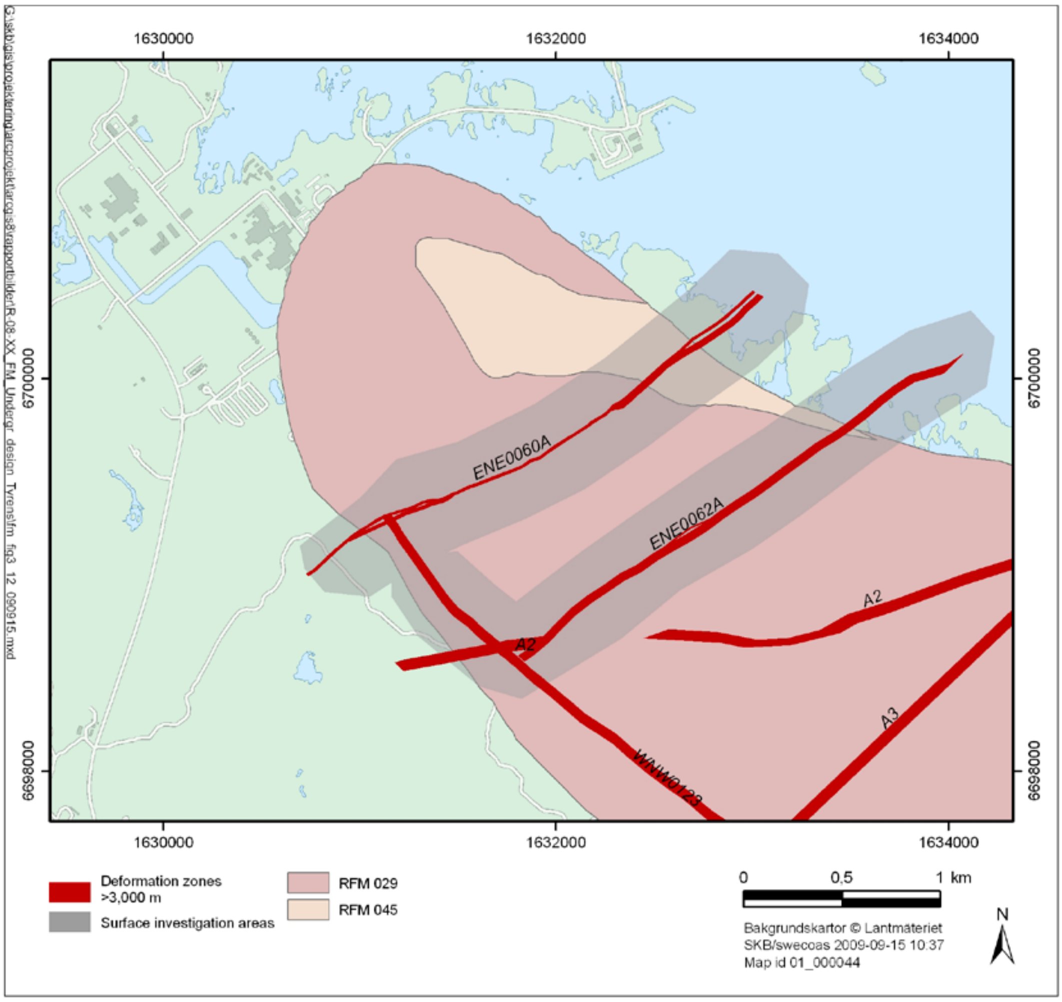


Figure 3-12. Proposal concerning areas that are to be investigated from the surface (shaded areas). Zones and rock domains refer to layout depth at –470 m (RHB 70).

In a later phase, in connection with tunnel construction, investigation drilling and investigation tunnels should be arranged in the planned position for main and transport tunnels. The purpose of these investigations is partly to confirm the dimensioning property-values that form the basis for configuring the repository and partly to further investigate, for example, the exact location of deformation zones in connection with which the surface investigations have given rise to varying interpretations. Investigation tunnels ought to be made even in connection with construction of the temporary transport tunnels.

3.3 Layout of surface facilities, ramp, shaft and central area

In cooperation with the design work of the surface facility, three locations for the underground central area have been proposed for further comparative studies. The degree of freedom for location of the central area is controlled by:

- The requirement that all rock facilities in their entirety are to be located within rock domains RFM029 and RFM045.
- The requirement that the surface facilities are to be located within the area restricted by the purple line in Figure 3-13.

The three proposed locations, “Infarten”, “Kylvattenkanalen” and “Söderviken”, lie in the most north-western part of the available area, as illustrated schematically in Figure 3-14. With minor adaptations of the main and transport tunnels locally around the respective alternatives, they are judged as being equal from the point of view of available deposition area.

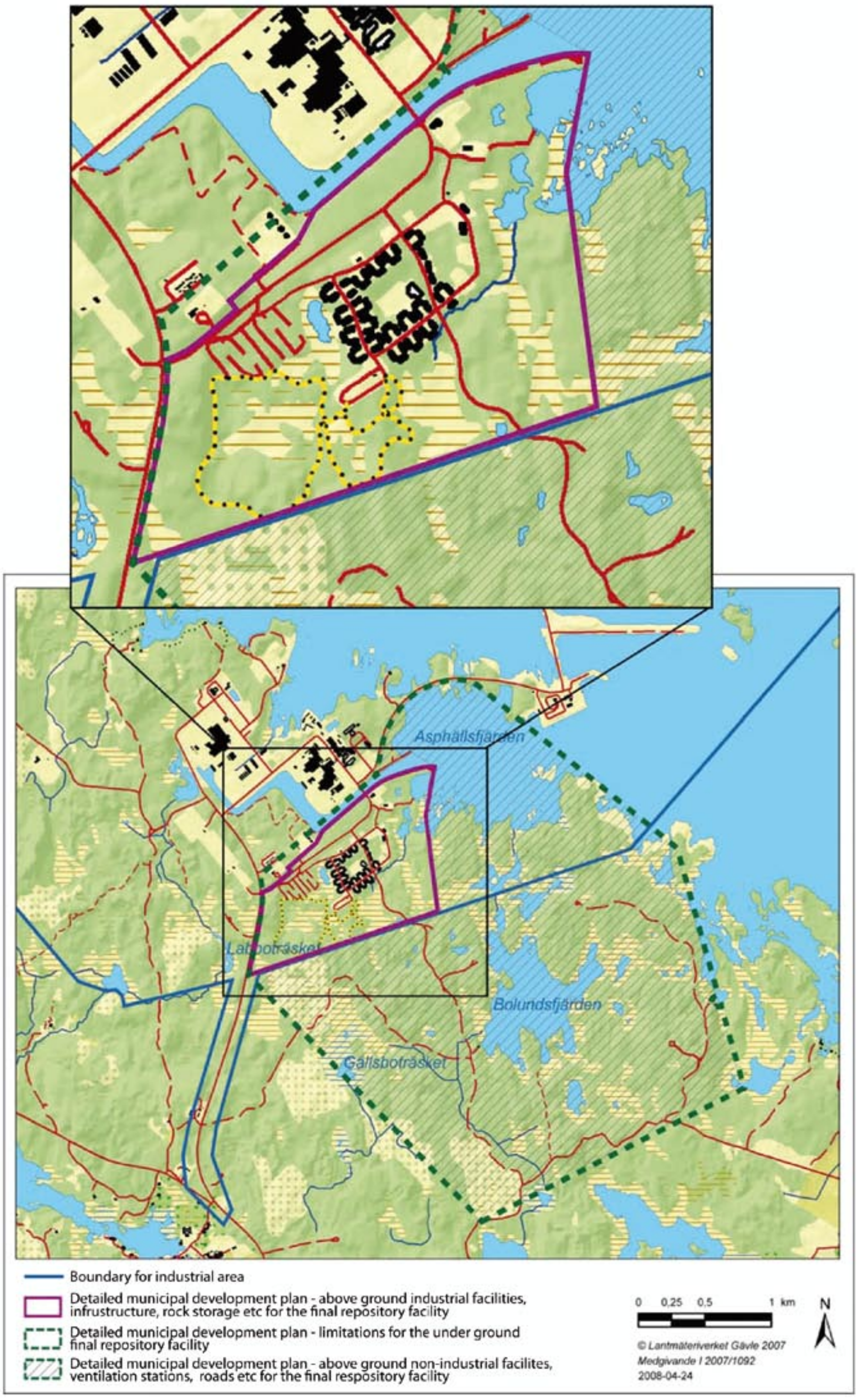


Figure 3-13. *Limitations for location of surface facilities for final repository and the central area /SKB 2008a/.*

The position of the ramp depends on the location of the surface facility and the central area. However, it applies in all three alternatives that the length of the ramp through fracture domain FFM02 is to be kept as short as possible. Length of the ramp through FFM02 is presented in Figure 3-15 and in Table 3-4 for the respective alternative.

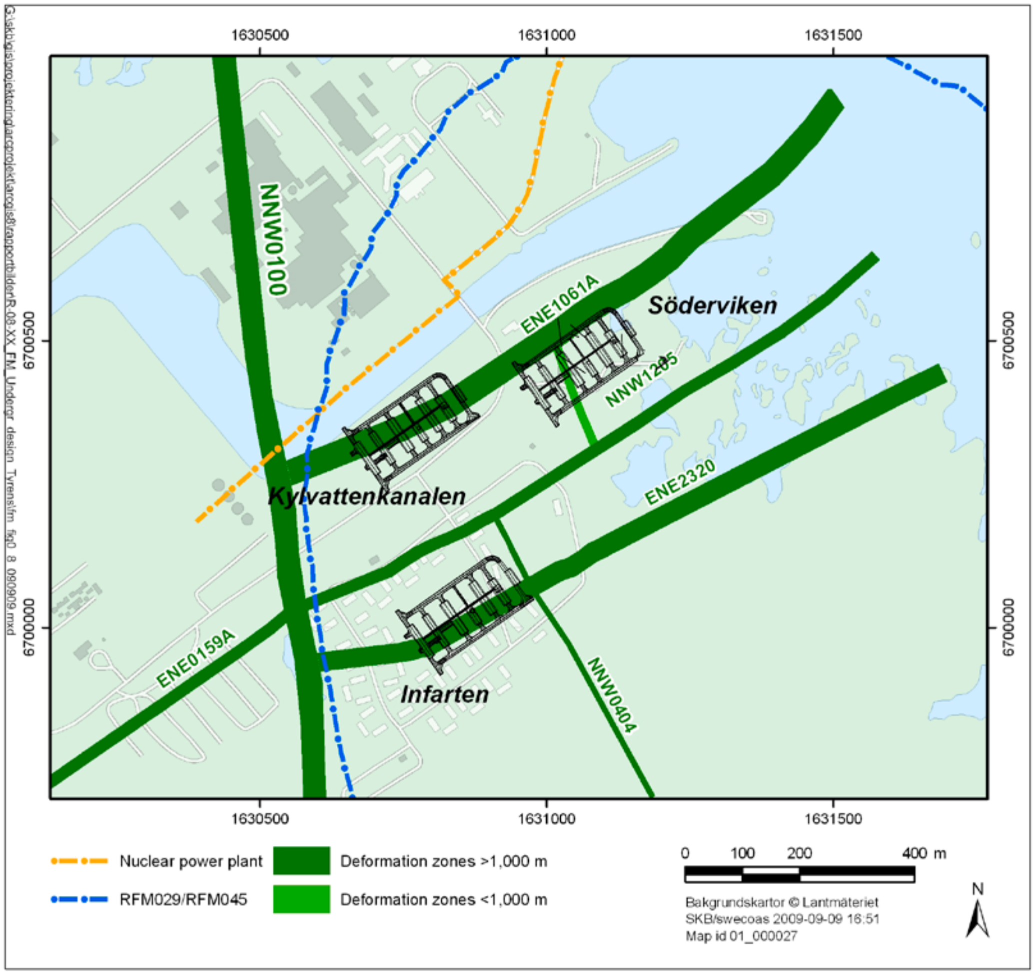


Figure 3-14. Three alternative locations for the underground central area, which is to be in direct relation to the surface facility. Deformation zones that are close to ramp and/or shafts at depth of 470 m (RHB 70) are also shown.

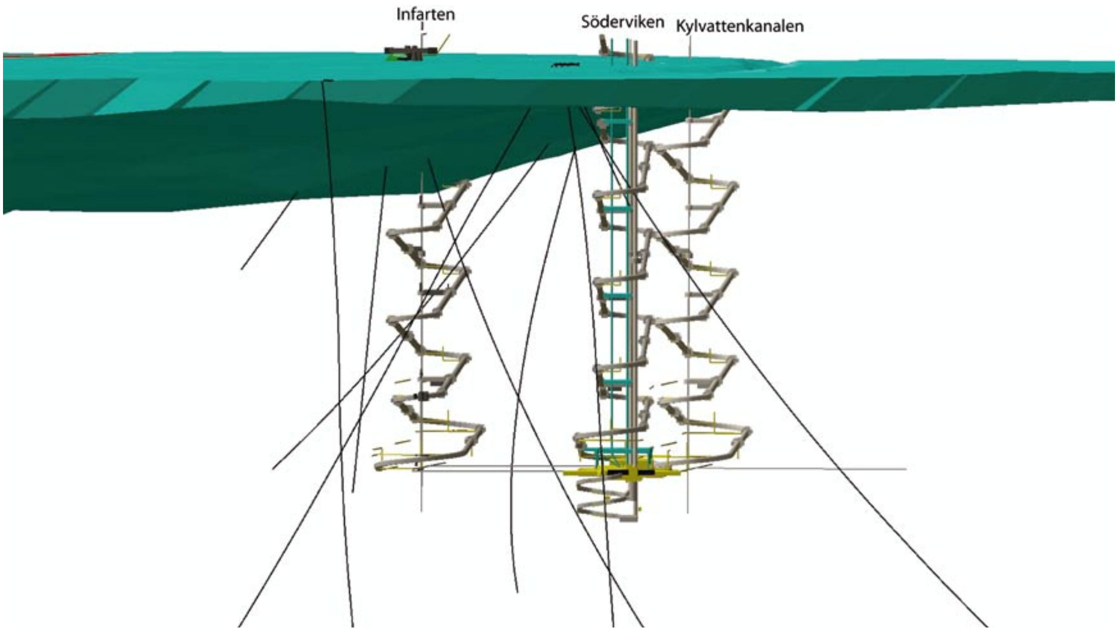


Figure 3-15. Three locations for the surface facility with appertaining ramp and shaft facility. The green-blue area represents fracture domain FFM02 while black lines represent core boreholes. View from north-east.

Table 3-4. Drive lengths of the ramp through fracture domain FFM02 for the different alternatives.

Alternative	Length ramp tunnel in FFM02
"Infarten"	1,430 m
"Kylvattenkanalen"	550 m
"Söderviken"	560 m

The number of zone passages and the passage length through fracture domain FFM02, due to its hydraulically connected horizontal fractures, have significance for the rock reinforcement and grouting methodology and amounts involved. Table 3-5 presents the number of zone passages for the different alternatives with regard to the ramp tunnel down to repository depth. The gently dipping zone 1203 is not shown in Figure 3-14, as it does not occur at the depth of the repository. However, the ramp from "Kylvattenkanalen" is close to that zone at a more shallow level and it is therefore included in table 3-5. Deformation zones that are shorter than 1,000 m, e.g. NNW1205, have less significance with regard to reinforcement and grouting and are not included in the calculation in Table 3-5.

As with the ramp, it applies that the shafts should have the shortest way possible through fracture domain FFM02. Drive lengths of shafts through FFM02 are presented in Table 3-6.

3.3.1 Selection of alternative 3, Söderviken

In the design work carried out, the choice of the central area alternative was made with consideration to the strategy – "Limit access length in FFM02 and deformation zones". As indicated by Tables 3-4 to 3-6 the alternative "Infarten" has both the longest part through FFM02 and the most zone passages. The alternatives "Kylvattenkanalen" and "Söderviken" are practically equal with regard to ramp length through FFM02. On the other hand, the zone passages are less in the Söderviken alternative. As a result of this reasoning, the "Söderviken" alternative is recommended rather than the other two. Therefore, the strategy – "Avoid contact with deformation zones in the central area" is presented below for the Söderviken alternative only.

Figure 3-16 shows the intersection between the minor deformation zone NNW1205 and the "Söderviken" accesses and central area. Due to the constraints from the surface industrial area and shaft connections, it was not considered viable to relocate the central area to avoid this small deformation zone, and instead it was considered feasible to accept the somewhat higher construction risk as additional requirements for grouting and reinforcement.

Table 3-5. Estimated number of zone passages for the ramp for different alternatives.

Zone	ENE2320	NNW0404	1203	NNW0100	ENE1061A
"Infarten"	10	5	2	0	0
"Kylvattenkanalen"	0	0	0	Borders to	7
"Söderviken"	0	0	0	0	Borders to

Table 3-6. Drive lengths of shafts through fracture domain FFM02 for the different alternatives.

Alternative	Shaft length (2 vent, 1 skip and 1 lift shaft)
"Infarten"	4·140 m = 560 m
"Kylvattenkanalen"	4·45 m = 180 m
"Söderviken"	4·46 m = 184 m

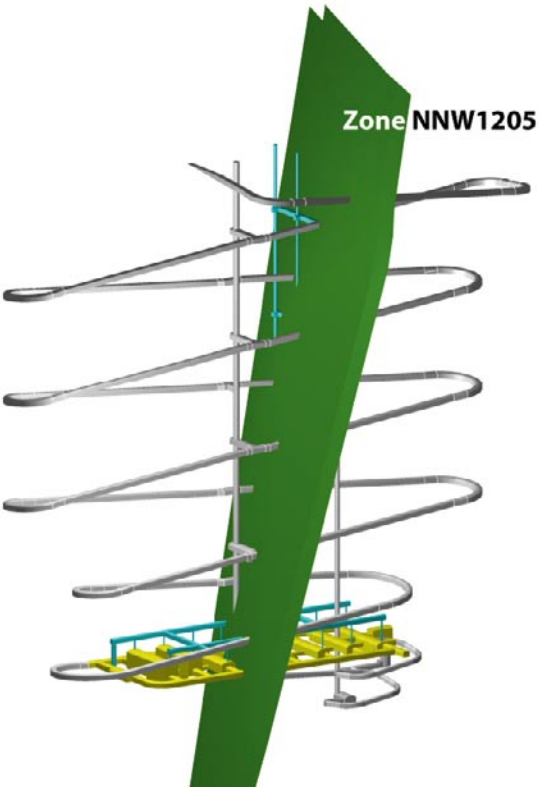
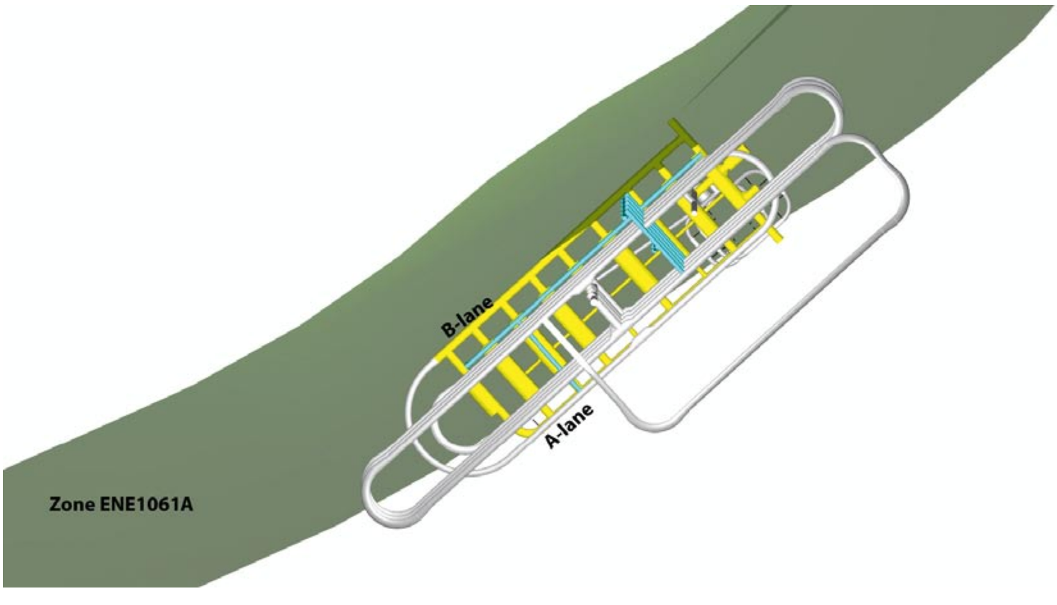


__Figure 3-16.__ The alternative "Söderviken". The central area in relation to the deformation zone NNW1205. View – from the south.

