R-99-07

Geoscientific evaluation factors and criteria for siting and site evaluation

Progress report

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Summary

General

In SKB's work to site a deep repository for spent nuclear fuel, it is essential to present the factors and criteria that will be taken into account when evaluating possible sites for a deep repository. The purposes of the present report are to:

- present the work that has been done to identify the parameters that need to be determined in a geoscientific site investigation and that serve as the basis for the work with geoscientific evaluation factors,
- give a progress report from the project that was initiated in 1997 named Siting Factors and Criteria for Site Evaluation, with an emphasis on definitions, outline and structure for the execution of the work,
- present geoscientific requirements on function both generally and in detail in the form of an example for the discipline rock mechanics,
- present geoscientific evaluation factors associated with different stages in the siting work in the form of an example for the discipline hydrogeochemical composition,
- present plans for further work as regards criteria for site evaluation in different siting stages.

At the same time, the present report provides the account of siting factors requested by the Government in conjunction with its decision of 19 Dec. 1996 in response to SKB's RD&D-Programme 95.

The following main goals have been set up for the project Siting Factors and Criteria for Site Evaluation:

- to identify and quantify requirements and preferences regarding conditions and properties in the rock from the perspectives of long-term safety and technology,
- to identify geoscientific evaluation factors and propose criteria that can be used to assess whether requirements are satisfied and to compare sites prior to site investigations and detailed characterization.

The project is mainly concerned with the general siting factors that were presented in the supplement to RD&D-Programme 92 /SKB, 1994/ and the work that has been conducted to identify the parameters of importance to determine during geoscientific site investigation. The project is under way, and this is to be regarded as a progress report since e.g. criteria for site evaluation will be presented at a later date.

The long-term performance and safety of the deep repository must always be evaluated by means of an integrated safety assessment. The work with factors and criteria can never take the place of such an assessment, but can provide guidance regarding its outcome. The results can concretize how the most important geoscientific conditions and properties are used in the safety evaluation, but also include aspects related to repository layout, construction and environmental protection. The overall evaluation is called geoscientific site evaluation and has the following main purposes:

- to ensure that fundamental safety requirements and other essential technical prerequisites are satisfied on a given site,
- to ensure that the deep repository is optimally adapted to the conditions and properties of the site.

The evaluation should also serve as a basis for comparison of different sites, primarily with respect to long-term performance and safety, but also with respect to other evaluation factors related to the bedrock. The geoscientific evaluation of the sites should provide the site-specific material on the bedrock that is needed in support of an application for permits for detailed characterization and construction of a deep repository.

Requirements and preferences regarding repository performance

Requirements and preferences regarding the function of the rock in the deep repository have been clarified in this progress report. These requirements and preferences are based on SKB's experience of safety assessments and construction analyses. What is new here is the structuring that has been carried out, with a classification into different geoscientific disciplines, and the formalism that has been given to the terms requirement, preference and function. This is a prerequisite for a consistent and hopefully complete presentation of requirements. Based on fundamental safety and construction functions, requirements on function have been specified for the disciplines geology, thermal properties, hydrogeology, rock mechanics, chemistry and transport properties. Furthermore, function analyses have been identified by means of which it is possible to concretize requirements on function and which geoscientific parameters are thereby involved.

Geoscientific evaluation factors

The term "siting factors" is used in many different contexts when siting of a deep repository is discussed. In the feasibility studies, use is made of general siting factors, which determine whether an area is suitable for further studies. The factors are divided into the following main groups:

Safety	Siting factors of importance for the long-term safety of the deep repository.
Technology	Siting factors of importance for the construction, performance and safe operation of the deep repository and for the transportation system to the deep repository.
Land and environment	Siting factors of importance for land use and general environmental impact.
Societal aspects	Siting factors connected to political considerations and community impact.

It can be noted that the term "geoscientific evaluation factors" is used in the present work. It is a delimitation in the sense that the focus is on questions surrounding technology and long-term safety. The geoscientific evaluation factors comprise a subset of all the geoscientific parameters that can be determined in a site investigation.

Requirements and preferences regarding the deep repository, and thereby the rock, are primarily formulated with respect to function and not directly for individual parameter values. In a similar manner as for requirements and preferences regarding the function of the rock, the evaluation factors have been arranged per geoscientific discipline.

A geoscientific parameter that can be measured or estimated in site investigations is considered to be a suitable evaluation factor if one of the following conditions is fulfilled:

- a direct requirement or an essential preference has been formulated for the parameter, or
- the parameter is expected to have a great influence on the result of one or more important function analyses.

Based on a preliminary list of possible evaluation factors, the level of knowledge that can or should be reached after the feasibility study, site investigation and detailed characterization have been completed is also discussed. It is not reasonable to designate a geoscientific parameter as an evaluation factor if the parameter cannot be measured or estimated with sufficient accuracy.

Criteria for site evaluation

Criteria for site evaluation will also be determined in the future work. A criterion is an application of evaluation factors in a given stage of the siting process as a basis for a decision. The criteria must be able to be used to judge whether a site satisfies stipulated requirements or not. When it comes to geoscientific parameters, criteria consist of indicative values or value ranges for measured or estimated evaluation factors. When it comes to repository performance, criteria consist of indicative values or value ranges of outcomes of performance assessments. The criteria can be changed during the course of the siting work as the information available on the sites changes. But requirements and preferences remain the same.

Criteria need to be linked to the information quantity that is available in the particular siting stage in question and to the decision situation in which they are to be used.

- Prior to a site investigation, it is important to be able to rule out obviously unsuitable sites and furthermore to be able to identify sites with good prospects of turning out to possess suitable properties. Criteria cannot be made too strict at this stage, in view of the limited information that is then available on the properties of the rock at depth. The criteria will be used to select suitable sites for further investigations.
- After completed site investigation, it should be able to be demonstrated with great certainty whether a site is suitable or unsuitable as a deep repository site. Further, it may be meaningful at this point to use criteria to compare sites. Even though the overall evaluation of the suitability of the sites is determined within the framework of an integrated safety assessment and an integrated construction analysis, the specified criteria should provide good guidance regarding the results of such an integrated assessment/analysis.

Criteria for evaluation of whether a site is suitable or unsuitable are based on the importance of the different evaluation factors and an assessment of the accuracy of the available information. These criteria can therefore be based on the evaluation factors already arrived at.

1 Introduction

1.1 Background

The Government's decision of 19 Dec. 1996 in response to SKB's RD&D-Programme 95 /SKB, 1995a/ entailed, among other things, that General Siting Study 95 /SKB, 1995b/ ought to be supplemented

> "…by giving a more detailed account of the factors that should govern the selection of a site suitable for a final repository for spent nuclear fuel and long-lived radioactive waste. SKB should also give an account of the consequences of a near-coast location versus an inland location of the repository and the consequences of a location in southern versus northern Sweden."

This supplementary information was to be reported in conjunction with the next research and development programme, i.e. in RD&D-Programme 98. The present report constitutes the account of site selection factors requested by the Government. Questions concerning coastal/inland location ("coast-interior") and comparisons between northern and southern Sweden ("north-south") are dealt with elsewhere /Leijon, 1998/.

The Government decision also says that concerned municipalities are to have access to the following information before the siting work progresses to site investigations on at least two sites:

- an integrated account of general siting studies and feasibility studies,
- other background and comparison material,
- criteria for evaluation of the sites, and
- factors which preclude further studies on a site.

This report deals with the last two points, even though further light will be shed on them before the siting work progresses to site investigations.

Precisely defined factors and criteria are of vital importance for evaluating candidate sites. In 1997, SKB therefore initiated the project *Siting Factors and Criteria for Site Evaluation.* The following main goals have been set up:

- to identify and quantify requirements and preferences regarding conditions and properties in the rock from the perspectives of long-term safety and technology,
- to identify geoscientific evaluation factors and propose criteria that can be used to assess whether requirements are satisfied and to compare sites prior to site investigations and detailed characterization.

Criteria in site evaluation are mainly intended to be used to ensure that fundamental safety requirements and other essential technical premises are satisfied on a given site. In addition, comparisons of sites can be made based on different evaluation factors. The criteria that can then be set for selecting a site will necessarily be relatively vague prior to the site investigations. At this stage, site-specific information on the bedrock conditions at depth are lacking in most cases, and judgements must be made based on incomplete and uncertain material. More precise criteria can be formulated for the stage after site investigations.

The evaluation of the safety and technical performance of the deep repository is based, among other things, on a weighing-together of results of safety and performance assessments and construction analyses. These are in turn based on a geoscientific descriptive model of the repository area based on measurement data and observations from the site in question – see Figure 1-1. From general safety requirements, specific functional requirements can be derived, which in turn can be broken down into quantitative or qualitative requirements on certain parameters for the rock. The safety requirements on the deep repository can, however, be satisfied in different rocks with different and/or varying conditions. The layout of the repository can – with given safety requirements within relatively wide limits – be adapted to the conditions prevailing on a given site. It is therefore not always meaningful to translate general requirements into specific requirements on the parameters of the rock. The safety of a deep repository on a given site must in the end always be evaluated by means of an integrated safety assessment using data from that particular site.

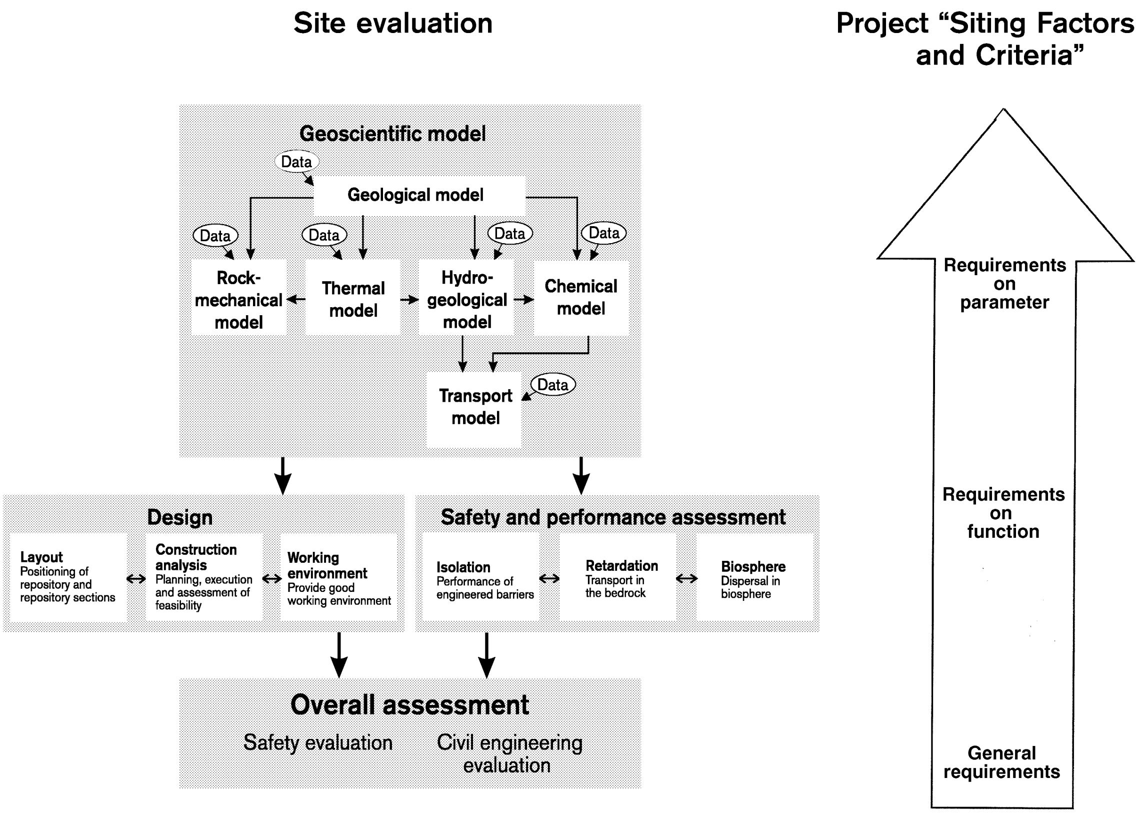

Figure 1-1. *Illustration of how geoscientific models are utilized for design and for safety and performance assessment. Note that the work with siting factors proceeds in the opposite direction compared with these assessments and evaluations. Starting from overall requirements, requirements on function are arrived at, which are broken down wherever possible to the parameter level.*

1.2 Purpose of the report

In summary, SKB wishes with the present report to:

- Present the work that has been done to identify the parameters that need to be determined in a geoscientific site investigation /Andersson et al. 1996/ and that serve as the basis for the work with geoscientific evaluation factors.
- Give a progress report from the project that was initiated in 1997 named Siting Factors and Criteria for Site Evaluation, with an emphasis on definitions, outline and structure for the execution of the work.
- Present geoscientific requirements on function both generally and in detail in the form of examples for the discipline rock mechanics.
- Present geoscientific evaluation factors associated with different stages in the siting work in the form of an example for the discipline hydrogeochemical composition.
- Present plans for further work as regards criteria for site evaluation in different siting stages.

Even though the project has been limited to the perspectives long-term performance, safety and construction technology, other factors are also discussed briefly in the present report, i.e. societal aspects, transport factors and land and environment questions, see Chapter 3.

2 Project: Siting factors and criteria for site evaluation

2.1 Previous experience

General siting factors have been presented previously by SKB, for example in conjunction with the supplement to RD&D-Programme 92 /SKB, 1994/. These factors were then accepted by the Government and regulatory authorities "…as a suitable point of departure for further work". At the same time, SKB considered it necessary to define factors and criteria more precisely prior to the site investigations. In General Siting Study 95 /SKB, 1995b/, SKB has reported on conditions on a national scale that are supposed to provide a general background to the fundamental prerequisites for siting of a deep repository. In 1996, an extensive project was carried out to identify all the parameters to be determined during a geoscientific site investigation. The results were published in a separate report /Andersson et al., 1996/.

It can also be noted that the term "siting factor" is used in many different contexts when siting of a potentially environmentally harmful activity is discussed. In this work, with a focus on a deep repository for spent nuclear fuel, a siting factor is to be regarded as a geoscientific evaluation factor. This is a delimitation in the sense that the focus is on questions surrounding technology and long-term safety. In this report and in all future work within the framework of the project, the term "geoscientific evaluation factor" is utilized.

2.2 Site evaluation

During the site investigation stage, SKB plans to carry out geoscientific investigations including drillings on at least two sites. The results of the investigations will be analyzed and the suitability of the sites for a deep repository evaluated. On this basis, one of the sites will be selected for an application for permits for detailed characterization and construction of a deep repository. Geoscientific site evaluation includes analyses and evaluation of geoscientific conditions and prerequisites with respect to the long-term performance of a deep repository, its radiological safety, its adaptation to the site and the rock, and its construction.

