

Technical Report

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**Preliminary safety evaluation,
based on initial site
investigation data**

Planning document

December 2002

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Preface

The work presented in this report was pursued by SKB during the autumn of 2002.

Johan Andersson, JA Streamflow AB, was the main author of chapter 3 and Appendix I. Ann Emmelin, SKB, provided input regarding repository engineering. The undersigned was responsible for chapters 1, 2 and 4, for Appendix II and for editing the report.

Several other persons at SKB contributed constructively to the discussions behind the material presented on the following pages.

Stockholm, December 2002

Allan Hedin
Project leader

Summary

This report is a planning document for the preliminary safety evaluations (PSE) to be carried out at the end of the initial stage of SKB's ongoing site investigations for a deep repository for spent nuclear fuel.

The main purposes of the evaluations are to determine whether earlier judgements of the suitability of the candidate area for a deep repository with respect to long-term safety holds up in the light of borehole data and to provide feed-back to continued site investigations and site specific repository design.

The preliminary safety evaluations will be carried out by a safety assessment group, based on a site model, being part of a site description, provided by a site modelling group and a repository layout within that model suggested by a repository engineering group. The site model contains the geometric features of the site as well as properties of the host rock. Several alternative interpretations of the site data will likely be suggested. Also the biosphere is included in the site model.

A first task for the PSE will be to compare the rock properties described in the site model to previously established criteria for a suitable host rock. This report gives an example of such a comparison.

In order to provide more detailed feedback, a number of thermal, hydrological, mechanical and chemical analyses of the site will also be included in the evaluation. The selection of analyses is derived from the set of geosphere and biosphere analyses preliminarily planned for the comprehensive safety assessment named SR-SITE, which will be based on a complete site investigation. The selection is dictated primarily by the expected feedback to continued site investigations and by the availability of data after the PSE.

The repository engineering group will consider several safety related factors in suggesting a repository layout:

- Thermal calculations will be made to determine a minimum distance between canisters avoiding canister surface temperatures above 100 °C, considering also uncertainties.
- The preliminary layout will take earthquake risks into account by means of respect distances to major structures of the host rock. The methodology for determining respect distances is under development.
- Also, the size of the area designated for canister deposition will be determined with regard to the estimated fraction of useable deposition positions. Positions with e.g. a flow higher than a given limit, yet to be established, will be avoided.

The safety assessment group will review the above results within the PSE, assessing the need for more sophisticated analyses in a comprehensive safety assessment, and the possible implications this has for continued site investigations.

Flow and transport trajectories in the host rock will be calculated using the flow models set up within the site modelling project, probably for several alternative models. Radionuclide release and dose calculations will then be carried out with simplified

analytic models and sensitivity analyses will be made on the results of these calculations. The results will provide feedback on portions of the host rock where more detailed hydraulic knowledge is required, on whether some of the suggested deposition positions are less favourable from the point of view of radionuclide transport and on discharge areas for which the biosphere may require additional characterisation. Furthermore, the sensitivity analyses, which will include also non site specific uncertain variables, will put the host rock uncertainties in a broader perspective.

Grouting needs and risk for upconing of saline groundwater during construction and operation will be estimated by the repository engineering group, based on the hydraulic understanding of the site. The chemical influence of these phenomena will be evaluated by the safety assessment group and feedback will be given as to whether the design needs modification to meet long-term safety requirements.

The ore potential of the sites will be assessed and feedback given as to whether further characterisation in this respect is warranted.

The total time required for a preliminary safety assessment project is estimated at five months, during which time many of the subtasks would be carried out simultaneously.

In parallel to the preliminary safety evaluation, a renewed safety assessment of the KBS-3 method, called SR-MET, will be reported, where new developments regarding analysis methodology and barrier performance will be accounted for. Much of the methodology presented in that report will require more detailed site data than will be available from the candidate sites at the required point in time and such data will be taken from other, previously investigated, sites. SR-MET can be regarded as a template for the safety report SR-SITE, which will be based on data from the complete site investigation. The results of the analyses presented in SR-MET will also provide feedback to continued site investigations and to repository engineering. An example of this would be the SR-MET analyses of the long-term evolution of different backfill materials for various external conditions, the results of which will provide feedback to repository engineering for the site specific choice of a suitable material.

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1 Introduction

1.1 Background

SKB is currently pursuing site investigations at two candidate sites for a deep repository for spent nuclear fuel. The investigations will be carried out in two stages, an initial investigation followed by a complete investigation, should the results after the initial stage be favourable. A preliminary safety evaluation is made at the end of the initial stage and based on available field data and preliminary layouts for the deep repository at this stage. The candidate sites are Forsmark in the municipality of Östhammar and Simpevarp in the municipality of Oskarshamn. The Simpevarp site consists of two parts, the Simpevarp Peninsula and an area on the mainland west of Simpevarp. Separate preliminary safety evaluation reports are planned for the two parts at Simpevarp as well as a separate report for Forsmark.

The main objectives of the evaluation are

- to determine, with limited efforts, whether the feasibility study's judgement of the suitability of the candidate area with respect to long-term safety holds up in the light of borehole data,
- to provide feed-back to continued site investigations and site specific repository design and
- to identify site specific scenarios and geoscientific issues for further analyses.

At this stage, a comparison to the criteria for the host rock established by SKB /Andersson et al, 2000/ is a significant component of a safety evaluation. This is complemented by other analyses in order to provide feedback to continued investigations and design work. The extent of the available site data is however not sufficient for e.g. comparisons between sites or to assess compliance with safety and radiation protection criteria.

The safety evaluation is concerned with radiological long-term safety. Direct environmental effects during to the construction and operation of the repository are addressed in an environmental impact assessment, which is not discussed in this document.

In parallel to the preliminary safety evaluation, a renewed safety assessment of the KBS-3 method, called SR-MET, will be reported, where new developments regarding analysis methodology and barrier performance will be accounted for. Much of the methodology presented in that report will require more detailed site data than will be available from the candidate sites at the required point in time and such data will be taken from other, previously investigated, sites. SR-MET can be regarded as a template for the safety report SR-SITE, which will be based on data from the complete site investigation. As will be described in detail in chapter 3, the geosphere and biosphere analyses made in the preliminary safety evaluation are a sub-set of those planned for the SR-SITE analysis. The sub-set is selected primarily so as to provide meaningful feedback for the continued investigations. Many of the analyses are pursued to a lower level of detail than what will be required and possible when data from the complete investigation is available. The results of the analyses presented in SR-MET will also provide feedback to continued site investigations and to repository engineering. An

example of this would be the SR-MET analyses of the long-term evolution of different backfill materials for various external conditions, the results of which will provide feedback to repository engineering for the site specific choice of a suitable material.

This report is a planning document for the preliminary safety evaluation, PSE. It summarises the data presumed available after the initial site investigation, and motivates a set of safety related analyses to be carried out at this stage, and what feedback these can be expected to give to continued site investigations and repository design work. Some of the analyses are exemplified with data from other sites. The report also contains a suggestion for a table of contents for the preliminary safety evaluation.

1.2 Relation to other activities during the site investigation phase

Figure 1-1 shows activities and products of relevance for safety evaluations during and after a site investigation. Site data emerging from field investigations are analysed by a Site Modelling Group (SMG) which produce a site description, composed of 2D and 3D models of the rock and its properties, and a report describing the models. The biosphere is included in the site description. The SM group will also present their understanding of how the site has reached its present state, based on the historic evolution of the site.

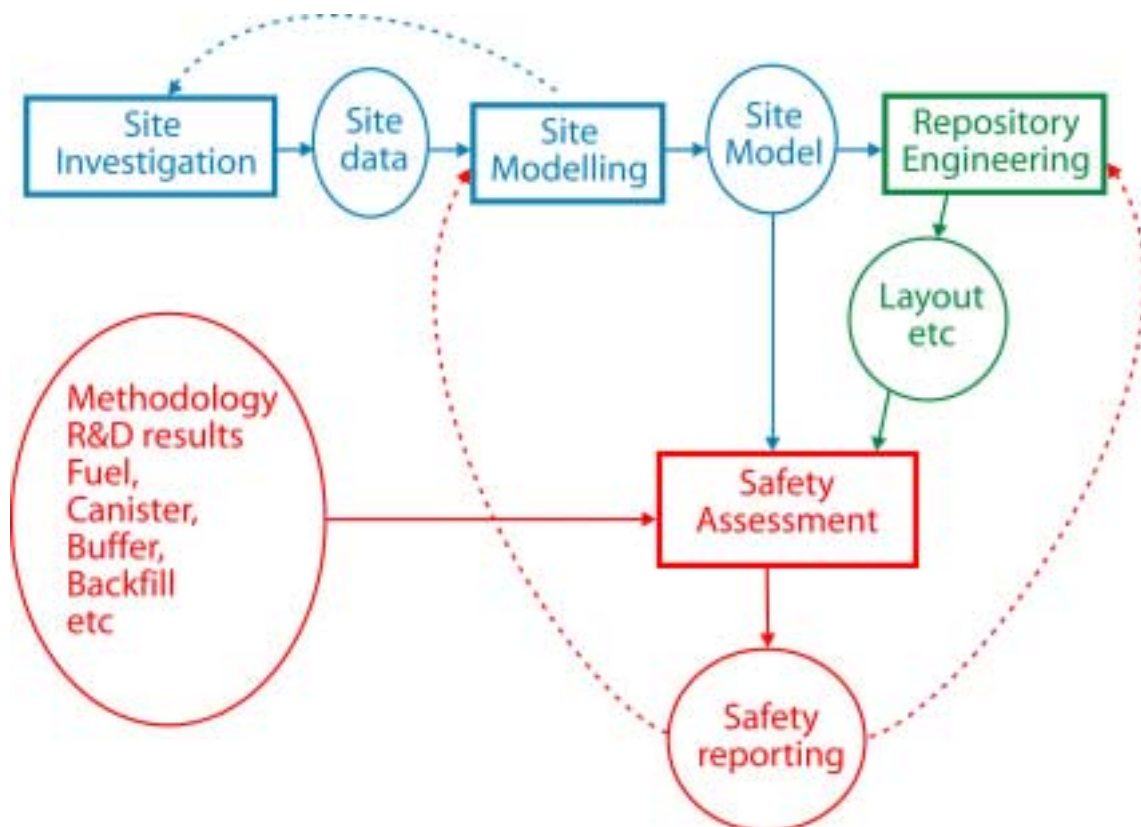


Figure 1-1. Activities (rectangles) and products (ellipses) during the site investigation phase.

A Repository Engineering Group (REG) suggest a repository layout based on the site description. Another important task for this group is to assess the feasibility of constructing the repository at the suggested site and to describe any critical uncertainties in the rock properties that need to be further investigated.

The site model, the site understanding and the repository layout form important parts of the basis for preliminary safety evaluations and, at later stages, comprehensive safety assessments. Also several safety related analyses will be made by SM and RE. This includes an analysis and implementation of earthquake respect distances, by the SM group, and thermal calculations yielding minimum canister distances, which is done by the RE group.