The central area includes two different lanes (A and B), a service tunnel and several rock caverns, which are further illustrated in Appendix 1 in /SKB 2008a/. Figure 3-17 shows that with the chosen location of the central area about half of the B-lane lies within zone ENE1061A. Grouting, rock reinforcement and construction risks are supposed to be in proportion to the cross-sectional area of the facility part intersected by the deformation zone. Therefore, deformation zones through rock caverns should be avoided while deformation zones through smaller tunnels such as the B-lane are acceptable.



__Figur 3-17.__ The alternative" Söderviken". The central area in relation to zone ENE1061A. Green colour marks the parts of the central area that lie in zone ENE1061A at –470 m (RHB 70). Top view.

3.4 Layout of ventilation shafts

At this preliminary design step the deposition area is assumed to need some ventilation shafts to ensure a favourable and safe working environment and to enable ventilation at the deposition level. SKB has specified positions for two ventilation shafts at the deposition area (Figure 3-18). Consideration is taken to environmental values on the surface, shaft length through the water-conductive fracture domain FFM02 and also contact with gently-dipping water-conductive zones when positioning the shafts. In constructing the ventilation shafts, both of them will go through fracture domain FFM02. Furthermore, the gently-dipping deformation zone B7 will be passed by the eastern ventilation shaft at 310 m depth (Figure 3-19). As the other gently-dipping zones, B7 might in some parts be severely water-conducting and difficult to seal /SKB 2008a and Brantberger and Jansson 2008/.

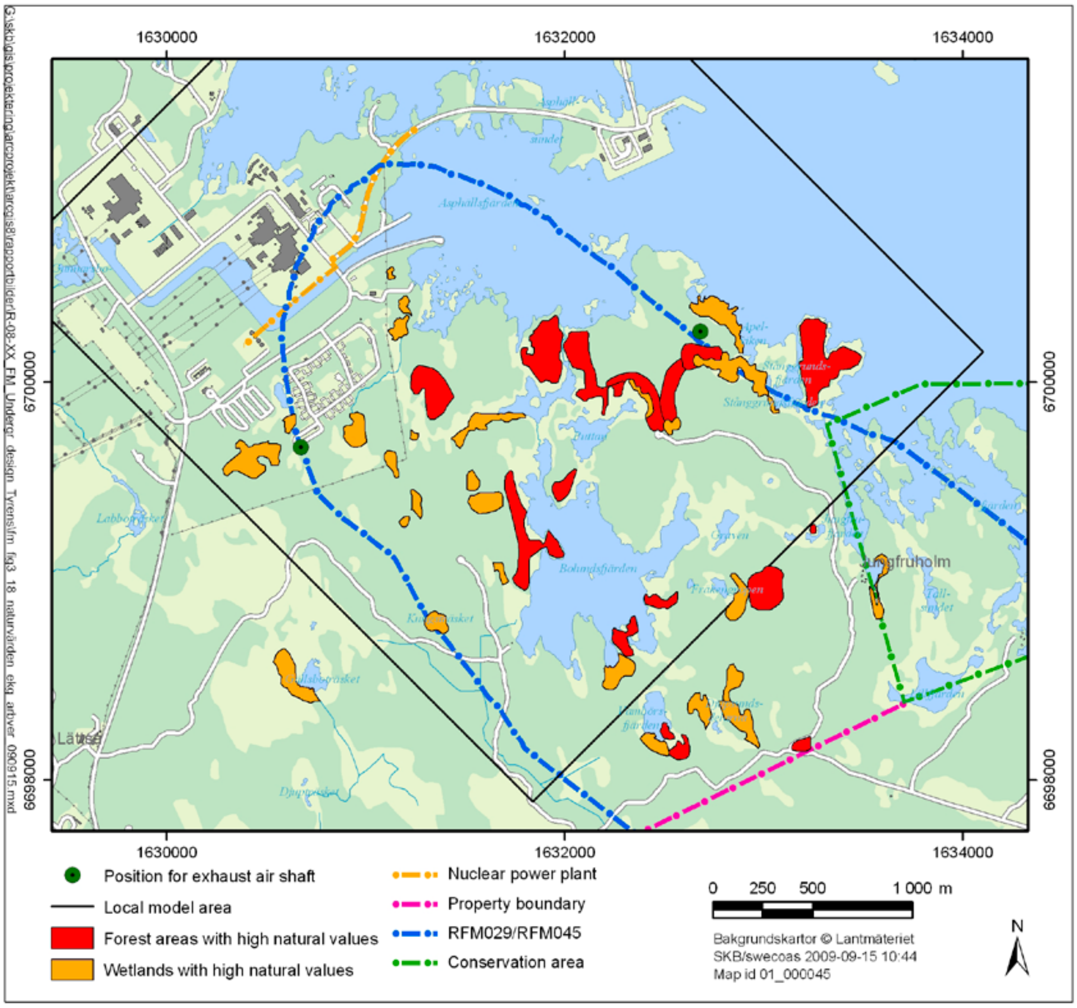


Figure 3-18. Proposed location of ventilation shafts.

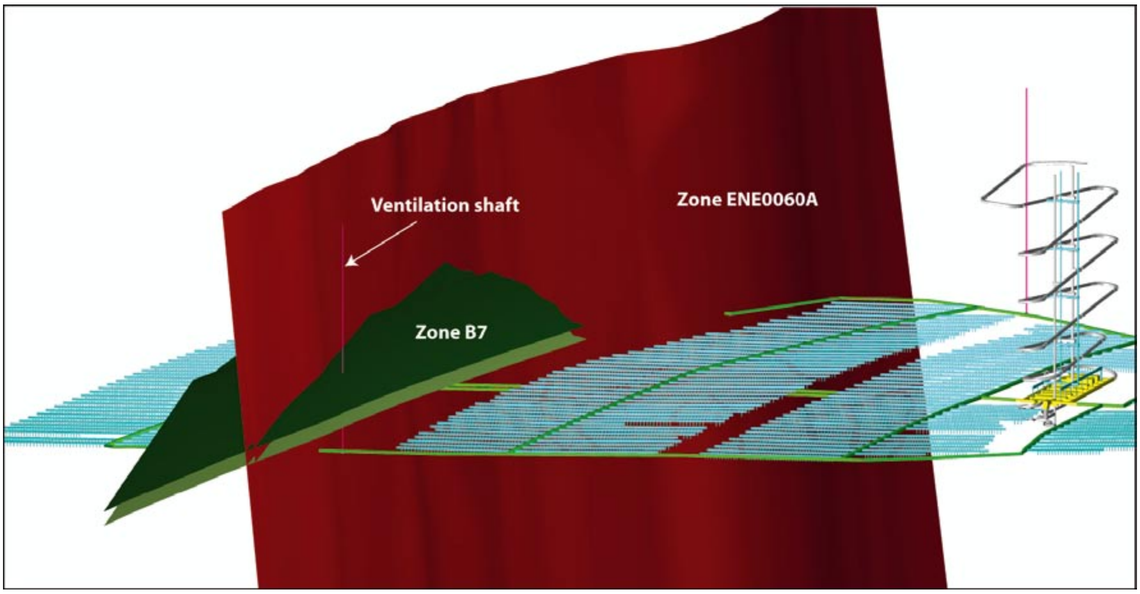


Figure 3-19. Illustration showing the intersection between eastern ventilation shaft (SA01) and B7 at a depth of 310 m (RHB 70). Underground facilities at –470 m (RHB 70). View from northeast.

3.5 Layout of deposition area

This chapter presents design considerations for the deposition area and the gross capacity, i.e. the theoretically possible highest number of deposition holes inside the boundaries of the designed deposition area considering premises and conditions given in Chapter 2. Chapter 5.1 presents possibilities for additional deposition holes, outside the designed area.

During the development of the proposed layout the strategies that were presented above (Chapter 3.2) have been taken into consideration. In agreement with these strategies, and with the below design considerations, a gross capacity of 7,818 canisters will be achieved, which allows for approximately 23% loss of deposition positions to achieve 6,000 net deposition positions.

The deposition tunnels in a deposition area are interconnected by main tunnels, whereas transport tunnels run between the deposition areas. To achieve the most efficient solution of the deposition area, the main tunnels and transport tunnels are placed sub-parallel to the geological boundaries, i.e. the boundaries of rock domains RFM029, RFM045 and deformation zones WNW0123 and ENE0062A (Figure 3-20). The north-eastern borderline of the tectonic lens (boundaries of rock domains RFM029 and RFM045) is according to /SKB 2008a/ established on the gradual increase in rock ductile strain, considered of minor importance to the construction of tunnels, allowing the transport tunnels to be located just outside the tectonic lens in rock domain RFM032 (Figure 2-3).

Furthermore, since there are no prerequisites regarding placement of transport tunnels the northeast transport tunnel has been located outside the rock domains RFM029/RFM045 (Figure 3-21). This enables enhanced use of the deposition area for deposition positions.

By placing the deposition tunnels sub-parallel to direction of the maximum horizontal stress the condition for parallel positioning of the transport tunnels in relation to boundaries of the deposition area is satisfied at the same time. Figure 3-22 shows the gross capacity with the deposition tunnels in area A lying with a maximum deviation of –22° from the main principal stress. The two other directions for the deposition tunnels, in area B and for the remaining deposition tunnels, deviate < 5° and c. 18°, respectively from the main principal stress.

The distance between endpoints of deposition tunnels located in different main tunnels must be minimum 80 m /SKB 2007/, which is the safety distance for the vibrations from blasting works in relation to a deposited canister.

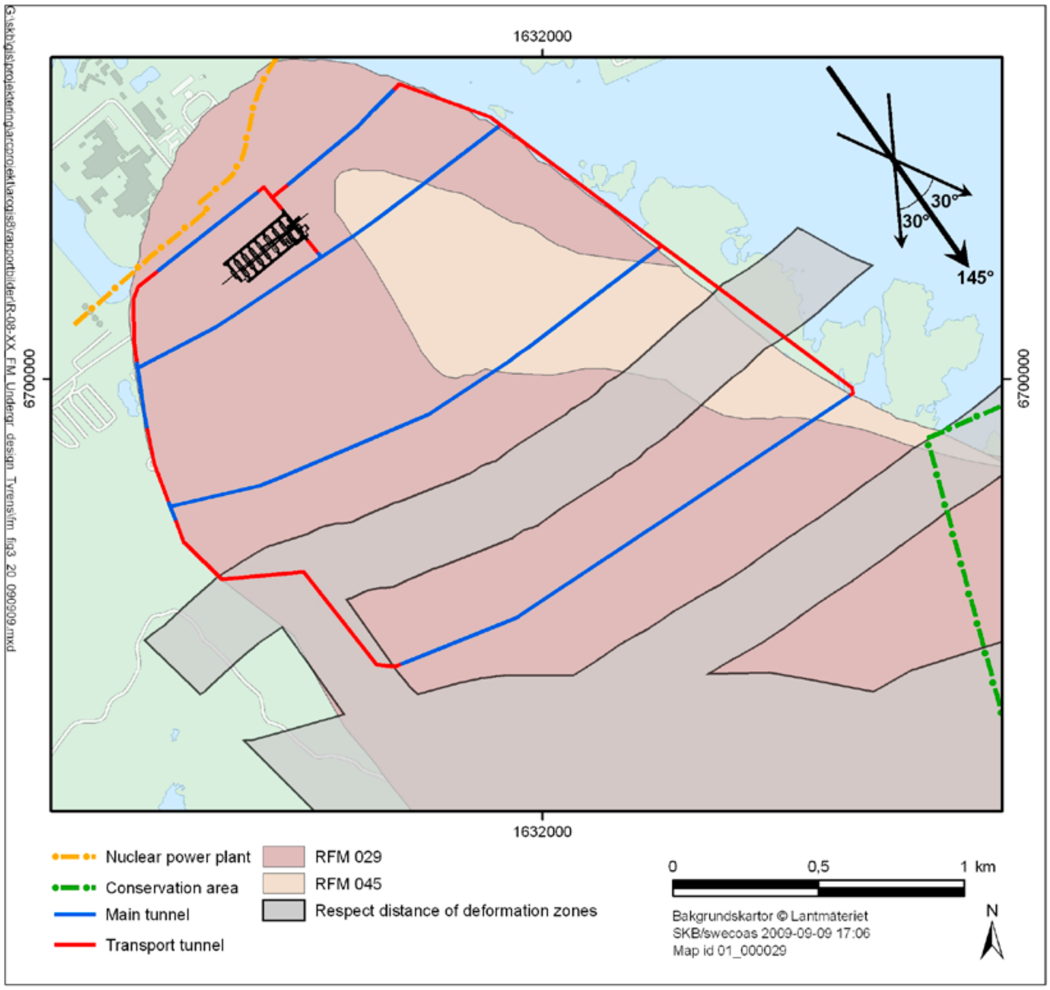


Figure 3-20. *Orientation of main and transport tunnels, section at 470 m depth (RHB 70).*

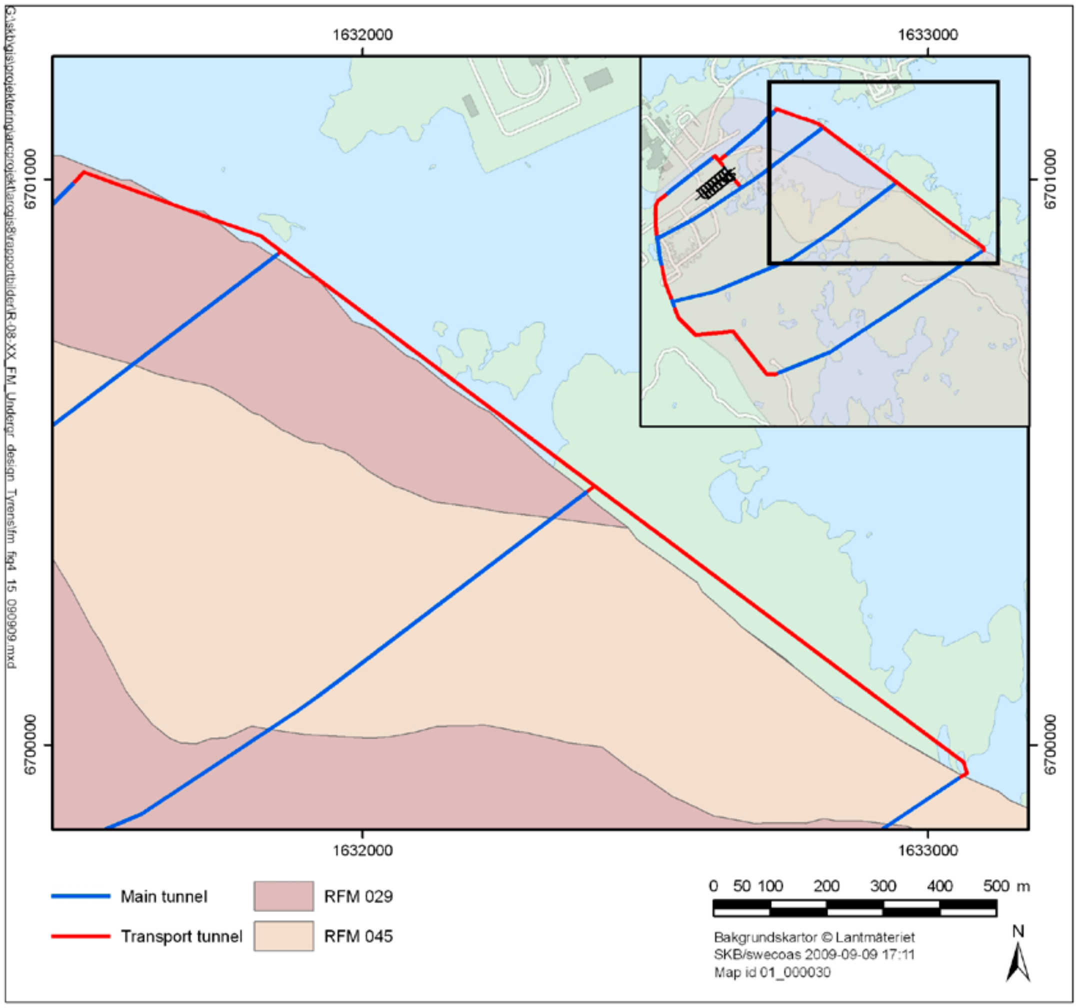


Figure 3-21. *Detail image of location for transport tunnel outside rock domains RFM029/RFM045 for improved deposition capacity, section at 470 m depth (RHB 70).*

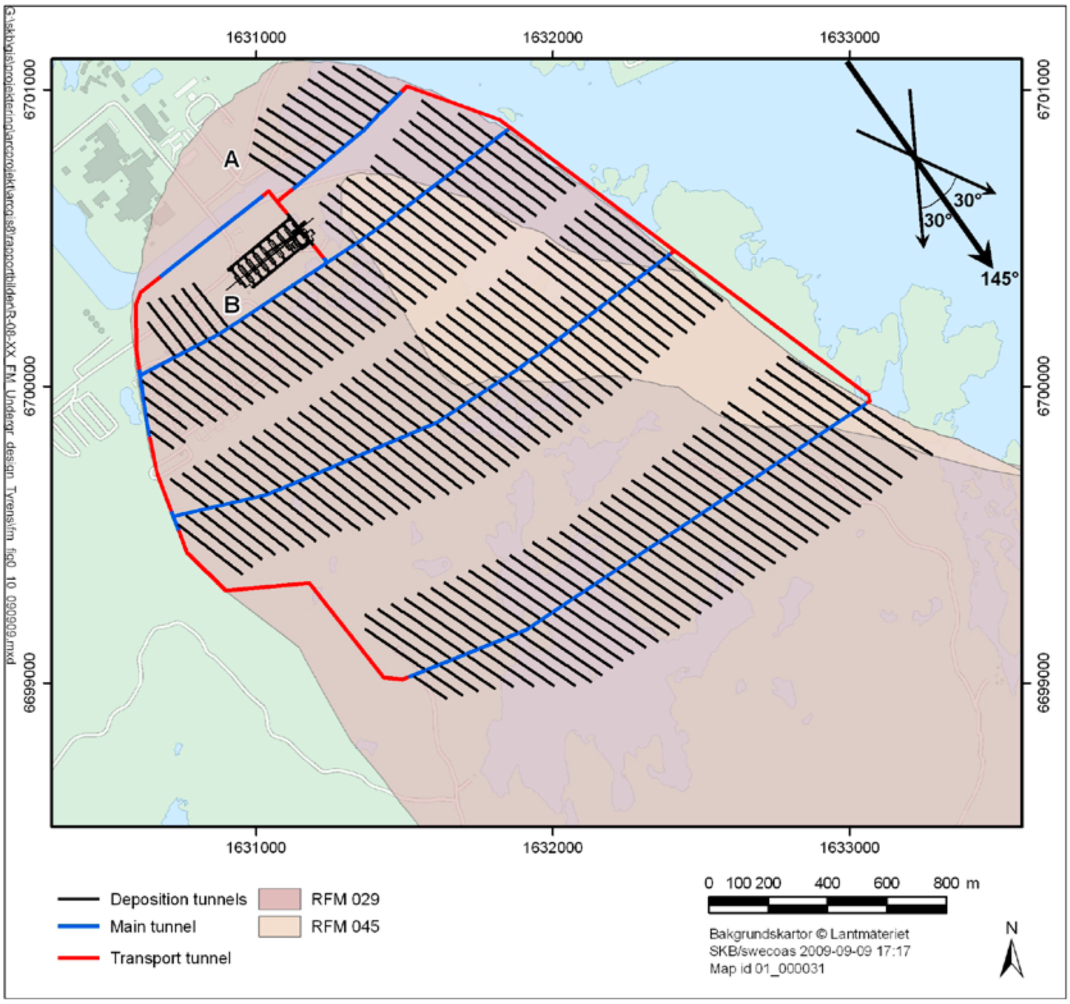


Figure 3-22. *Deposition tunnels oriented sub-parallel to the maximum horizontal stress, shown in the upper right corner. Section at 470 m depth (RHB 70).*

As presented above, one of the proposed strategies to optimize the amount of deposition positions is to plan main and transport tunnels in smaller deformation zones, whenever possible. A closer consideration shows that only a few transport tunnels are in question for this strategy. Figure 3-23 shows where this strategy is applied.