The geoscientific site evaluation has the following main purposes:

- to ensure that fundamental safety requirements and other essential technical prerequisites are satisfied on a given site,
- to ensure that the deep repository is optimally adapted to the conditions and properties of the site.

The evaluation should also serve as a basis for comparison of different sites, primarily with respect to long-term performance and safety, but also with respect to other evaluation factors related to the bedrock. Figure 2-1 illustrates how the activity "geoscientific site evaluation" utilizes results from the project "Siting Factors".

The geoscientific site evaluation can be regarded as the motor for the interaction between the different technical activities in conjunction with geoscientific investigations.

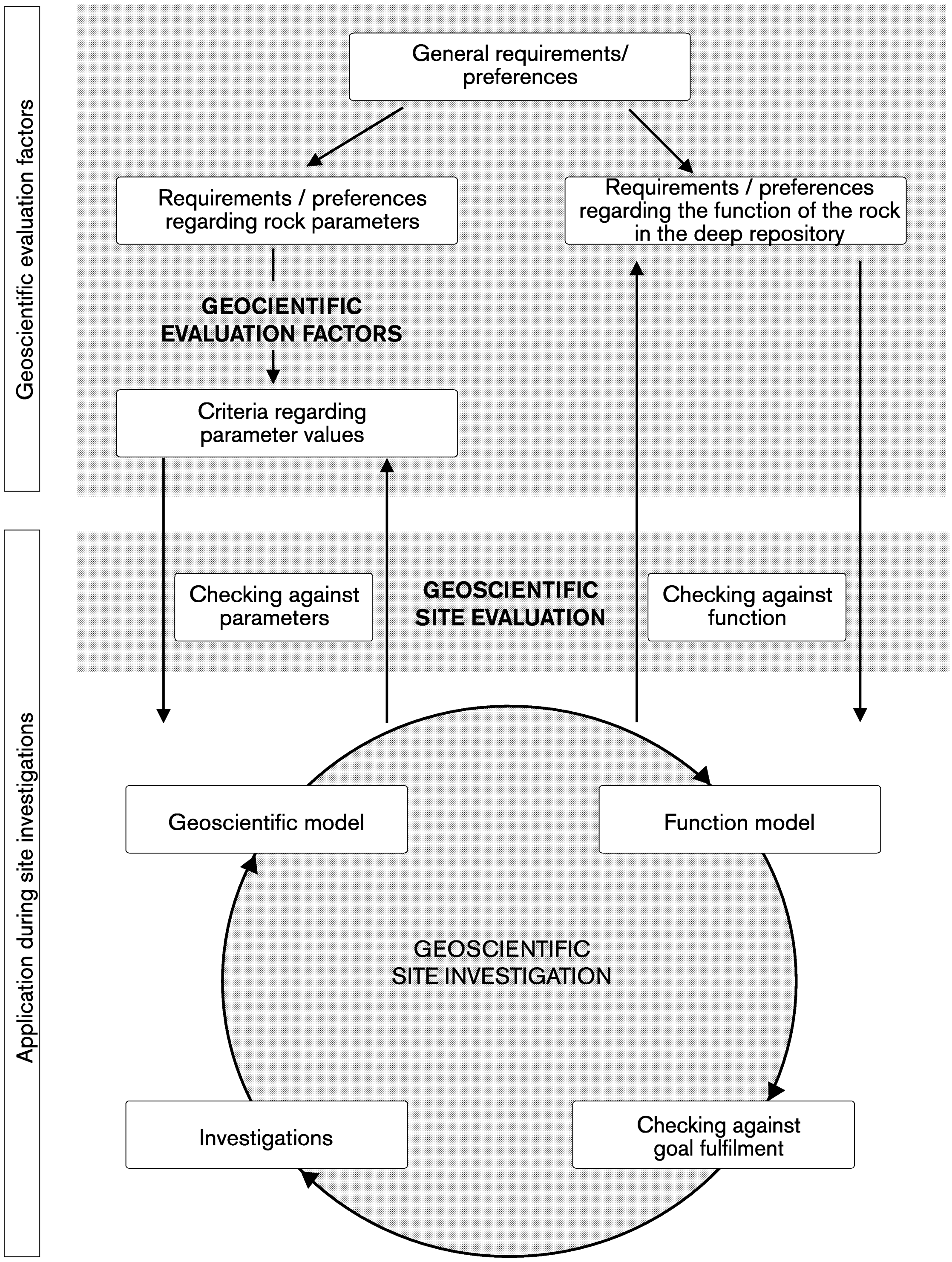

Figure 2-1. Illustration of the activity "geoscientific site evaluation". Checking against requirements and criteria takes place at different times during the course of the work.

2.3 Project goals

The project "Siting Factors and Criteria for Site Evaluation" is intended to give results that can be used in the evaluation of sites. The project comprises an important part of the work of siting and site selection that has been pursued since RD&D-Programme 92. The following main goals have been set up for the project:

- to identify and quantify requirements and preferences regarding conditions and properties in the rock from the perspectives of long-term safety and technology,
- to identify geoscientific evaluation factors and propose criteria that can be used to assess whether requirements are satisfied and to compare sites prior to site investigations and prior to detailed characterization.

The siting stages referred to here are mainly:

- prior to site investigation, i.e. selection of sites for site investigation, based on information from feasibility studies and national and regional general siting studies,
- after site investigation, i.e. selection of site for detailed characterization and construction of the deep repository, based on information from completed site investigations.

The project is described more fully in the following chapters. A final account will be given during 1999.

2.4 Premises

The following premises apply for the project:

- The identified factors should in principle not differ from those applied in general siting and feasibility studies. The evaluation grounds shall be consistent through all siting and investigation stages.
- Reported requirements, factors and criteria do not take the place of the need to carry out broad and thorough construction analyses and safety assessments on investigated sites.
- The project is limited to the formulation of requirements, preferences, factors and criteria. There are, however, many links to the development of a site evaluation programme.
- Requirements and preferences pertain to a KBS-3-like repository, situated at a depth of approximately 500 m in crystalline bedrock in Sweden.
- The project is limited to the properties of the rock and the soil. This delimitation entails that matters pertaining to e.g. transportation, land use and management of natural resources, as well as societal factors, are not dealt with other than superficially. These factors are dealt with in other parts of SKB's siting studies.
- Requirements and preferences regarding the rock can mainly only be stipulated with regard to the function of the rock, which is normally evaluated by performance and safety assessments and construction analyses. When possible, however, these requirements and preferences shall be concretized so that they apply to the properties of the rock. Requirements and preferences formulated from the different perspectives of long-term safety and technology shall be mutually consistent.

- Factors and criteria that can be applied during detailed investigation and repository construction are not discussed in this project. To be able to formulate requirements and preferences, however, it may be necessary to discuss parameters that can only be meaningfully determined at these later stages.
- To be able to determine requirements and preferences regarding the properties of the rock from the perspective of performance and safety, feedback to ongoing safety assessment work (SR 97) is required.

2.5 Terms and definitions

The terms "factors" and "criteria" are sometimes used with somewhat different meanings when siting of a deep repository is discussed. Stricter definitions of these concepts and some associated terms are made for this project. The intention is to clarify the goals of the project and the description of the activities that must be carried out to achieve these goals. The definitions do not conflict with the ordinary meanings of the words. The following definitions are used (see also Tables 2-1 and 2-2):

- By the "function" of a deep repository is meant purposes which the deep repository is intended to serve, for example to have an isolating and retarding function. Example of function: the canister should isolate the waste from the surroundings, the rock should retard escaping radionuclides. By "performance" is meant how well this function is served.
- By "parameter" is meant a physical or chemical quantity (property and condition in the rock) of relevance to the deep repository. A parameter can assume different values. Example: orientation of water-bearing structures, flow porosity, pH.
- By "requirements" is meant conditions that must be satisfied, while "preferences" refer to conditions that ought to be satisfied. May relate to either function or individual parameters. The requirements define absolute limits for what is not acceptable on a site, while the preferences are negotiable. Example: the requirement the parameter "groundwater at repository level free from dissolved oxygen" can be established based on the fundamental safety function "good isolating capacity".
- By "geoscientific evaluation factors" is meant parameters (i.e. conditions and properties) for which there exist site-specific values or assessment grounds and which can be used at one or more stages of the siting work to determine to what extent requirements and preferences are satisfied. Example: the redox potential of the groundwater in conjunction with site investigations.
- By "criteria for site evaluation" is meant indicative values of evaluation factors in a given siting stage that are decisive for the assessment of whether a site satisfies stipulated requirements and preferences. Criteria are changeable with changes in knowledge. A criterion is coupled to an action or a decision. Example: measured Eh< -100 mV for water samples during site investigation could be used as a criterion for verifying the requirement that the groundwater must not contain dissolved oxygen at repository depth.

Requirements and preferences pertain to actual conditions and they remain the same during different stages of the siting work. The only thing that could change requirements and preferences is if the fundamental premises change, for example if the repository concept is modified or new general knowledge is obtained. Satisfying preferences generally leads to lower costs, simpler investigations or a simpler design of the repository. All preferences do not have to be satisfied in order for a site to be approved as a deep repository site. Unsatisfied preferences can be compensated for by changes in repository layout so that the overall requirement on safety is nevertheless satisfied.

The distinction between requirements and criteria is necessary, since geoscientific investigations never provide complete knowledge of the properties of the rock. When assessing site-specific data, it is therefore necessary to evaluate the precision of the parameter estimate against stipulated requirements and preferences. An evaluation factor, and thereby a criterion as well, is based on something that can be measured or estimated. An example in Chapter 6 (Table 6-1) further illustrates these differences between requirements/preferences and criteria. Note once again that evaluation factors and criteria are associated with different stages in the siting work.

Requirements and preferences regarding function are thoroughly discussed in Chapter 3. Geoscientific parameters and evaluation factors are described in Chapter 4. Criteria for site evaluation are dealt with in section 6.1.

Table 2-1. Brief definitions of terms used.

Term	Definition
Function	Purpose which the deep repository is intended to serve, for example to have an isolating and retarding function.
Parameter	Physical or chemical quantity (property and condition in the rock).
Requirement	Condition that must be satisfied, refers to actual conditions regardless of siting stage.
Preference	Condition that ought to be satisfied regardless of siting stage. All preferences do not have to be satisfied, however.
Geoscientific evaluation factors	Measurable or estimable site-specific properties that can be used in a given siting stage to assess whether requirements and preferences are satisfied.
Criteria for site evaluation	Values for evaluation factors in a given siting stage that are decisive for the assessment of whether a site satisfies stipulated requirements and preferences, particularly on performance and safety.

Table 2-2. Definitions of various terms presented from an etymological viewpoint.

Term	Definition
Factor	Something (as an element, circumstance, or influence) that contributes to the production of a result: *people and people's doings are the essential ~; such ~s as availability of adequate power, transportation, and a labor source must be considered in appraising an industrial site;* fr. Latin *factor,* maker, doer. *Synonyms:* Important circumstance; influential force; constituent, element, ingredient *Other uses:* 1) any of the quantities in a multiplication 2) commercial agent who sells or buys goods on commission for others
Function	The action for which a person or thing is specially fitted or used: *the ~ that older people can perform in city life today; it is the ~ of stockholders to assume the risk; glass has an important ~ in modern architecture; literary criticism serves complex psychological and sociological ~s;* fr. Latin *function,* performance. *Synonyms:* Role, duty, use, purpose *Other uses:* 1) either of two magnitudes so related to each other that to values of one there correspond values of the other 2) the performance or fulfilment of a function
Requirement	Something required, something that is wanted or needed, something called for or demanded, a requisite or essential condition: *production was not sufficient to satisfy both civilian and governmental ~s for automobiles; permit agriculturalists to buy their ~s upon favorable conditions.* *Synonyms:* Necessity, demand, prerequisite
Criterion	A characterizing mark or trait, a standard on which a decision or judgement may be based, a standard of reference: *increased speed, climb, and ceiling, three of the four basic criteria of air combat; the accepted criteria of adequate diet;* fr. Greek *kriterion, krites*, judge, separate, decide. *Synonyms:* Yardstick, standard *Other uses:* 1) an expression by whose value varieties of a mathematical form may be distinguished
Parameter	A measurable or quantifiable characteristic or features; an arbitrary constant characterizing by each of its values some member of a system, a quantity that describes a statistical population: *we now develop an equation which, for suitable choice of a ~, will represent either a parabola, an ellipse, or a hyperbola; a clear distinction should always be drawn between ~s and estimates, i.e. between quantities which characterize the universe, and estimates of those quantities calculated from observations;* fr. Greek *para + metron,* beside + measure.
Preference	Someone or something that is preferred, an object of choice: *which is your ~?;* fr. Latin *praeferens,* pres. part. of *praeferre*, to prefer, which means to like better or value more highly. *Synonyms:* Favorite, choice

Sources:
Webster's Third New International Dictionary, unabridged, 1976.
Merriam-Webster's Collegiate Dictionary, 1994.
The Concise Oxford Dictionary of Current English, Eighth Edition, 1990.

3 Requirements and preferences regarding repository performance

3.1 Introduction

It might seem desirable to formulate requirements and preferences that pertain directly to the geoscientific parameters that can be measured or estimated in a coming site investigation. On closer consideration, however, it becomes clear that the requirements and preferences that can be formulated with regard to the deep repository mainly apply to an intended function. An analysis of the function includes a number of geoscientific parameters, and in some cases the requirements on a given function can, after analysis, be broken down into requirements on individual parameters. In many cases, however, it is difficult to carry out this breakdown, and only a few geoscientific parameters can be subject to requirements. It is for this reason, among others, that the present report and the project initially focus on the function concept.

Based on overall safety requirements, SKB has in earlier studies, mainly in /SKB, 1994/ and in the feasibility studies, formulated fundamental safety functions regarding isolation, retardation and biosphere conditions. The work of designing the deep repository is predicated in a similar manner on requirements and preferences with regard to repository layout, construction analysis and working environment. The following structure is used here, which also corresponds to the work sequence in the project (see also Figure 3-1):

Based on fundamental safety and civil engineering functions (Chapter 3):

- identify and specify requirements and preferences regarding function for the disciplines geology, thermal properties, hydrogeology, rock mechanics, hydrogeochemistry and transport properties,
- identify function analyses which can be used to concretize the requirements on function, and which geoscientific parameters are thereby involved.