As more data emerge from field investigations, the site model, repository layout and safety evaluations are revised and refined. Feedback from safety evaluations to both field investigations (via the SM group) and repository engineering occurs throughout the site investigation phase. Much of the feedback is provided informally since, to some extent, the same individuals take part in the site modelling and safety evaluation activities. The preliminary safety evaluation is an important occasion for more detailed and formalised feedback.

1.2.1 Hydrological modelling

Several actors need to carry out hydrological modelling to fulfil their tasks. This is the case for the site modelling group, for which the hydrological understanding of the site will be an essential theme, for the repository engineering group which will have to assess e.g. the amount on grouting needed to manage the hydraulic situation during repository operation and for the safety assessment group in order to evaluate the long-term flow and transport properties of the site for a range of future conditions.

The site modelling group will set up hydrological models on different scales and these models will be adapted and used for all the modelling exercises mentioned above, both for reasons of efficiency and of consistency. The responsibility for carrying out all hydrological modelling will thus rest with the site modelling group and the different actors will request different modelling tasks according to their specific needs.

1.3 Terminology

The following terminology and abbreviations are used in this report.

PSE	Preliminary Safety Evaluation
SR-MET	Safety Report to demonstrate methodology for SR-SITE, based on data from a previously investigated site, to be published in 2004
SR-SITE	Safety Report based on data from complete site investigation
SM(G)	Site Modelling (Group)
RE(G)	Repository Engineering (Group)
SA(G)	Safety Assessment (Group)

2 Basis for the preliminary safety evaluation

2.1 Data and analyses from Site Modelling

The site model and the site description will be developed and refined in a number of steps according to an established program /SKB, 2001/. The preliminary safety evaluation will be based on model version 1.2 in the program.

The field investigations, site model and modelling activities of the Laxemar area presented by /Andersson et al, 2002/ give a reasonable impression of what can be expected in version 1.2 of a site model. The model version 1.2 from the analysis group will be the product within which a layout will be suggested and on which the preliminary safety evaluation is based.

Descriptions of the expected level of detail of various aspects of version 1.2 of the site model are presented in chapter 3 in connection with the safety related analyses where this input is used.

2.2 Data and analyses from Repository Engineering

Based on the site model, the repository engineering group will suggest locations and layouts for the deep repository, including the operational facilities above ground. Regarding the underground areas, a number of other issues apart from layout will be addressed. These include estimated needs for grouting based on the hydraulic properties of the repository area and for rock support during construction and operation.

Apart from the long-term safety, the governing issues for site adaptation are geoscientific conditions, environmental concerns and the overall requirement of the owner to have a well functioning facility for the operational phase.

During the initial site investigation stage the information received from the site description will be limited. The presented layout and other results will therefore partly be founded on rough estimates and assumptions based on experience.

The extent and scope of the analyses carried out by the repository engineering group throughout the site investigation phase will be presented in a report series entitled "Requirements for rock design". The report series starts from a description of general design premises /SKB, 2002, in Swedish/ and will be gradually developed to suit the increasingly deepened level of detail of the design. Here, it will be specified what kinds of analyses are to be carried out at what stage of the program and under what circumstances, how to choose and describe distribution of input values, how to describe uncertainties in results etc. The report series will also specify methods for risk assessments and what construction materials can be used.

Apart from analyses related to the determination of layout (see below), descriptions of the expected level of detail of the input from repository engineering to the PSE after the initial site investigation are presented in chapter 3 in connection with the safety related analyses where this input is used.

2.2.1 Some layout related issues

The geometry of the 3D site model will provide information on available volumes for the repository. Based on the properties of deformation zones and intervening rock blocks described in the geological model, a division of the rock into domains useable for different types of openings, i.e. for different parts of the underground facilities, will be made. During the initial site investigation stage, the level of detail of this division will be limited as the details and the confidence in the rock mass description will be limited. An example layout will be suggested and potential deposition areas in excess of what is actually needed will be identified. Alternative layouts will be considered within these volumes in the complete site investigation.

The details of the layout will be determined by a number of factors:

- The estimated number of canisters to be deposited and their thermal output.
- An estimated depth of the repository based on the rock stress situation and groundwater salinity.
- A minimum required canister separation along a deposition tunnel, determined by the requirement that the canister surface temperature must not exceed 100 °C.
- A preferred tunnel orientation and an approximate tunnel separation determined primarily by the rock stress situation.
- Respect distances to deformation zones of the rock.
- An estimated size of the repository area, determined by the above factors and an estimate of the fraction of candidate deposition hole positions that will be useable with regard to e.g. inflow and presence of minor fracture zones.

In the following, respect distances and the fraction of useable deposition positions are briefly discussed.

Respect distances

The design will consider preliminarily assessed “respect distances” regarding mechanical properties of the rock. Mechanical respect distances are related to potential consequences of future earthquakes in the host rock, including the dynamic influence of expected future glaciations. Such respect distances will be added to the site model as part of the repository engineering work, see further section 3.4.5.

Hydraulic respect distances to water conducting features of the rock will not be considered. Rather, the suitability of various sections of the suggested repository area from the point of view of radionuclide transport properties will be evaluated by the safety assessment group, see further Appendix II.

Fraction of useable deposition positions

As mentioned above, the repository size will be determined by a number of factors. One of these is the fraction of useable deposition positions within the area of the repository designated for canister deposition. This factor is mainly determined by the hydraulic properties of the rock and of the distribution of fractures. A high flow rate would probably be an important criterion for abandoning a deposition position. Throughout the site investigation phase, the fraction of such deposition positions will only be possible to assess statistically. Furthermore, criteria for this are not yet established and will be developed within the repository engineering group.

3 Safety related analyses

3.1 Overview

A number of analyses will be carried out to fulfil the objectives of the preliminary safety evaluations, stated in chapter 1.

SKB has established criteria to which the properties of a candidate host rock will be compared /Andersson et al, 2000/. Some of these are absolute requirements whereas others are preferable conditions that would influence safety in a positive manner. The criteria are based on the state of knowledge and the repository design plans at the time when the criteria were formulated. New R&D results and/or a modified repository design could motivate modifications of the criteria. A comparison to the criteria is an important component of a preliminary safety evaluation. Appendix I is an example of such a comparison, applied to a site model of the Laxemar area in southern Sweden /Andersson et al, 2002/. This level of detail of that site model is similar to what can be expected in version 1.2 of the site models, i.e. the version based on initial site investigation data.

In order to meet all objectives of the preliminary safety evaluation, in particular that of feedback to continued investigations and site specific repository design, further analyses are required. The safety assessment SR-SITE, which will be based on data from a complete site investigation, will contain a range of safety related geosphere and biosphere analyses. Some of these can provide meaningful information already after the initial site investigation, whereas others require more detailed data than what is available at this stage or do not provide any essential feedback for the continued activities.

Table 3-1 gives an overview of the safety related geosphere and biosphere analyses that can today be foreseen in SR-SITE. For each analysis, an indication is given of whether it is carried out also in this preliminary safety evaluation and, if not, a motivation.

Some analyses are carried out by Safety Analysis whereas others are performed by Repository Engineering or Site Modelling, and the results are subsequently used by Safety Analysis as a basis for the preliminary safety evaluation.

A number of the analyses will be carried out several times, based on successively updated site models and repository layouts, to give feedback to further site investigations and repository design.

An outline of how all these analyses will be handled and integrated in the full safety assessment, including realistic examples, will be given in the safety report SR-MET, to be published by SKB in 2004.

Table 3-1. Safety related geosphere and biosphere analyses at various stages of the site investigation. The column “Initial SI” indicates the analyses on which this preliminary safety evaluation is based. The abbreviations in the columns indicate which of the three project groups involved in the site investigation will be responsible for the analysis; Site Modelling (SM), Repository Engineering (RE) or Safety Assessment (SA).

Type of analysis	Initial SI	Complete SI
Thermal analyses		
Thermal evolution of canister surface, buffer and near field rock		
– for present climate conditions	RE	RE, SA
– for future climate conditions	No	SA
Thermal evolution on site scale		
– for present climate conditions	No	SA
– for future climate conditions	No	SA
Hydraulic analyses		
Groundwater flow calculations (and salinity evolution) in superregional, regional and local scale		
– for historic conditions	SM	SM
– for present climate conditions	SM	SM
– for future climate conditions	No	SA
Particle tracks for t_w , F and discharge point distribution in the flow field		
– for present climate conditions	SA	SA
– for future climate conditions	No	SA
Drawdown and upconing analysis	RE	RE
Resaturation	No	RE, SA
Mechanical analyses		
Thermally induced rock stresses, considering inhomogeneous thermal rock properties	RE	RE
Mechanical stability during construction and operation	RE	RE
Earthquake analyses, all time frames	SM, SA	SM, SA
Long-term stability, effects of glacial load, ridge push etc	No	SA
Chemical analyses		
Groundwater chemical evolution including colloids		
– historic and initial state	SM	SM
– future evolution (different scenarios)	No	SA
Chemical evolution of buffer and canister	No	SA
Backfill chemical evolution	No	SA
Radionuclide speciation calculations	No	SA
Assessment of ore-potential	SM and SA	SM and SA
Influence of construction materials etc	SA	SA
Radionuclide transport analyses (geosphere)		
Transmission calculations and transport modelling		
– for present climate conditions	SA	SA
– for future climate conditions	No	SA
Colloid facilitated transport	Check need	SA
Biosphere analyses		
Near surface hydrology		
– for present conditions	SM	SM
– for future climate conditions	No	SA
Biosphere model for radionuclide transport		
– for present conditions	No	SA
– for future climate conditions	No	SA
Dose calculations	No	SA

In the following, the contents of Table 3-1 is elaborated on, giving levels of ambition for the various analyses based on initial site investigation data, motivations for including/excluding the particular analyses etc.

3.2 Thermal analyses

3.2.1 Input from Site Description

The thermal site description will consist of a (statistical) distribution of thermal conductivity and heat capacity as well as the initial rock temperature. However, the confidence in the description will be limited since only a minor portion of the rock mass will have been explored after the initial site investigation.

3.2.2 Input from Repository Engineering

Repository engineering will calculate the thermal evolution of the canister surface, buffer and the rock in the vicinity of the tunnels for present day climate as this is a primary factor influencing the space needed for the repository. The layout produced will be adapted to fulfil the temperature requirements. If there is judged to be a need for local adaptations (i.e. increased separation in low thermally conductive regions) this will only be considered based on available level of detail in the lithological description, which in turn would affect the size of the repository. The REG will not carry out any thermal calculations on the repository scale.

3.2.3 Thermal evolution

SR-SITE will need to consider the thermal evolution of the canister surface, buffer and geosphere both for the present climate and for future climate conditions. However, the temperature analysis made within RE is sufficient for the PSE needs.

The thermal analysis for other scenarios than the present day climate, is not expected to imply any major safety issues, and certainly not any site specific ones. Thermal analyses for other scenarios are therefore not made for the PSE.

The PSE need to consider the thermal evolution of the canister surface, buffer and the near field rock. This will be done by simply referring to the analyses conducted within RE. Also verifying calculations will be made, using a simplified model. The handling of uncertainties in those analyses will be evaluated as part of the PSE.