The deposition tunnels northwest of zone ENE0060A are somewhat shorter than the stipulated maximum length of 300 m (Figure 3-24). This is to enable flexibility of tunnel length as the exact position of the deformations zones cannot be determined until investigation drillings have been performed. Since ENE0060A requires respect distance, it is important to enable flexibility of the layout until the exact position is known. The length of flexibility is approximately 30 m.

The future transportation from the central area to the central parts of the two main tunnels furthest to the southeast is unnecessarily long. To improve this relationship, some deposition tunnels will be established as temporary transport tunnels, i.e. short-cuts (Figure 3-25). An overall estimate made in a generic model shows that a central transport path can reduce the work of transport by about 30%. However, no site-adapted estimate with planned order of extension has been made, so the indicated reduction of transport work is an approximation only. Since the cross-sectional area of the deposition tunnels does not allow vehicles to meet it is proposed that the central transport path should consist of two tunnels alongside each other. The excavation work to construct the short-cuts through zone ENE0060A will plausibly request grouting and rock reinforcement.

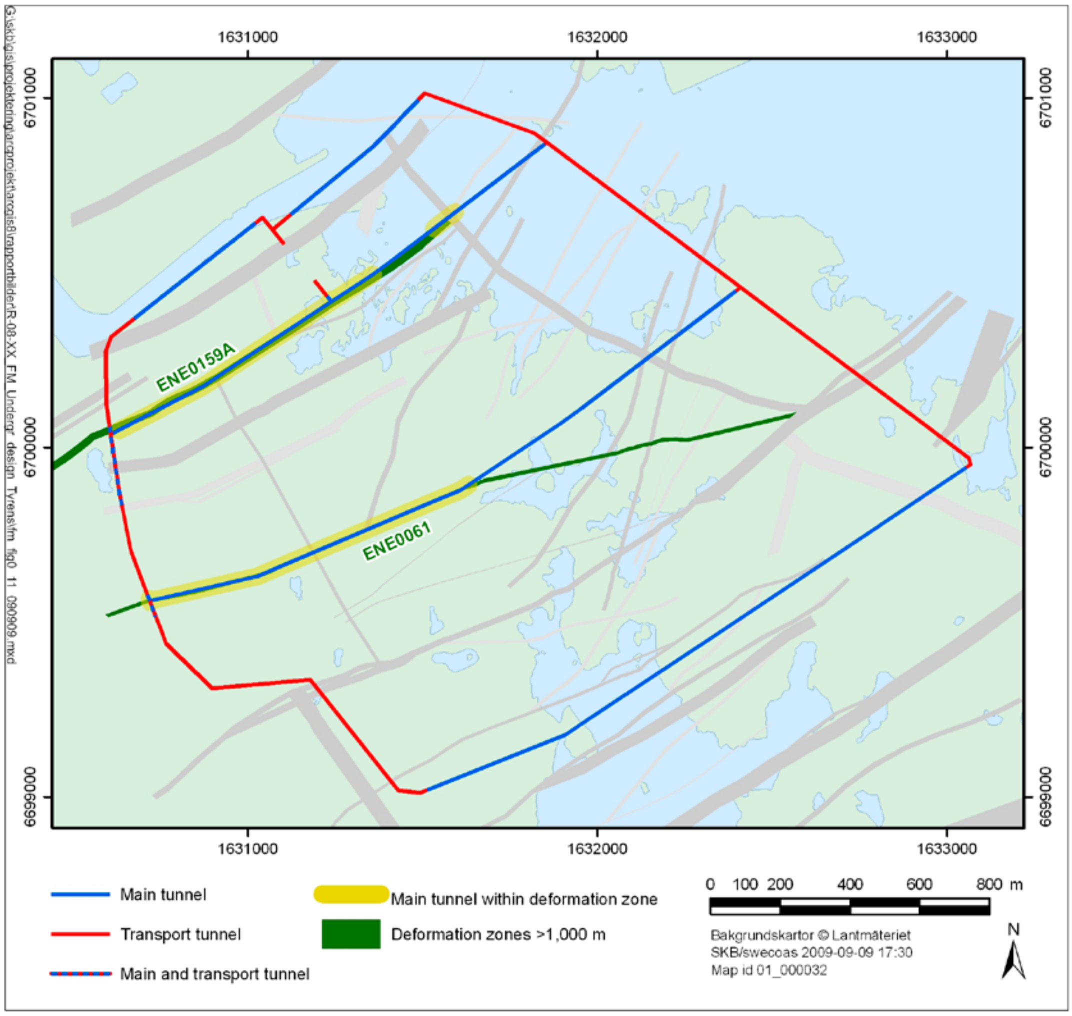


Figure 3-23. *Main tunnels planned in volumes with minor deformation zones shown in yellow. Section at 470 m depth (RHB 70).*

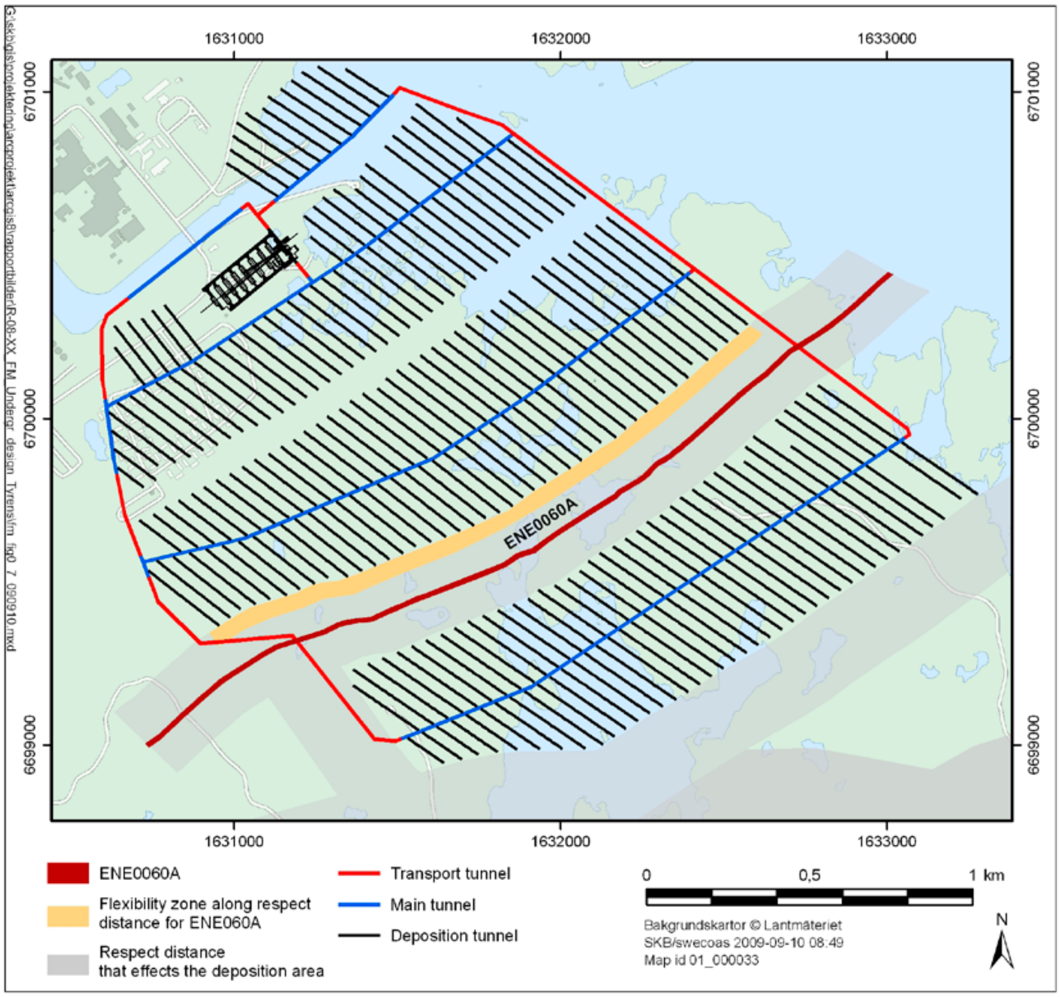


Figure 3-24. *Flexibility zone of deposition tunnels due to uncertainty of position of zone ENE0060A. Section at 470 m depth (RHB 70).*

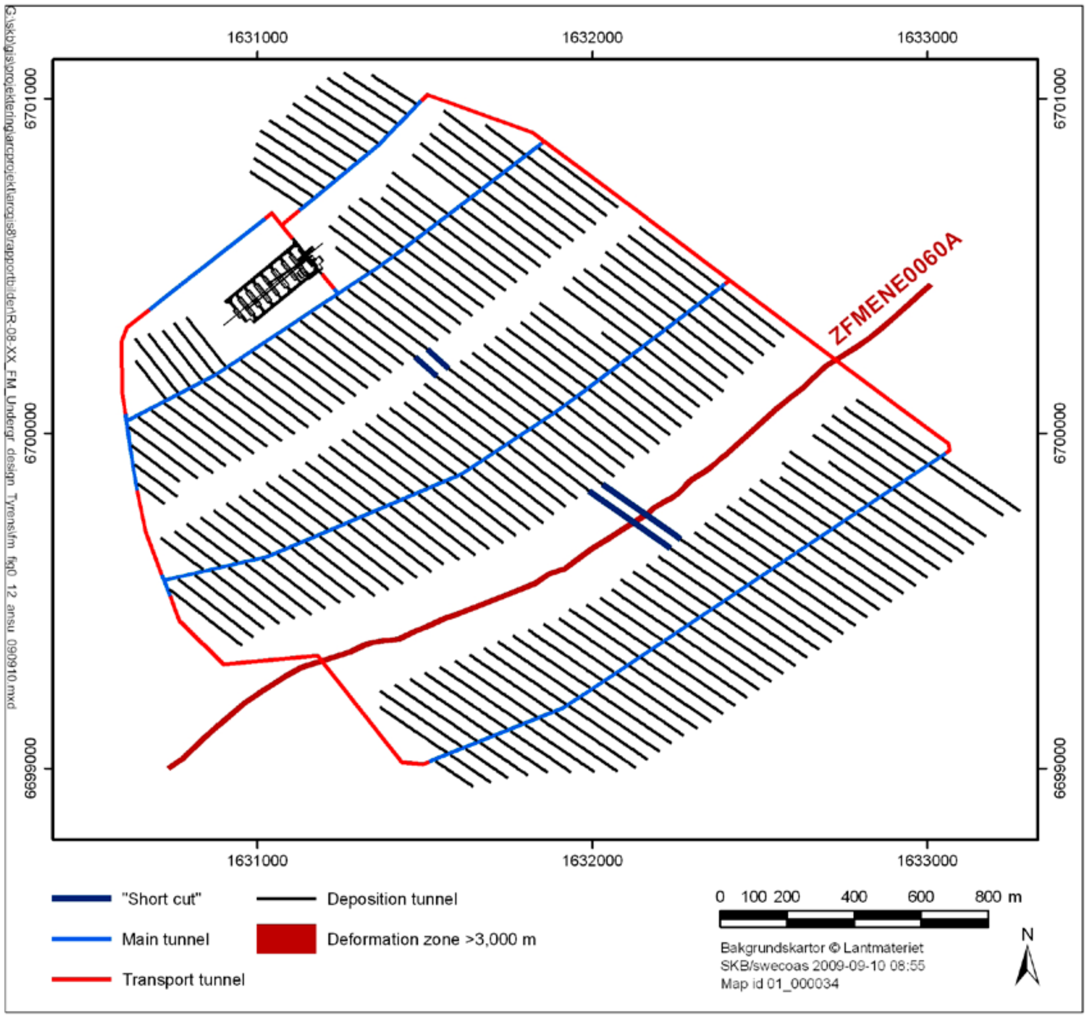


Figure 3-25. Position of temporary transport tunnels, section at 470 m depth (RHB 70).

3.5.1 Drainage system

Drainage of the deposition area is arranged by means of a gravity system, where all tunnels are inclined 1:100 towards local pumping pits located in the main-/transport tunnel system (Figure 3-26). Local pumping pits are in general arranged at a distance of 1 km from each other, allowing the maximum height difference in the repository being limited to approximately 5 m. From the local pumping pits the drainage water is pumped up and on to the next section of the deposition area, and by gravity subsequently led further on until it reaches next pumping pit or the central area. At the central area temporary storage basins for removal of sediments and oil fragments is arranged, and from these basins the water is pumped up to the surface water treatment plant. The water handling system will be designed to withstand a power cut of minimum 24 hours for the central area electrical system. In case of emergency as major fire, explosion, etc, jeopardizing the power supply for longer periods, an additional storage capacity for drainage water will also be arranged by an automatic overflow system leading surplus drainage water to the bottom of the skip shaft.

Drainage water from ramp and shafts in the central area will be collected at every 100 m level, where it directly will be pumped up to the surface water treatment plant. Since most of the leakage into the ramp and shafts is expected at the upper parts (located in fracture domain FFM02) the major part of the total drainage thus only has to be pumped up 100 m, which considerably will reduce energy costs.

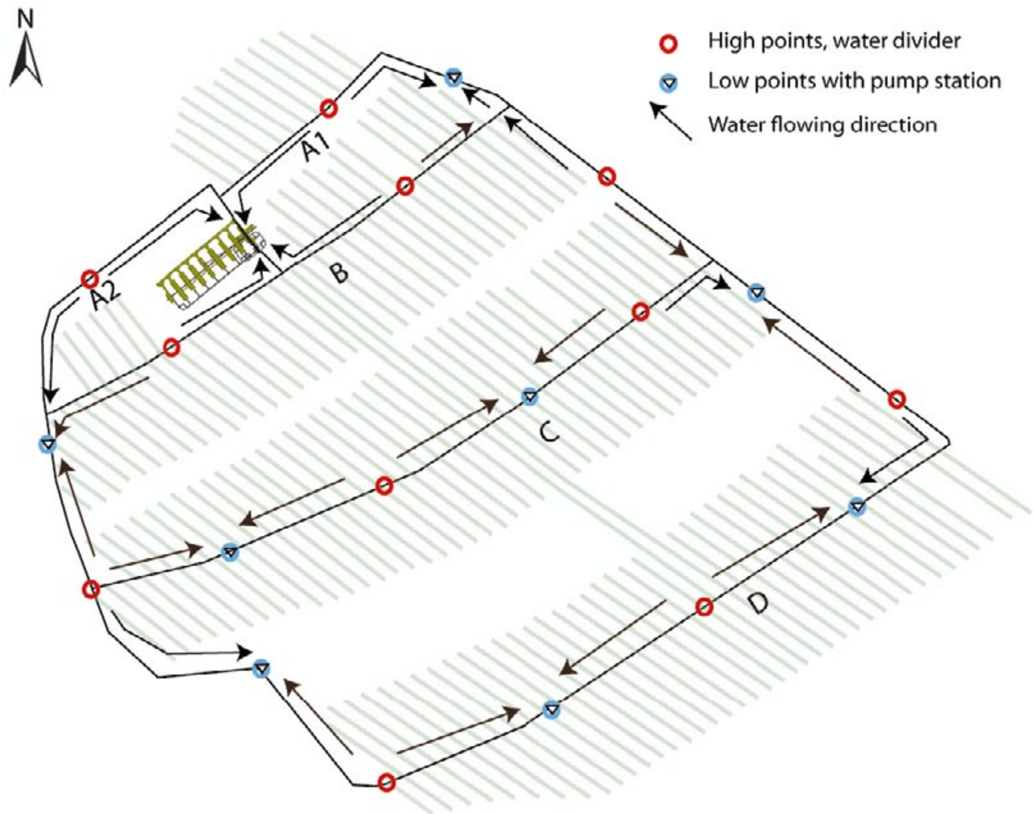


Figure 3-26. *Drainage system, plan at 470 m depth (RHB 70). The water will run from the higher points (water divider) to lower points where it will be pumped on to next section.*

3.6 Estimated excavated volumes

For the proposed localization of access ramp, shafts (including ventilation shafts) and central area the volume of excavated rock has been estimated. The amounts are presented in Table 3-7. The term "theoretical volume" refers to the volume calculated on stipulated construction dimensions, whereas in reality this volume tends to be underestimated due to ordinary overbreak (10–25%) for drill and blast rock excavation.

The volume of excavated rock has been estimated individually for the proposed layout of the deposition area. The calculations have been carried out for the transport tunnels, main tunnels and deposition tunnels, respectively. The summarized amounts for each type of tunnel are presented in Table 3-8. In Chapter 4, below, the excavated volume during each construction step is presented.

Table 3-7. Estimated excavated volumes for access ramp, shafts, rock loading station and Central area.

	Access ramp and shafts	Rock loading station	Central area	Total
Theoretical volume ($m^3 * 10^3$)	205.5	7.1	111.5	324.1

Table 3-8. Excavated volume and tunnel length, transport-, main-, and deposition tunnels.

	Transportation tunnels	Main tunnels	Deposition tunnels incl. deposition holes	Total
Theoretical volume ($m^3 * 10^3$)	182.1	384.1	1,287.9	1,854.10
Tunnel length (km)	4.6	6.4	61.1	72.1

4 Proposed construction plan for the repository area

The underground facility is to be configured so that main activities for excavation work and deposition work can be kept separate from one another. This was achieved in the generic construction strategy based on using the linear development method, presented in Chapter 3.1, which has been applied in the proposed construction plan described below. The separating doors/walls will, during normal operation, be designed to stop all traffic and passage of personnel but should be provided with openings for ventilation to pass. In case of emergency, personnel will be able to pass the door/wall and use it as an emergency exit in case of fire. The doors/walls will also be equipped with automatic closing of all ventilation openings in case of fire.

Whenever blasting is needed the closest deposition position is always at a distance of at least 80 m /SKB 2007/. The excavation and construction work is planned in such manner that the following deposition work enables deposition of 150–200 canisters/year.

Further surface investigations are proposed to be made in the respective area before the excavation work begins, as explained in Chapter 3.2.2. Underground investigations comprising drilling and investigation tunneling is proposed to be made in connection with the construction of main and transport tunnels.

The main tunnels of the deposition area are named A1, A2, B, C and D where main tunnels A1 and A2 are located on a diagonal to the northwest of the central area and main tunnels B, C and D are located stepwise further away from the central area in a southeast direction (Figure 4-1).

The estimated excavated volumes during each construction step are stated in following tables whereas a summarizing figure is presented in Chapter 4.2 (Figure 4-15).