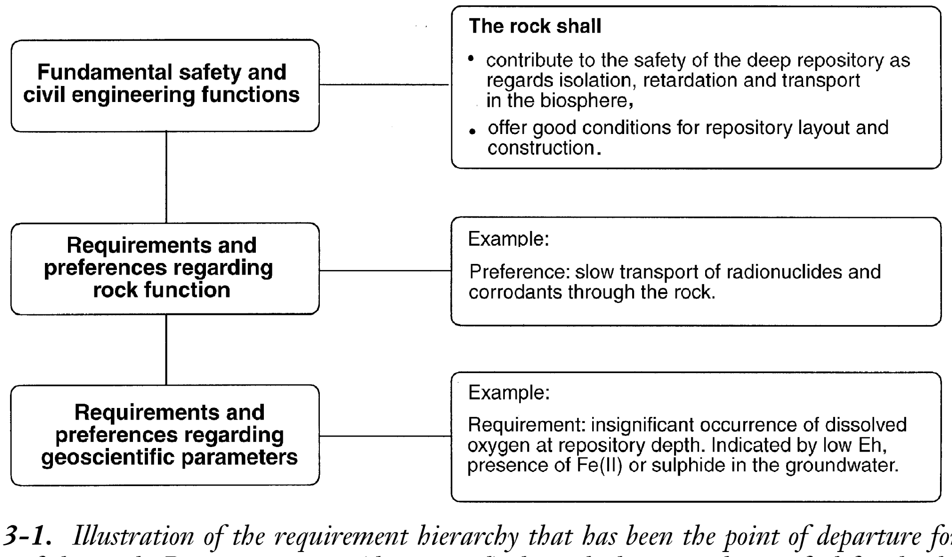

Figure 3-1. *Illustration of the requirement hierarchy that has been the point of departure for the execution of the work. Requirements on (the site and) the rock that must be satisfied for the deep repository to be considered safe for disposal pertain to actual conditions, regardless of siting, construction or operating stage.*

Based on requirements and preferences regarding function (Chapter 4):

- identify and specify requirements and preferences regarding parameters for the disciplines geology, thermal properties, hydrogeology, rock mechanics, hydrogeochemistry and transport properties,
- identify which parameters can constitute evaluation factors in a given siting stage.

3.2 Fundamental requirements on the deep repository

There are fundamental requirements that must be met by a deep repository. These requirements are defined by laws and regulations issued by the regulatory authorities. In addition, SKB has specified more precisely defined requirements and preferences regarding the different parts of the deep repository.

3.2.1 Acts, ordinances and regulations

Nuclear Activities Act and Radiation Protection Act

Requirements on safety and radiation protection in a deep repository are set forth in the Nuclear Activities Act and the Radiation Protection Act. The Nuclear Activities Act prescribes in general that nuclear activities shall be conducted in a safe manner. The Radiation Protection Act prescribes in general that anyone conducting activities with radiation shall, depending on the nature of the activities and the conditions under which they are conducted, adopt whatever measures and precautions are needed to prevent or counteract harm to humans, animals and the environment. The ordinances issued by the Government pursuant to the Nuclear Activities Act and the Radiation Protection Act contain some more detailed provisions and regulate SKI's and SSI's activities, but are still couched in very general terms regarding requirements on the safety and radiation protection of the deep repository.

Proposed regulations from SKI and SSI

In addition to the laws mentioned above, SKI and SSI are empowered to issue regulations.

The National Radiation Protection Institute (SSI) recently issued regulations concerning final disposal of spent nuclear fuel /SSI, 1998/. Some provisions of these regulations have a bearing on the work with siting factors and criteria. The final disposal of spent nuclear fuel shall be radiologically optimized and based on the best available technology. Final disposal shall be planned so that the annual risk of injury after closure is no more than 10^{-6} for the individual exposed to the greatest risk. Furthermore, final disposal shall be carried out in such a manner that biological diversity is preserved and a sustainable utilization of biological resources is protected against the harmful effects of radiation.

The Swedish Nuclear Power Inspectorate (SKI) has produced a memorandum /SKI, 1997/ concerning premises for regulations governing safety in the final disposal of spent nuclear fuel etc. It is stated there that safety, in both the short and long term, shall be based on multiple engineered and natural barrier functions so that any deficiencies that might occur with reasonable likelihood in one barrier function do not impair the performance of the entire repository. Based on a main scenario, analysis cases that are relevant to long-term performance should be formulated. These cases shall cover both uncertainties in external events and natural variation in the geological, hydrogeological, hydrogeochemical and mechanical properties of the site and in the engineered barriers. Based on the main scenario, design-basis cases for the performance of the barrier system can be identified, i.e. cases that are determinant for requirements on barrier properties so that the safety criteria will be satisfied.

The question of whether the fundamental requirements are met for a deep repository on a specific site will be considered in conjunction with the regulatory review of the safety assessments and environmental impact statements which SKB will submit.

Finally, it can be observed that regulations do not directly stipulate requirements on the performance of different parts of the deep disposal system, but discuss in more general terms requirements on the system as a whole. Concretization to a given system is SKB's responsibility.

3.2.2 Fundamental safety functions

The supplement to RD&D-Programme 92 /SKB, 1994/ presented fundamental safety functions of a deep repository, generally favourable conditions and factors that are disqualifying for the possibility of siting and building a safe deep repository. Based on the fundamental safety functions and on favourable and unfavourable conditions, siting factors were identified. The structure is shown in Figure 3-2. In the present report, this structure has been taken as a point of departure for specifying requirements on repository performance.

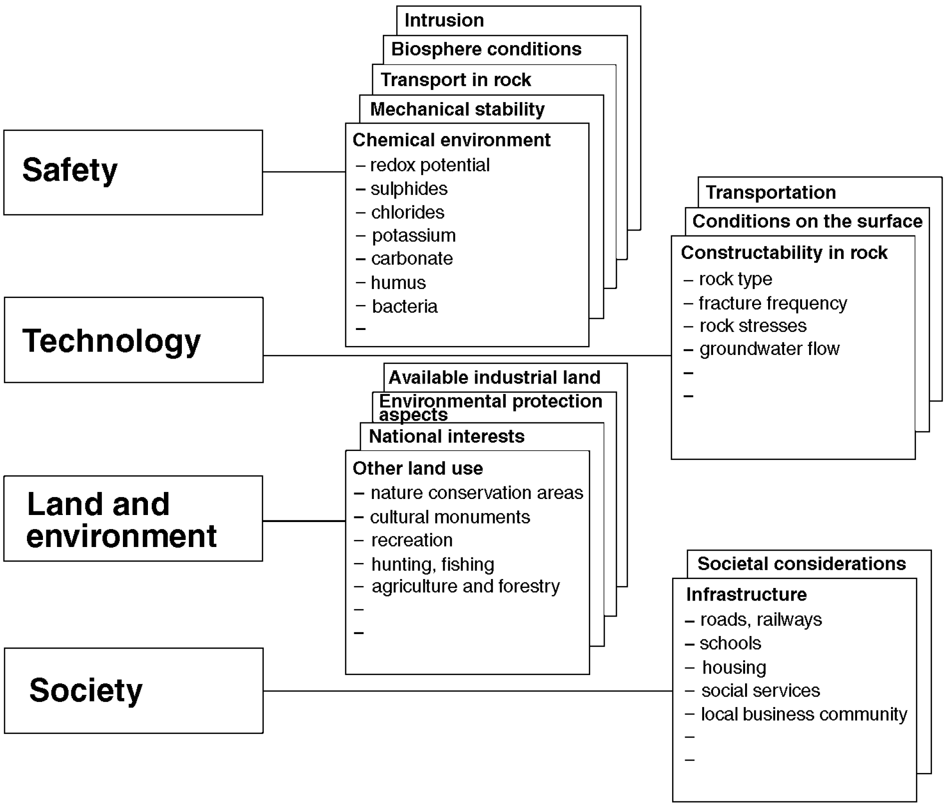

Figure 3-2. *The structure for discussion concerning fundamental safety functions and siting factors that was introduced in conjunction with the supplement to RD&D-Programme 92. Requirements on function (Chapter 3) and evaluation factors (Chapter 4) are further defined in the present report.*

The present report uses the following formulations of SKB's fundamental safety functions:

- **Isolation canister**
  The canister shall isolate the waste from its surroundings.
- **Isolation bentonite**
  The bentonite shall contribute to the isolation of the waste, mainly by creating favourable conditions for the canister.
- **Isolation rock**
  The rock shall contribute to the isolation of the waste, mainly by creating favourable conditions for the bentonite and the canister.
- **Intrusion**
  The waste shall be protected against inadvertent intrusion.
- **Retardation waste**
  Dissolution of the waste, i.e. release of radionuclides, shall take place very slowly.
- **Retardation canister**
  The canister shall, if isolation fails, prevent or retard the transport of radionuclides from the fuel to the bentonite.
- **Retardation bentonite**
  The bentonite shall retard the arrival of released radionuclides in the rock/geosphere.
- **Retardation rock**
  Transport of radionuclides (as well as transport of groundwater with unsuitable chemistry) shall be retarded.
- **Biosphere conditions**
  Effective radiation doses to individuals of a potentially exposed group shall not exceed levels specified in SSI's regulations. Furthermore, the impact of the deep repository on biological diversity shall be small. A preference is that dilution should take place to low concentrations in the biosphere of substances from the repository that may be carried up towards the ground surface.

If the layout or intended functions of the deep repository as described above are changed in a decisive manner, the more precisely defined requirements and preferences will also need to be revised.

3.2.3 Fundamental civil engineering aspects

Requirements and preferences that are framed from the perspective of planning and design of the rock works are of a somewhat different character than the direct safety requirements. The repository layout is designed primarily to achieve as good performance and safety as possible: canister and tunnel spacing is determined by requirements on temperature in and around the repository, major discontinuities are avoided, etc. Furthermore, pure rock excavation aspects such as water seepage, rock stresses and unstability will be taken into account.

The overall safety function for a given repository layout must be checked in a safety assessment. The given repository layout also gives the premises for the construction analysis, where constructability, time and material consumption, working environment etc. of the rock excavation work are analyzed. If the safety assessment or construction analysis reveals unacceptable consequences or costs for the chosen layout, then it needs to be changed. In other words, the construction analysis, as well as working environment considerations, do not impose any direct requirements, since adaptations can generally be made to suit prevailing conditions. There are, on the other hand, a number of factors that influence constructability and costs.

3.2.4 Other general requirements

As noted earlier, the work reported here is restricted to the properties of the rock and the soil. This delimitation entails that matters pertaining to e.g. transportation, management of natural resources (including different protected areas) and societal factors are not dealt with in the present project. The fundamental requirements that have previously been formulated for these other perspectives /SKB, 1994/ are therefore recounted in this section in order to complete the general requirement picture.

Transportation

The requirement of safe transportation can be satisfied by the use of appropriate technology and necessary investments. All transport to the site of the deep repository shall take place in compliance with applicable rules and regulations. An analysis of safety and environmental and radiation protection in connection with transportation shall be included in the environmental impact assessment (EIA). If new construction of road or railway is required, an analysis of the effects on the environment shall be included in the environmental impact statement (EIS).

Conditions on the surface

The surface facilities shall be designed and equipped so that the requirements on safety, worker protection, radiation protection and environmental protection are satisfied. An analysis of the safety and environment of the surface facilities shall be included in the EIS. The requirements that are made on the bearing capacity of the soil do not differ from what is required for other construction projects.

Land and environment

The site for the deep repository shall have:

- few competing interests for land use,
- good prospects for being able to build and operate the facilities in compliance with all environmental protection requirements.

Societal aspects

The siting of a deep repository shall be carried out so that:

- Investigation activities in different stages, as well as construction, commissioning and operation are firmly rooted in a democratic decision-making process.
- Social and socioeconomic consequences are taken into consideration.

Summary

Requirements and preferences from the perspectives of transportation, land and environment, societal factors etc. were formulated in /SKB, 1994/. Siting factors related to these requirements and preferences have been applied in completed or ongoing feasibility studies. This is further discussed in section 5.2.

Ongoing and coming EIA consultations deal with these matters and can in the long term contribute towards developing or clarifying these other aspects.

3.3 Detailed requirements and preferences regarding repository performance

One of the goals of the first phase of Project Siting Factors has been to clarify requirements and preferences regarding the function of the bedrock where the deep repository is located. These requirements and preferences are based on SKB's experience of safety assessments and construction analyses. What is new here is the structuring that has been carried out, with a classification into different geoscientific disciplines, and the content that has been given to the terms requirement, preference and function. This is a prerequisite for a consistent and hopefully complete presentation of requirements from a functional perspective.

3.3.1 Structure for the work – function tables

Requirements from a functional perspective have thus been arranged by geoscientific discipline. The structuring has been carried out with the aid of tables divided into the disciplines geology, thermal properties, hydrogeology, rock mechanics, hydrogeochemistry and transport properties. Each discipline gives rise to a table whose rows correspond to the fundamental safety functions.

Further, each table is divided into the following columns (see Table 3-1):

- fundamental safety function/civil engineering aspect,
- specific conditions that influence function,
- requirements regarding function,
- preferences regarding function,
- function analysis and concerned parameters, and
- references and other comments.

The purpose of these columns is discussed in the following. The example in Table 3-1 is taken from the discipline "transport properties" and the fundamental safety function pertaining to the isolating function of the canister. The preference is couched in general terms. Function analyses have been identified by means of which the preference can be more precisely defined.

Table 3-1. Structure for presentation of requirements and preferences regarding the rock that is utilized in the ongoing project concerning siting factors.

Fundamental safety function	Transport conditions that influence function	Requirements regarding rock's transport function	Preferences regarding rock's transport function	Function analysis and concerned parameters	References and other comments
Isolation canister The canister shall isolate the surroundings	Influx of oxygen and other corrodants		Limited influx, i.e. slow influx of long duration or high but brief loading can be tolerated	• Analysis of mass transport of corrosion process (see also table for hydrogeology and chemistry • Model of local groundwater flow (see also table for hydrogeology, chemistry and fracture aperture in deposition hole)	Ahonen et al., 1994, YJT-94-13. Worgan et al., 1996, SKI TR 96:46.

Fundamental safety function

Fundamental safety functions have been discussed in section 3.2.

Specific conditions that influence function

The discipline-specific conditions of importance, i.e. the ones that can influence function, are given for each fundamental safety function.

Requirements regarding function

Discipline-specific requirements are given where possible. In principle, only prohibitive requirements are noted here, i.e. if the requirement is not satisfied, this means that the site for the deep repository is unsuitable or that the repository layout has to be decisively modified. Furthermore, the safety function is not automatically satisfied even if all requirements are met. The requirements should indicate limits for what is *not* acceptable, not for what is acceptable.

