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Johan Andersson, JA Streamflow AB

Raymond Munier, Anders Ström, Björn Söderbäck
Svensk Kärnbränslehantering AB

Karl-Erik Almén, KEA Geo-konsult

Lars Olsson, Geostatistik AB

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Preface

This report aims at providing guidance on how to judge when the (surface based) Site Investigation Phase does not need to continue and the deep repository programme can continue with underground exploration. SKB started site investigations for a deep repository for spent nuclear fuel in 2002 at two different sites in Sweden, Forsmark and Oskarshamn. The investigations should provide necessary information for a license application aimed at starting underground exploration. The overall objectives of the site investigation phase are as follows /SKB, 2000a/ "The geoscientific work is supposed to provide the broad knowledge base that is required to achieve the overall goals of the site investigation phase… The knowledge will be utilized to evaluate the suitability of investigated sites for the deep repository and must be comprehensive enough to:

- Show whether the selected site satisfies requirements on safety and technical aspects.
- Serve as a basis for adaptation of the deep repository to the characteristics of the site with an acceptable impact on society and the environment.
- Permit comparisons with other investigated sites."

Furthermore, the investigations are discontinued when the reliability of the site description has reached such a level that the body of data for safety assessment and design is sufficient, or until the body of data shows that the rock does not satisfy the requirements. These objectives are still valid, but do not provide sufficient and concrete guidance. For this reason SKB has conducted this project. Obviously, there is no unique answer to the question when to stop the site investigation. Different perspectives, available resources and to whom the question is raised affects the answer. The overall question will be further developed in the recently initiated work for developing the programme for the completion of the Site Investigations.

The project has been carried out during 2003 by a group consisting of Johan Andersson (project leader), Karl-Erik Almén, Raymond Munier, Lars Olsson, Björn Söderbäck and the undersigned.

Anders Ström
Site Investigations – Analysis

Summary

SKB has started site investigations for a deep repository for spent nuclear fuel at two different sites in Sweden. The investigations should provide necessary information for a licence application aimed at starting underground exploration. The investigations and analyses of them are supposed to provide the broad knowledge base that is required to achieve the overall goals of the site investigation phase. The knowledge will be utilized to evaluate the suitability of investigated sites for the deep repository and must be comprehensive enough to:

- Show whether the selected site satisfies requirements on safety and technical aspects.
- Serve as a basis for adaptation of the deep repository to the characteristics of the site with an acceptable impact on society and the environment.
- Permit comparisons with other investigated sites.

Furthermore, the investigations are discontinued when the reliability of the site description has reached such a level that the body of data for safety assessment and design is sufficient, or until the body of data shows that the rock does not satisfy the requirements. These objectives are valid, but do not provide sufficient and concrete guidance. For this reason SKB has conducted this project which should acquire concrete guidance on how to judge when the surface based Site Investigation Phase does not need to continue.

After a general assessment of the problem, the following specific objectives of the current work were identified:

- Demonstrate concretely how the assessed uncertainties in a Site Description based on a specific level of investigations, together with expected feedback from Safety Assessment and Engineering, can be used to decide whether the site investigations are sufficient – or need to continue. This demonstration will be based on a practical application of relevant aspects of decision analysis tools.
- Highlight and make concrete the type of feedback to be expected from Safety Assessment and Engineering and show how this feedback can be used in the decision whether and how to continue the investigation.
- Highlight uncertainty evaluation of aspects of the Site Description judged to be critical to the decision of investigation sufficiency ("uncertainty of key aspects") and to help substantiate how these uncertainties should be explored such that they can be used in the decision analysis.

In addressing these objectives the report describes some formal decision analyses tools, assessed potential feedback from Safety Assessment and Rock Engineering, explores some key uncertainty in the Site Description and also explores an example where the decision analyses tools are applied.