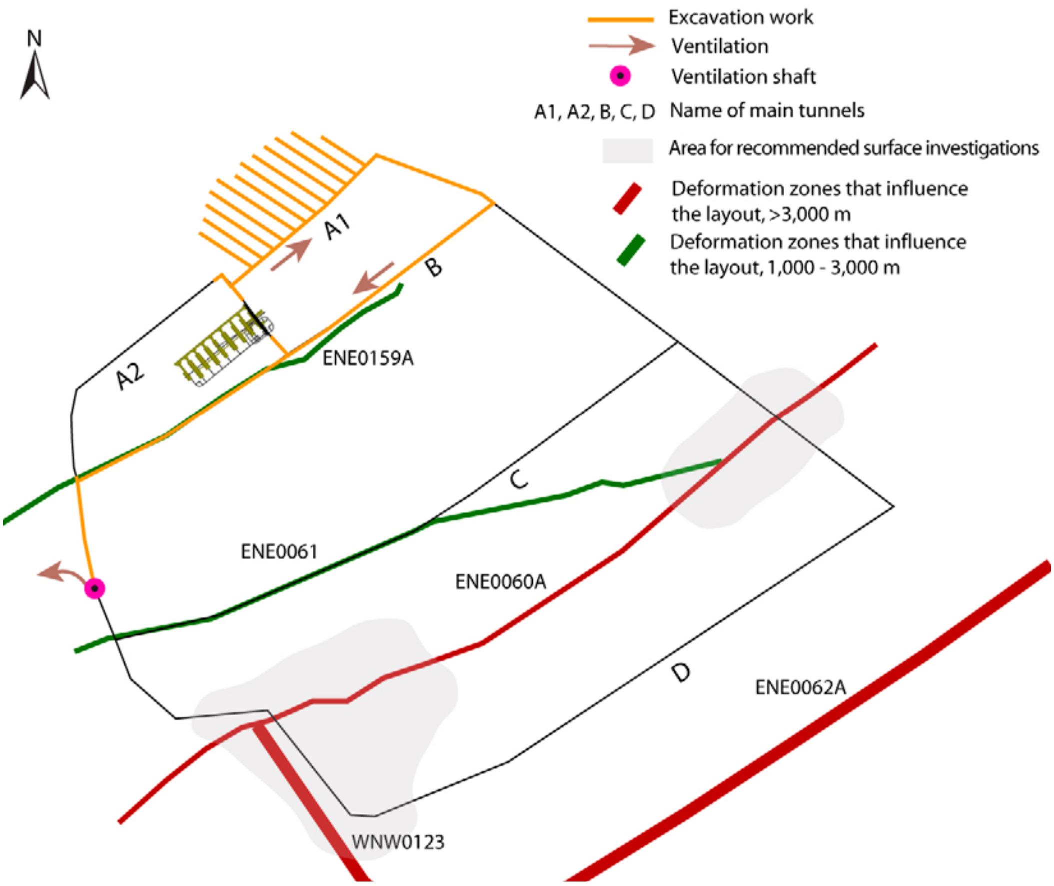


Figure 4-1. Order of extension, year 0. In this figure the shown deformation zones have name tags. In the following figures that illustrate the different steps of the construction plan the name tags are left out but the zones are the same.

4.1 Construction plan

As this report mainly describes the excavation order and deposition work of the underground facility the following construction plan precludes the needed initial construction of the access ramp, shafts, central area, western ventilation shaft and the excavation work for the first deposition tunnels. Therefore, in Figure 4-1 above, year 0 describes the time when these facilities have been constructed and deposition can begin. During the construction the ventilation of the underground facility has been made by intake through the central area and evacuation through the western ventilation shaft.

Investigation drillings, and possibly geophysical investigations, are made from the surface in the zones ENE0060A and WNW0123 in the southwest part of the area and in zone ENE0060A in the east part of the area (Figure 4-1). Investigation tunnels are made as required in connection with construction of main tunnels, mainly in the southwest part of main tunnel B to determine the position of zone ENE0159A.

By year five, deposition has been completed along the main tunnel named A1 (Figure 4-2). The deposition is separated by a door/wall in the transport tunnel, between A1 to the next main tunnel named B.

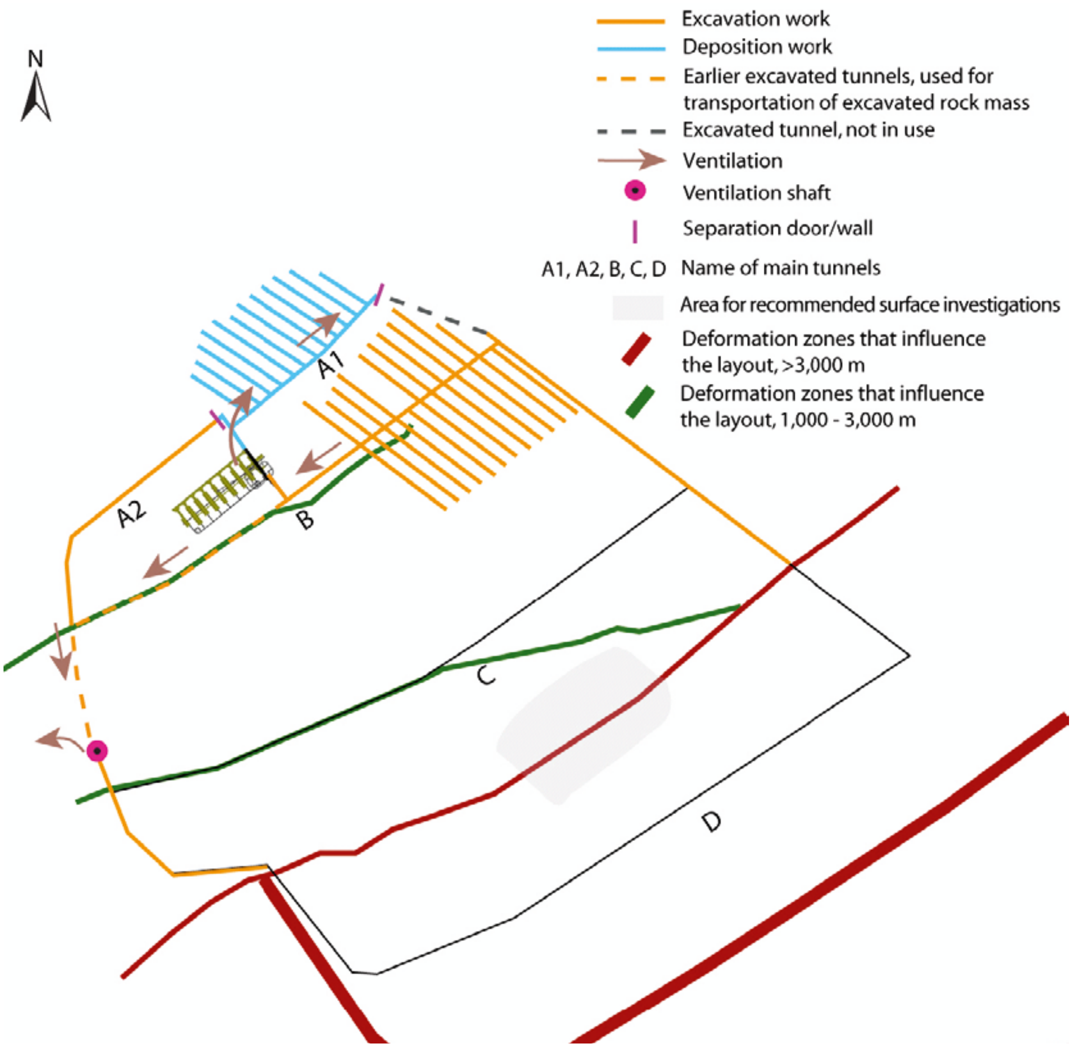


Figure 4-2. *Order of extension, year 5.*

Table 4-1. Estimated excavated volume until year 0.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	26,321
Main tunnels	131,040
Deposition tunnels	56,909
Total	214,270

Excavation work has been completed:

- In main tunnel B where the initial deposition tunnels of this main tunnel have been constructed.
- In the transport tunnel between main tunnel B and forward to the position where the eastern ventilation shaft is planned and to the position of zone ENE0060A along the north- to northeast part of the repository.
- In main tunnel A2, in the northwest part of the repository. During the excavation work of this main tunnel, a separating door/wall is needed in connection to the deposition side of the central area.
- In the southwest transport tunnel, passing zone ENE1061A where main tunnel C is to be located (see also Figure 3-23), and forward to the position of zone ENE0060A.

Ventilation of the facility is made by intake through the central area and evacuation through the western ventilation shaft.

Surface investigations are made in the central parts (according to Figure 4-2) between main tunnels C and D, down in zone ENE0060A. Investigation drillings and tunnels are made from the transport tunnels for determining the position of zone ENE0060A.

By year nine, both deposition and excavation work has been carried out in main tunnel B (Figure 4-3). The main activities have been separated by a door/wall and by two deposition tunnels that constitute a security zone between the main activities. The temporary transport tunnels from main tunnel B to main tunnel C have been excavated.

The repository is ventilated by intake air via the central area and exhaust air through the western ventilation shaft.

Table 4-2. Estimated excavated volume until year 5.

Tunnel type	Excavated theoretical volume (m^3)
Transportation tunnels	80,512
Main tunnels	30,420
Deposition tunnels	120,307
Total	231,239

Table 4-3. Estimated excavated volume until year 9.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	6,828
Main tunnels	0
Deposition tunnels	61,152
Total	67,980

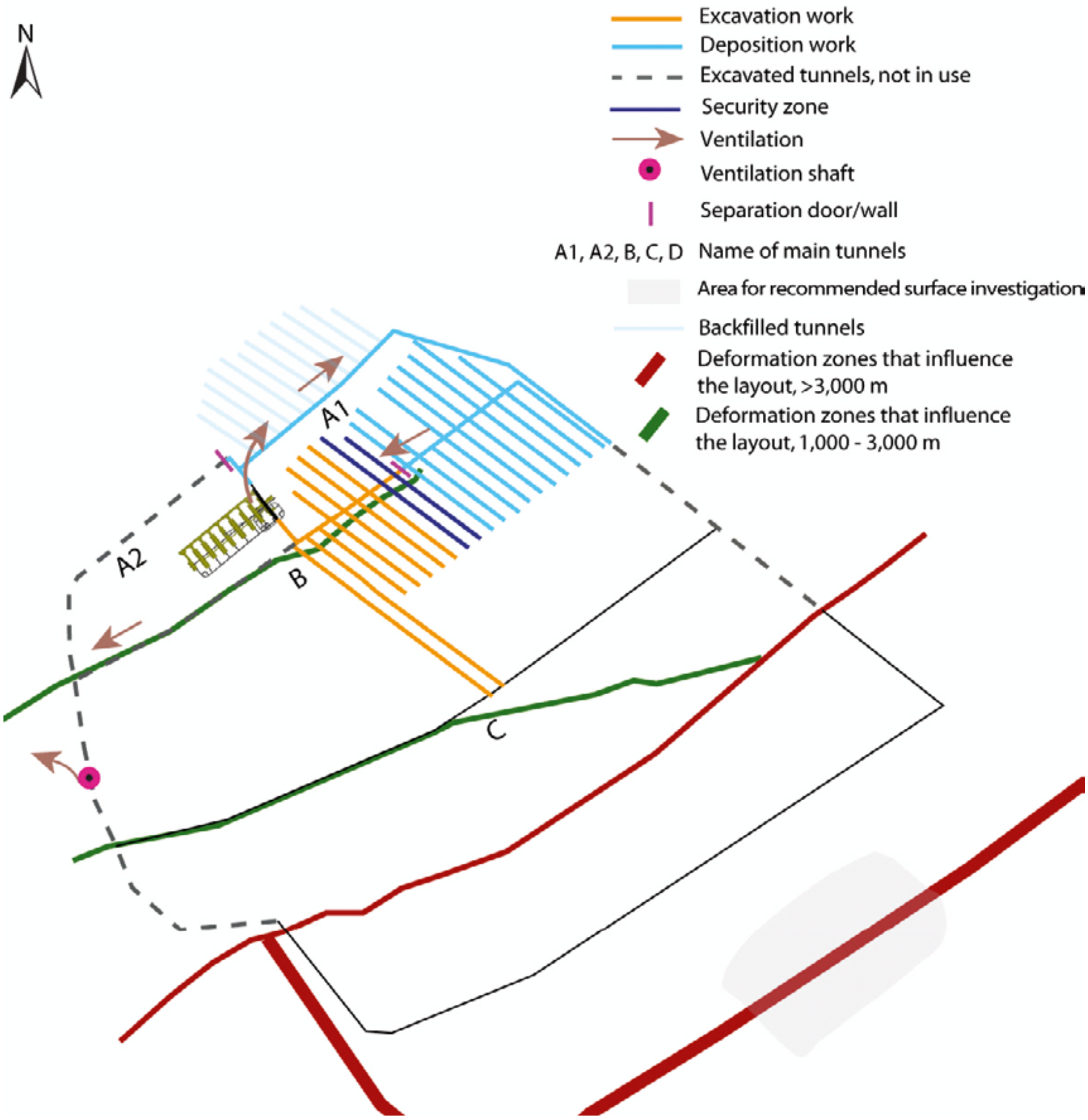


Figure 4-3. *Order of extension, year 9.*

Surface investigations are carried out in the central parts southeast of main tunnel D, in the area where zone ENE0062A is anticipated. Investigation tunnels are made from the temporary transport tunnels to investigate the position of zone ENE1061A.

By year 12, deposition has been completed in main tunnel B east of the central area (Figure 4-4). Excavation work has been carried out in the same main tunnel, south of the central area. Separation of the main activities is done by a door/wall and two security tunnels.

The repository is ventilated by intake air via the central area and exhaust air through the western ventilation shaft.

Surface investigations are carried out in the east parts of the area southeast of main tunnel D, where zone ENE0062A is anticipated.

Table 4-4. Estimated excavated volume until year 12.

Type of tunnel	Excavated theoretical volume (m³)
Transportation tunnels	0
Main tunnels	0
Deposition tunnels	53,875
Total	53,875

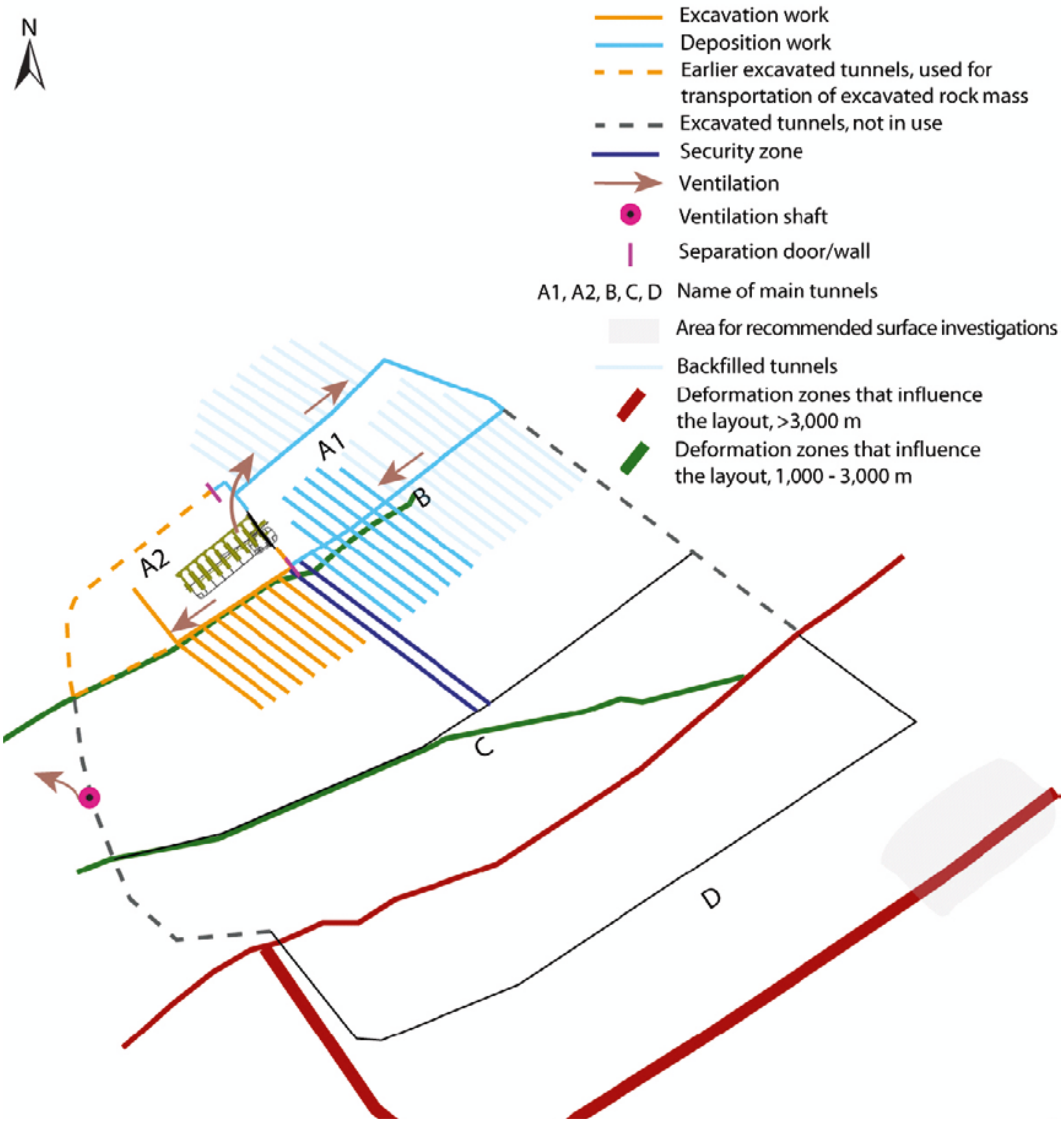


Figure 4-4. Order of extension, year 12.

By year 15, deposition has been completed in deposition tunnels south of the central area in main tunnel B (Figure 4-5). Excavation work has been carried out in the remaining part of main tunnel B and in main tunnel C, which has been constructed in its entirety.

The repository is ventilated by intake air via the central area. Exhaust air is done through the western ventilation shaft.

Surface investigations are carried out in the southern area where zone ENE0062A is anticipated, south of main tunnel D. Investigation tunnels are made as required in connection with the construction of main tunnel C.