3.3 Hydraulic analyses

3.3.1 Input from Site Description

As a result of the modelling efforts during the initial site investigation, the hydrogeologic site descriptive model will comprise a permeability distribution (both continuous and DFN) in regional and local scale with present day boundary conditions. The geometrical distribution will to a large extent depend on the geometric framework provided by the geological description. Several alternative geometrical descriptions will likely be propagated to the safety evaluation. The confidence in the description will be limited since only a minor portion of the rock mass will have been explored after the initial site investigation.

In developing this description, numerical hydrogeologic simulations will also be conducted. These simulations will be of two kinds (possibly combined in practice):

- Direct evaluation of hydraulic tests etc in order to check/calibrate that the description is consistent with available measurements.
- Groundwater flow simulations in super regional, regional and local scale in order to assess current (and past) groundwater circulation and geochemical (essentially only salinity) situation. Salinity effects will be included if this is judged necessary.

This means that the hydrogeological site description(s) will be transferred/adapted to the numerical model framework (i.e. discretized and adapted to the input requirements of the simulation codes).

3.3.2 Input from Repository Engineering

RE will assess the hydrogeologic impact of construction and operation. Connected to this is also the issue of how to assess the consequences of the resaturation phase. Such evaluations need to be performed quantitatively (i.e. using numerical models) after the complete site investigation. After the initial site investigation phase, simplified assessments of the inflow will be made, primarily in order to estimate the grouting needs and the extent of upconing. If specific hydrological modelling efforts are deemed necessary for these purposes, these will be carried out by the site modelling group. Regarding the effects of grouting materials and upconing on long-term safety, see section 3.5.

3.3.3 Flow modelling

Modelling needed in SR-SITE and PSE

SR-SITE will need to consider the groundwater circulation and the resulting distributions of flow (q) and transport resistance (F) for a variety of future conditions, including present day climate. The primary product is the q , F , advective travel time (t_w) and discharge point distributions for the repository as designed, but super-regional and regional flow simulations may be required for proper boundary conditions. The q , F , t_w and discharge point distributions need to be given for each canister position (or each starting point in the particle tracking) in order to evaluate differences between sections of the layout. It will also be necessary to address the confidence in the distributions obtained.

The hydrogeologic description as provided will essentially give the needed input for the present climate conditions, but not fully. Calculations of the distributions will require the emplacement of a repository in the (local) numerical model and particle tracking in the flow solution in order to get the F and discharge area distribution. Also, the impact of the tunnels and the EDZ need to be considered (see sections 3.4.3 and 3.4.4). Assessing other scenarios would require a new set of hydraulic simulations as well. Furthermore, the hydraulic description involves uncertainties and alternatives. It is not evident that the numerical hydrogeological simulations made within the Site Description will consider different realisations or all suggested variants.

For the PSE, the q , F , t_w and discharge point distributions for the given hydraulic numerical model will be calculated, using the boundary conditions as set up by the super-regional and regional models. The major effort in setting up the numerical model

would already have been done, at least for some realisation(s) and alternatives. The relevance of present day hydraulic boundary conditions for the long-term safety evaluation will have to be discussed, in particular if land-uplift is significant. Also the significance of including deposition tunnels and the excavation damaged zone surrounding them in the hydraulic model will have to be considered.

The q , F and t_w distributions are effective in judging the retardation capacity of the rock in themselves, and even more so as input to transmission and transport calculations (see section 3.6). Indications of the retardation capacity will be valuable in assessing the suitability of the site and also in directing further investigation efforts (see below). It is also likely that the Site Description will include different alternatives, both as regards geometry and properties (e.g. continuum or DFN with 'extreme' fracture size-transmissivity correlation). Exploring whether these alternatives have different safety implications would provide important feedback to the continued work with the Site Modelling.

There is little reason to suggest flow modelling for other scenarios at the initial site investigation stage. The retention function of the geosphere will be well covered by the present climate analysis. This would require major simulation efforts and the proper formulation of boundary conditions for scenarios describing altered climate. The uncertainty in the initial site investigation Site Description would also be too large to warrant the effort.

Potential feedback to site investigations and RE

The suggested PSE flow simulations may provide the following important feedback to site investigations and RE:

- The estimated F -distributions could be directly compared with the (preference) criterion $F > 10^4$ yr/m given in SKB TR-00-12, yielding a rough and general assessment of the suitability of the site from the point of view of rock retention.
- The calculated migration paths will designate a volume of the explored rock were it is particularly important to have high confidence in the Site Description; this could be compared with the current confidence and would thus lead to assessments of the need to increase borehole density etc.
- Similarly, the distribution of discharge points would indicate which portions of the surface environment are of most interest, at least for radionuclide turn-over modelling for present day conditions.
- Exploring the impact of different alternatives would suggest if there is a need for site investigation efforts (critical measurements and modelling) in decreasing the span of alternatives in the Site Description, both regarding geometry and properties.
- It may also be explored/assessed whether modifications of layout would significantly and positively affect the q and F distributions.

The Safety Assessment team may also review the plausibility of the confidence in the provided (from SM) hydrogeological description. Are the confidence statements well supported? If not – how could they be improved?

3.4 Mechanical analyses

3.4.1 Input from Site Description

After the Initial Site Investigation, the rock mechanics site descriptive model will comprise rock mass mechanical properties and the in-situ stress distribution. The geometric framework, as well as deformation zones and statistical fracture models, will be provided by the geological description. The confidence in the description will be limited to general preliminary understanding of the mechanical properties of the dominating rock types, since only a minor portion of the rock mass will have been explored after the initial site investigation.

3.4.2 Input from Repository Engineering

At the initial site investigation stage, Repository Engineering will assess the mechanical stability of the underground excavations considering the stresses during excavation and operation as well as the thermally induced load from the waste. The design produced by RE will be such that this stability will be ensured. The extent of the numerical analysis at the initial site investigation stage will focus on stochastically based studies of the stability of especially the deposition holes. Studies of the overall stability for other openings may be more general, due to lack of data. Tentative shapes and orientations of the various openings are proposed, based on estimates and scoping calculations. This includes also early estimates on the most suitable excavation method (TBM or drill and blast technology).

RE will also consider mechanical respect distances to major fracture zones when the repository layout is determined.

3.4.3 Thermally induced rock stresses

Modelling needed in SR-SITE and PSE

SR-SITE needs to assess the mechanical impact from the thermally induced rock stresses, both as regards stability of deposition holes and tunnels but also as regards potential disturbances (MH-coupling) on the rock mass itself, which may be seen as part of the EDZ estimation. The latter is provided by RE. For the PSE, Safety Assessment will not conduct any site specific analyses of this nature. The issue will however be addressed in SR-MET.

Potential feedback to site investigations and RE

Assessing importance of (potential) heterogeneous rock type mixture will provide feedback to site investigations on the ambition level and approach for describing the rock type variability.

Safety Assessment will also explore to what extent the mechanical analyses provided by RE allow assessment of the hydraulic impact on the rock mass but this is a development need rather than a PSE need. The H-M coupling will be discussed in SR-MET.

The Safety Assessment group may also review the plausibility of the confidence in the provided (from SM) mechanical description. Are the confidence statements well supported? If not – how could they be improved?

3.4.4 Mechanical stability during construction and operation

The mechanical stability of the underground excavations, during construction and operation is essentially an issue for Repository Engineering. RE is also responsible for the safety assessment for the operational phase. For the long term safety there is a need to assess potential excavation damages etc. Safety Assessment will need an estimate of the EDZ from this kind of analysis. This is based on the overall prediction of the status of the openings after all known loading situations from RE: There is therefore no reason to suggest independent safety assessment calculations of the mechanical stability during construction and operation.

Specifically for the PSE, only reference to the conducted RE analyses will be needed.

3.4.5 Earthquake analyses

Reactivation of a deformation zone, due to future glaciotectonics, will affect the host rock in the vicinity of the zone, and trigger other fractures to reactivate in the surrounding host rock. Deposition of canisters in the volumes estimated to be affected must be avoided, which to some extent will affect the repository layout. This can be handled by introducing “respect distances” to the deformation zones.

An attempt has been made earlier /SKB, 1999/ to determine or quantify these distances /LaPointe and Caldouhos, 1999; LaPointe et al, 1999/. The methodology used was considered highly conservative as fractures were assumed to be frictionless. This aspect was evaluated further in /LaPointe et al, 2000/. Work is currently in progress to develop a supplementary methodology aiming at calculating these distances that, in contrast to the previous work, also takes into account the dynamic effects of earthquakes.

Aside from the distance from an earthquake generating structure, an important factor to consider is the nature of the fracture that can be triggered to slip due to faulting along a larger zone nearby (the earthquake). Both previous studies /LaPointe et al, 1999/ and preliminary results from the ongoing modelling, indicate that slip hazardous to a canister requires a fracture of substantial size; about 100–200 m diameter. It is believed that such fractures will be detected during mapping of deposition tunnels and deposition holes, and these may thus be properly avoided. The only consequence would be that the total tunnel length is compensated for the loss of canister positions.

A recent empirical study /Bäckblom and Munier, 2002/ indicates that the respect distances obtained from modelling might be exaggerated. Case studies from Japan, USA, Taiwan and China suggest that deformation in deeply located tunnels in granitic rock decay rapidly away from the zone of slip. Though the study did not yield quantitative results, the authors concluded that a respect distance of 100–200 meters from the boundaries of a major deformation zone would suffice to ensure the integrity of the barriers.

While the methodology for simulating earthquakes is still under development, the intention, for the purpose of the PSE, is to use respect distances of 100 m and 50 m for regional and major local deformation zones respectively. The loss of canister positions due to intersection with larger fractures (> 100 m radius), and hence the final size of the volume needed for the repository, will be estimated using a stochastic approach by means of DFN models.

Handling in SR-SITE and PSE

SR-SITE will include earthquake analyses. Even if designs made by RE will be based on respect distances etc to a large extent motivated by earthquake safety, the analyses in SR-SITE need to confirm the safety (and quantify the risk) for the design as given.

Deformation zone geometry and fracture statistics are the most important site specific input data to the earthquake analysis. Such data will be available already at the initial site investigation stage, although with limited confidence. Earthquakes will therefore likely be handled with respect distances in the PSE. However, given the potential importance of earthquakes and the need to obtain feedback on the deformation zone /fracture geometry it could be of interest to perform earthquake analyses already for the PSE. The methodology for handling earthquakes is under development and will be presented in SR-MET. Simulations within SR-MET may result in revised respect distances. Presently (December 2002) it is premature to finally determine how the earthquake analyses will be carried out in the PSE.

Potential feedback to site investigations and RE

As discussed above, earthquake analyses could provide interesting feedback to site investigations and RE already at the initial site investigation stage. Alternative geometrical models could be compared, which could give indications as to what extent efforts would be needed to discriminate among the alternatives. This feedback will either be given within the PSE or at a later stage, depending on the ongoing development of methods for handling earthquakes.

3.4.6 Long-term stability

SR-SITE will also need to assess more long-term mechanical changes, such as the effects of ridge push, glacial loads etc. While such analysis are important for the overall safety case, they seem to offer little potential feedback to site investigations or RE in addition to what would have already been provided by other mechanical analyses. In addition, the methodology for making such analyses is under development. Consequently, the PSE will not include any long-term stability analyses.