Preferences regarding function

Discipline-specific preferences are given where possible. The preferences should provide guidance on what is needed in order for a performance or safety assessment to result in acceptable conditions. The preferences can thereby relate to e.g. known value ranges for acceptable function, but do not have to define the exact limit for unacceptable function, since such a limit is in many cases relative, unknown or can be influenced by modification of the repository layout.

In support of a siting application for permits for detailed characterization and construction of a deep repository, a complete safety assessment must in any case be carried out. If essential preferences are satisfied, this should lead to acceptable safety for the deep repository and good constructability as shown by the construction analysis.

Function analyses

In the column headed “function analyses”, the function analyses that can be used to analyze the function and the primary parameters that are taken into account in such an analysis are specified. After completed function analyses, the requirements and preferences can be more precisely defined.

3.3.2 Experience

The factual contents of the tables are developed by expert groups. Representatives of different scientific disciplines are assembled and work according to the methodology described here. The project then processes the contents. Recurrent review of the factual contents is necessary.

Work on the parameter tables is underway. The preliminary table developed for the discipline “rock mechanics” is presented in Appendix A. The following conclusions can be noted from the work to date:

- Relatively few requirements have been formulated, but many preferences.
- The preferences indicate value ranges that can be more precisely defined by means of function analyses.
- Requirements and preferences need to be checked against the safety assessment, SR 97. Parts of the function analyses described in the tables are being carried out within the framework of SR 97.

3.3.3 Identified function analyses

When requirements and preferences regarding function were reviewed, a number of function analyses were identified that may need to be carried out in order to define requirements and preferences more precisely. Many function analyses are well known from before, others are currently in progress within different projects, and some function analyses may require more extensive development work. Following are some examples of the latter group.

Methodology for function classification

There is a need to clearly describe the methodology for characterization and functional classification of geological structures /Almén et al., 1996/. The functional classification could be built up in different steps from purely geological conditions to rock-mechanical, hydrological and transport conditions.

Hydrogeological, rock-mechanical and thermal requirements on near rock

- A number of requirements and preferences are made on the rock near the deposition holes. The project Prototype Repository at the Äspö HRL is, for example, studying temperature impact, the importance of water seepage and the importance of lithological inhomogeneity. The various requirements and preferences pertain to coupled questions and can therefore not be formulated independently of each other.

- In order to be able to formulate any hydrogeological requirements on the deposition hole, a detailed model for the local groundwater flow needs to be devised. The model should be able to handle water flow before deposition, during deposition and after closure.
- A rock-mechanical analysis on a near-rock scale could, for example, evaluate whether requirements on rock type boundaries need to be made in order to avoid temperature cracks in the near field.

4 Geoscientific parameters and evaluation factors

4.1 Introduction

This chapter first discusses geoscientific parameters that can be determined in site investigations. Then it describes how requirements and preferences have been defined for certain parameters, and how geoscientific evaluation factors have been identified in the ongoing project. In conclusion, the methodology for finding evaluation factors is exemplified for the discipline "chemistry", i.e. chemical composition of the groundwater.

It can once again be noted that the term "siting factor" is used in many different contexts when siting of a potentially environmentally harmful activity is discussed. In this work, with a focus on a deep repository for spent nuclear fuel, a siting factor is to be regarded as a geoscientific evaluation factor. The evaluation factors comprise a subset of all the geoscientific parameters that can be determined in a site investigation. The following sections explain how this selection can be made.

As discussed in the preceding chapter, requirements and preferences are mainly formulated with regard to an intended function. An analysis of the function includes a number of geoscientific parameters, and in some cases the requirements on a given function can, after analysis, be broken down into requirements on individual parameters. Only a few geoscientific parameters can be subject to requirements, which is further discussed in 4.3.2.

4.2 Geoscientific parameters

4.2.1 General

SKB has identified parameters of importance to determine during geoscientific investigation /Andersson et all, 1996/. They are classified according to the geoscientific disciplines: geology, rock mechanics, thermal properties, hydrogeology, hydrogeochemistry and transport properties. This report has also been translated to English /Andersson et al., 1998/, with some marginal changes and a few supplementary figures.

The term "parameter" has been given a very broad interpretation and can consist of measurable data, interpreted information or derived parameters for a given conceptual model. The parameters in the report include all siting factors presented in /SKB, 1994/. The work/report:

- identifies, describes and evaluates geoscientific parameters that are of importance to know in order to be able to carry out performance and safety assessments of a deep repository, and that can be obtained from a site investigation,
- discusses how identified parameters are used and which site-specific measurements may be employed to determine the parameter in question,
- presents and discusses data needs for planning and design of rock works,
- presents and discusses data needs for description of other environmental aspects,
- presents other data needs for analysis and a general understanding of geoscientific conditions.

The report /Andersson et al., 1996/ shows how the properties of the rock can be described with different parameters. The report comprises a point of departure for describing how requirements on function can lead to requirements on the bedrock. In the following section, hydrogeological parameters have been selected as an illustrative example.

4.2.2 Example – hydrogeology

Hydrogeological models have several areas of application in performance and safety assessment and supporting activities. A hydrogeological understanding also needs to be built up to explain long-term hydrogeochemical changes and coupled hydraulic and rock-mechanical effects. These processes can be regarded on different spatial scales and the need for model parameters varies. In brief, the models are used for:

- hydrogeological understanding, boundary conditions for detailed models, predictions of large-scale changes in groundwater chemistry,
- predictions of inflow during the construction period, and resaturation after closure,
- input data to migration models,
- input data to near-field models,
- input data to biosphere models,
- evaluation of near-surface environmental consequences (land and environment).

The hydrogeological analyses are coupled, as is illustrated schematically by Figure 4-1.

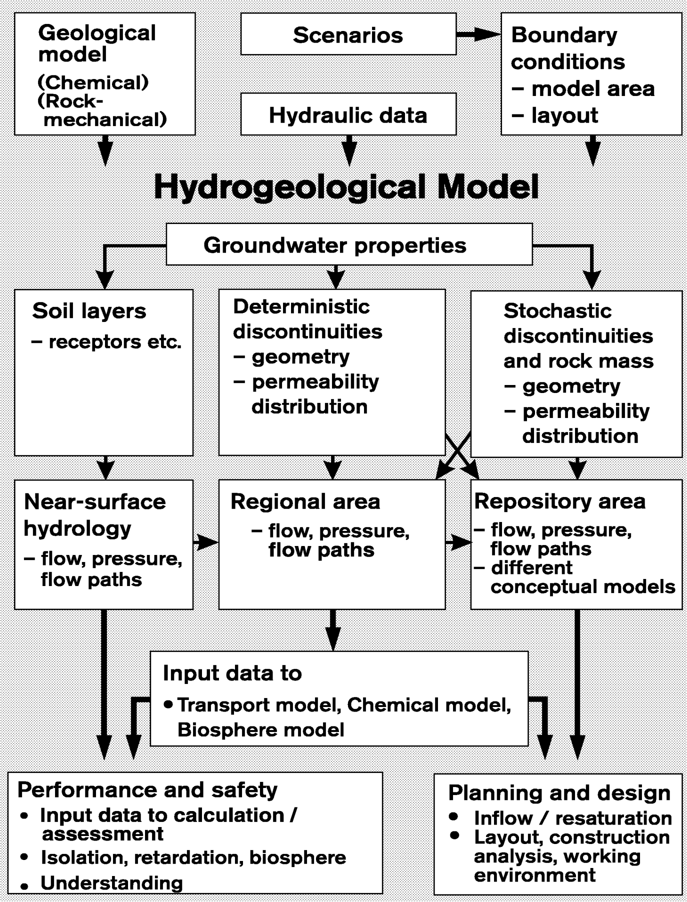

Figure 4-1. Schematic illustration of structure and use of hydrogeological models.

Table 4-1 summarizes which data are primarily necessary to be able to construct the different hydrogeological models that are needed. The table also attempts to show examples of what measurements can be used to estimate the parameters and how they are used.

Table 4-1. Hydrogeological parameters divided into groups. Overview of data requirements for description of hydrogeology, measurement methods and areas of application.

Parameter	Method	Used for
Deterministically modelled discontinuities		
Geometry – see geological model	See geological model	Input data to models on site scale
Permeability distribution	Hydraulic tests in and between boreholes	Input data to models on site scale
Flow porosity	Lab test drill core/Tracer test	Transient model
Stochastically modelled discontinuities and fractures as well as rock mass		
Stochastic description of discontinuities	See geological model	Discrete models (DFN), Stochastic continuum models (SC) indirect on repository scale
Permeability distribution	Hydraulic tests in and between boreholes – Extrapolation	Model data
Flow porosity and Storage coefficient	Pumping test, Extrapolation	Transient model
Compressibility of rock	Generic/Measurements on drill cores	THM model
Hydraulic properties of groundwater		
Salinity	Water samples	Model data/calibration
Temperature	Borehole/Experience	Model data
Soil layers etc.		
Identification of recipients	Hydro(geo)logical mapping	Groundwater models for Land and environment, Biosphere models,
Meteorological and hydrological data	Hydro(geo)logical mapping	Interpret boundary conditions for groundwater models in repository area.
Conductivity, thickness, porosity, etc.	Pumping test, layer sequences etc.	
Boundary conditions and supporting data		
Regional boundary conditions, historical and future development	Climate modelling, Topography	Paleohydrogeology, Analysis of scenarios,
Pressure or head distribution	Topography, Boreholes (see text), large-scale model	Boundary conditions/calibration
Recharge/discharge areas	Mapping	Calibration, Recipient model
Breakthrough curves	Large-scale tracer tests	Calibration
Groundwater flow boreholes	Dilution probe etc.	Calibration

Individual geohydrological parameters are defined more precisely in the report /Andersson et al., 1996/. In addition, area of application and different methods for determining the parameter in question are described in detail. Geoscientific parameters for other disciplines are presented in a similar manner.

Few geoscientific parameters are measured directly, but are often determined by means of an interpretation procedure that gives rise to various errors, one being measurement error, but also upscaling problems and conceptual uncertainties. The relevance of different geoscientific parameters therefore needs to be considered in relation to the methods of measurement and evaluation that are available for determining the parameter. Most tests that are performed in the field (e.g. injection tests, hydraulic fracturing, tracer tests etc.) provide indirect information on e.g. hydraulic conductivity, rock stresses or retention properties.

4.3 Determination of geoscientific evaluation factors

4.3.1 Introduction

The evaluation factors comprise a subset of all the geoscientific parameters that have been discussed in preceding sections. This section describes how the factors can be selected based in part on the function tables presented in Chapter 3, and in part on the methodology presented below. A systematic method has been used, just as in the process for determining detailed requirements on the function of the rock in a deep repository.

4.3.2 Structure for the work – tables

Requirements and preferences regarding the deep repository, and thereby the rock, are primarily formulated with respect to function and not directly for individual parameter values, see discussion in section 3.1. In the function tables, the fundamental safety functions regarding isolation, retardation and transport in the biosphere have been taken as a point of departure for specifying requirements and preferences regarding function per discipline: geology, thermal properties, hydrogeology, rock mechanics, hydrogeochemistry and transport properties.

In a similar manner, evaluation factors have been arranged per geoscientific discipline. Each discipline gives rise to a table whose rows correspond to the geoscientific parameters as per /Andersson et al., 1996/. Furthermore, each table is divided into the following columns (see Table 4-2):

- reference to function in function table,
- requirements regarding parameter,
- preferences regarding parameter,
- value range in Swedish crystalline bedrock,
- suitability as evaluation factor, and
- level of knowledge at a given siting stage.

The example is taken from the discipline "chemistry" (hydrogeochemical composition) and the parameter "Eh" (redox potential). Clear requirements could be formulated for this parameter. The complete, but preliminary, chemistry table is reproduced in Appendix B.

Table 4-2. Structure used to identify and explain geoscientific evaluation factors.

Geoscientific parameter	Requirements regarding parameter	Preferences regarding parameter	Value range in Swedish crystalline bedrock	Suitable evaluation factor – explanation	Level of knowledge that can be reached in different stages
Eh	Insignificant occurrence of dissolved oxygen at repository depth. Indicated by low Eh, Fe(II) or sulphide in the groundwater	The value of Eh is a function of pH and [Fe(II)]. For pH around 7, the preference is that Eh < -100 mV. (Eh is lower at higher pH)	Nearly ideal conditions prevail at depths below 100 m. Eh in the range -308 mV – (-202 mV) is used for the safety assessment SR 97	YES – since the parameter is linked to requirements and strong preferences.	*Generic:* See value ranges. *Feasibility study*: Adds nothing new. *Site investigation:* Water samples from boreholes permit qualified estimation. *Detailed characterization:* No essential new knowledge

The column that refers to the description of functions and analyses in the function table has been omitted for reasons of space. Information on how the geoscientific parameter in question enters into different function analyses is given in this column. The column is, however, included in the example in Appendix B.

The purpose of the columns is discussed in the following.

Requirements regarding parameter

Wherever possible, requirements are sought that can be directly related to individual parameters. In some cases it is possible to directly stipulate an unpermissible value range for the parameter on the basis of requirements made on function, see Table 4-2. As a rule, it is difficult to relate requirements directly to geoscientific parameters. There are several reasons for this:

- the parameter is only one of several parameters that determine a function, and the suitable value range depends on the value of the other parameters,
- the parameter may influence several functions, and it is not certain that a good value range for one function is also good for other functions,
- the parameter influences a function that is "only" a preference according to the function table.

Preferences regarding parameter

Preferences for the parameter in question are given in this column. See discussion above.

Value range in Swedish crystalline bedrock

In cases where general knowledge exists regarding the parameter's value or value range in Swedish crystalline bedrock, this has been documented. This does not pose any particular difficulty for certain parameters, such as pH. In other cases it may be more difficult.

Information on expected value range is a valuable aid in concretizing preferences later on. It may also turn out in practice that most preferences consist in fact of expected values.

Value ranges are discussed for all geoscientific parameters and not just for the selected evaluation factors, see example in Appendix B.

Suitability as evaluation factor

The main purpose of the table as a whole is to systematically ascertain whether the geoscientific parameters at any stage during the siting work can be a possible evaluation factor. In ongoing projects, a geoscientific parameter is a suitable evaluation factor if one of the following conditions is fulfilled:

- a direct requirement or an essential preference has been formulated for the parameter, or
- the parameter is expected to have a great influence on the result of one or more important function analyses.