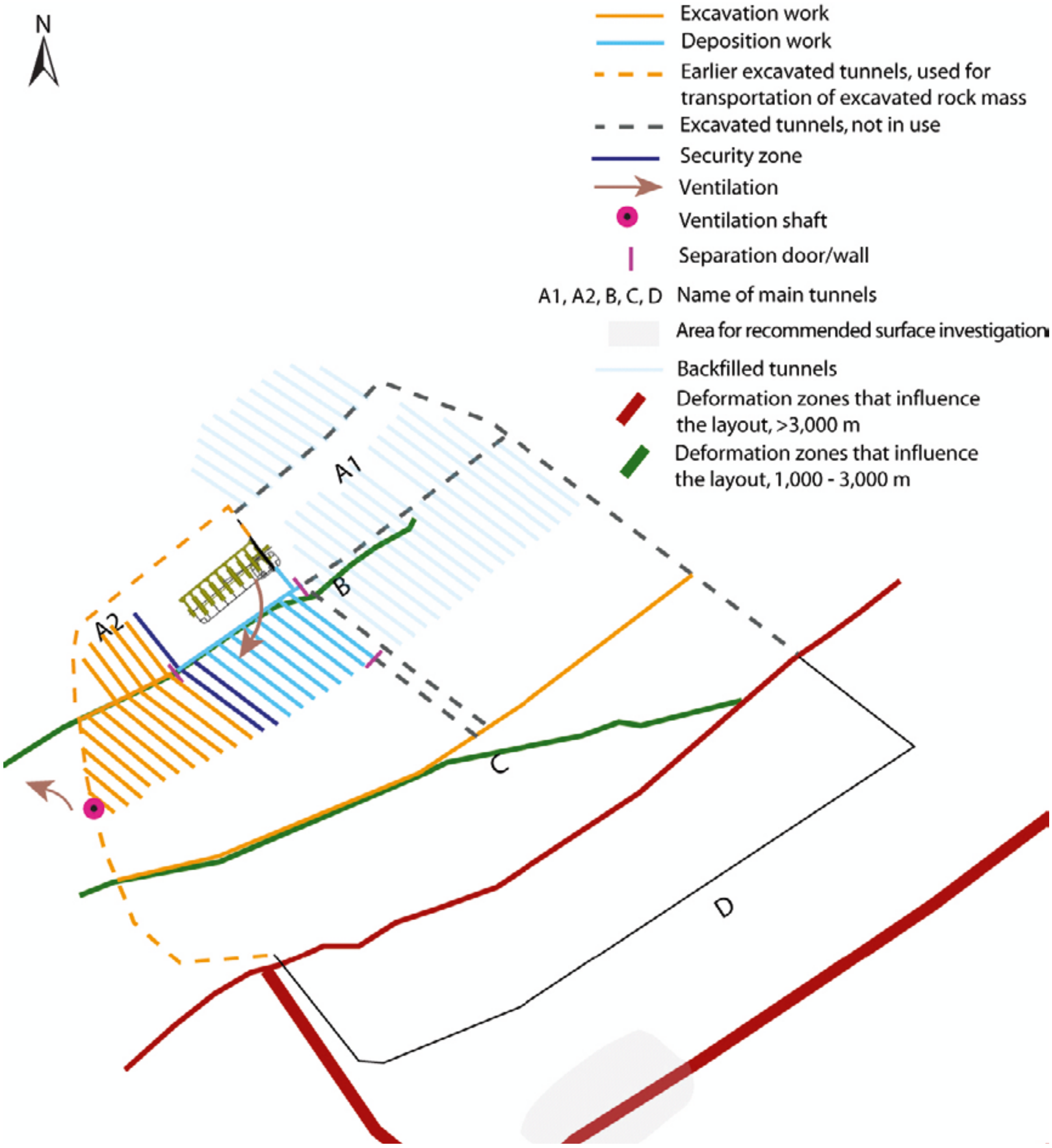


Figure 4-5. Order of extension, year 15.

Table 4-5. Estimated excavated volume until year 15.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	0
Main tunnels	113,880
Deposition tunnels	70,560
Total	184,440

By year 18, deposition has been completed in the remaining part of the constructed deposition tunnels in main tunnel B (Figure 4-6). Excavation work has been carried out in main tunnel C, where deposition tunnels have been made. The ventilation shaft to the east is completed. The transport tunnel from zone ENE0060A to main tunnel D in the southwest part of the repository has been constructed.

The repository is ventilated by intake air via the central area. Exhaust of air is done through the western ventilation shaft.

No surface investigations are carried out. Investigation drilling is carried out in zones ENE0062A and A2 in the southwest.

By year 22, deposition takes place in the deposition tunnels in main tunnel C (Figure 4-7). Excavation work is carried out in the same main tunnel, where deposition tunnels are made. The main activities are separated by a door/wall and by two deposition tunnels that constitute a security zone between the main activities. The temporary transport tunnels in the middle of the repository from main tunnel C passed main tunnel D have been constructed. The reason for passing main tunnel D is to investigate the location of zone ENE0062A.

The repository is ventilated by intake air via the central area. Exhaust air is done through the eastern ventilation shaft.

No surface investigations are carried out. Investigation tunnels are made in connection with construction of the temporary transport tunnels between zone ENE0060A and zone ENE0062A.

Table 4-6. Estimated excavated volume until year 18.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	19,096
Main tunnels	0
Deposition tunnels	134,381
Total	153,477

Table 4-7. Estimated excavated volume until year 22.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	26,678
Main tunnels	0
Deposition tunnels	101,626
Total	128,294

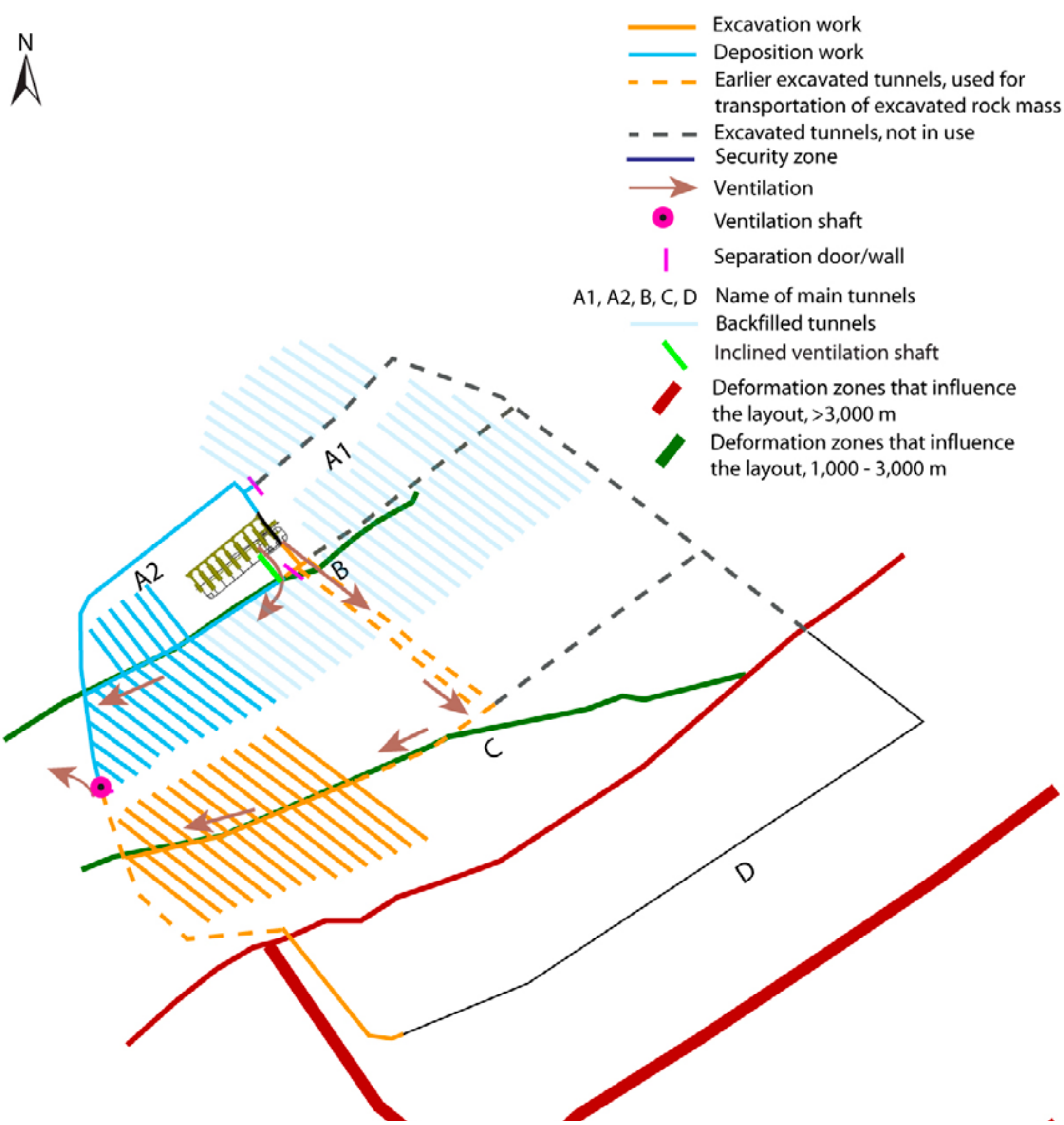


Figure 4-6. *Order of extension, year 18.*

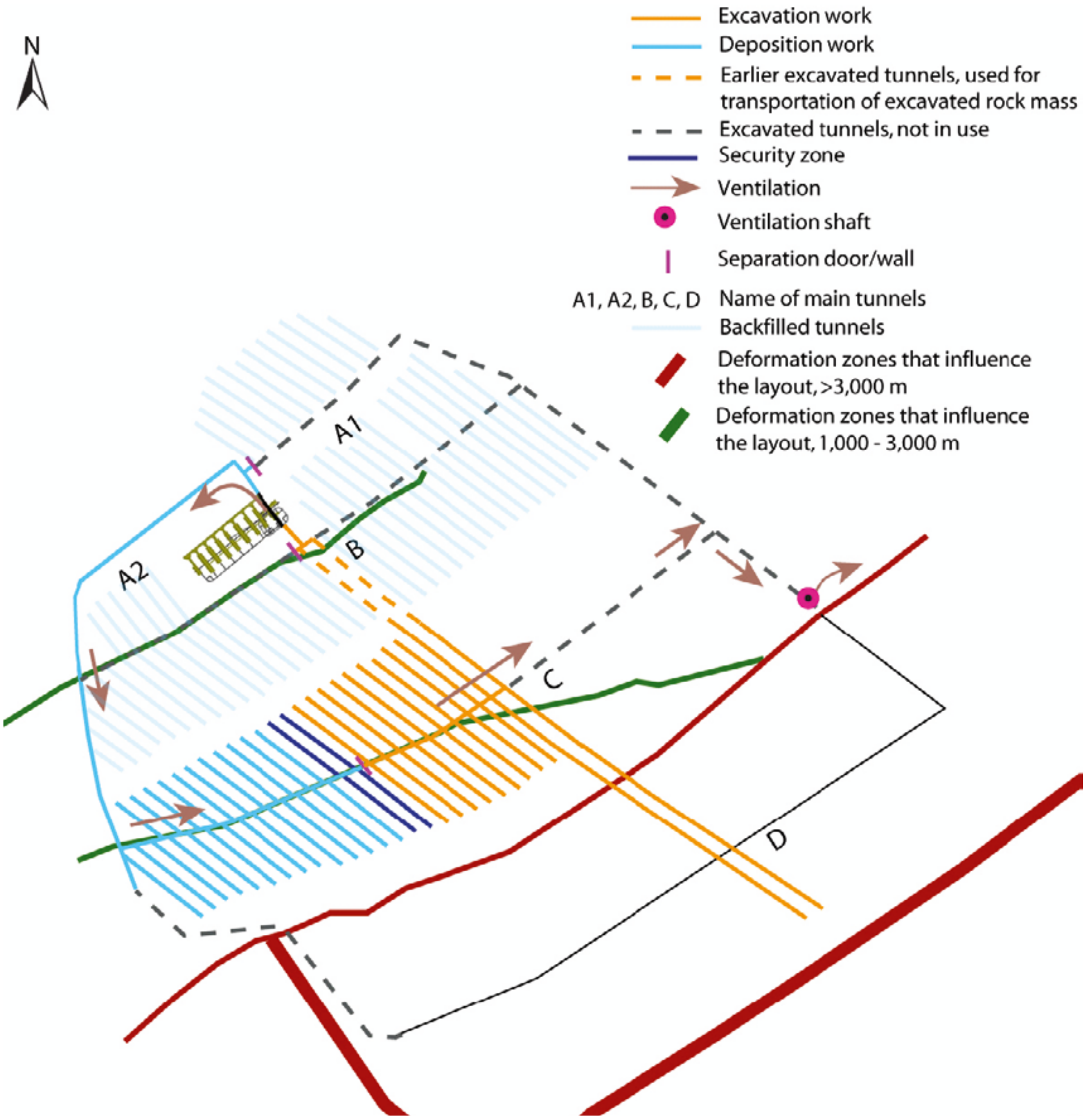


***Figure 4-7.** Order of extension, year 22.*

By year 26, deposition takes place in the deposition tunnels in main tunnel C (Figure 4-8). Excavation work is carried out in the same main tunnel, where deposition tunnels have been made. The main activities are separated by a door/wall and by two deposition tunnels that constitute a security zone between the main activities.

The repository is ventilated by intake air via the central area. Exhaust air is done through the eastern ventilation shaft.

No surface investigations are carried out. Investigations are made underground as required in connection with tunnel construction.

Table 4-8. Estimated excavated volume until year 26.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	0
Main tunnels	0
Deposition tunnels	104,237
Total	104,237

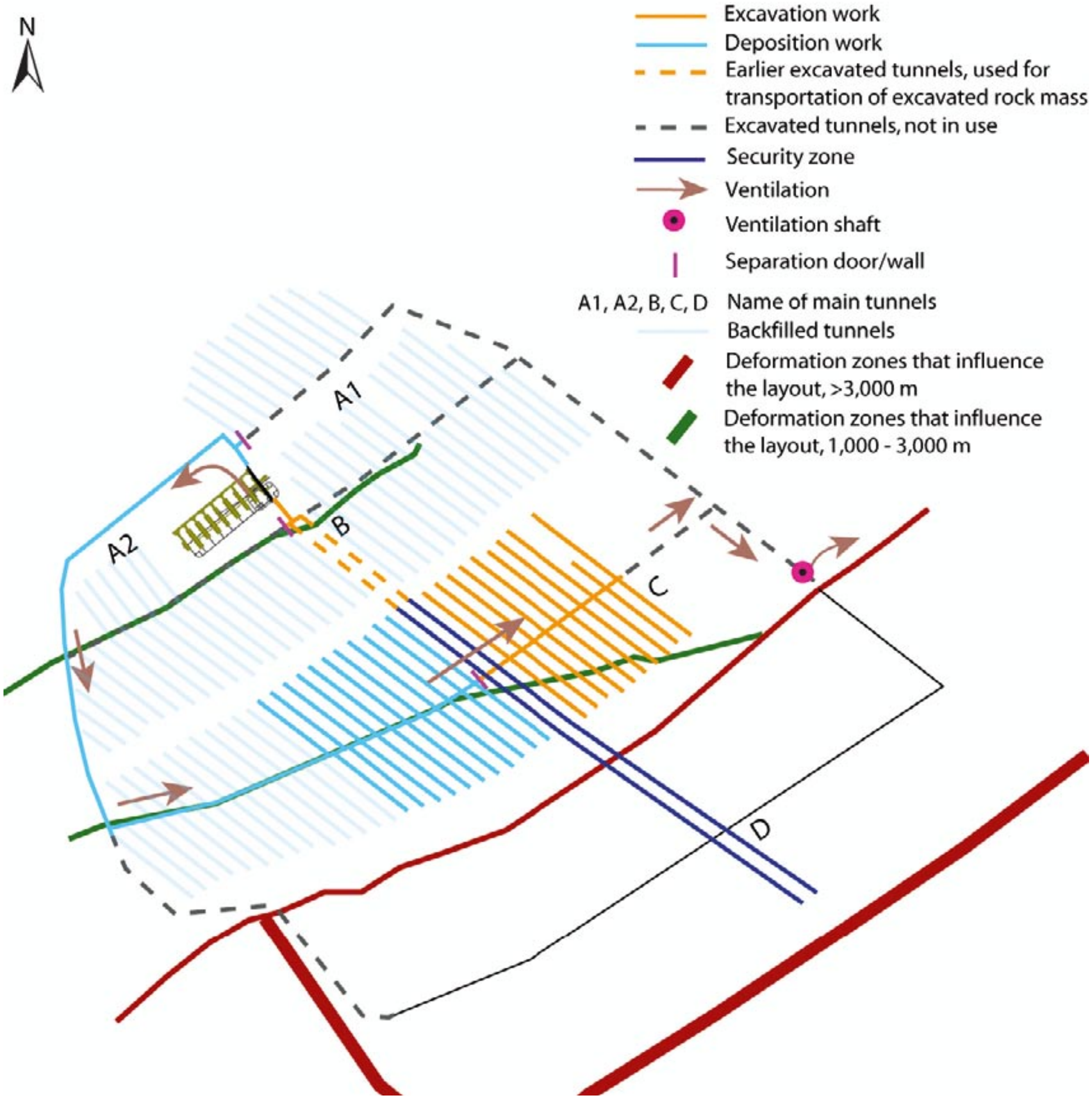


Figure 4-8. Order of extension, year 26.

By year 30, deposition takes place in the deposition tunnels in main tunnel C (Figure 4-9). Excavation work has been completed in the same main tunnel, and also in the transport tunnel from the ventilation shaft in the east to main tunnel D. The eastern part of main tunnel D has also been constructed. The main activities are separated by a door/wall and by two deposition tunnels that constitute a security zone between the main activities.

The repository is ventilated by intake air via the central area. Exhaust air is done through the eastern ventilation shaft.

Table 4-9. Estimated excavated volume until year 30.

Type of tunnel	Excavated theoretical volume (m³)
Transportation tunnels	22,708
Main tunnels	45,540
Deposition tunnels	72,710
Total	140,958

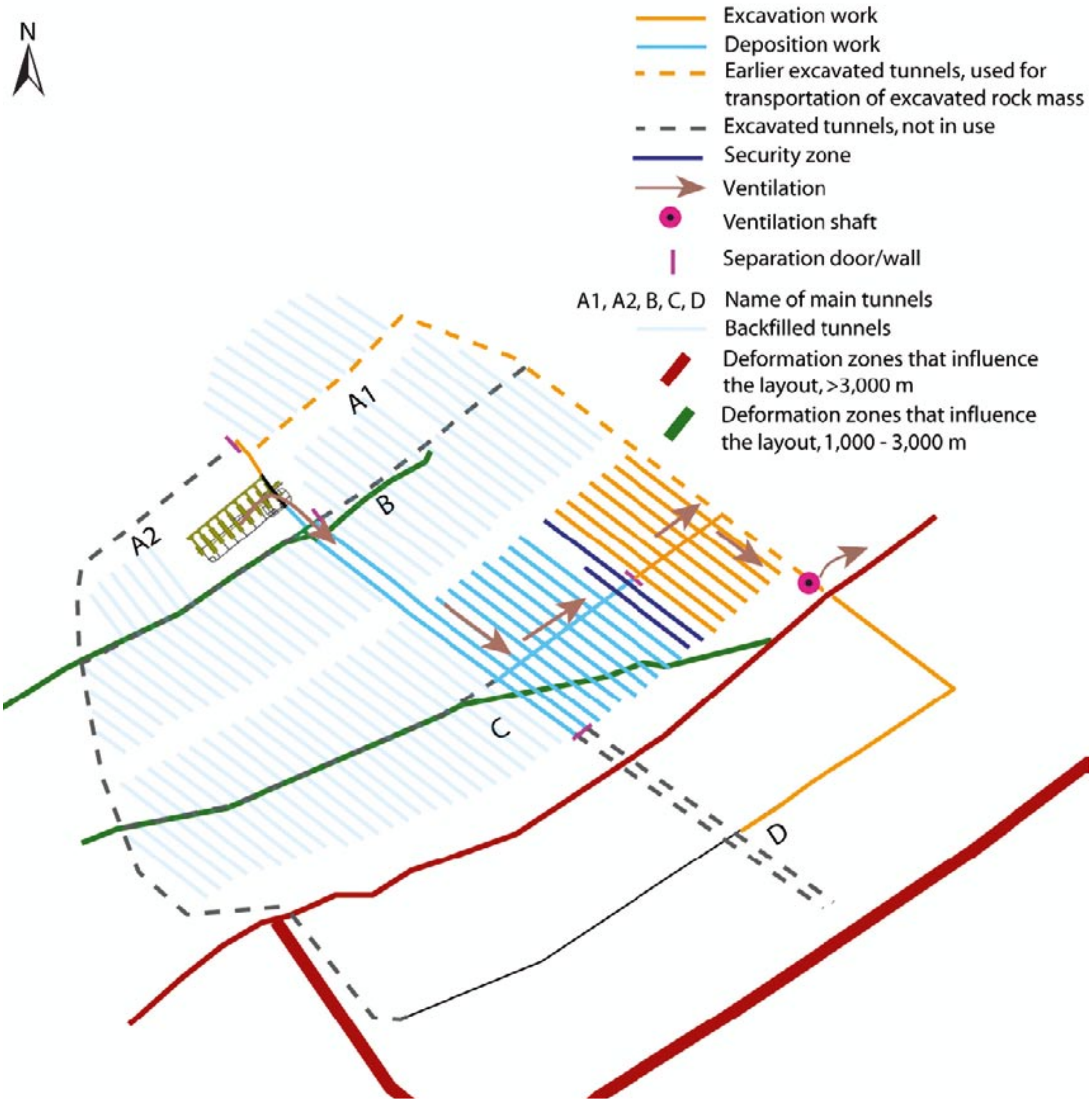


Figure 4-9. *Order of extension, year 30.*

By year 34, deposition has been completed in the remaining deposition tunnels in main tunnel C (Figure 4-10). Excavation work has been carried out in main tunnel D, where deposition tunnels have been made. The remaining part of main tunnel D to the southwest has also been constructed.