3.5 Chemical analyses

3.5.1 Input from Site Description

After the initial site investigation, the hydrogeochemical site descriptive model will comprise the initial state of the groundwater composition (including colloids etc), assessment of the historical evolution (partly through hydrogeologic analyses, see section 3.3.1) and description of fracture mineralogy. A model of the rock type distribution will be available in the geological description. The confidence in the description will be limited, but will possibly be higher than that in the other descriptions. The general water composition at potential repository depth will probably be rather well known. Details in the three dimensional distribution of the main water bodies may however be less well known (like details in the depth to highly saline waters).

3.5.2 Input from Repository Engineering

RE will estimate the amounts of construction materials that may be used during construction and operation, including the grouting needs based on simplified hydrological analyses according to section 3.3.2. The chemical composition will also affect the final choice of backfill, but this will likely not be made in time for the completion of the initial site investigation.

3.5.3 Groundwater chemical evolution

Modelling needed in SR-SITE and PSE

SR-SITE will model the groundwater chemical evolution, both for present day and future climates as the groundwater composition is a crucial input to several other analyses (boundary condition to the chemistry in the buffer/backfill, speciation in the geosphere etc). The initial state as given in the Site Description will be a necessary input, but new simulations/assessments will be needed for predicting the future. These could be qualitative (as in SR 97) or possibly more quantitative. The methodology for this is currently being developed within the SR-MET project.

For the PSE, assessment of the future evolution of the groundwater composition will not be carried out. The initial state (as given in the Site Description) would be sufficient as input for other analyses (e.g. assessment of migration parameters, 3.6.3).

Attention may be given if high colloid levels are found, or if there are other chemical conditions outside preferred ranges as given in TR-00-12. Then the potential impact on this would require more specific analyses in order to explore whether simplifications or other assumptions made in Safety Assessment modelling would still be valid.

Potential feedback to site investigations or RE

Attention may be given if high colloid levels are found, or if there are other chemical conditions outside preferred ranges as given in TR-00-12. This may also stress efforts for further establishment of the true conditions at the site.

The Safety Assessment group will also review the plausibility of the confidence in the historical chemical evolutions and its consistency with the hydrogeologic description. Critical uncertainties may be identified (e.g. assumptions on boundary conditions) to be more carefully explored during the complete site investigation.

3.5.4 Chemical evolution of buffer and canister

SR-SITE will model the chemical evolution of the canister and the buffer, where the varying groundwater composition and flow conditions in the rock would determine the boundary conditions. However, the issues at stake are not really site specific as long as the criteria in TR-00-12 are met. Consequently, no such analyses are planned for PSE.

3.5.5 Backfill chemical evolution

SR-SITE will model the chemical evolution of the backfill, where the varying groundwater composition and flow conditions in the rock would determine the boundary conditions. However, at the time of finalisation of PSE the selection of the backfill will likely not have been made. In addition, the backfill evolution for several

backfill materials will be treated in SR-MET. In conclusion, there seems to be little ground for additional calculations within PSE. The results of SR-MET, which will be available when the PSE is being finalised, should however be used for a discussion of suitable backfill materials in PSE. This would provide important feedback to RE.

3.5.6 Radionuclide speciation calculations

SR-SITE will calculate the radionuclide speciation, where the groundwater composition in the rock will constitute one essential input. However, the issues at stake are not really site specific as long as the criteria in TR-00-12 are met. Consequently, no such analyses are planned for PSE.

3.5.7 Assessment of ore-potential

Modelling needed in SR-SITE and PSE

SR-SITE will need to assess the potential occurrence of ore-potential minerals etc at the site, and its implication for safety (future intrusions).

The significance of ore-potential minerals found (if any) will need to be considered already in the PSE. According to the criteria established in /Andersson et al, 2000/ *“It is a requirement that the rocks in the deposition area not have ore potential, ..., i.e. consist of such valuable minerals that this could justify mining at a depth of hundreds of metres. Since it can be difficult to predict the possible uses of different rock types in the future, it is an advantage if the deep repository is sited in commonly occurring rock types”*. If large amounts are found, this would directly disqualify the site according to the criteria, but if minor low grade amounts are indicated, the continuation of the Site Investigation may still be a debatable issue. At the minimum any occurrence of ore potential minerals from the site will need an assessment of the ore potential and the feasibility of mining etc to be made.

Potential feedback to site investigations or RE

If the results of the PSE suggest there is a problem with mineral deposits found, this may require a more careful assessment, by continued site investigations, of the extent of the deposits.

3.5.8 Influence of grouting materials etc

Modelling needed in SR-SITE and PSE

SR-SITE will assess the consequence of grouting and other materials, as estimated by RE, in the repository. Methods for assessing such consequences will be developed in SR-MET. These methods will be applied already in the PSE, due to the important feedback to RE in this matter.

Potential feedback to site investigations or RE

The PSE will provide important feedback to RE, on whether the expected grouting needs or other construction materials would imply any safety problem. If so, the design may need to be altered or optimised in this sense.

3.6 Radionuclide transport analyses

3.6.1 Input from Site Description

After the initial site investigation, the transport site descriptive model will essentially comprise site specific sorption and diffusivity parameters and designate means for how to assess the groundwater flow related migration parameters.

The confidence in the chemically related transport parameters will probably be low since much of the transport related core analyses come late in the programme.

3.6.2 Input from Repository Engineering

RE will provide a preliminary layout after the initial site investigation and possibly also an indication of whether blasting or boring will be used for the deposition tunnels, as well as a prediction of the extent of the EDZ.

3.6.3 Radionuclide transport modelling

A number of metrics of the retention potential of the bedrock will be calculated for a range of deposition positions in the repository area in the PSE. The positions will be those selected as starting points for the particle tracking in the calculation of F distributions, see section 3.3.3. The calculations will be made with a simplified analytic model /Hedin, 2002a/, which has been demonstrated to yield results in good agreement with numerical models for the three sites analysed in SR 97. The calculation method is probabilistic so that all relevant data uncertainties can be evaluated in an integrated manner. The metrics preliminarily considered for evaluating each start position are

- average q and F values, directly obtained from the calculated distributions, discussed in section 3.3.3,
- average transmission coefficients for a number of important radionuclides and
- average dose estimates if releases would occur to a well or to a peat bog.

An outline of the planned analyses with an example of an application to one of the SR 97 sites is given in Appendix II.

The transmission calculations, based on ideas also shown in SR 97, do not require a source term. In addition to the correlated F and t_w distributions from the hydrogeologic modelling, they require also distributions of sorption and diffusivities along the migration paths and an estimate of the Peclet number to describe longitudinal dispersion. Should these three latter parameters not exist, they can be estimated using data from a similar site.

The dose calculations require a source term, in the form of releases from the near field. Most of the near field data, with uncertainties, are not site specific and will be taken from calculation cases further developed /Hedin, 2002b/ from those reported in SR 97. The site specific q distribution may have a significant impact on the near field release and will be taken from the site specific hydro modelling described in section 3.3.3. It is emphasised that the dose estimates must be used with caution at this preliminary stage, in particular since the biosphere is handled in a pessimistic manner in the calculations.

The dose figures are not useful for comparisons to compliance criteria, but should serve as a meaningful metric for evaluating the suitability of different deposition areas within the suggested repository.

The analytic model does not require extensive resources regarding computers or manpower, once the results from the flow modelling have been obtained.

Sensitivity analyses

SKB has recently selected suitable methods for sensitivity analyses of probabilistic transport and dose calculation results. The methods identify the input parameters related to overall output uncertainty /Hedin, 2002b, 2002c/ and those specifically related to high dose results /Hedin, 2002b/. Both methods can readily be applied to the results of the dose calculations described above.

Potential feedback to site investigations and RE

As regards transport, the type of feedback will be similar to the feedback from the groundwater flow calculations (see section 3.3.3).

The results of the sensitivity analyses will provide a systematic ranking of all uncertain variables affecting dose results and also put the site specific uncertainties in a broader perspective since essentially also non site specific variables are included in the analyses.

The Safety Assessment group may also review the plausibility of the confidence in the provided (from SM) transport property description. Are the confidence statements well supported? If not – how could they be improved?

Modelling in SR-SITE

Full transport modelling with numerical models for both source term and geosphere transport as well as radionuclide turnover and dose calculations in the biosphere will be done in SR-SITE. However, the potential gain in feedback to site investigations and RE, compared to the feedback already provided from the simpler calculations suggested above, does not seem to warrant the substantial additional effort. Nor is the site specific biosphere model expected to be mature enough for such an application after the initial site investigation.

3.6.4 Colloid transport

Modelling needed in SR-SITE and PSE

SR-SITE will address colloid facilitated transport. However, if colloid levels are found to be small, quantitative analyses may not be needed.

In the PSE, the colloid levels should be assessed and a decision be made whether the levels warrant quantitative colloid modelling in SR-SITE. According /Andersson et al, 2000/, this would occur if the colloid concentration is > 0.5 mg/l. If so, a simplified estimate of the magnitude of the potential problem will given already in the PSE.

Potential feedback to site investigations and RE

The important feedback would be to Safety Assessment itself, regarding the need for more quantitative colloid modelling. In addition, in case colloid levels are high feedback to site investigations would be given to enhance effort in careful colloid characterisation.

3.7 Biosphere analyses

3.7.1 Input from Site Description

After the Initial Site Investigation, the site descriptive model will essentially comprise a description of the surface and the regolith (the surface deposits), geology, hydrology and hydrogeochemistry as well as a description of the ecosystems. The near-surface hydrology/hydrogeology model will be developed in co-operation with the hydrogeology team.

The biosphere characterisation will be fairly complete already after the initial site investigation and the characterisation during the complete site investigation will focus on complementary data needed for Safety Assessment, focused study of selected important parameters and continued long term monitoring.

3.7.2 Input from Repository Engineering

At the initial site investigation there is probably minor input related to the biosphere from RE. In planning the surface facilities and in assessing the (direct) environmental impact of both surface and subsurface facilities, a close interaction between the site investigations, the environmental impact assessment work and RE will be needed. However, these assessments have a limited impact on the Safety Assessment work.

3.7.3 Near surface hydrology

Modelling needed in SR-SITE and PSE

A near-surface hydrology model will be an essential part of the biosphere modelling in SR-SITE. The potential radionuclide release from the repository will enter the biosphere through the aquatic system and the migration in the biosphere will also, largely, be governed by the near-surface hydrology. Consequently, the biosphere models (for dose calculations etc) presently being developed within SR-MET will use the surface hydrology as input. Safety Assessment will also need to consider the future evolution of the biosphere, and thus also the future evolution of the near surface hydrology. SA will use the hydrogeology model developed by the site modelling group, but in assessing the future development, additional efforts are needed.

Also the PSE will explore the properties of the near-surface hydrology as provided in the Site Description. No additional modelling is planned, but combining results of the hydrogeological analyses of the discharge point distribution (see section 3.3.3), with the current understanding of the near-surface hydrology will provide important feedback to the subsequent characterisation work. However, there is little reason to consider the future evolution of the system at this stage.

Potential feedback to site investigations and RE

Assessing how the current surface hydrology interacts with the discharge from the repository will provide feedback to site investigations on where to focus further characterisation and modelling efforts.