The parameter must furthermore be able to be estimated during feasibility studies or site investigations. A brief explanation, based on the above rules, is included in the table for each parameter, see Appendix B.

Knowledge level in different siting or investigation stages

Based on the list of possible evaluation factors, the level of knowledge that can or should be reached after a completed feasibility study, site investigation and detailed characterization is discussed. It is not reasonable to designate a geoscientific parameter as an evaluation factor if the parameter cannot be estimated.

To be able to indicate whether a parameter is a suitable evaluation factor, but above all to be able to specify criteria, knowledge is needed concerning what precision can be expected in the parameter estimation after a given investigation stage. Knowledge of the parameter increases from the feasibility study (FS), the site investigation (SI) and detailed characterization (DC). However, the importance of the different investigation stages varies greatly between parameters. Naturally, the ambition level for the different investigation stages can also influence the extent to which a parameter can be determined.

It is difficult to quantify the expected precision. However, it is possible to discuss precision qualitatively; Table 4-3 illustrates this with an example. Such a qualitative discussion is valuable as a basis for deciding which criteria can be coupled to a given parameter at a given investigation stage. Based on information of this kind, it is then possible to judge when the evaluation factor will be applicable.

Of the parameters in the table, only topography can be used as an evaluation factor after FS. Eh and discontinuities (without fractures) can be used after SI. Knowledge of individual fractures can only be used in determining repository layout after DC.

4.3.3 Experience

The tables are above all necessary for achieving systematics in the work. Descriptive texts on the evaluation factors are also needed for a complete account. Such texts are written for each discipline. An evaluation factor report on the discipline "chemistry" follows in section 4.4. For this discipline in particular, it can be pointed out that a large body of knowledge will exist after completed site investigations, and before that only generic knowledge. Detailed characterization yields more observation points and thereby a more detailed description, but is not expected to add much new knowledge.

Table 4-3. Example of how knowledge of a geoscientific parameter changes as the siting work progresses.

Geoscientific parameter	Knowledge after feasibility study (FS)	Knowledge after site investigation (SI)	Knowledge after detailed characterization (DC)
Eh	Generic	Site-specific information from deep boreholes, which is sufficient to characterize the repository area	No essential new knowledge, risk of disturbed sampling
Topography	Full knowledge	Full knowledge	Full knowledge
Location, size, direction of discontinuities	Location of regional zones on surface can be judged	Reasonable precision for regional and local discontinuities Stochastic information on local minor discontinuities Fractures only frequency – size generic	High precision for regional and local discontinuities in the repository area. Fair for local, small ones. Stochastic information for fractures. Knowledge of location of discontinuities at tunnels
Conductivity value for rock mass	Generic for selected geology	Spatial distribution and mean values	Direct knowledge near tunnels

4.4 Example: Evaluation factors – chemistry

4.4.1 Introduction

The results of the work to determine evaluation factors for the discipline "chemistry" (hydrogeochemical composition) are presented in this section. The text should be read as a description of the more detailed tables presented in Appendix B. It can be noted that this account is preliminary and serves above all as an example of how use of the methodology can yield systematically selected evaluation factors.

The hydrogeochemical parameters have been divided into groups. Each parameter group corresponds to a subsection below.

4.4.2 Indications of occurrence of dissolved oxygen

Description of parameters and their influence on different functions

There are several different chemical parameters that can be used to see whether dissolved oxygen is present in the groundwater. The presence of dissolved oxygen in the groundwater is indicated very sensitively in Eh measurements. For well-buffered systems without any dissolved oxygen, Eh is a function of pH and the concentration of Fe^{2+}. In other cases, Eh may be difficult to determine, even if the groundwater does not contain dissolved oxygen. For these cases, other indications of the absence of dissolved oxygen are valuable, such as the occurrence of Fe^{2+}, the occurrence of Mn^{2+}, or the occurrence of HS^-.

If there were dissolved oxygen in the groundwater, this could lead to corrosion of the copper canister. Sulphide in the groundwater can also attack the copper canister. Oxygen is much more harmful than sulphide, however, since it can cause pitting. Moreover, much higher concentrations of sulphide are needed in order for sulphide corrosion to be of any significance. Indication of the absence of dissolved oxygen is therefore essential to satisfy the fundamental safety function that the canister should remain fully intact.

The occurrence of oxygen also influences fuel dissolution and sorption properties in buffer and rock. For these functions as well, it is advantageous if dissolved oxygen is absent.

Requirements and preferences

For the canister's isolation function, it is a *requirement* that dissolved oxygen should not occur at repository depth. In order for this requirement to be satisfied, at least one of the indicators low Eh, occurrence of Fe^{2+} or occurrence of HS^- must be satisfied.

In order to be able to show convincingly that the groundwater does not contain dissolved oxygen, it is a *preference* that the Eh should clearly indicate reducing conditions. But Eh is a function of pH and Fe^{2+}. At a pH of around 7, the Eh should therefore be less than -100 mV, while at higher pHs the Eh should be even lower. The groundwater at repository depth should furthermore contain Fe^{2+}, but the concentrations may be low and will then be difficult to measure. The groundwater should also contain Mn^{2+}, but the higher minimum detection limit for Mn^{2+} makes it less useful than Fe^{2+}. The sulphide concentrations should lie in the range 0< [HS] <10mg/l in the repository area. Concentrations greater than zero are good, since they indicate oxygen-free water, but very high concentrations (over 10 mg/l) influence copper corrosion.

If the preferences are not satisfied, further checking of data is necessary, along with a more thorough hydrochemical assessment of whether there is a risk of oxygen at repository depth.

Value ranges

Measurement data from deep groundwaters in Sweden and Finland show that the above requirements and preferences are as a rule always satisfied. For Eh, favourable conditions are as a rule found at depths greater than 100 m. Concentrations of Fe^{2+} lie in the range 5 mg/l–10 mg/l at repository depth. For sulphide, the concentrations lie in the range 0.1–5 mg/l at repository depth.

Prospects for determining parameters in different stages

Different general siting studies or feasibility studies do not contribute any new knowledge about the aforementioned oxygen indicators beyond the general knowledge that already exists. The essential site-specific information on the parameters is obtained in water samples from the deep boreholes that are drilled in conjunction with site investigations. Detailed characterization (investigations from tunnels) does not contribute any essential new knowledge. In these studies, there is instead a risk of temporary disturbances that render further chemical analysis impossible.

Suitable evaluation factor

Eh, and other indicators of dissolved oxygen, are clearly very important evaluation factors, since they are linked to requirements and strong preferences. The parameters can moreover be successfully determined in a site investigation.

4.4.3 pH

Description of parameter and its influence on functions

The pH value in water is a measure of its acidity. The pH of the groundwater primarily influences canister corrosion (isolation canister) and sorption (retardation). Within a wide pH range, sorption in particular is affected, but very low pH values combined with very high TDS (Total Dissolved Solids) also affect the stability of the copper.

Requirements and preferences

It is a requirement that undisturbed groundwater at repository depth should lie within the range $4 < pH < 12$. The influence of the repository, for example the concrete, can be permitted to range beyond this requirement if the pH in the bentonite pore water instead lies within this pH range. The main purpose of the requirement is to guarantee the isolating function of the canister.

It is a preference that the groundwater below the 100 m level should lie within the range $6 < pH < 10$. All pH values within this range are in principle equally suitable. There are no preferences for the groundwater above 100 m depth. The preference is above all based on the fact that the knowledge base for sorption constants utilized in the safety assessment is based on measurements within the preferred pH range. If values lie outside the range, the database for these transport parameters needs to be supplemented.

Value ranges

Measurement data from deep groundwaters in Sweden and Finland show that below depths of 100 m, the pH is generally in the range 6–10, but deviations occur e.g. at Stripa. Above 100 m, the expected range is greater.

Prospects for determining the parameter in different stages

Different general siting studies or feasibility studies do not contribute any new knowledge on pH beyond the general knowledge that already exists. The essential site-specific information on the parameters is obtained in water samples from the deep boreholes that are drilled in conjunction with site investigations. Detailed characterization does not contribute any essential new knowledge. In these studies, there is instead a risk of temporary disturbances that render further chemical analysis impossible.

Suitable evaluation factor

pH is clearly a very suitable evaluation factor, since it is linked to requirements and strong preferences. The parameter can moreover be successfully estimated in a site investigation.

4.4.4 Total salinity and important ions

Description of parameters and their influence on functions

TDS (Total Dissolved Solids) is a designation of total salinity. TDS mainly influences canister corrosion, and bentonite stability and sorption capacity. Some of the ions included in TDS (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, NO_2^-, NH_4^+, HPO_4^{2-}) also each influence repository performance. Requirements and preferences regarding TDS therefore need to be supplemented with requirements and preferences regarding these different constituent ions.

Low concentrations of Na^+, Ca^{2+}, Mg^{2+} can reduce the stability of the bentonite gel, creating colloidal particles that can be carried away with the groundwater. The bivalent ions are most important.

The bentonite contains carbonate. High carbonate concentrations, in addition to what is contributed by the bentonite, may however be an indication of extensive biological activity and reduction of sulphate to sulphide. The sulphate concentrations in themselves are hardly limiting, even though very high concentrations are unsuitable.

High concentrations of nitrogen compounds can cause stress corrosion in copper. Furthermore, these and other nutrients, such as phosphate, are undesirable because they stimulate bacterial growth.

Requirements and preferences

It is a requirement that TDS <100 g/l at repository depth. Below these levels, the bentonite retains its isolating capacity. Careful analyses are required to determine whether the bentonite can withstand higher concentrations from this aspect. Furthermore, canister corrosion is affected at even higher levels (around 200 g/l), so that Cu is not thermodynamically stable at low pH.

It is a preference that the concentration of TDS be lower than 50 g/l. Sorption of Cs and Sr especially is affected at even lower TDS levels. Up to marine concentration (i.e. 35 g/l), however, the impact is less. Above this limit things get worse the higher the concentration is, from the viewpoint of both sorption and bentonite stability. If the TDS concentration is higher than the preferred value, a thorough analysis is required of resulting swelling and corrosion consequences and of the impact on sorption.

Another preference is that the depth from the repository down to groundwater with too high TDS concentrations is greater than around 300 m, see /Follin, 1995/, in view of the risk of "upconing" and large-scale groundwater movements. If groundwaters with high TDS concentrations are located too close to the repository area, thorough analysis of the risk that these waters may later reach the repository area is required.

Besides the preferences regarding TDS, there are preferences regarding individual ions. For adequate bentonite stability, $[Ca^{2+}]+[Mg^{2+}]$ should be > 4 mg/l at repository depth. Higher values are of no advantage, however. Furthermore, the concentration of [K^+] should be less than 400 mg/l.

High concentrations of Cl^- are not alarming per se, but extremely high concentrations can increase the sensitivity of the copper canister to pH.

For NO_3^-, NO_2^-, NH_4^+, HPO_4^{2-} it is preferable that the concentrations be less than 1 mg/l. For HCO_3^- it is preferable that the concentrations lie within the range 10–1,000 mg/l at repository depth. From a measurement viewpoint it is optimal to have about 100 mg/l, since then the system is well-buffered, which simplifies pH measurements, but otherwise the entire range is equally suitable. There is also a preference that the concentration of SO_4^{2-} be less than 1,500 mg/l.

Value ranges

Measurement data from deep groundwaters in Sweden and Finland show that down around a depth of 1,000 m, TDS lies within the range 0–35 g/l. Even higher concentrations occur at greater depths. Close to 100 g/l (brine) has been measured at a depth of 1,700 m at Laxemar. As a rule, the depth to groundwaters with high TDS concentrations is greater in inland locations.

For Ca^{2+} the concentrations lie in the range 21–1,890 mg/l, for Mg^{2+} in the range 1–110 mg/l, for K^+ in the range 4–880 mg/l and for SO_4^{2-} in the range 0–500 mg/l. For HCO_3^- the concentrations at repository depth normally lie within the range of about 50–200 mg/l, but 0–1,200 mg/l has been measured.

Prospects for determining parameters in different stages

Different general siting studies or feasibility studies do not contribute any new knowledge on TDS or concentrations of essential ions beyond the general knowledge that already exists. In near-coast locations, however, it can be expected that the depth to groundwaters with high TDS values will be less than at inland locations. The essential site-specific information on the parameters is obtained in water samples from the deep boreholes that are drilled in conjunction with site investigations. Detailed characterization does not contribute any essential new knowledge. In these studies, there is instead a risk of temporary disturbances that render further chemical analysis impossible.

Suitable evaluation factor

The concentration of TDS at repository level and the distance to waters with high TDS values are suitable evaluation factors, since requirements and important preferences are linked to these parameters. HCO_3^- should also be an evaluation factor, but is essential only if extremely high (over 1,000 mg/l) values are noted.

4.4.5 Organic compounds

Description of parameter and its influence on functions

DOC stands for "Dissolved Organic Carbon", i.e. the quantity of organic matter in the groundwater measured as total quantity of organic carbon in solution. The availability of organic matter influences, for example, the bacterial conversion of sulphate to sulphide, which in turn influences canister corrosion.

Requirements and preferences

There is no basis for a requirement on DOC, since the organic matter in itself does not influence any of the barrier functions.

At repository depth, it is preferable that DOC <20 mg/l. The lower DOC is the better. Near the surface, however, DOC should exceed 10 mg/l in order to ensure reduction of dissolved oxygen in infiltrating groundwater.

Value ranges

Measurement data from deep groundwaters in Sweden and Finland show that at the projected repository depth, DOC is as a rule less than 10 mg/l.

Prospects for determining the parameter in different stages

Different general siting studies or feasibility studies do not contribute any new knowledge on DOC at repository depth beyond the general knowledge that already exists. The essential site-specific information on the parameters is obtained in water samples from the deep boreholes that are drilled in conjunction with site investigations. Detailed characterization does not contribute any essential new knowledge. In these studies, there is instead a risk of temporary disturbances that render further chemical analysis impossible.

Suitable evaluation factor

DOC is not a primary evaluation factor, since the preferences are not so important.

4.4.6 Colloids, humus, free gas, etc.

Description of parameters and their influence on function

The occurrence of colloids, humus, free gas (such as H_2, N_2, CH_4, CO_2, He and Ar) and bacteria influence the conditions for radionuclide transport. Sorbing radionuclides could in principle be transported with the water if they adhered to colloidal particles in the groundwater. Complexation with humic and fulvic acids can reduce sorption of some of the radionuclides. Gas bubbles and bacteria can also in principle work in this way.

Requirements and preferences

No requirements can be made on the above parameters.