The repository is ventilated by intake air directly via the central area. Exhaust air is done through the western ventilation shaft.

Investigations boreholes/tunnels are made underground if requested, in main tunnel D.

Table 4-10. Estimated excavated volume until year 34.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	0
Main tunnels	63,180
Deposition tunnels	98,573
Total	161,753

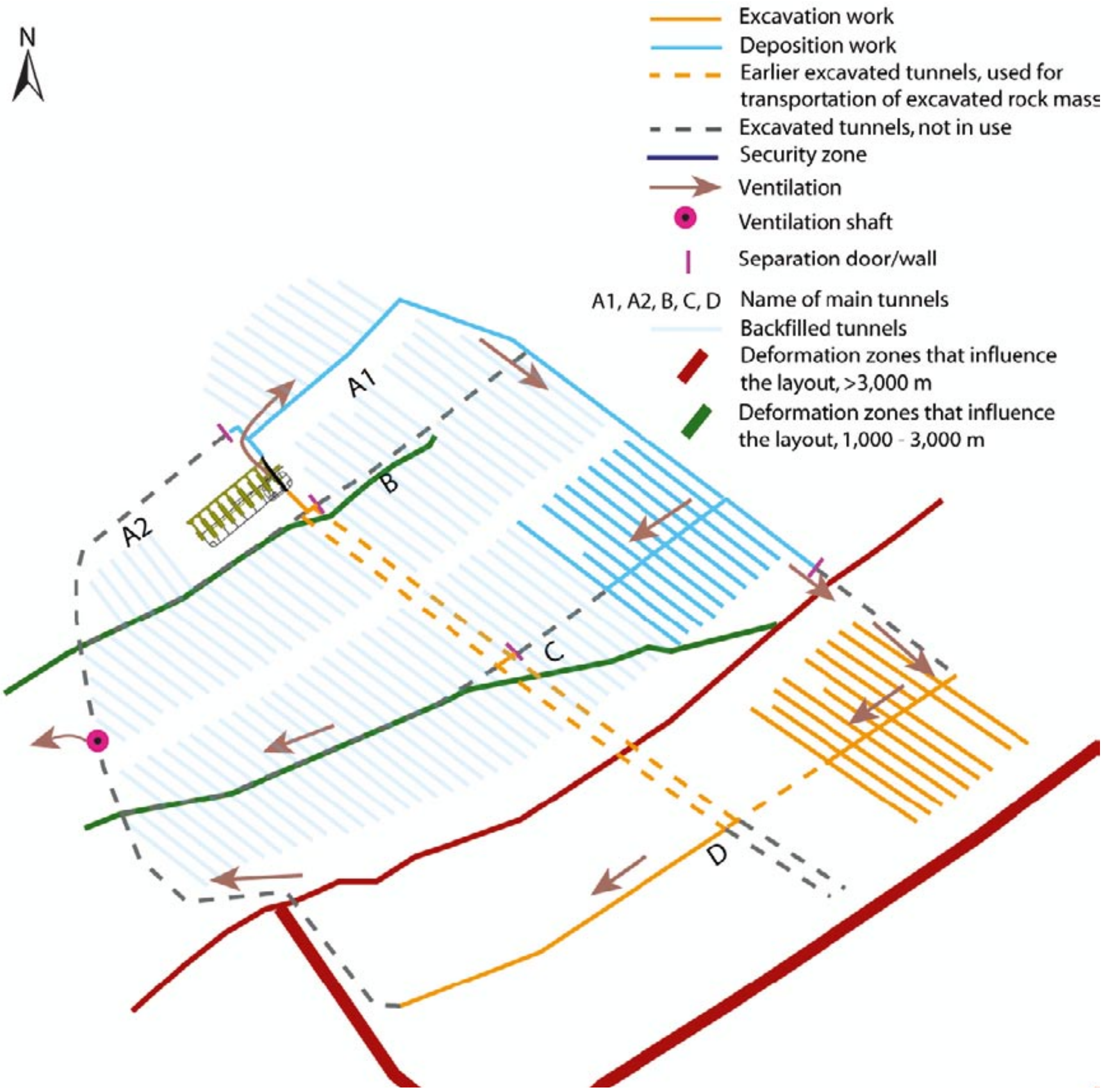


Figure 4-10. Order of extension, year 34.

By year 38, deposition has been completed in the first deposition tunnels in main tunnel D (Figure 4-11). Excavation work has been carried out in the same main tunnel, where deposition tunnels have been made. The main activities are separated by a door/wall and by two deposition tunnels that constitute a security zone between the main activities.

The repository is ventilated by intake air via the central. Exhaust air is done through the western ventilation shaft.

Investigations boreholes/tunnels are made underground if requested, during the course of tunnel work.

Table 4-11. Estimated excavated volume until year 38.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	0
Main tunnels	0
Deposition tunnels	72,480
Total	72,480

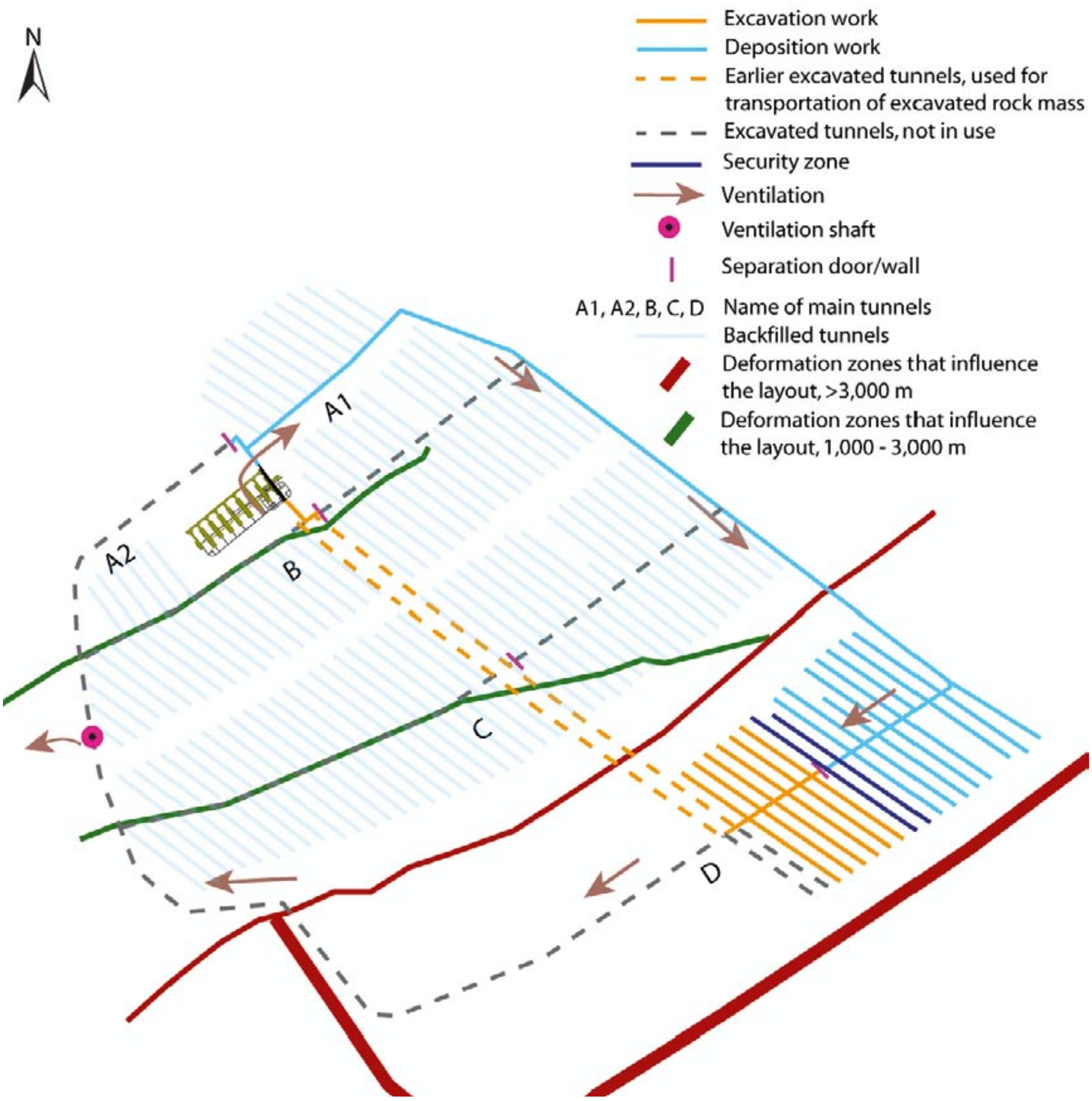


Figure 4-11. Order of extension, year 38.

By year 42, deposition takes place in the deposition tunnels in main tunnel D (Figure 4-12). Excavation work is carried out further in main tunnel D, where deposition tunnels have been made. The main activities are separated by a door/wall and by two deposition tunnels that constitute a security zone between the main activities.

The repository is ventilated by intake air via the central area. Exhaust air is done through the western ventilation shaft.

Investigations are made underground, if requested, in connection with tunnel construction.

Table 4-12. Estimated excavated volume until year 42.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	0
Main tunnels	0
Deposition tunnels	123,302
Total	123,302

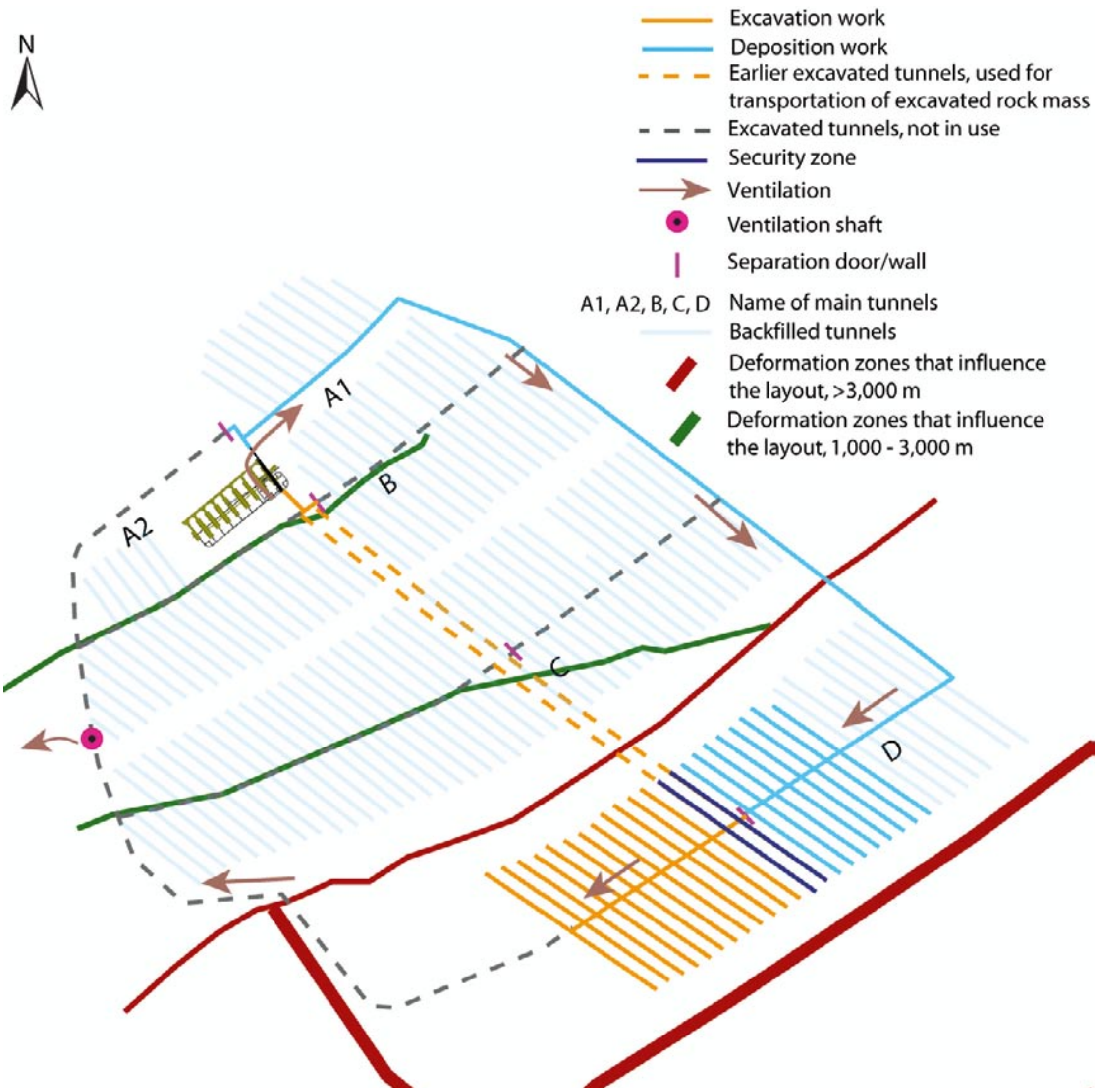


Figure 4-12. *Order of extension, year 42.*

By year 46, deposition takes place in the deposition tunnels in main tunnel D (Figure 4-13). Excavation work has been carried out in the same main tunnel, where the last deposition tunnels have been made. The main activities are separated by a door/wall and by two deposition tunnels that constitute a security zone between the main activities.

The repository is ventilated by intake air via the central area. Exhaust air is done through the western ventilation shaft.

Investigations boreholes/tunnels are made underground if requested, during the course of tunnel work.

Table 4-13. Estimated excavated volume until year 46.

Type of tunnel	Excavated theoretical volume (m^3)
Transportation tunnels	0
Main tunnels	0
Deposition tunnels	102,336
Total	102,336

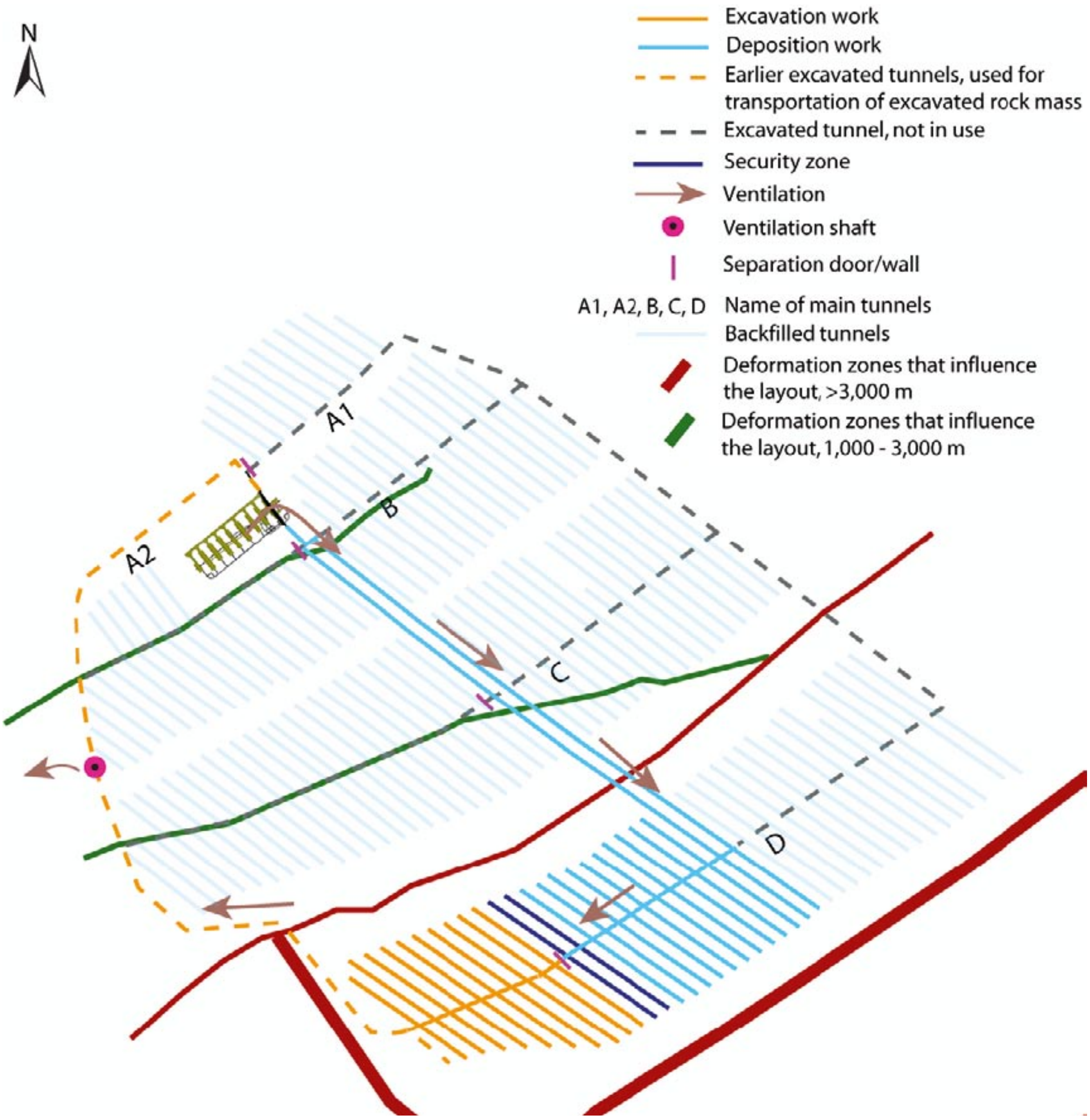


Figure 4-13. Order of extension, year 46.

By year 50, deposition has been completed in the remaining deposition tunnels in main tunnel D (Figure 4-14). Deposition holes have been constructed in the deposition tunnels which have been used as temporary transport tunnels at main tunnels D, C and B, in that order. However, deposition holes are only created along the original length of the tunnels and not where the tunnels are intersected by deformation zones. The deposition of canisters in these holes constitutes the final depositing.

The repository is ventilated by intake air via the central area. Exhaust air is done through the western ventilation shaft.