3.7.4 Biosphere model for radionuclide transport

SR-SITE will set up a biosphere model for radionuclide transport and transfer. This model will include the relevant biosphere processes and interactions in order to model future doses to man and the environment sufficiently well. The modelling will be done within the framework of Safety Assessment, and will build on the Site Description of the ecosystems and the near-surface hydrology.

Full biosphere dose calculations will be done in SR-SITE. For the PSE, the potential gain in feedback to site investigations and RE, compared to the feedback already provided from the simplified calculations described in section 3.6.3 and the identification of potential discharge points etc does not warrant the substantial additional effort.

3.8 Assessment of confidence in the site description

As stated under each subject above the Safety Assessment team should also review the plausibility of the confidence statements made by SM on the Site Descriptive Model as a whole. Are the confidence statements well supported? If not – how could they be improved?

4 Further project planning information for a PSE

4.1 Tentative structure of a PSE

The following is a tentative table of contents for a PSE, along with brief descriptions of the intended contents of each chapter.

- Introduction
 - Description of site investigation programme and present stage of programme.
 - Purpose of the preliminary safety evaluation as given in section 1.1 of this report.
- Basis for the safety evaluation
 - Brief account of the site model version 1.2 delivered by the Site Modelling Group and the analyses made to obtain it.
 - Brief account of the suggested layout delivered by the Repository Engineering Group and accompanying analyses.
- Overview of and motives for analyses to be performed within the Safety Evaluation Project
 - See Table 3-1 of this report and related text.
- Detailed description of analyses performed and results obtained
 - Comparison to criteria, see Appendix I for an example.
 - Other modellings, essentially hydro and transport analyses.
 - Other evaluations (chemical impact of construction materials; assessment of ore potential etc).
- Discussion and conclusions
 - Discussion of analyses results, including those performed by SMG and REG.
 - Evaluation of confidence in site model.
 - Recommendation regarding decision on continued site investigation.
 - Feedback to continued site investigations (should this be recommended).
 - Conclusions regarding safety assessments at later stages of the site investigation programme, including treatment of identified site specific issues to be further analysed.

4.2 Activities and resources for a PSE

The following list summarises main activities and an estimated need of resources during a PSE.

- | | |
|--|---------|
| 1. Comparison to criteria, including documentation | 2 weeks |
| 2. q, F calculations, including documentation | 4 weeks |
| 3. Transport calculations and sensitivity analyses, including documentation | 1 week |
| 4. Other safety related assessments (ore potential, chemical impact of construction materials etc) | 1 week |
| 5. Evaluation of safety related analyses provided by SM and RE (earthquakes, thermal analyses etc) | 1 week |
| 6. Evaluation, discussion of analysis results, possibly refined analyses | 8 weeks |
| 7. Reporting | 8 weeks |

Many of these activities can be carried out in parallel, at least partly. The total “real time” needed for a preliminary safety evaluation, following delivery of the required material from SM and RE, is estimated at five months.

4.3 Summary of essential feedback expected from a PSE

The PSE will provide feedback both to the Site Modelling Group and to Repository Engineering. This section summarises the expected type of feedback.

4.3.1 Feedback to the Site Investigation

Feedback concerning the Site Description and the Site Investigation will primarily be communicated to the Site Modelling Group. They may then, in turn, assess to what extent this feedback also has implications for the actual investigations during the complete site investigation.

In general, the Safety Assessment team will review the plausibility of the confidence statements made by SM on the Site Descriptive Model as a whole. Are the confidence statements well supported? If not – how could they be improved?

The following, more specific, feedback may be expected:

- Comparison with criteria as given in TR-00-12 and, based on this, a general recommendation of whether site investigations should continue.
- The calculated migration paths will designate a volume of the explored rock where it is particularly important to have high confidence in the Site Description. This could be compared with the current confidence and would thus lead to assessments of the need to increase borehole density etc.

- Similarly, the distribution of discharge points will indicate which portions of the surface environment are of most interest, at least for radionuclide turn-over modelling for present day conditions.
- The transport calculations and sensitivity analyses will provide similar feedback of higher precision. They will also help in putting the site specific uncertainties in a broader perspective.
- Exploring the impact of different alternatives will suggest if there is a need to spend efforts (critical measurements and modelling) in decreasing the span of alternatives in the Site Description, both regarding geometry and properties.
- Assessing importance of (potential) heterogeneous rock type mixture will provide feedback to site investigations on the ambition level and approach for describing the rock type variability.
- Earthquake analyses on different alternative description could give indications as to what extent efforts would be needed to discriminate among the alternatives.
- Indication whether further attention is needed as regards colloid levels.
- If the results of the PSE suggest there is a problem with indications of mineral deposits found, this may require a more careful assessment of the extent of the deposits.

4.3.2 Feedback to Repository Engineering

Feedback concerning Repository Engineering will concern the layout rules applied and possibly also suggested technical solutions. The following specific feedback may be expected:

- The transport analyses will indicate whether modifications of layout would significantly and positively affect the q and F distributions. This may be used to improve the layout.
- The qualitative assessment of upconing (and the SR-MET analyses of different backfills) will provide feedback to Repository Engineering as regards the proper choice of backfill.
- Assessing the need for refined analysis of the hydraulic impact on the rock mass (EDZ).
- If the expected grouting needs or other construction materials imply any safety problem, the design may need to be altered or optimised in this sense.

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Comparison to Criteria

This appendix contains a simplified comparison of the site descriptive model developed within the so called Laxemar project /Andersson et al, 2002/ to the suitability criteria for the host rock established in /Andersson et al, 2000/. The comparison is of a preliminary nature and must not be taken as a realistic safety evaluation. The comparison is made in order to test the possibility of comparing the contents of a site descriptive model to the criteria, and to identify difficulties in this task.

An effort to provide feedback to the site investigations and site modelling activities is also made.

Table AI-1. Suitability indicators for geology

Parameters – by group	Requirements or preferences	Criteria after feasibility study (FS) and after site investigation (SI)	Value range Laxemar	Assessment
Topography	–	Important basic information, but no primary indicator. See hydrogeology.		
Soils	Preference for thin soil layer and high proportion of exposed rock	FS: – SI: Not relevant after site investigation	82% of the area has no or little (<0.5 m) soil cover. 18% is covered by Quaternary deposits (mainly in valleys) (section 3.3.1 in TR-02-19)	No direct influence on the safety evaluation, but low soil cover increases confidence in the description of the deformation zones.
Rock types	Requirement that the rock types in the deposition area do not have ore potential and do not contain such valuable minerals as to justify mining at a depth of hundreds of metres. Preference that there is no occurrence of valuable utility stone or industrial minerals. Preference for common rock type. (Indirect requirements /preferences from rock mechanics and hydrogeology).	FS: Avoid areas with known ore potential and heterogeneous or unusual bedrock. SI: Local adaptation of repository with reference to indicator. If extensive occurrence of ore-bearing minerals is encountered, the site should be abandoned.	According to Table 5-1, the bedrock (in the base model) consists of 77% granite, 3% aplite, 10% granodiorite and 10% volcanite. In the alternative model, however, a smaller rock domain (RLX01, Table 5-23 in TR-02-19) with a high content (70%) of gabbro is identified. There are no signs of ore potential	Areas with ore potential are not judged to occur in the area. All information suggests that requirements and preferences can be met. The bedrock's formation history gives no cause for questions either. (A feedback from the Safety Assessment Group to the Site Modelling Group could, however, be to pose this question more sharply than is evident from the text in the report.)
Plastic shear zones	Regional plastic shear zones are avoided, if it cannot be shown that the properties of the zone do not deviate from those of the rest of the rock. There may, however, be tectonic lenses near regional plastic shear zone that can be suitable for a deep repository.	FS: Avoid known regional plastic shear zones. If sufficient repository volume cannot be obtained, another area must be chosen. SI: Revise layout according to new knowledge. If the repository cannot be positioned in a reasonable manner (if it would have to split up into a very large number of parts), another area must be chosen.	The area is intersected by a regional deformation zone ZLXEW1 and another regional deformation zone lies south of the area. The distance between these zones is about 2 km.	See next

Fracture zones	<p>Deposition tunnels and holes may not pass through or be located near regional and local major fracture zones. Assumed respect distances will be used in conjunction with the stepwise site investigation and the design process. But the real distances that are needed are determined via a site-specific function analysis.</p> <p>Deposition holes may not intersect identified local minor fracture zones. Moderate densities (fracture surface area per volume) of fractures and of local minor fracture zones are preferable.</p>	<p>FS: Choose area for continued studies so that a deep repository can be positioned with good margin in relation to the fracture zones identified in the feasibility study. If the repository cannot be positioned in a reasonable manner, another area must be chosen.</p> <p>SI: Suitable respect distances to identified regional and local major fracture zones can only be determined site-specifically but are assumed to comprise at least several tens of metres to local major zones and at least 100 metres to regional zones. If the repository cannot be positioned in a reasonable manner (would have to be split up into a very large number of parts) in relation to plastic shear zones, regional fracture zones or local major fracture zones, the site is not suitable for a deep repository.</p>	<p>The base model contains 21 and the alternative model 20 deformation zones (local major zones or larger). Most of these are relatively steeply-dipping. The distance between the local zones is a couple of hundred metres. Confidence in the description varies. The exact extent in depth is unknown for a large proportion of the zones. Additional zones may be added. A large part of the model area lacks boreholes. Seismic reflection only “sees” reflections within a given direction interval.</p>	<p>A repository with a distance of at least 100 m between canisters and known regional zones can easily be positioned in the area. The minimum distance to local zones can only be estimated after a more concrete effort from Repository Engineering. The location of the deformation zones in depth is, however, so uncertain that the layout cannot be determined even preliminarily at this time, but the prospects of being able to accommodate a repository are deemed to be good (preliminary judgement).</p> <p>Feedback: Safety The Safety Assessment Group needs to have much better confidence in the deformation zones within the intended repository volume. To start with, Repository Engineering really needs to be able to show that a repository can fit into the volume. However, the description is included concretely as a basis for hydraulic and mechanical analyses, for example. Confidence in these analyses requires confidence in the underlying description. In other words, the Safety Assessment Group should judge whether different alternatives have different safety implications. After the ISI, this means a need for additional boreholes and possibly more surface geophysics (but precisely what needs to be done to improve confidence is determined in the discussion between the Site Modelling Group and Site Investigation.</p>
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Table AI-2. Suitability indicators for rock mechanics