Low concentrations of colloids (<0.5 mg/l) are preferable, since this makes it unnecessary to take these effects into account in transport modelling, along with the absence of free gas (gas bubbles) at repository level.

Value ranges

The median concentration of colloids in the groundwater is less than 0.05 mg/l /Laaksoharju et al., 1995/.

Prospects for determining the parameter in different stages

Different general siting studies or feasibility studies do not contribute any new knowledge at repository depth beyond the general knowledge that already exists. The essential site-specific information on the parameters is obtained in water samples from the deep boreholes that are drilled in conjunction with site investigations. Detailed characterization does not contribute any essential new knowledge. In these studies, there is instead a risk of temporary disturbances that render further chemical analysis impossible.

Suitable evaluation factor

Very high concentrations are not suitable, but are not a discriminating factor.

4.4.7 Other chemical parameters

Description of parameters and their influence on function

The composition of the groundwater constitutes necessary information for safety and performance assessments. That is why sampling can never be solely limited to the parameters judged to be most important.

- Even if the influence of some parameters has no direct importance (Al, Li, Cs, Sr, Ba, I, Br, F), they are nevertheless important to know since they are included in chemical calculation models.
- Parameters such as ^{18}O and D (in H_2O), ^{13}C, ^{34}S (in SO_4 and HS), ^{18}O (in SO_4), $^{87}Sr/^{86}Sr$ and U^{234}/U^{238} are important to know in order to be able to judge the history and evolution of the water. An understanding of the origin of the groundwater is crucial for being able to predict how groundwater chemistry will evolve in the future. Parameters such as T in H_2O and ^{14}C are further used for this dating.
- The concentration of Ra and Rn determine which measures are needed for worker protection during repository construction.

Requirements and preferences

There is no basis for requirements on any of the other chemical parameters.

In principle it would be preferable if the concentration of tritium were so low that it indicated that the groundwater is free of "bomb tritium". This would then be an indication that there are no fast flow paths. It is difficult to obtain reliable results in site investigations. The uncertainty in the measurements makes tritium concentration unsuitable as an evaluation factor /Smellie et al., 1992/.

For a safe working environment, it is desirable to have low concentrations of Ra and Rn, but suitable protective measures can be adopted to enable higher concentrations to be handled safely.

Suitable evaluation factors

None of the other chemical parameters are suitable as evaluation factors.

4.4.8 Summary: Evaluation factors – chemistry

The preceding section has examined which hydrogeochemical evaluation factors can be considered in different stages of the siting work. A complete presentation of the results of this work is shown in Appendix B. Note that hydrogeochemical composition provides relatively many quantitative values in comparison with other disciplines.

Evaluation factors are mainly used to judge whether requirements and preferences are satisfied. Table 4-4 is a compilation of the evaluation factors that have been preliminarily identified for hydrogeochemical composition. The explanation is also given.

Table 4-4. Preliminary list of evaluation factors for hydrogeochemical composition.

Concerned chemical parameters – by group	Identified evaluation factors – explanation	Stage when site-specific information is obtained
Indications of occurrence of dissolved oxygen, i.e. Eh, $[Fe^{2+}]$ and $[HS^-]$	Very important evaluation factors. Link exists to requirements and strong preferences.	Site investigation (deep boreholes)
pH	Very suitable evaluation factor, since it is linked to requirements and strong preferences.	Site investigation (deep boreholes)
Total salinity (TDS) and important ions	The TDS concentration at repository level and the distance to water with high TDS values are suitable evaluation factors, since both requirements and important preferences are linked to these parameters. Carbonate concentration should also be an evaluation factor, but is essential only if extremely high values are noted.	Site investigation (deep boreholes)
Organic compounds	Not a primary evaluation factor, since the preferences are not so important.	–
Colloids, humus, free gas	Not primary evaluation factors.	–
Other chemical parameters	None of the other chemical parameters are suitable as evaluation factors.	–

5 Siting factors – other experience

5.1 Introduction

It is valuable in this context to take a look at other experience with siting factors and how they are used in different studies. Thus, this chapter does not describe how the results of the ongoing project are utilized; this direct application lies outside the scope of the report, but is dealt with to some extent in Chapter 6. Instead, experience from feasibility studies and general siting studies is presented, and in each section the term "siting factor" is defined, at the same time as the link to RD&D-Programme 92, Supplement /SKB, 1994/ is mentioned. Finally, work with siting factors and criteria in other countries is commented on.

5.2 Experience from the feasibility study work

General siting factors are used in the feasibility studies to determine whether an area is suitable for further studies for siting of a deep repository. A general point of departure in the feasibility study work is the division of siting factors into the following main groups (see also Figure 3-2):

Safety	Siting factors of importance for the long-term radiological safety of the deep repository.
Technology	Siting factors of importance for the construction, performance and safe operation of the deep repository and for the transportation system to the deep repository.
Land and environment	Siting factors of importance for land use and general environmental impact.
Societal aspects	Siting factors connected to political considerations and community impact.

Completed feasibility studies show how areas can be ruled out at an early stage because they are deemed to be unsuitable or uninteresting on a municipal scale. They further show how areas of interest for further investigation are selected based on information available prior to a site investigation. To exemplify the approach in the feasibility studies, the feasibility study in Malå is discussed /SKB, 1996/. Only the methodology and factors that have been used to evaluate the safety-related prospects for a deep repository within the municipality and to identify areas of interest for further investigations are presented below.

The siting factors used in the feasibility study are thus an application of the siting factors presented in /SKB, 1994/. The following observations are also made:

- Some siting factors have the character of absolute requirements which a site must fulfil. Fundamental requirements of this type can be defined from the start as points of departure in the siting work.
- Quantitative values for many individual parameters are not meaningful until they can be placed in their site-specific context.

From the safety perspective, the following factors must be taken into account:

- chemical environment for canister, bentonite clay and fuel,
- mechanical stability of the rock,
- conditions for transport of corrodants and radionuclides in the rock,
- risk of future intrusion, i.e. mainly potential utilization of natural resources in the bedrock.

The following conditions are said to be favourable:

- a large area with few major fracture zones, since this provides wider options for placement of the repository,
- a high degree of rock exposure, simple and homogeneous bedrock conditions and a regular system of fractures and fracture zones, since this provides good prospects for obtaining at an early stage a good understanding of bedrock conditions of importance for safety and rock construction.

From the technology perspective, the following requirements were formulated:

- the ground must have a bearing capacity that permits normal construction activities,
- the rock properties must be such that the work can be carried out with adequate safety and known technology.

To determine whether the requirements on the rock are satisfied, important factors are homogeneity, locations and character of fracture zones, and rock stresses.

From the land and environment perspective, the preference is that:

- conflicts with competing interests are minimized.

The feasibility study observes that SKB's overall evaluation is that Malå Municipality could offer good prospects for a deep repository establishment, although the results of the feasibility study must be evaluated in the light of results from other feasibility studies and general siting studies on a national and regional scale before a final judgement can be made on suitability. The feasibility study also points out areas that may be of interest for further studies and thereby uses the following criteria (for the perspectives safety and technology):

- rock types or areas with potential for future mineral extraction shall be avoided,
- regional fracture zones (which have been interpreted from lineament interpretations) shall be avoided,
- good homogeneity and interpretability are advantageous,
- possible signs of abnormal groundwater chemistry or high water discharge shall be taken into account, and
- general experience from rock construction in granites of this type, which are situated in areas that are judged from the safety point of view to have the best potential for a deep repository, generally indicates good conditions, even though generally elevated rock stress levels have been noted.

In summary, it can be said that the feasibility studies demonstrate the practical application of SKB's methodology for site selection and are thereby based on the methodology presented in RD&D-92, Supplement /SKB, 1994/. The feasibility studies illustrate what quantity of information is available prior to a site investigation.

5.3 Experience from regional general siting studies

5.3.1 Background

In 1995, SKB carried out a general siting study on a national scale of siting prospects for a deep repository /SKB, 1995b/. This material is currently being supplemented with county-specific general siting studies. The results from ten counties will be published during 1998. The county-specific general siting studies will cover more or less the entire country, except for Gotland County. The reason why Gotland is not being considered is that crystalline bedrock does not exist at the depth being considered for a deep repository.

The purpose of the county-specific general siting studies is to:

- determine roughly where potentially suitable versus unsuitable areas may exist within each county. The results will be used to identify municipalities that are suitable for feasibility studies,
- gather material that can be used as a basis for comparison in the selection of areas for site investigations,
- gather material to place investigated areas in their regional context.

Long-term safety is the most important issue in the county-specific general siting studies. This in turn entails a focusing on the bedrock. Besides geological conditions, the county-specific studies also include general surveys of nature and culture protection areas, industrial areas, roads, railways and harbours. Potentially suitable areas found in feasibility studies are smaller and more well-defined than the larger, more generalized areas yielded by the geological county general siting studies.

5.3.2 Siting factors and criteria

To determine whether an area may be of interest for further studies, the following geoscientific criteria have been applied in the county-specific general siting studies:

- **Rock types –** In order for a rock type to be suitable for a deep repository, it should be present in large volumes. It should not contain ore or otherwise be unusual. It should be suitable for tunnelling. A homogeneous bedrock permits more reliable forecasts of bedrock conditions between boreholes and facilitates calculations of thermal and mechanical effects of the repository, for example how heat from the repository spreads in the rock. In the general siting studies, certain volcanic rock types and greenstone have in many cases been deemed unsuitable, while gneiss and granite have been regarded in most cases as suitable.
- **Soils –** Areas with thin soil layers and with a high proportion of exposed rock are generally superior from a siting viewpoint to areas with thick soil layers. The reason is that a thin soil layer facilitates mapping of rock types and deformation zones. Glaciofluvial deposits (such as eskers) are unsuitable since they are important as groundwater sources.

- **Deformation zones –** Certain parts of the bedrock have been deformed in extensive zones. The deformation may have been plastic or brittle. In the general siting study, large deformation zones have been regarded as unsuitable, since they may conduct water or be planes of weakness where rock movements may be triggered. The zones may also be disadvantageous from a constructability point of view.
- **Long-term stability –** Sweden is situated in a geologically stable area. Studies show that earthquakes with the magnitudes that have occurred in Sweden during recorded history will probably not affect a deep repository. However, much more violent earthquakes occurred in conjunction with the retreat of the continental ice sheet about 10,000 years ago, which would probably have affected a repository in the vicinity of the earthquake. There are parts of Sweden where earthquakes occur more frequently than at other places. The location of these areas is shown in the general siting studies. Furthermore, areas are designated where rock movements have occurred in conjunction with the most recent ice age (postglacial fault movements). Special attention will be given to the question of long-term stability in feasibility studies carried out in areas with increased earthquake frequency or postglacial rock movements.
- **Hydrogeology –** If the water capacity of drilled wells is low, this indicates that the hydraulic conductivity of the rock at repository depth is also low, which is favourable from a repository viewpoint. Areas where there is a large recipient, such as the Baltic Sea, are also considered favourable.

The composition of the bedrock, the ore potential and the occurrence of deformation zones have been the most important factors in the overall assessment. There are suitable and unsuitable areas in all the counties studied thus far. In summary, it is concluded that bedrock of interest for further siting studies is present in all counties studied.

5.4 Experience from other countries

There are many reasons to study experience from other programmes. SKB can take advantage of international experience at the same time as it makes use of the results of its own studies. Following is a survey of international experience in the field. The focus of the survey is on how the question of technical criteria has been handled and what criteria have been established. Other experience concerning the actual siting process is not dealt with, or only briefly touched upon.

5.4.1 Finland

The situation in Finland is of special interest to SKB, since their proposed deep disposal method is very much like the Swedish one, their bedrock conditions are similar, and since the Finnish programme faces a number of crucial choices in the next few years.

At present, four different candidate sites are being investigated in a way that corresponds to site investigation in the SKB programme. One of these sites, which is situated adjacent to the Lovisa Nuclear Power Plant, has been added later, while the other three sites have been selected in a stepwise screening procedure. In the early 1980s, five sites were selected for preliminary site investigations. An important criterion for this site selection was to find areas with sufficiently large blocks of rock. Among these five, three sites were selected in 1992 for more detailed site investigations. The safety assessment TVO-92 /Vieno et al., 1992/, which showed that all investigated sites possess the prerequisites for a safe final repository, comprised an important basis for this selection, but formal criteria for site evaluation, other than requirements on safety and radiation protection, were not used. The choice was accepted by the Finnish authorities, but they also said that a more site-specific assessment was needed prior to the next step in the process.

According to a decision by the Council of State (the Government) in Finland, a site will be selected for detailed characterization underground in 2000. This choice of site must be supported by a site-specific safety assessment. No later than at the time of the site selection, but possibly earlier, the project is furthermore approaching the "decision-in-principle phase" of the licensing process, which is the first formal licensing step towards a deep repository in Finland.

Before the Council of State makes the decision in principle, it must find (according to the Finnish Nuclear Energy Act) that no facts have emerged that indicate inadequate prerequisites for building the final repository. The safety of the final repository must further be based on passive barriers that guarantee each other's function, which means that the failure of one barrier must not appreciably weaken the total safety of the repository and that changes in the repository environment may only affect one barrier, while other barriers may only be affected to a limited extent. The overall safety and radiation protection criteria are similar, but not identical, to those in Sweden. Detailed requirements and preferences regarding the parameters of the rock are not formulated.

5.4.2 Other countries

In some countries, special selection criteria have been stipulated in advance for the selection of candidate sites for site investigation. However, site selection is as a rule also governed by other factors that purely geoscientific ones. If geological factors are stipulated, they usually concern stable bedrock conditions and factors that indicate low groundwater flux. The work in all countries is focused on crystalline rock, clay formation or salt formations as the host medium. In countries where these geological media only exist in limited areas, the type of geological formation thereby becomes an important selection criterion. In countries with more homogeneous geology, such as Sweden, this selection factor is usually taken for granted.

In principle, detailed criteria based on geoscientific parameters have not been presented anywhere for evaluation of the suitability of an appointed candidate site that has been thoroughly investigated. The suitability of such sites is being, or is planned to be, evaluated by means of an integrated analysis where a safety assessment is often of central importance. Criteria stipulated in advance pertain to general functions and not individual parameter values.

Belgium

Since 1974, the work in Belgium has been focused entirely on comprehensive experimental studies of a clay formation in Mol, where an underground laboratory has also been built. The focus on clay is natural, since Belgium lacks crystalline bedrock or salt formations.