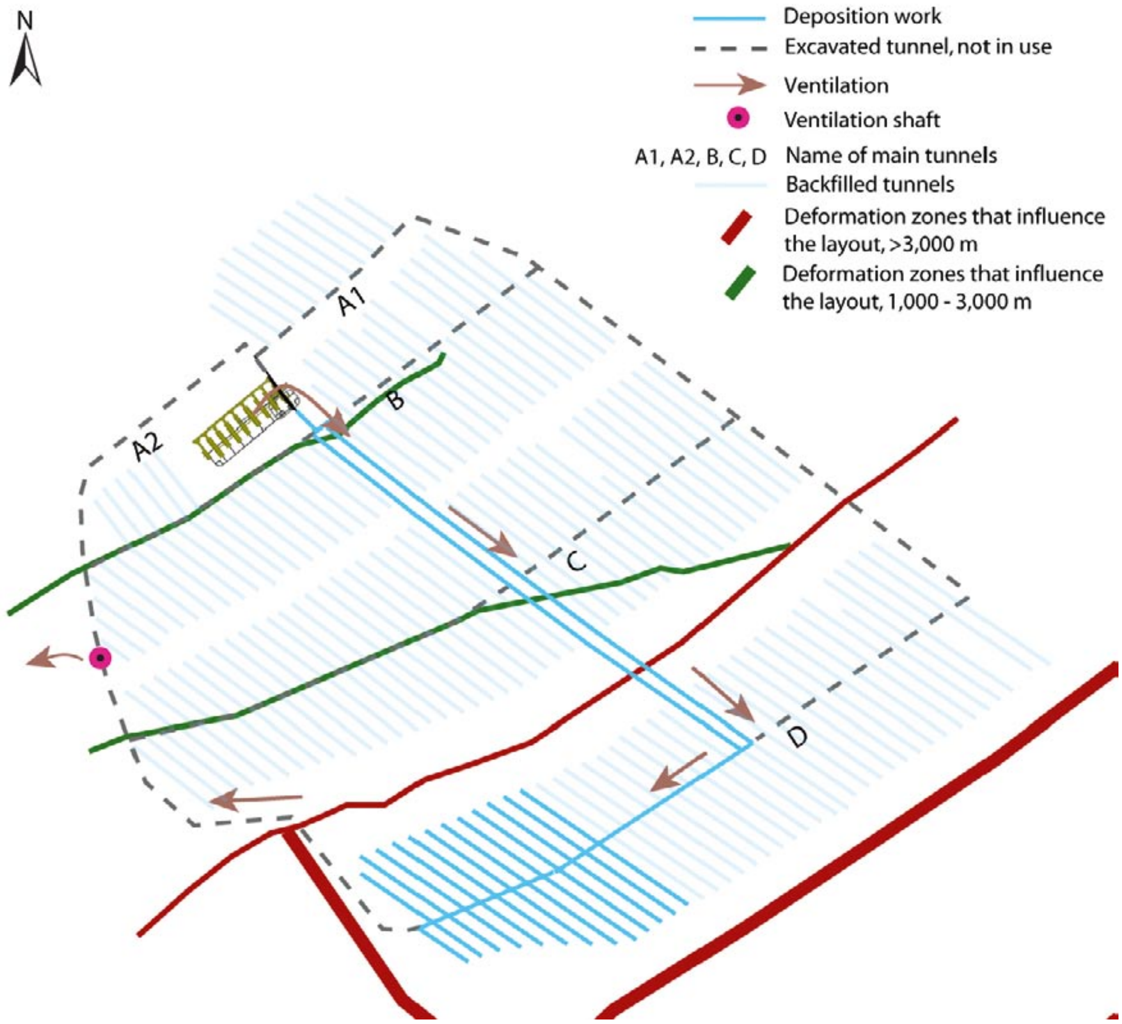


Figure 4-14. *Order of extension, year 50.*

4.2 Estimated excavated volumes

The excavated theoretical volume for each individual step has been summarized and is illustrated in Figure 4-15. As can be seen the excavated amount for deposition tunnels remain stable throughout the construction phase whereas the excavated theoretical volumes varies for deposition tunnels and main tunnels. The excavated volumes for the access ramp, shafts, rock loading station and central area are not included in the figure.

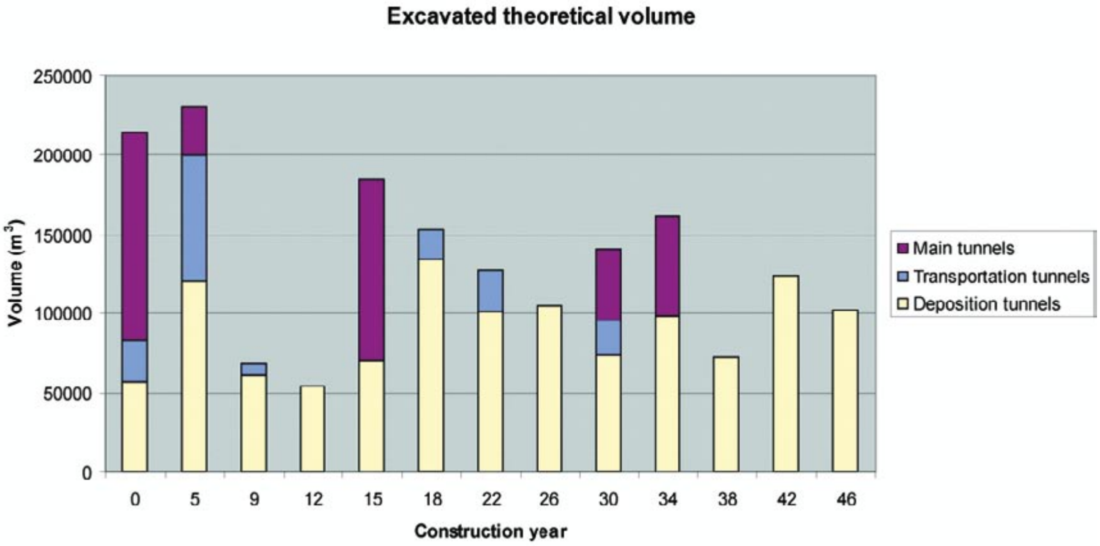


Figure 4-15. *Estimated excavated volumes during each construction step.*

4.3 Comparison of amount of transported volumes

As described in Chapter 3.1 the strategy of using the linear development method rather than working with the side-change concept has several advantages. However, the transportation is one of the drawbacks of the linear development method. To decrease the transportation work "short-cuts" were presented, which have also been used in the described construction plan (Chapter 4.1). Below four different transportation scenarios are presented for comparison:

1) separation of main activities by the linear development method – and using short-cuts
2) separation of main activities by the linear development method – without short-cuts
3) separating main activities by side changes – and using short-cuts
4) separating main activities by side changes – without short-cuts

All calculated transport work quantities are based on the theoretical tunnel area with an increase for surplus (overbreak) excavated rock of 25% and 20% for deposition tunnels and other tunnels respectively. The specific weight of rock and backfill is assumed at 2.67 and 1.73 kg/m^3 respectively. Calculated transport work quantities only include transports at repository level to and from the central area, and for backfill only volumes in the deposition tunnels are included (i.e. transport of backfill for main- and transport tunnels is not included). Figure 4-16 illustrates the differences in total transportation work quantities, with regard to the different construction strategies.

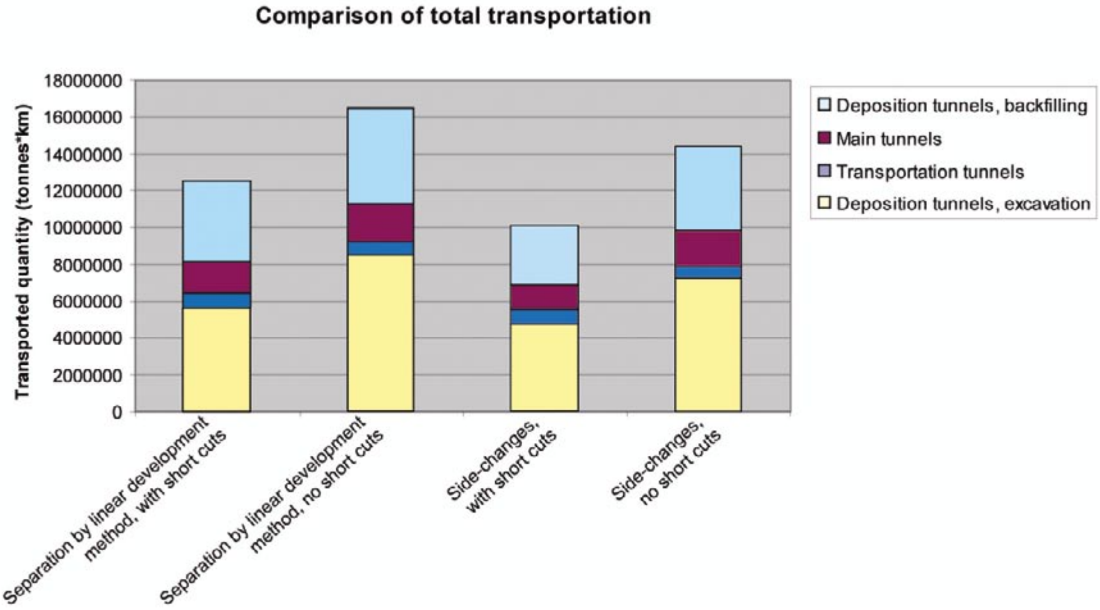


Figure 4-16. *Total transport work quantities for each of the various construction strategies. The bar furthest to the left represents the construction strategy proposed in this study whereas the bar furthest to the right represents the strategy initially proposed by SKB.*

5 Discussion

5.1 Reserve areas

The presented gross capacity regarding the number of deposition positions in the available deposition areas is 7,818, as noted in Chapter 3.4. This falls short of the number that is required to reach 6,000 canisters with estimated loss of deposition positions of 30%, i.e. 8,571 deposition holes, which is the upper proportion of loss noted in /SKB 2008a/. Thus, reserve areas need to be assessed to reach an increased number of deposition positions.

Figure 5-1 shows the two reserve areas that have been identified, i.e. the area south of deformation zone ENE0062A and the area underneath the nuclear power plant, FKA.

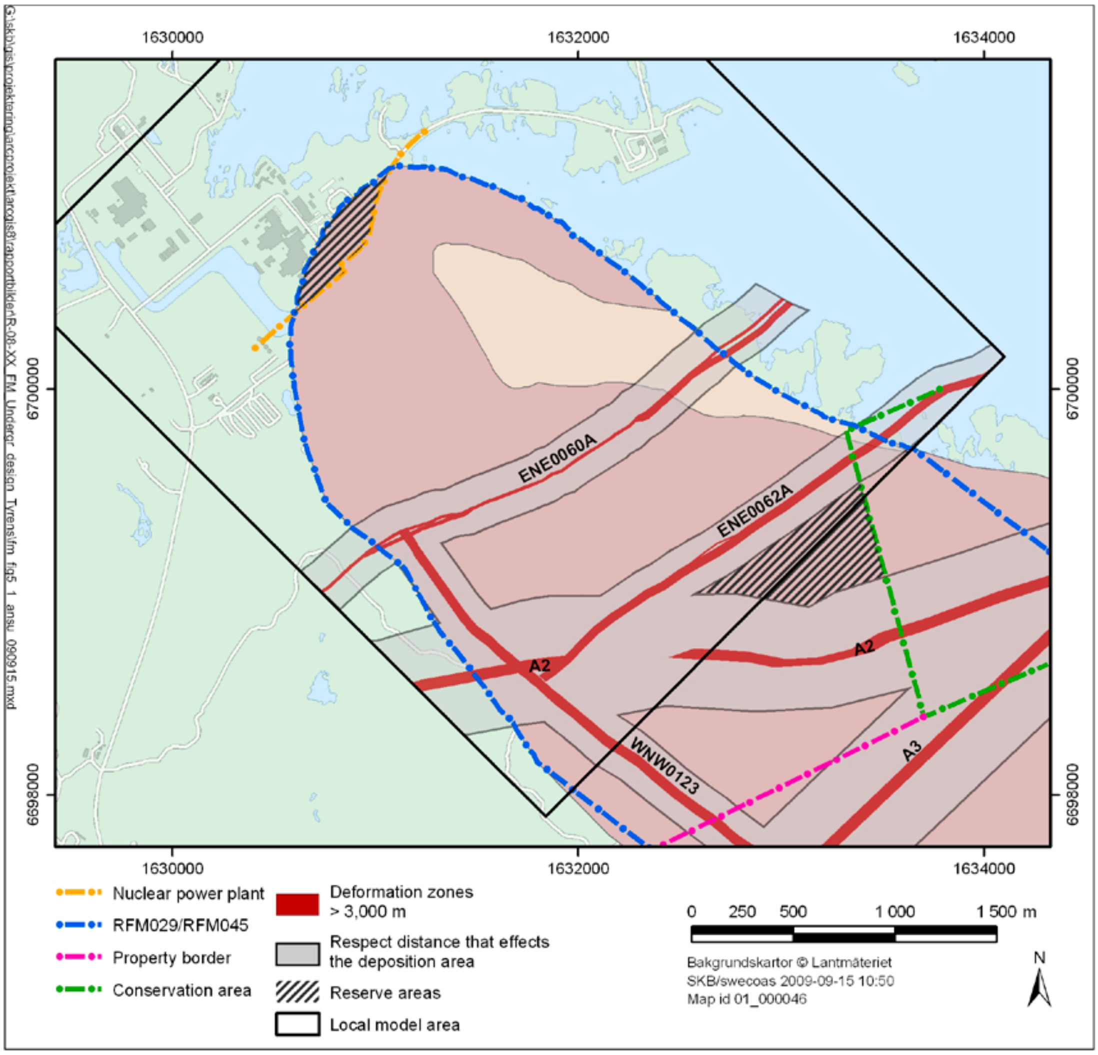


Figure 5-1. Presentation of the two reserve areas that have been identified, i.e. the area south of deformation zone ENE0062A and the area underneath the nuclear power plant, FKA. Section at 470 m depth (RHB 70).

The area south of zone ENE0062A is available for deposition, within the limits of the earlier described administrative boundaries. The available area was not included in the layout presented in Chapter 4.4 as it was considered small in relation to the possible problems that could arise when passing zone ENE0062A. Most of the area lies outside the local deformation zone model where the data density is lower and therefore the assessment of deposition capacity is made by determining (from general layout and thermal conductivity requirements) the required area per deposition position within the deposition area at main tunnel D. This amounts to 341 m^2 per deposition position, and the number of deposition positions averages 730 within this reserve area.

By deviating from the project premises and going northwest outside the administrative boundary, underneath FKA, a reserve area can also be gained here, see Figure 5-2. The deviation is justified because deposition outside the boundary towards the nuclear power plant FKA is anticipated at the very end of the operating period, when FKA is most probably no longer in operation but is being decommissioned or is already decommissioned. The area lies within the local deformation zone model which allows planning of deposition tunnels and appertaining canister positions see Figure 5-3. With configuration according to Figure 5-3 there will be space for some 350 canister positions in the reserve area underneath the nuclear power plant FKA.

The two areas together provide a reserve capacity of c. 1,080 canister positions, giving a total capacity (gross capacity and reserve capacity combined) of c. 8,900 canister positions. The total capacity corresponds to a proportion of loss amounting to 32.6%, which exceeds the 30% proportion of loss noted in /SKB 2008a/.

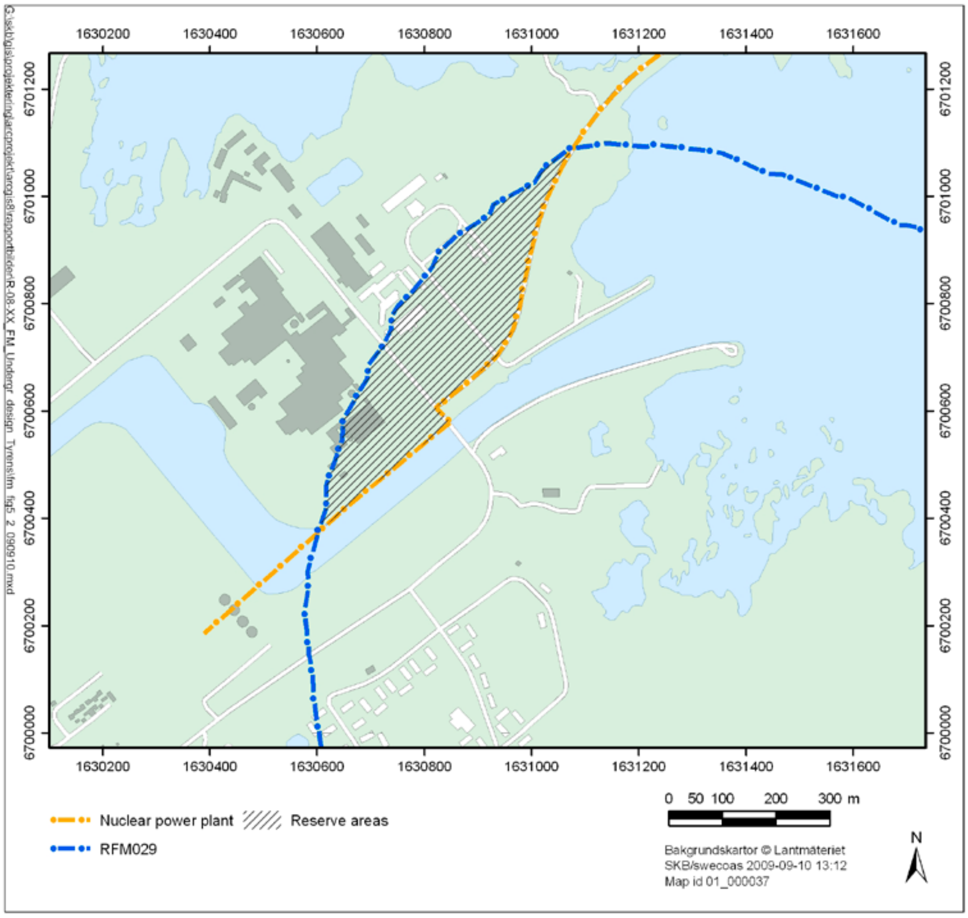


Figure 5-2. *Possible deposition area if deviation is made from current administrative boundary underneath FKA. Figure refers to 470 m depth (RHB 70).*

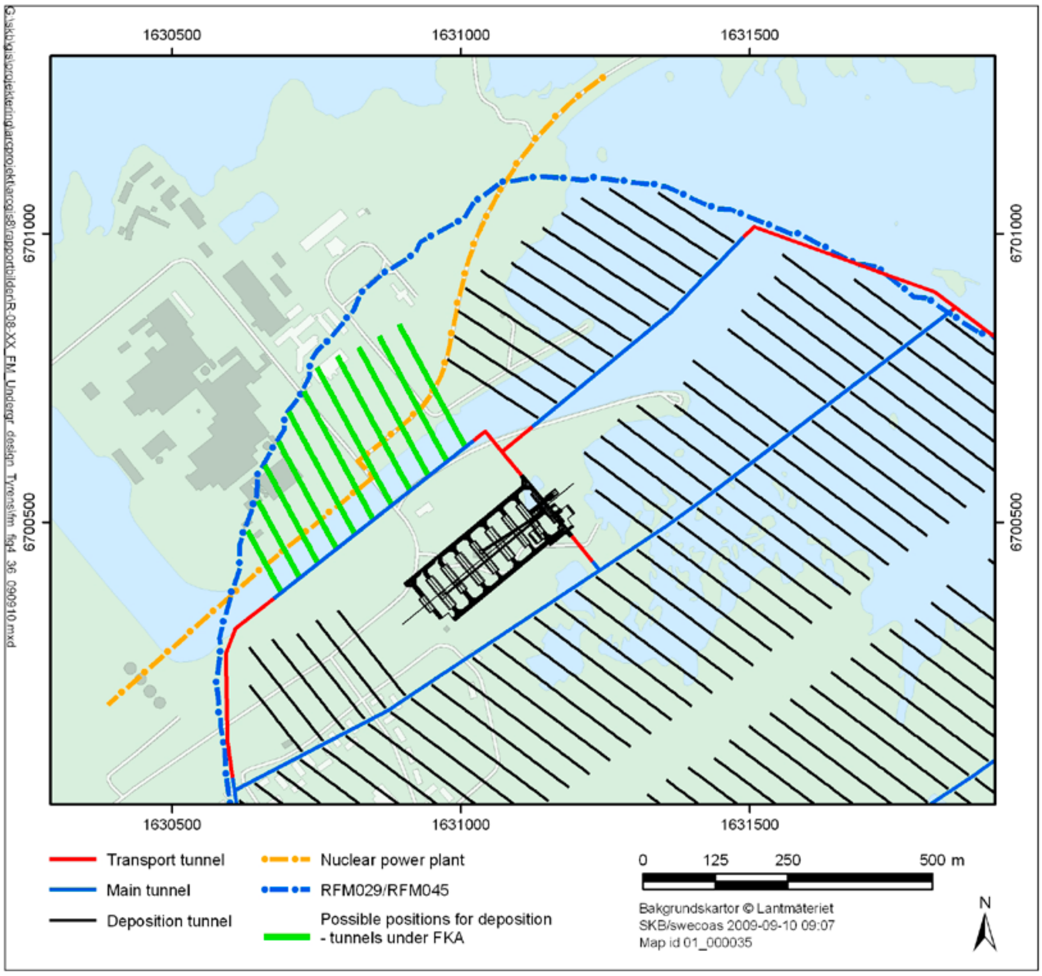


Figure 5-3. Configuration of the reserve area underneath the nuclear power plant, FKA. Section at 470 m depth (RHB 70).