Parameters – by group	Requirements or preferences	Criteria after feasibility study (FS) and after site investigation (SI)	Value range Laxemar	Assessment
Initial rock stresses	<p>Extensive spalling or other extensive overbreak may not occur within a large portion of the deposition area. Function is verified by means of a site-specific analysis.</p> <p>Preference for normal (considerably lower than 70 MPa) at repository depth.</p>	<p>FS: No criteria.</p> <p>SI: Calculated stress situation in the rock nearest the tunnels and the resultant rock stability during and after the construction phase is used mainly to adapt repository depth and layout. If the repository cannot be reasonably configured in such a way that extensive and general stability problems can be avoided, the site is unsuitable and should be abandoned. Extensive problems with “core discing” should directly give rise to the suspicion that problems may be encountered with spalling during tunnelling.</p>	<p>Estimated in-situ stress is shown in Table 5-35 in TR-02-19. At about 500 m, $\sigma_1 = [25, 40]$ MPa and $\sigma_3 = [6, 18]$ MPa.</p> <p>The uncertainties increase markedly at depths below about 600 m.</p> <p>The stress model’s uncertainty intervals are relatively large due to few and “low-quality” measurements.</p>	<p>Estimated stress levels give no cause for concern despite the great uncertainties. However, at depths greater than about 600 m, the uncertainties are too great to be able to say anything about the conditions with the current model. See further next point. (After actual ISI, it is anticipated that Repository Engineering will have conducted a mechanical analysis.)</p> <p>Feedback. A stress model with higher precision is needed for forecasts of tunnel construction and optimization of layout.</p>
Intact rock (E, σ , compressive strength etc)	<p>Extensive spalling or other extensive overbreak may not occur within a large portion of the deposition area.</p> <p>It is preferable that the intact rock have strength and deformation properties that are normal for Swedish bedrock.</p>	<p>FS: Assessment based on preliminary rock type forecast may not indicate unfavourable conditions.</p> <p>SI: Special attention if the strength of the rocks deviates from normal values in Swedish bedrock. See also “initial rock stresses”.</p>	<p>The estimated mechanical properties of the rock and the rock mass are shown in Table 5-37 in TR-02-19.</p> <p>The strength of the intact rock is judged to lie within [100, 280] MPa with good confidence (known rock types). Assessment of the properties of the rock mass has low confidence due to few site-specific measurements/analyses.</p>	<p>The strength of the intact rock is high in relation to in-situ stress.</p> <p>Feedback. Higher confidence in the determination of the deformation module and strength of the rock mass within the intended repository volume is needed for future forecasts in the safety assessment (e.g. influence of thermal load).</p>

Fractures and fracture zones	<p>For adaptation to geometry of fracture zones and fractures – see “geology”.</p> <p>Tunnel layout/location is chosen based on stresses and fracture directions.</p> <p>Large friction angle suitable.</p>	<p>FS: For adaptation to geometry of fracture zones and fractures – see “geology”.</p> <p>SI: For adaptation to geometry of fracture zones and fractures – see “geology”.</p> <p>Rock-mechanical analysis of function (see “Intact rock” above).</p>	<p>A discrete fracture network model (DFN) is available (see Table 5-1 in TR-02-19 for the base model and Table 5-24 for the alternative model.) Confidence relatively low due to lack of clarity in surface mapping. Even though confidence is low, more boreholes will only provide a marginally improved model. Better surface mapping (and modelling technique) is crucial for improving confidence.</p>	<p>The information is mainly used by Repository Engineering. The DFN model could be used there as input data for calculating the deformation module and strength of the rock mass.</p> <p>These parameters are also included in the Safety Assessment Group’s mechanical analysis. The DFN model can also provide input data to earthquake analysis.</p> <p>The Safety Assessment Group needs to consider whether mechanical analysis should be done. If the analysis indicates “problems”, the Safety Assessment Group should have an interest in improving confidence (see left).</p>
Rock mass strength and deformation modulus	<p>No requirements</p> <p>Preference for properties at least on a par with normal conditions in Swedish bedrock.</p>	<p>FS: No criteria.</p> <p>SI: The forecast of the properties of the rock mass that is made in conjunction with the site investigation is used for repository layout and the constructability forecast. The constructability forecast is included in the total comparison material between sites, but has no direct safety-related importance. Good constructability is of course advantageous.</p>	See above	See above

Coefficient of thermal expansion α	No requirements Preference for normal values for Swedish bedrock. Not too inhomogeneous.	FS: No criteria SI: Assessment of inhomogeneities – if very inhomogeneous, broader analysis of consequences is needed. Choice of deposition holes made during repository construction.	Has not been determined in the Laxemar model (beyond scope). But could be estimated in the same way as the strength of the intact rock. The bedrock composition is relatively homogeneous on the model scale (RLX02 in the alternative model occupies 70% of the volume), but on a smaller scale the bedrock is relatively non-homogeneous regarding the occurrence of fine-grained granite and minor mafic bodies. Gabbro also occurs as small-scale intrusions.	Thermal expansion in itself does not constitute a problem, but needs to be better determined to permit quantitative forecasts. Feedback Heterogeneities constitute an unknown and knowledge is needed of whether the different rock types have different expansion coefficients. (It should be possible to determine this without sampling.) The Safety Assessment Group may need to perform calculations to see if the span of variation between different rock types gives cause for concern. If so, a more sophisticated description of the spatial variation of the rock types may be needed.
Future loads (seismicity, glaciation...)	No requirements	No ground for comparisons with respect to uncertainties in forecasts.	No information at present.	Feedback. If the Safety Assessment Group wants such a description, the need should be clarified.

Table AI-3. Suitability indicators for thermal properties

Parameters – by group	Requirements or preferences	Criteria after feasibility study (FS) and after site investigation (SI)	Value range Laxemar	Assessment
Heat transport (thermal conductivity and heat capacity)	<p>No requirements</p> <p>Preference for good thermal conductivity (influences repository layout, repository size), i.e. $\lambda > 2.5 \text{ Wm}^{-1}\text{K}^{-1}$</p>	<p>FS: If an assessment is made (from rock types) that thermal conductivity is below the preferred value, the size of the area that must be studied is affected.</p> <p>SI: Detailed knowledge of rock types and thermal conductivity is used to adapt the repository layout. However, Thermal conductivity only has to be taken into account if there is a risk that it is below the preferred level ($2.5 \text{ Wm}^{-1}\text{K}^{-1}$).</p>	<p>No determination has been made. See however discussion above about “small-scale variation” in rock type composition.</p> <p>There may be fears of low thermal conductivity from Äspö.</p>	Information is primarily needed for Repository Engineering. However, the Safety Assessment Group can conclude at this time that there is no ground for quantitative temperature calculations. (In an actual ISI, however, a simple temperature model will be available!!)
Ambient temperature (initial, external temperature, geothermal gradient)	<p>Areas with potential for geothermal energy extraction (very high geothermal gradient) should be avoided.</p> <p>Preference that initial temperature at repository depth $< 25^\circ\text{C}$.</p>	<p>FS: Avoid areas with assessed large potential for geothermal energy extraction. If the initial temperature is judged to exceed the maximum preferred, it must be taken into account in the choice of how large an area needs to be investigated.</p> <p>SI: Like FS. The initial temperature must be taken into consideration in determining the repository layout if it is above or near the maximum preferred.</p>	<p>No determination in the Laxemar project (but there may be data that have not been analyzed).</p> <p>Good knowledge exists from Äspö – measured temperatures far below maximum desired.</p>	No reason to fear that preferences will not be met.

Table AI-4. Suitability indicators for hydrogeology

Parameters – by group	Requirements or preferences	Criteria after feasibility study (FS) and after site investigation (SI)	Value range Laxemar	Assessment
Permeability for fracture zones and fractures	<p>Deposition holes are not allowed to be positioned closer near regional or local major fracture zones. (An exception can be made from this requirement if it can be shown that the permeability of the zone does not deviate significantly from that of the rest of the rock mass.) See further fracture zones geology.</p> <p>It is an advantage if a large portion of the rock mass in the deposition area has $K < 10^{-8}$ m/s (on 30 m scale). Integrated function analysis is needed.</p> <p>Zones that need to be passed during construction should have such low permeability that passage can take place without problems. (Zones with $T < 10^{-5}$ m²/s or zones that are not wide and clay-filled.)</p>	<p>For adaptation to geometry of fracture zones and fractures – see geology.</p> <p>FS: No criteria.</p> <p>SI: A large portion of interpreted K values in the rock mass are $K < 10^{-8}$ m/s. (Otherwise need for local detailed adaptation if the safety margin is to be met.)</p> <p>Fracture zones that need to be passed during construction should have an interpreted transmissivity of $T < 10^{-5}$ m²/s and lack clay filling (otherwise increased attention to grouting and other construction-related risks).</p>	<p>Regional zones $T = 10^{-4}$ m²/s</p> <p>Other deformation zones $T = 3-7 \cdot 10^{-6}$ m²/s.</p> <p>However, confidence in these values is low since measurements are lacking in most zones.</p> <p>LogK in the rock mass between deformation zones (HRD) is $N(-9.0, 1.8)$ on a 30 m scale.</p> <p>There is also a DFN model where logT is $N(-8, 0.77)$ (T in m²/s). A revised fracture zone model could possibly reduce the variance in T (as well as T mean), since more flow would then be assigned to the deterministic zones.</p>	<p>Stipulated values for deformation zones and rock mass lie within given criteria. The site is therefore deemed suitable for further investigations from this aspect.</p> <p>Confidence in T-distribution (and geometry) of the fracture zones is limited, however. This confidence needs to be improved within the parts of the volume that may be considered for the repository. (All zones that must be passed by tunnels need to be investigated to provide data for the constructability analysis.)</p> <p>The K-distribution in the rock mass is OK according to the criteria, but a certain proportion of high flows (i.e. low Fs) will probably result if flow and transport simulations are done. It is conceivable that the DFN description will further increase the spread in this distribution (if it is analyzed).</p> <p>Feedback. There is reason to a) improve confidence in the description of the rock mass in conceivable repository volumes; b) test different hypotheses for distribution of T between deterministic deformation zones and stochastic ones; c) test different hypotheses regarding T-distributions for stochastic fractures.</p> <p>If these analyses show that drastically different F-distributions (see “Transport”</p>

				below) result from different assumed relationships, the Site Modelling Group and Site Investigation should consider whether there are hydraulic tests (e.g. interference test) that could shed light on which relationships have the highest confidence.
Flow porosity and storage coefficient	No, since the parameters do not influence retardation of sorbing substances or long-lived non-sorbing substances (see transport).	–		
Density and viscosity	Density differences influence the hydrogeological modelling, but no ground for requirements/preferences (see “Chemistry” however).	–		
Near-surface ecosystems	Areas protected by law are avoided. Avoid areas for the deep repository’s surface facilities where biological diversity and species worth protecting can be threatened and areas that are or may be important water sources, soil sources or farmland. Data on the near-surface ecosystems are primarily valuable for building up a credible model description.	FS: Areas protected by law shall be avoided. It is a preference that areas of interest for site investigations have few competing interests and that the surface facilities can be preliminarily adapted so that there is little impact on the near-surface ecosystem. SI: Criteria as above.	Not part of the Laxemar model	Has already been dealt with in connection with site selection.

Supporting data (pressure levels, recharge/discharge areas)

Data are primarily needed to build up credible groundwater models.
Advantage if the local gradient <1% at repository level (but no advantage if even lower).

FS: Areas with an unsuitably high gradient (much greater than 1%) are rejected.
SI: Information on supporting data is mainly used to build up credible models.

There are few observations, but the groundwater level largely coincides with the topography. The maximum topographic gradient is 0.3%.
Boundary conditions etc (section 4.2.9 in TR-02-19). The central area is a local recharge area. Associated discharge areas are primarily located in the sea immediately east of the area (not thoroughly analyzed).
Boundary conditions to the west incompletely determined, but quasi-steady-state with impervious margin on the west provides satisfactory description of salinity distribution – but not reliable as boundary condition in the event of major changes.