France

An inventory of possible sites for deep disposal of long-lived waste in France was concluded in 1983. A site selection was carried out on geological and technical grounds, and in 1987 site investigations were started on 4 sites but soon had to be interrupted. Under the terms of a new nuclear waste act, investigations have been underway since 1994 on three sites for the purpose of siting underground rock laboratories. These may, however, later be designated as candidate sites for a deep repository. Site selection was only partially based on technical criteria. Two of the sites are clay formations and one is a granite formation which is, however, covered by sediment of great thickness. An application for permission to build the rock laboratories has been submitted to the Government, which has not yet made a decision.

Japan

The work of developing a final repository for high-level nuclear waste in Japan has focusd on developing technology and methods for investigating whether a site is suitable. Neither specific sites nor specific geological conditions have yet been designated as suitable (or unsuitable). There are today no established principles or criteria for selecting or approving a site. The Japanese Atomic Energy Commission (AEC) has, however, presented general guidelines for how a site for a deep repository should be identified. They recommend that a nuclear waste law be enacted that identifies which organization is to carry out final disposal and that stipulates criteria for the choice of site. The AEC's guidelines further emphasize the importance of maintaining an open and clear process that engages the public, local decision-makers and independent technical experts. The AEC's recommendations are expected to be implemented around 2000. It is likely that the criteria will focus on the capability of the barrier system and the near field to provide good containment, as well as on the chances of being able to predict future seismic and volcanic activity.

Canada

In 1994, Atomic Energy of Canada Ltd (AECL) presented a comprehensive environmental impact statement (EIS) focused on the technical prospects for building a deep repository for spent nuclear fuel that is produced in Canada. Both the federal government and the province of Ontario have stipulated that the site selection process for a repository may not commence until the technical concept has been approved. The review panel that has evaluated the EIS recommended in March 1998 that site selection and investigations of specific sites should not begin now either, but instead recommended additional measures to seek public support for how the programme for nuclear waste management should be carried out.

Russia

Several different concepts for deep geological disposal are currently being evaluated in Russia. The work is focusing on areas surrounding the nuclear facilities at Krasnoyarsk and Chelyabinsk, since these facilities already have considerable waste quantities. Among other things, different sites in crystalline bedrock are being studied, and plans exist to commence site investigations and to build an underground rock laboratory. Studies are also being conducted on the Kola Peninsula regarding, among other things, the possibilities of building a final repository in permafrost.

Switzerland

Geological conditions in Switzerland are such that only limited areas of the country are suitable for a final repository. Investigations have been concentrated to crystalline formations and to clay formations. Comprehensive investigations have been carried out, and an underground rock laboratory has existed at Grimsel since 1983. There are, however, no concrete candidate sites for a deep repository for high-level waste. Officials in the programme also insist that the safety of the deep repository is largely dependent on its engineered parts and that the properties of the rock are not decisive for safety.

Spain

The work of siting a final repository for high-level nuclear waste was begun in 1986 and is focusing on crystalline rock, salt formations and clay formations. In a first, regional phase, favourable formations were inventoried based on geological data, hydrogeological data, data on earthquakes and environmental and societal data. These studies were intensified in a second phase. This work was interrupted in 1997, however. During 1997, the Spanish senate evaluated the plan for the continued programme for nuclear waste management and disposal.

UK

At present, no work is underway to find a final repository for the high-level nuclear waste. The work of siting a final repository for the long-lived intermediate-level nuclear waste in the UK has previously focused on areas adjacent to the nuclear installations in Dounreay and Sellafield. After 1991 the studies continued at Sellafield as the only candidate site. Comprehensive tests and site characterization have been conducted, and the next step that was planned was to build an underground facility for further studies. The proposal was not accepted by the authorities, however, and the plans to go further with the site are currently on ice.

Czech Republic

Siting work has been underway in the Czech Republic for the past seven years. Criteria for site selection are based on the size and thickness of the geological unit, its homogeneity, lack of tectonic disturbances, lack of useful minerals, low hydraulic conductivity and low seismic activity. 27 areas were studied in an initial phase, but the investigations have now been focused on 13 areas. According to plan, a site will be proposed based on the results of these studies.

Germany

In Germany the plan is to develop a final repository in a salt formation. Investigations are currently underway at the abandoned salt mine in Gorleben. The site has been chosen based on a general inventory and because it was known to contain a potentially suitable salt formation. The work is now being focused on a comprehensive investigation programme to determine the properties of the site so as to be able to adapt a repository and judge the suitability of the site.

Hungary

The assessment has been made in Hungary that only a few sites in the country possess the geological prerequisites for a final repository. At present, comprehensive site investigations are being conducted in a claystone formation in the Mecsek Mountains. The investigations are aimed at verifying that the area has suitable hydrological and chemical properties and at finding a suitable location for a final repository. The area has been chosen due to its presumed low permeability to water and small number of faults.

USA

A comprehensive site selection programme for the final disposal of civilian nuclear waste was begun in the early 1980s. Nine different candidate sites were identified using a large number of different criteria. Based on preliminary studies of these sites, three sites were selected for more intensive studies. The work at two of these sites was interrupted in 1987 when the United States Congress decided that further studies would be concentrated to Yucca Mountain, Nevada. The decision also stipulated that the studies were to be interrupted immediately if Yucca Mountain was found to be unsuitable. After initial difficulties obtaining a local permit to investigate the site, comprehensive investigations are now underway. An underground facility has also been designed. The final assessment of the suitability of the site will be done in connection with the licensing process, in which an overall safety assessment will constitute a vital supporting document. In dialog with the authorities, especially the US NRC, numerous different questions that need to be cleared up for future licensing processes are being identified and documented. The questions are both of a more general nature and very specific for conditions on the site in question.

6 Planned work

6.1 Criteria for site evaluation

During 1998, the project work will be expanded to include criteria for site evaluation as well. The criteria are to be used to judge whether a site satisfies stipulated requirements or not, and to what extent preferences are satisfied. When it comes to geoscientific parameters, criteria consist of indicative values or value ranges for estimated evaluation factors. When it comes to repository performance, criteria consist of indicative values or value ranges of outcomes of performance assessments. The criteria can be changed during the course of the siting work as the information available on the sites changes. But requirements and preferences remain the same.

6.1.1 Siting stages and criteria

It has already been emphasized that the work with geoscientific evaluation factors and criteria for site evaluation is predicated on the availability of results from general siting and feasibility studies, and does not aim to define detailed factors and criteria during these early siting stages. Instead, efforts are concentrated on the stage prior to site investigation, i.e. based on information from feasibility and general siting studies, and prior to detailed characterization, i.e. based on information from completed site investigations. Figure 6-1 illustrates the stages in the siting work.

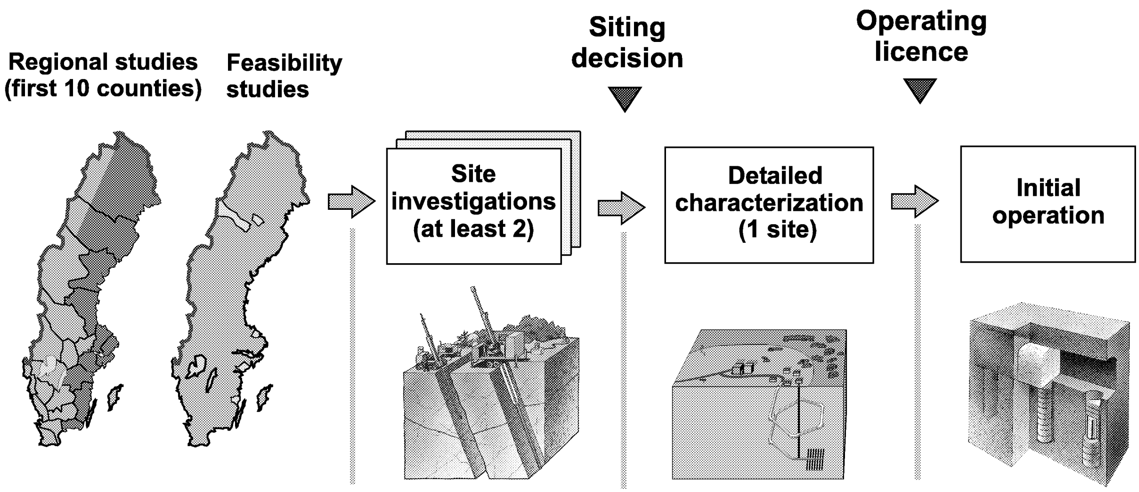

Figure 6-1. *Use of geoscientific evaluation factors and criteria takes place at different stages of the siting or investigations for a deep repository.*

Criteria need to be linked to the information quantity that is available in the particular siting stage in question and to the decision situation in which they are to be used.

- Prior to a site investigation, it is important to be able to rule out obviously unsuitable sites and furthermore to be able to identify sites with good prospects of turning out to possess suitable properties. Criteria cannot be made too strict at this stage, in view of the limited information that is then available on the properties of the rock at depth. The criteria will be used to select suitable sites for further investigations.
- After completed site investigation, it should be possible to be demonstrated with great certainty whether a site is suitable or unsuitable as a deep repository site. Further, it may be meaningful at this point to use criteria to compare sites. Even though the overall evaluation of the suitability of the sites is determined within the framework of an integrated safety assessment and an integrated construction analysis, the specified criteria should provide good guidance regarding the results of such an integrated assessment/analysis.

Criteria for evaluation of whether a site is suitable or unsuitable are based on the importance of the different evaluation factors and an assessment of the accuracy of the available information. These criteria can therefore be based on the evaluation factors already arrived at.

Criteria for comparison of the sites that have already been judged to be suitable must in addition be based on some kind of weighting between different factors. It may be appropriate to study different weighting systems within the framework of a decision analysis linked to the site evaluation. It is also important to report whether certain parameter values or outcomes of performance assessments (within the suitable area) are better than others. Qualitatively, it should also be indicated whether these outcomes entail a significant improvement in the function or whether the improvement is only of limited interest.

The term "criteria" is further elucidated in Table 6-1, which shows possible criteria in different stages of the process of arriving at a deep repository. The table can also serve to clarify the difference between different terms, above all the difference between requirements and criteria. Requirements refer to actual conditions regardless of siting stage. Criteria are an application of evaluation factors in a given stage as a basis for a decision. See also Figure 6-1.

In conclusion, it can be noted that criteria in certain stages can also be based on evaluation factors that have not been subject to requirements. This is, for example, the case with preferences regarding the thermal conductivity of the rock. Good thermal conductivity is advantageous, and this evaluation factor can therefore be a basis for a criterion in early siting stages. If this preference is satisfied, costs are lowered since the repository can be made smaller. If the preference is not satisfied, however, this can be compensated for by modifying the repository layout so that the overall safety requirement is nevertheless met (low thermal conductivity is compensated for by greater spacing between the canisters in the deep repository).

6.1.2 Planned work for criteria

The work of determining criteria is based on the already identified evaluation factors and is concentrated primarily on verifying whether a site is suitable or unsuitable. Criteria for comparison between sites will also be dealt with. Based on the estimated information quantity and decision situation before and after site investigation, the already identified evaluation factors are analyzed according to the following scheme:

Table 6-1. Two examples of how knowledge, evaluation factors and criteria change in the different stages of the siting process, based a fundamental requirement. Note particularly the difference between requirements and criteria.

	General siting studies	Feasibility studies	Site investigation	Detailed characterization	Operation
Requirement: No dissolved oxygen in groundwater at repository level					
Knowledge	Generic	Generic	Site-specific information from deep boreholes which sufficient to characterize the repository area.	No essential new knowledge, risk of disturbed sampling	No essential new knowledge, risk of disturbed sampling
Evaluation factors	No factors (to assess requirement satisfaction)	No factors	Eh, [Fe^{2+}] and [HS] as indicators of occurrence of dissolved oxygen	–	–
Examples of possible criteria	No criteria	No criteria	At least one of the indicators low Eh, occurrence of Fe^{2+} or occurrence of HS^- shall be met. Otherwise the site must be abandoned	–	–
Requirement: Disposal tunnels must not be intersected by local discontinuities					
Knowledge	Location of regional zones at surface can be judged	Location of regional zones at surface can be judged	Reasonable precision for regional and local discontinuities Stochastic information on minor local discontinuities. Fractures only frequency – size generic	High precision for regional and local discontinuities in repository area. Fair for minor, local ones. Stochastic informtion on fractures. Knowledge of location of discontinuities at tunnels.	Knowledge of location of all discontinuities at deposition hole. Otherwise no essential new knowledge
Evaluation factors	Location, length, width of regional discontinuities	Location, length, width of regional discontinuities	Location, length and width of regional and local discontinuities, etc.	Location, length and width of regional and local discontinuities, etc.	–
Examples of possible criteria	Large areas with homogeneous bedrock conditions	Occurrence of areas with large rock blocks a prerequisite to proceed	If repository adaptation is not possible, the site must be abandoned. (Regional discontinuities set limits for the repository area. Local discontinuities may not intersection disposal tunnels.)	Confirmation of location, length and width of regional and local discontinuities provides direct verification of the requirements in this stage	–

- Can precise and quantified criteria be expressly defined for a specific stage, and what are the consequences if the criterion is not satisfied?
- Can criteria only be defined in terms of a site-specific performance assessment or construction analysis? In that case, which one needs to be done and what are the consequences of different outcomes?

- Is it possible to specify whether certain outcomes, within the suitable range, of parameter estimates or of performance assessments are better than others? Do these outcomes entail a substantial improvement of the function, or is the improvement of subordinate interest?

An example of a quantified criterion can be a range of values or a median value with a measure of scatter. An example of a function analysis can be calculation of groundwater flow or retention capacity. An example of the consequences of a criterion's not being satisfied can be that the site is directly judged to be unsuitable, but could also be that there is a need for a performance assessment, an integrated safety assessment, an integrated construction analysis, better data or a modified repository layout.

It is already clear that it will be simple to define clear-cut criteria for certain already identified evaluation factors (for example those that provide indications of dissolved oxygen in the groundwater). For other factors the criteria will need to be more complex. This is probably the case for factors associated with the permeability of the rock, which influence different functions in different ways. They exhibit considerable spatial variability and analysis of field data often involves extensive modelling work. The work of defining criteria will therefore not lead to precise ranges of values for all evaluation factors. It must, however, be clearly indicated for each factor how information about them is to be dealt with in performance assessments or in the integrated safety assessment or construction analysis. In cases where precise criteria cannot be defined, the reason for this must be given.

6.2 Planned work in the project

This progress report in conjunction with RD&D-Programme 98 constitutes a milestone in the project on evaluation factors and criteria. Subsequent milestones are:

- Presentation of proposals for requirements and preferences regarding functions in the deep repository and regarding parameters.
- Information activities and circulation for review and comment carried out internally and externally.
- First proposal ready for criteria to use prior to and after site investigations based on formulated requirements and preferences.
- Final report ready covering both functions for the deep repository, geoscientific evaluation factors and criteria for site evaluation.