5.2 Further optimisation

The geometrical conditions for the underground facility, for example the distance between two adjacent deposition tunnels and the distance between deposition holes, are noted in /SKB 2008a/. Continued studies are recommended to optimize these distances since they are directly relevant to the available storage capacity of the main deposition area. Moreover, it ought to be possible to differentiate spacing between deposition-holes with regard to their location, i.e. a deposition position at the outer edge of a deposition area will probably have somewhat different thermal development compared to a position at the central part of the area.

The position of deposition holes in relation to deformation zones have not been customized in the prepared layout, see Figure 5-4. The storage capacity can be increased by placing a deposition hole immediately after the deposition tunnel passes a deformation zone.

In this layout, the deposition positions that end up in deterministically modelled deformation zones are removed. Some of the zones are minor deformation zones (< 1,000 m trace length) are included in this model. These deformation zones are also included in the stochastic fracture model (DFN) that form the basis for stated proportions of loss of deposition holes, i.e. the loss has been accounted for twice and therefore the storage capacity of the deposition area is somewhat underestimated. In the layout produced, the number of possible deposition positions lying in these deformation zones, shorter than 1,000 m, amount to about 290 positions (Figure 5-5).

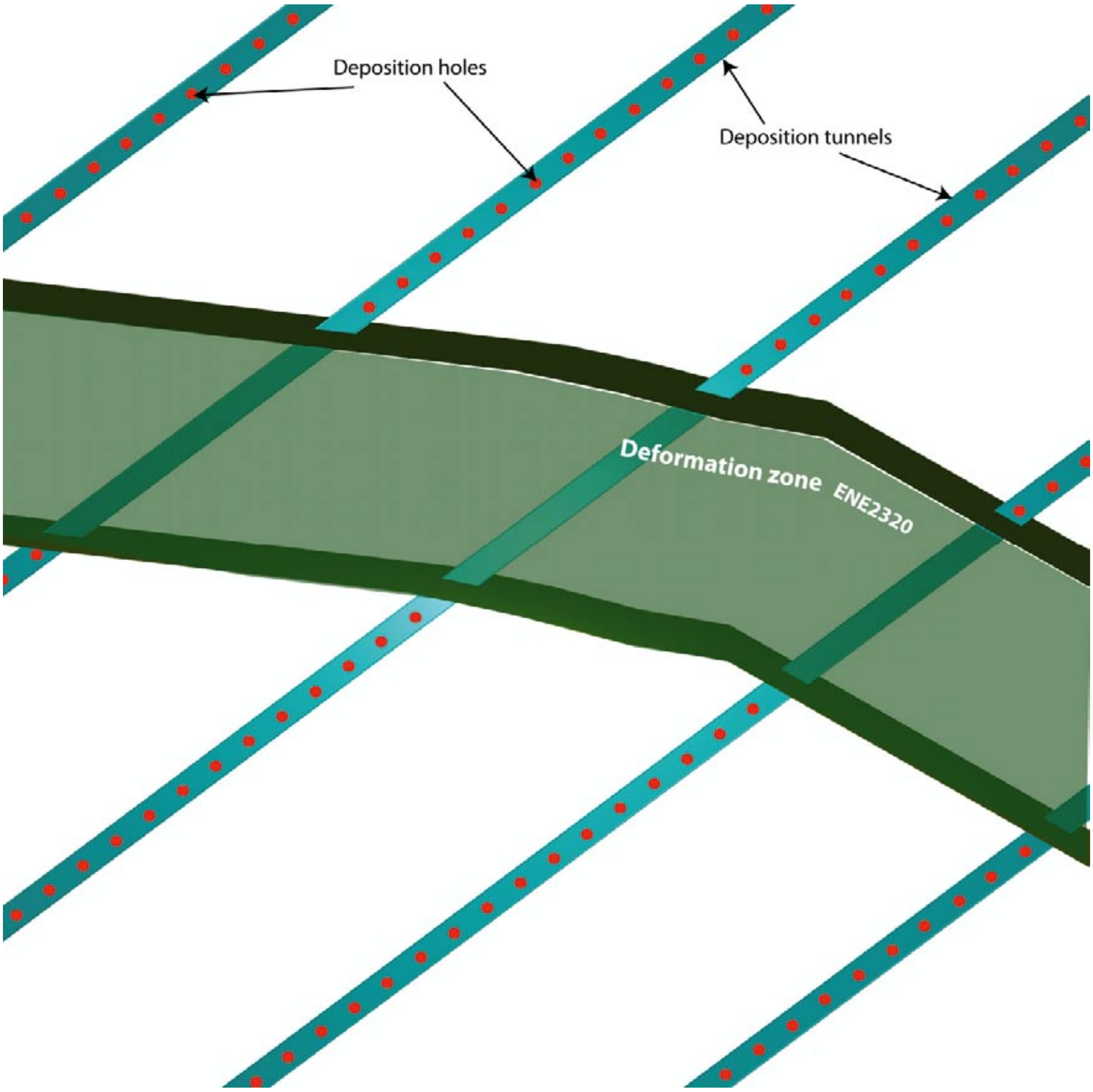


Figure 5-4. *Example of deposition positions in relation to minor deformation zones. Green field indicates deformation zone, blue lines are deposition tunnels and red dots are deposition holes. Deposition holes are removed in the zone location while the deposition holes outside the zone are unmodified in relation to the zone boundaries.*

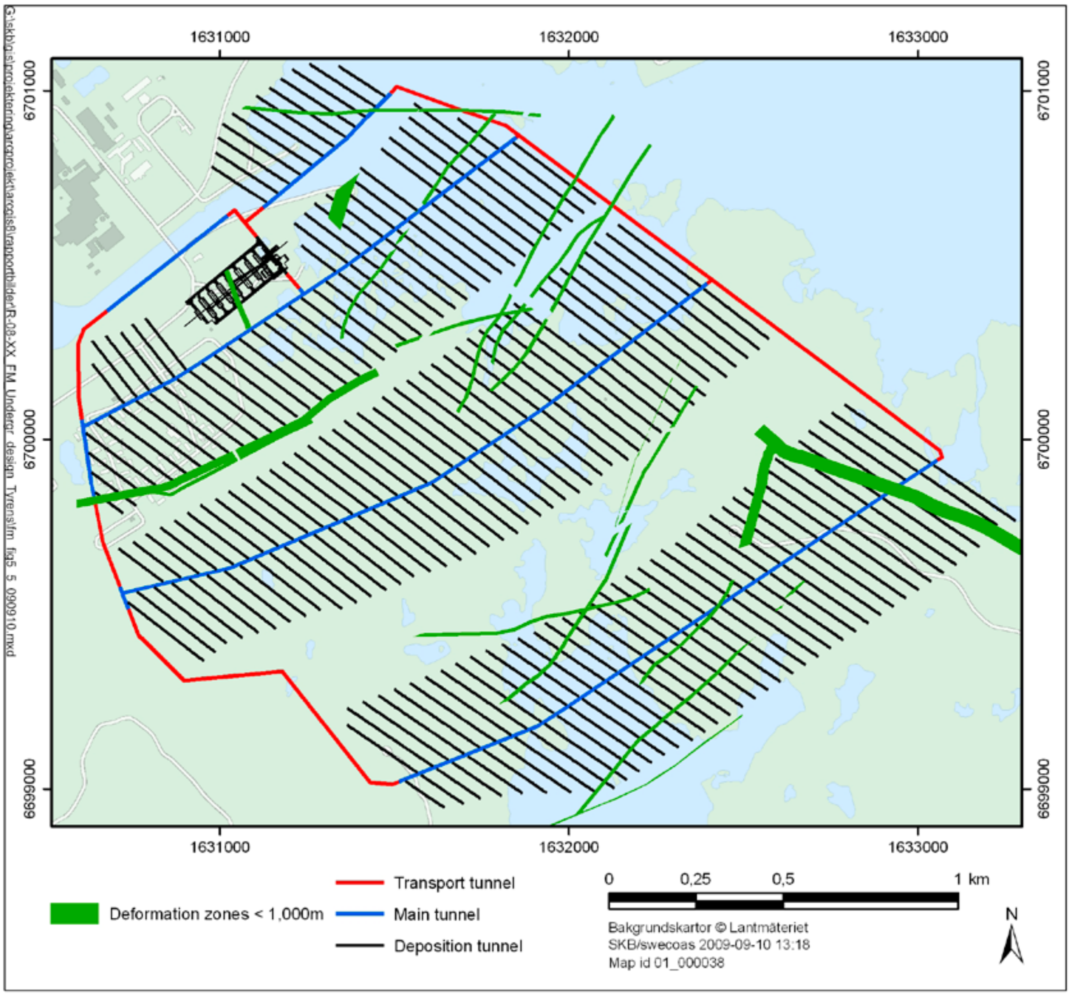


Figure 5-5. Proposed layout in relation to deterministically modeled deformation zones that are shorter than 1,000 m. Section at –470 m (RHB 70).

The prerequisite, according to /SKB 2008a/, that deposition tunnels may not be longer than 300 m limits the possibility for optimum utilization of the available deposition area. The storage capacity can be increased by accepting longer deposition tunnels. Furthermore it would enable the main-tunnel length to be reduced, which in turn would reduce the excavation work and consequently the amount of rock to be excavated.

The prerequisite, according to /SKB 2008a/, that blasting work may not be done closer than 80 m from a deposited canister limits the possibility for optimum utilization of the available deposition area. In the proposed layout it is this requirement, among other items, that controls the relationship between deposition area B and C. By accepting shorter distance and instead imposing requirements on blasting vibrations, it would not only increase the storage capacity but it would also simplify work with the order of extension.

In case of a low future loss of deposition holes due to discriminating fractures, the layout should be reduced in the parts where the area is poorly utilized and/or where large transport work is required for the construction. Figure 5-6 shows parts (in yellow colour) of the deposition area where short deposition tunnels and tunnels with significant loss are located, and these areas should preferably be the first parts to be deleted from the layout if a smaller capacity is needed.

Figure 5-7 shows a layout prepared for a loss of 13% due to discriminating fractures, which is the proposed design value not considering uncertainties in DFN-models according to /SKB 2008a/.

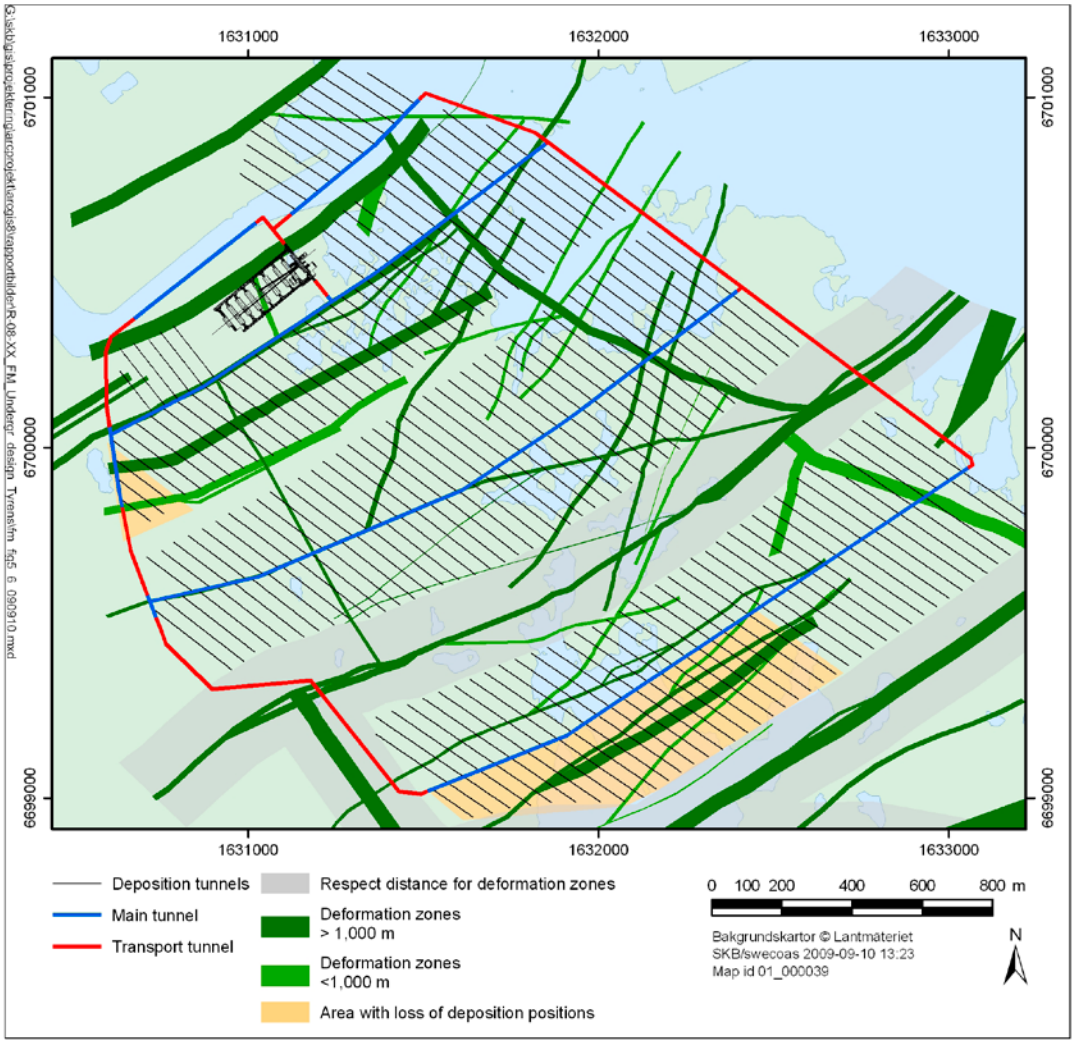


Figure 5-6. *Presentation of short deposition tunnels or tunnels with significant loss. Section at –470 m (RHB 70).*

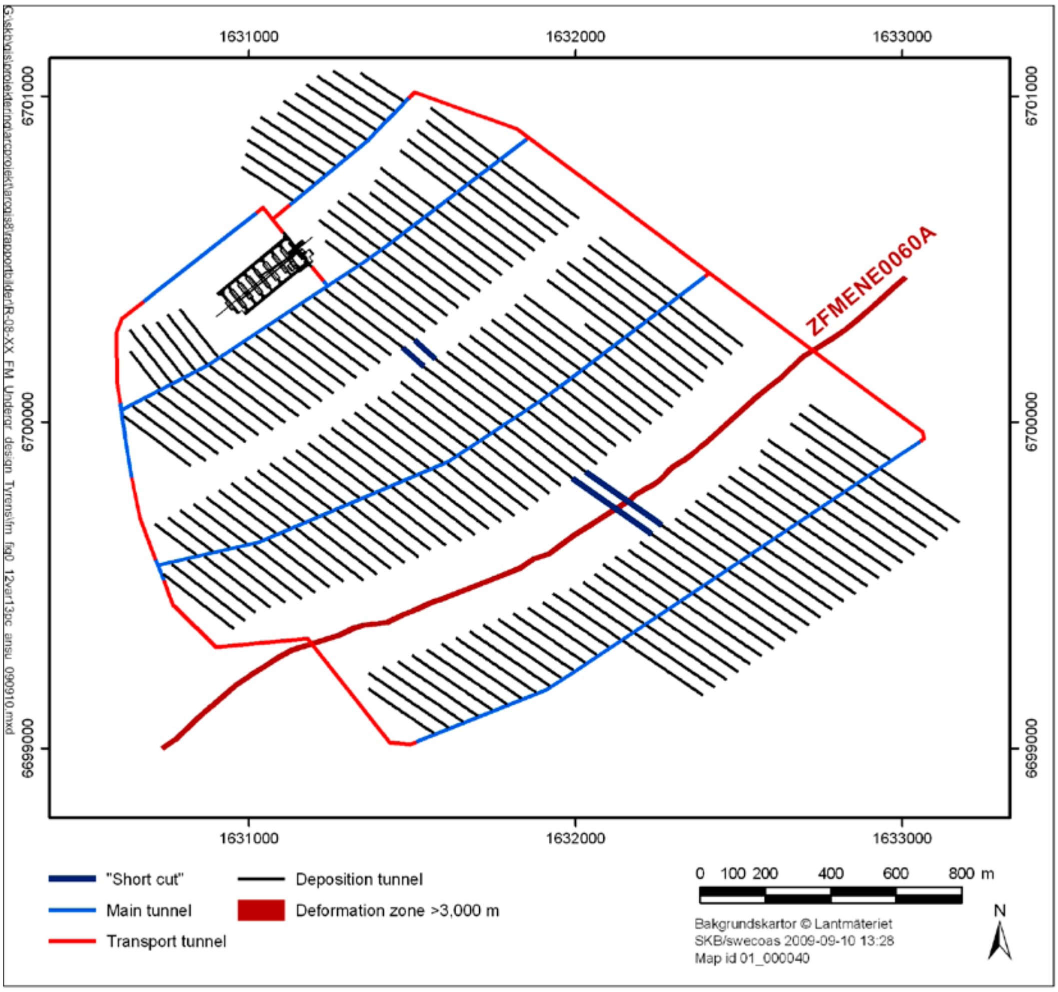


Figure 5-7. *Presentation of layout assuming 13% loss of deposition holes due to discriminating fractures. Section at –470 m (RHB 70).*

6 Conclusions

This study manages and fulfils the described objectives in Chapter 1.1. The objective of presenting a robust and constructible layout proposal for the surface and underground facilities of the final repository require that the geological aspects have been investigated and evaluated. This has been done prior to this report and is presented in /SKB 2008a/, which is the engineering geological description that serves as basis for the D2 projecting. To confirm the geological conditions and to further improve the knowledge of such conditions an investigation programme has been proposed. The results will serve as basis for further investigations when constructing the underground facilities.

The choice of construction strategy is decisive for the building of the final repository facilities. The proposed construction strategy based on using the linear development method corresponds to, and fulfils a number of the stated objectives, e.g. separation of the two main activities, robustness and effectiveness. The layout and construction plan has been developed in line with the construction strategy based on the linear development method.

The objective to present a layout that can account for a minimum net deposition capacity of 6,000 deposition positions is fulfilled. The percentage of loss of deposition is held within the stated limits.

A few questions remain, which shall be further investigated by SKB:

- Design of ventilation of the underground facilities
- Design and description of fire escape routes
- Design of separating doors/walls, necessary for the linear development method, with respect to pressure waves from blasting works, fire and ventilation

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