The area gets no criticism from the criteria viewpoint. More analysis/evaluation of the boundary conditions is needed to lend sufficient confidence to forecasts of groundwater flow during the construction phase and under future changed boundary conditions.

Table AI-5. Suitability indicators for chemistry (groundwater composition)

Parameters – by group	Requirements or preferences	Criteria after feasibility study (FS) and after site investigation (SI)	Value range Laxemar	Assessment
Dissolved oxygen	Requirement: Absence of dissolved oxygen at repository level (indicated by negative Eh, occurrence of Fe(II) or occurrence of sulphide).	FS: No criteria (no data available) but there is no reason to believe that the requirement cannot be met. SI: At least one of the indicators Eh, Fe ²⁺ , HS ⁻ must be satisfied.	For representative samples at conceivable repository depth (Table 5-35, in the Laxemar report TR-02-19): KLX01: 456–461: Eh= –308 mV KLX02:235–341: Eh= –200 mV	Requirement satisfied without problem or question.
PH	Preference: Undisturbed groundwater at repository level should have a pH in the range 6–10.	FS: No criteria (no coupling to surface water). SI: below the –100 m level, quality-approved values should lie in the range 6–10.	KLX01: 456–461: pH=8.2 KLX02: 235–341: pH=8.2	Requirement satisfied without problem or question.
TDS (Total Dissolved Solids)	Requirement: TDS<100g/l	FS: No criteria SI: Quality-approved measured TDS at repository level must meet this requirement. Occasional higher values can be accepted if it can be shown that the water is located in areas that can be avoided.	KLX01: 456–461: 3 g/l, 10g/l at about 800 m. KLX02: 235–341: 0.6 g/l, 10 g/l at about 1000 m. The levels agree with hydrogeological simulation.	Requirement satisfied. Great distance to higher salinities. Feedback: Confidence in the distribution is good, but TDS should naturally be checked in new boreholes and verified. Changes in salinity are probably due to large-scale changes in flow patterns. Attention on construction and operating periods.
Other chemical parameters	Preference: [DOC]<20 mg/l, colloid concentration <0.5mg/l, low ammonium concentrations, [Ca ²⁺]+[Mg ²⁺]>4mg/l at repository depth, low concentrations Rn, Ra.	FS: – SI: Attention if measured concentrations deviate from preferences.	KLX01: 456–461: DOC=1.4 mg/l KLX02: 235–341: DOC N/A Colloids: Not Analyzed KLX01: 456–461: [Ca ²⁺]+[Mg ²⁺]= 241 mg/l KLX02: 235–341: [Ca ²⁺]+[Mg ²⁺]= 42 mg/l	All preferences satisfied. Deviations from these preferences can only occur if relatively great changes occur. “The samples can undergo considerable changes before some of the criteria are no longer met (addition of 75% precipitation water and 30% glacial meltwater)”. (TR-02-19) Feedback: See further discussion in section 5.3.2 in the Laxemar report (TR-02-19) about which measurements should be performed to improve confidence in the description.

Table AI-6. Suitability indicators for transport properties of the rock.

Parameters – by group	Requirements or preferences	Criteria after feasibility study (FS) and after site investigation (SI)	Value range Laxemar	Assessment
Groundwater flux (Darcy velocity) on canister scale and the total fracture aperture	<p>Requirement that the flow and the apertures are not so large that the bentonite is damaged. (Can scarcely occur and can always be avoided.)</p> <p>Low water flux and small apertures (Darcy velocity on deposition hole scale lower than 0.01 m/y). Final judgement in safety assessment.</p>	<p>FS: –</p> <p>SI: Advantage if the estimated Darcy velocity (on a scale of 10 m) is lower than 0.01 m/y for a large number of positions in the rock. Final judgement is made within the framework of a safety assessment.</p>	Not calculated but probably, say, around 25% with $q > 0.01$ m/y	See hydro
Flow-related transport parameters (q , a_r , $a_r L/q$, etc)	Substantial retardation an advantage. This is achieved in flow paths where $F > 10^4$ y/m.	<p>FS: –</p> <p>SI: Advantage if a large fraction of the estimated statistical distribution of the flow paths have a transport resistance $F > 10^4$ y/m. Unsuitable flow paths could perhaps be avoided later by a suitable choice of repository layout and canister positions. Final judgement is made within the framework of a safety assessment.</p>	Not calculated but probably a certain percentage $F < 10^4/m$	<p>(See hydrogeology table) A certain percentage of high flows (low Fs) will probably result if flow and transport simulations are done. It is conceivable that the DFN description will further increase the spread in this distribution (if it is analyzed).</p> <p>Feedback. There is reason to a) improve confidence in the description of the rock mass in conceivable repository volumes; b) test different hypotheses for distribution of T between deterministic deformation zones and stochastic ones; c) test different hypotheses regarding T-distributions for stochastic fractures.</p> <p>If these analyses show that drastically different F-distributions (see “Transport” below) result from different assumed relationships, the Site Modelling Group and Site Investigation should consider whether there are hydraulic tests (e.g. interference test) that could shed light on which relationships have the highest confidence.</p>

Properties “rock matrix” diffusivity D_e and matrix porosity ϵ_r	It is advantageous if matrix diffusivity and matrix porosity are not much lower than the value ranges analyzed in the safety assessment SR 97 (see Ohlsson and Neretnieks, 1997). The accessible diffusion depth should at least exceed a centimetre or so.	FS: – SI: Measured values should not be significantly more than 100 times lower than the values normally encountered in Swedish crystalline bedrock. Otherwise, special attention is required in the coming safety assessment.	No data from Laxemar	Generic data may suffice for Preliminary Safety Evaluation. On the other hand, some analysis of drill cores will probably be done already during the ISI.
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Radionuclide transport analyses

The following is an outline of how the radionuclide transport properties of a site will be analysed in a preliminary safety evaluation.

Based on data from an initial site investigation, it will be interesting to preliminarily evaluate the retention properties of the rock mass in general and in particular to analyse whether a suggested repository area seems to contain portions which are more or less suited for canister deposition, from the point of view of retention.

The analyses suggested here are based on the same understanding of radionuclide transport phenomena as earlier SKB analyses, see e.g. the SR 97 reporting.

Within a repository area suggested by the REG a number, typically 100, of representative positions are selected to illustrate the transport properties of the rock. For each position, correlated distributions of flow (q), rock transport resistance (F) and advective travel time (t_w) are calculated probabilistically, see further section 3.3.3.

The q , F and t_w distributions are in themselves important estimates of the retention properties of the rock. More direct measures of these properties are however obtained if the F distributions are transformed into transmission distributions for a number of important radionuclides or if full calculations of integrated near field and far field radionuclide release and dose distributions are performed. The latter is however very resource consuming if the traditional numerical near field and far field transport models are used. Therefore, analytical models for near field and far field transport, which have been demonstrated to yield results in good agreement with numerical models /Hedin, 2002a/, will be used.

To test and demonstrate the methodology, it has been applied to data for the Finnsjön (Beberg) site previously analysed in SR 97 /Gylling et al, 1999/. Figure AII-1 shows the 120 selected starting positions within the repository area for the Finnsjön site. Correlated distributions of q , F and t_w were determined by hydrological modelling for each position within the SR 97 analysis and used as input here. For each position, the following metrics were now determined, either directly from the q and F distributions or using the analytical transport models:

- Average q and F values, denoted $\langle q \rangle$ and $\langle 1/F \rangle$, directly obtained from the calculated distributions, discussed in section 3.3.3.
- Average transmission coefficients, $\langle T \rangle$, for a number of important radionuclides. The transmission metric, T , is defined in /Hedin, 2002a/ based on work by /Sudicky and Frind, 1982/.
- Average dose estimates if releases would occur to a well or to a peat bog.

Beberg, -600 m

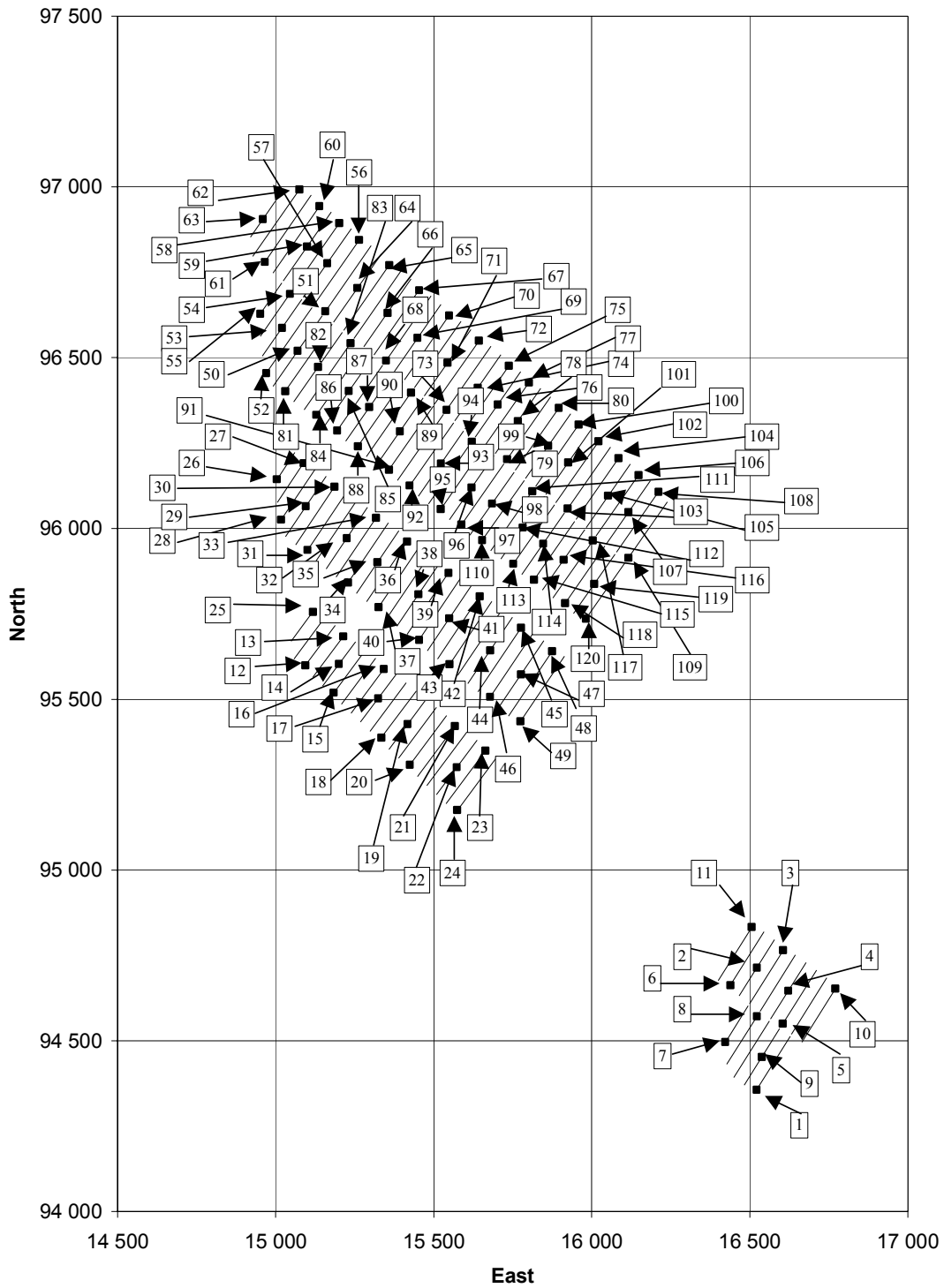


Figure All-1. The analysed positions within the repository area at Finnsjön. From /Gylling et al, 1999/.