After completion of the project, the work will be expanded to also include SFL3–5. The chosen repository layout for SFL3–5 will influence the result of such an expansion of factors and criteria. All premises must be given before the work proceeds.

7 References

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Rock-mechanical requirements and preferences regarding function

Fundamental safety function and civil engineering aspects	Rock-mechanical conditions that influence function	Requirements regarding rock-mechanical function	Preferences regarding rock-mechanical function	Performance assessment and concerned parameters
Isolation canister The canister shall isolate the waste from its surroundings.	1) Deformation of deposition hole.	Deformation may not cause damage of the canister. Means that instantaneous deformation of canister hole < 100 mm. Cumulative deformation < 350 mm. (Avoid major discontinuities – respect distance.)		1) Rock-mechanical analysis model on local scale. Design for deposition hole, discontinuities, mechanical properties of the latter and of' intact rock, density and thermal properties, stress distribution, future loads (rock-mechanical model on larger scale).
	2) Lithostatic pressure.	The canister cannot withstand lithostatic pressure (creep from rock). The deposition hole must be a loadbearing construction that does not collapse due to creep.		Seismic analysis. 2) Rock-mechanical analysis model on local scale (see above, creep properties).
Isolation bentonite The bentonite shall contribute to the isolation of the waste, mainly by creating favourable conditions for the canister.	1) Deformation of deposition hole.	Deformation may not cause damage of the bentonite for "normal" scenarios. Probably requires fault, i.e. large-scale rock-mechanical change. Avoid major discontinuities (respect distance).		Rock-analysis model (see above). Special analysis of risk of faults (rock-mechanical analysis on larger scale) for different scenarios.
	2) Fracturing/cavities can affect bentonite – erosion.	Cavities not so large that the bentonite function is lost.		Analysis of largest permissible fracture (combination with hydrological analysis). Also dependent on groundwater chemistry (greater risk at higher salinity). Requirement probably satisfied if above deformation requirement satisfied.
Isolation rock The rock shall contribute to the isolation of the waste, mainly by creating favourable conditions for the bentonite and the canister.	1) See above.	Requirement that rock deformation will not damage the containment function as described above.		See above.
	2) New fracturing between repository and discontinuity.		Should not occur.	Rock-mechanical analysis – check of ultimate strengths etc.
Retardation bentonite The bentonite shall retard the arrival of released radionuclides in the rock/geosphere.	1) See isolation bentonite.	Deformations of the deposition hole (instantaneous and/or cumulative) may not be so great that the diffusion distance through the bentonite is too small.		See Isolation bentonite. Analysis of retention for given geometry of deposition hole.

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Rock-mechanical requirements and preferences regarding function (contd.)

Fundamental safety function and civil engineering aspects	Rock-mechanical conditions that influence function	Requirements regarding rock-mechanical function	Preferences regarding rock-mechanical function	Performance assessment and concerned parameters
Retardation rock Transport of radionuclides (as well as transport of groundwater with unsuitable chemistry) shall be retarded.	1) Formation of discontinuity directly to repository (canister hole). Deformation of rock mass and discontinuities affect hydraulic conductivity.		See Isolation rock. Preference regarding “moderate changes” – requirement, see above.	See Isolation rock. Rock-mechanical analysis model (see above). Interpretation of hydrogeological consequences.
Biosphere conditions Effective radiation doses to individuals in the critical group shall not exceed levels specified in SSI’s regulations. Furthermore, the impact of the deep repository on biological diversity shall be small. A preference is that dilution should take place to low concentrations in the biosphere of substances from the repository that may be carried up towards the ground surface.	1) Recipient changes due to faults.			
Design – layout Layout is done to obtain as good retention and containment conditions as possible.	1) Risk of large deformations and faults. 2) Breakout. 3) Rock stresses.	Layout is controlled so that above isolation requirement is satisfied. At present, this is based on respect distances from major discontinuities and rock stress directions. Avoid rock burst and other surprises. Special requirements are also made during tunnel boring – otherwise breakout.	Preference that repository areas are not too scattered. Minimize quantity of breakout.	Rock-mechanical analysis for given layout (see Isolation canister). Rock-mechanical analysis for layout. Rock-mechanical analysis for layout.
Design – construction analysis Analysis of constructability.	1) Risk of cave-in etc. (Assessment of reinforcement needs, downtimes etc.).	Requirements on safe working environment (i.e. avoid cave-ins, breakout etc.)	Preference that constructions costs are reasonable.	Rock-mechanical analysis for layout.
Design – working environment Provide good working environment.	1) See above.	See above.		See above.

Chemical Parameters

Geoscientific parameter	Reference to function in function table	Requirements regarding parameter	Preferences regarding parameter	Value range in Swedish crystalline bedrock explanation	Suitable/conceivable evaluation factor	Level of knowledge that can/should be reached after FS, SI and DC
Groundwater chemistry						
Eh	Isolation, canister Retardation, fuel Retardation, bentonite Retardation, rock	Insignificant occurrence of dissolved oxygen at repository depth. (Indicated by low Eh, Fe(II) or sulphide in groundwater.	Value of Eh is a function of pH and [Fe(II)]. For pH around 7, the preference is Eh < -100 mV. (Eh gets lower at higher pH).	Nearly ideal conditions prevail at depths below 100 m. Eh in the range -308 mV – (-202 mV) is used for the safety assessment SR 97.	Yes, since the parameter is linked to requirements and strong preferences.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge.
pH	Isolation, canister Isolation, bentonite Retardation, fuel Retardation, bentonite Retadation, rock	In the undisturbed groundwater at repository depth, pH must be between 4 and 12. The influence of the repository, for example the concrete, can be permitted to range beyond this requirement if the bentonite pore water lies within this pH range.	Within the range 6 < pH < 10 in groundwater below 100 m depth. No preference within this range. No preference above 100 m depth.	Below depth of 100 m, the pH is generally between 6 and 10, but deviations occur (e.g. Stripa). Above 100 m the expected range is larger. SR 97: 7.0–9.30	Yes, since linked to require-ments and strong preferences.	Generic: see value ranges. FS: adds nothing new – no link to superficial groundwater. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge, risk of (temporary) disturbances.
TDS	Isolation, canister Isolation, bentonite Retardation, bentonite Recipient	TDS < 100 g/l	TDS < 50 g/l Swelling and sorption (mainly of Cs and Sr) are affected at even moderate ionic strenghts. Up to marine concentration (i.e. 35 g/l), however, the impact is less. At higher concentrations, the negative effect increases with concentration. Lower limit, see Ca. Distance from deep repository to brine > 300 m to avoid upconing.	Down to depth of 1,000 m 0–35 g/l. Higher concentrations at greater depths. Up around 100 g/l (brine) has been measured at 1,700 m depth (Laxemar). As a rule, depth to groundwaters with high TDS concentrations is greater in inland locations. SR 97: 338–11,107 mg/l	Yes, since linked to requirements and important preferences.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. DC: no essential new know-ledge, risk of (temporary) disturbances.
DOC	Isolation, canister Redardation, bentonite	No basis for requirement.	DOC < 20 mg/l at repository depth. The lower the better. Near the surface, however, DOC should exceed 10 mg/l in order to ensure reduction of infiltrating groundwater.	At repository depth DOC is generally less than 10 mg/l. (For SR 97, 1.0–5.7 mg/l applies, Laaksoharju et al., 1997.)	No, mainly because preferences are not so important. Rock's retention capacity can only be slightly degraded in the unfavourable range.	Generic: see value ranges. FS: adds nothing new – superficial groundwater can be assessed. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge, risk of (temporary) disturbances.
Na	Isolation, canister Isolation, bentonite Retardation, bentonite Retardation, rock	See TDS	See TDS		No, no specific requirements or preferences.	

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Chemical Parameters (contd.)

Geoscientific parameter	Reference to function in function table	Requirements regarding parameter	Preferences regarding parameter	Value range in Swedish crystalline bedrock explanation	Suitable/conceivable evaluation factor	Level of knowledge that can/should be reached after FS, SI and DC
K	Isolation, bentonite Retardation, bentonite	$[K^+] < 400$ mg/l	Normal value range 4–80 mg/l	At repository depth in the range 4–880 mg/l. SR 97: 1.9–13 mg/l (13 mg/l for Beberg)	No, the preference is not important enough.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge, risk of (temporary) disturbances.
Ca	Isolation, bentonite Retardation, bentonite Retardation, rock	See TDS	$[Ca^{2+}]+[Mg] > 4$ mg/l at repository depth to ensure that the bentonite forms a stable gel and does not create colloids. Higher values no advantage. See TDS.	In the range 10 mg/l to 10s of g/l (see TDS). SR 97: 21–1,890 mg/l	No, TDS requirements and preferences more important.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge, risk of (temporary) disturbances.
Mg	Isolation, canister Isolation, bentonite Retardation, bentonite	See TDS	See Ca	See Ca SR 97: 1.1–110 mg/l	No, see Ca	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge, risk of (temporary) disturbances.
HCO_3	Isolation, canister Retardation, fuel Retardation, bentonite Retardation, rock		Within the range 10–1,000 mg/l at reporsitory depth. Much higher levels indicate extensive micro-biological activity. From a measurement viewpoint, about 100 mg/l is optimal, since then the system is well-buffered, which simplifies pH measure-ments, but otherwise the entire above range is equally suitable.	At repository depth normally about 50–200 mg/l, but 0–1,200 has been measured. SR 97: 10–278 mg/l	Yes, but only if extremely high (above 1,000 mg/l) levels noted.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge, risk of (temporary) disturbances.
SO_4	Isolation, canister Retardation, rock	See TDS	$[SO_4] >1,500$ mg/l High concentration in combination with high DOC is unsuitable.	0–500 mg/l SR 97: 0.1–560 mg/l	Yes, see preference.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge, risk of (temporary) disturbances.

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Chemical Parameters (contd.)

Geoscientific parameter	Reference to function in function table	Requirements regarding parameter	Preferences regarding parameter	Value range in Swedish crystalline bedrock explanation	Suitable/conceivable evaluation factor	Level of knowledge that can/should be reached after FS, SI and DC
Cl	Isolation, canister Retardation, rock	See TDS	See TDS		See TDS	
Fe	Isolation, canister Retardation, fuel Retardation, bentonite Retardation, rock		The groundwater at repository depth should contain Fe(II) as an indication of the absence of dissolved oxygen. In view of mesurement problems, higher values are more reliable. At high TDS, however, the concentration becomes so low that it is difficult to measure.	At repository depth within the range 5 µg/l–1 mg/l. The lower values apply to water with high TDS. SR 97: 0.05 (Ceberg)–1.80 (Beberg) mg/l.	Not alone, but as part of basis for judging occurrence of dissolved oxygen.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. The measurement limit is about 5 µg/l, however. DC: no essential new knowledge, risk of (temporary) disturbances.
Mn	Retardation, rock		The groundwater should contain Mn(II). Indication of absence of oxygen. See Fe(II)		See Fe(II), but higher measurement limit for Mn(II) makes it less interesting.	
HS	Isolation, canister Retardation, fuel Retardation, bentonite Retardation, rock	Not OK if [HS] = 0 in the repository area if there are no other indications of the absence of dissolved oxygen	0<[HS]<10 mg/l in the repository area. Levels higher than 0 indicate absence of oxygen, but very high levels (above 10 mg/l) influence Cu corrosion.	At repository depth within the range 0.1–5 mg/l (see SR 97). SR 97: Below measurement limit – 0.15 mg/l.	Yes, see requirements and preferences.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes permit qualified estimation. DC: no essential new knowledge, risk of (temporary) disturbances.
U	Working environment		Low concentrations	Within the range 1 µg/l–150 µg/l. SR 97: 0.17–19.3 µg/l.		
Ra	Working environment		Low concentrations			
Si	Working environment		Normal concentrations	SR 97: 4.1–5.6 mg/l	No	
Al					No	
Li					No	
Cs					No	
Sr					No	
Ba					No	
I					No	

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Chemical Parameters (contd.)

Geoscientific parameter	Reference to function in function table	Requirements regarding parameter	Preferences regarding parameter	Value range in Swedish crystalline bedrock explanation	Suitable/conceivable evaluation factor after FS, SI and DC	Level of knowledge that can/should be reached
Br					No	
F	Retardation, rock				No	
^{18}O (in H_2O)					No	
D (in H_2O)					No	
^{13}C (in DIC)					No	
^{13}C (in DOC)					No	
^{34}S (in SO_4)					No	
^{18}O (in SO_4)					No	
^{34}S (in HS)					No	
$^{87}Sr/^{86}Sr$					No	
T		No	TU <1 at repository depth. Higher values may be an indication of fast flow paths (“bomb tritium“).	Rainwater in 1997 has about 20 TU. Between 0.4–100 TU has been measured at hypothetical repository depth. High values probably due to contaminated samples. SR 97: 3–8 TU.	In principle yes, but the measurements are uncertain, so T is not suitable in practice as a siting factor.	Generic: see value ranges. FS: adds nothing new. SI: water samples from boreholes provide information, but difficult to measure with risk of contamination leading to artificially high measured values. DC: no essential new knowledge, risk of (temporary) disturbances.
^{14}C (in DIC)					See tritium	
^{14}C (in DOC)					See tritium	
U^{234}/U^{238}				1–10	No	
HA/FA	Retardation, rock	See DOC	See DOC			
NO_3	Isolation, canister Retardation, rock		<1 mg/l			
NO_2	Isolation, canister Retardation, rock		<1 mg/l			

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Chemical Parameters (contd.)

Geoscientific parameter	Reference to function in function table	Requirements regarding parameter	Preferences regarding parameter	Value range in Swedish crystalline bedrock explanation	Suitable/conceivable evaluation factor	Level of knowledge that can/should be reached after FS, SI and DC
NH_4	Isolation, canister Retardation, rock		<1 mg/l			
HPO_4	Isolation, canister Retardation, rock		<1 mg/l			
N_2	Isolation, canister Retardation, rock		No free gas form at repository depth			
H_2	Isolation, canister		See N_2			
CH_4	Isolation, canister Retardation, rock		See N_2			
CO_2	Isolation, canister		See N_2			
Ar	Retardation, rock					
He	Retardation, rock					
Rn	Working environment		Low concentrations			
Bacteria	Isolation, canister Retardation, rock					
Colloids	Retardation, rock					
O_2						
He-4						
Trace metals other						