For the transport calculations, all near field and far field input data were taken from extended versions of the SR 97 probabilistic radionuclide transport calculations /Hedin, 2002b/. The most important differences compared to the probabilistic calculations reported in SR 97 are:

- Uncertainty regarding the fuel dissolution rate is included by assuming a 90 percent likelihood of the rate being 10^{-8} /year and a 10 percent likelihood of it being 10^{-4} /year
- All distributions assumed to be discrete in SR 97 are now log-normal
- Distributions of biosphere dose conversion factors are taken directly as the output distributions from the biosphere, rather than being based on statistics of those results
- 17 radionuclides are modelled, rather than 9 in SR 97 and a number of variables given pessimistic constant values are now treated probabilistically, based on the SR 97 database
- The number of initial canister failures is a binomial distribution with an average of 10^{-3} , i.e. the design specification value.

These and other modifications of the SR 97 calculations are results of the ongoing efforts to improve the basis for the probabilistic dose estimates in upcoming safety assessments.

Figure AII-2 shows the results for the different calculations for each position. All input data distributions except q and F are the same for each position. The metric “average peat dose”, <Peat Dose>, should be interpreted in the following way: If **all** positions would have the same q and F distributions as the particular position being considered, and if the releases from **all** these positions would occur to the same peat bog, then a dose distribution with an average value of that shown in Figure AII-2 would be calculated. These doses are thus pessimistic upper limits of the doses that would be calculated if the spread of release locations to the biosphere had been taken into account. 5000 probabilistic realisations were run for each position, using Latin Hypercube Sampling. Figure AII-2 thus represents the results of 600,000 probabilistic realisations. The entire calculation of transmissions and doses was run overnight on a 1.7 GHz Personal Computer.

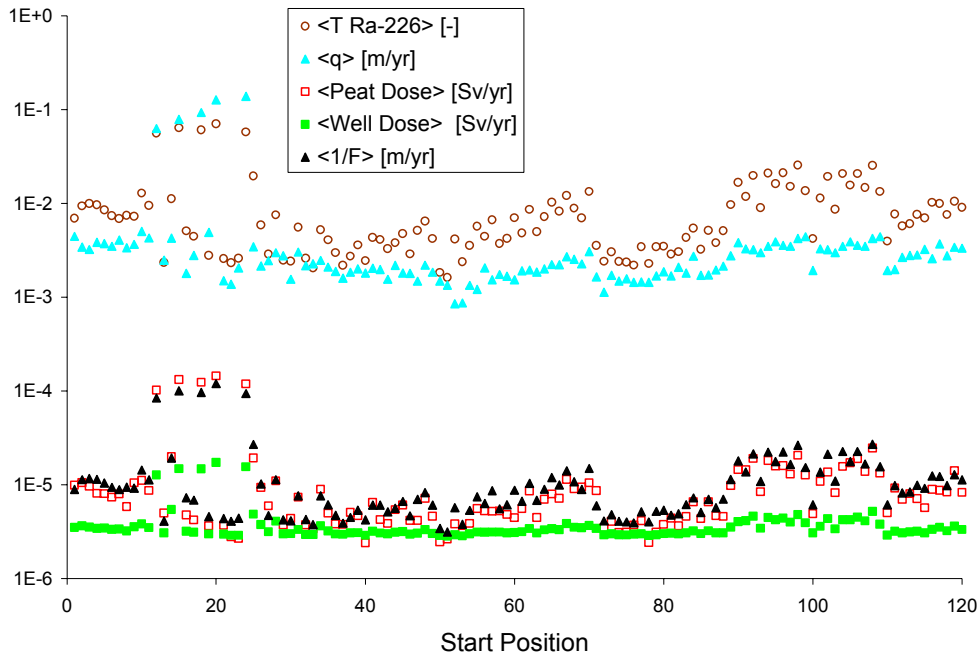


Figure AII-2. Retention metrics for the canister positions in Figure AII-2

It is clear from Figure AII-2 that several of the metrics are strongly correlated and that a few positions are associated with less favourable values of all the metrics than the majority of positions. In particular positions number 12, 15, 18, 20 and 24 (see Figure AII-1) have markedly higher values of all the metrics. Figure AII-3 shows the same data as Figure AII-2, but with the starting positions renumbered so that they are now ranked according to their <Peat Dose> value. This gives a more clear demonstration of the correlation between the different metrics. Based on these results, one could e.g. reconsider the suitability of the portion of the repository area containing the mentioned positions in Figure AII-1.

Figure AII-4 shows the resulting total average dose to a peat bog or to a well if an increasing number of the best canister positions were to be utilised. Excluding the five least favourable positions would yield a dose reduction from $1.3 \cdot 10^{-5}$ Sv/yr to $7.8 \cdot 10^{-6}$ Sv/yr. The effect can not be considered dramatic since the uncertainty in any of the total doses is at least one order of magnitude.

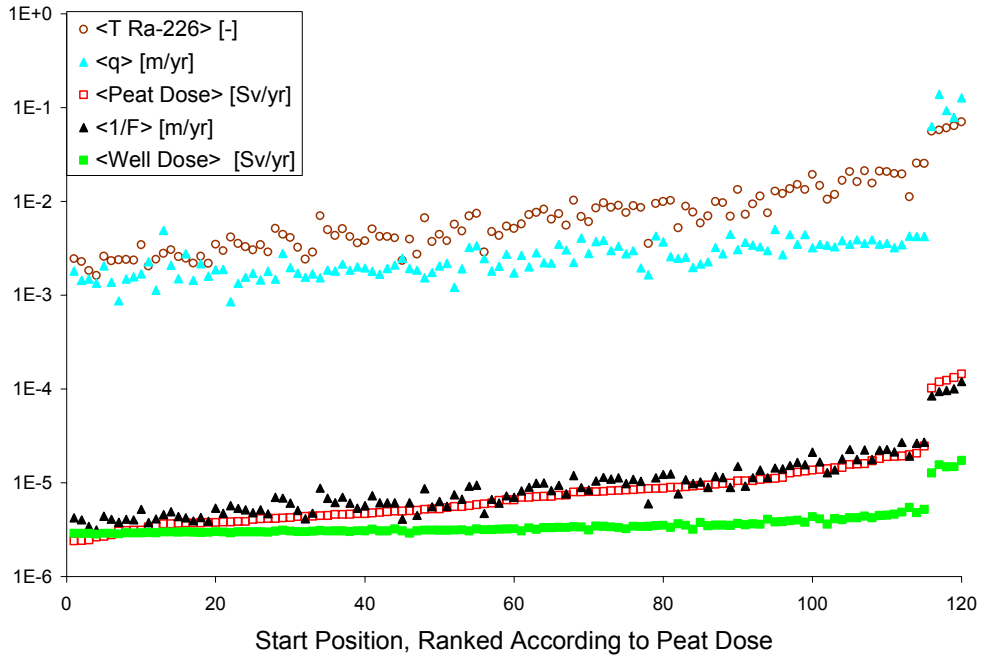


Figure AII-3. Retention metrics, with canister positions renumbered as ranked by the metric <Peat Dose>.

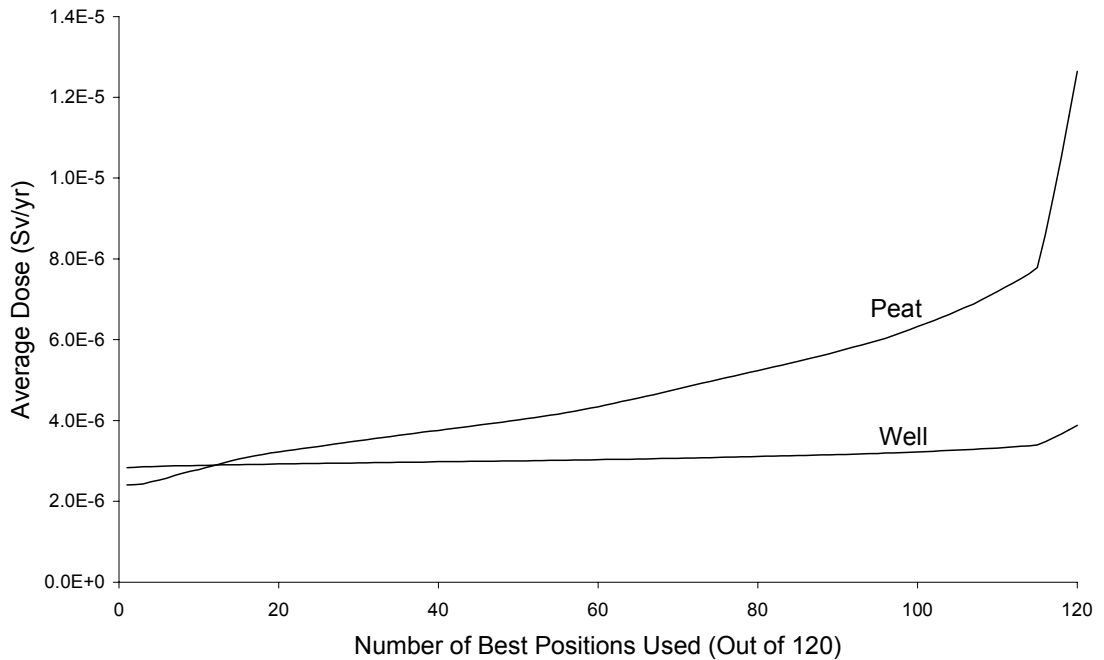


Figure AII-4. Average dose as a function of the number of best positions utilised for canister deposition.

In the preliminary safety evaluation, the types of analyses outlined above will be performed. The q and F distributions will be site specific. To the extent that the investigation program has also resulted in data on rock sorption, diffusivity and Peclet number, also these site specific data will be used. Otherwise, these latter data will be taken from e.g. one of the sites analysed in SR 97. This is motivated by sensitivity analyses of the SR 97 results which have demonstrated that the F distribution is the site specific input parameter that *i*) gives the highest contribution to output uncertainty in dose and *ii*) is the input parameter which can vary most pronouncedly between sites /Hedin, 2002b, 2002c/. Non site specific near field data will be taken from either the SR 97 database or from more recent sources.

In conclusion, the following has been demonstrated above:

- Probabilistic radionuclide transport calculations for a number of representative positions within a repository area are readily carried out with analytic models, once the position specific q and F distributions have been calculated probabilistically in a geohydrologic model.
- As expected, the metrics $\langle 1/F \rangle$, and $\langle T \rangle$ exhibit good correlation with dose. Also $\langle q \rangle$ is well correlated with dose, which is expected since q influences the near field release and since it is strongly correlated to F .
- The dose reduction obtained by excluding a reasonable number of deposition positions is limited in this particular case. The methodology appears useful in order to give feedback to refinement of the repository layout.

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