Based on this work it is generally concluded that the question *When to stop the site investigation* is a decision problem. In simple words the site investigations should stop when the expected net gain of further investigations is zero or negative, where gain is related to the total cost, which includes several factors besides the direct monetary outlay. Furthermore, this decision perspective should be applied not only in determining the sufficiency of the programme, but also when optimising the remaining parts of the ongoing

programme. In particular, it needs to be understood that the Site Investigation is only a step towards the ultimate decision of disposing waste and eventually sealing a repository. The cost and value of information obtained in the Site Investigation Phase, needs to be weighted against the costs and value of obtaining information during later stages. All issues need not be resolved during the Site Investigation Phase. Some could be much better handled later, e.g. during the construction and detailed investigation phase.

More specifically, it is recommended to:

- to actively solicit feedback from Safety Assessment and Repository Engineering,
- keep track of the uncertainty evaluation of the key aspects of the Site Descriptive Models,
- develop the Underground Characterisation Programme as this is the next step against which to evaluate whether the surface based investigations should continue and,
- occasionally apply formal decision aiding tools as a means to provide further insights into the decision problem, but not as the main mechanism of reaching and motivating decisions.

Contents

1 Introduction

SKB has conducted a project (PLUSLUT) which should acquire concrete guidance on how to judge when the (surface based) Site Investigation Phase does not need to continue. The current findings of this project are provided in this report.

1.1 Background

The overall objectives of the Site Investigation Phase are as follows /SKB, 2000a/ “The geoscientific work is supposed to provide the broad knowledge base that is required to achieve the overall goals of the site investigation phase… The knowledge will be utilized to evaluate the suitability of investigated sites for the deep repository and must be comprehensive enough to:

- Show whether the selected site satisfies requirements on safety and technical aspects.
- Serve as a basis for adaptation of the deep repository to the characteristics of the site with an acceptable impact on society and the environment.
- Permit comparisons with other investigated sites.”

Furthermore, “the investigations are discontinued when the reliability of the site description has reached such a level that the body of data for safety assessment and design is sufficient, or until the body of data shows that the rock does not satisfy the requirements.”

Sufficiency in information needs to be understood in the step-wise repository implementation approach. At some stage surface based investigations need to be supplemented by information from the underground. This is also internationally recognised. In an assessment of the role of Underground Research Laboratories, the OECD Nuclear Energy Agency conclude that /OECD/NEA, 2001/, “...at some point, performance-assessment modelling, engineering design, and other aspects of a repository programme require detailed information that can only be obtained underground at the repository site.”

The previously stated overall objectives of the Site Investigation Phase are still valid, but do not provide sufficient and concrete guidance. For this reason SKB has conducted a new project which should acquire concrete guidance on how to judge when the Site Investigation Phase does not need to continue, i.e. when it is better to obtain more detailed and accurate information from the next phase (i.e. the Constructions and Detailed Investigation Phase).

1.2 Scope and objectives

When the project was initiated the following project objectives were stated:

- Develop the logical reasoning to be used for assessing sufficiency of the investigations.
- Identify different quantitative analyses to be used in support of an assessment whether sufficient investigations have been made.

However, it was also clear from the start that these objectives needed development in a "problem identification phase". This has resulted in a refinement of the more general objectives stated here (see Section 2.5). Evidently, most of the actual implementation and assessment on when the programme can stop will need to happen after the conclusions of the specific PLUSLUT project. The current project should pave the way for "real" activities to come.

1.3 Methodology and organisation of work

The work has been performed by a project group consisting of the authors of this report. Given the complexity of the task, it was found necessary to spend effort in more precisely defining the problem to be analysed. This was achieved through a series of project group meetings were the problem definition was developed and various specific studies identified. These studies, reported in Chapters 3 to 6, were carried out by individuals of the project group, but then discussed by the project group. A working group exercise has also been conducted in connection to the ongoing Site Descriptive Modelling work. The project group have also jointly discussed the final recommendations of the work.

1.4 Vocabulary

This report deals with some expression with very precise meaning in the SKB planning. As most of these expressions also have a general meaning their SKB definition is given here in order to avoid misunderstanding.

Site Investigation Phase (*Swedish: platsundersökningsskedet*). The specific phase of surfaced based investigations made in order to prepare a licence application for detailed investigations, construction and repository operation. The general scope of this phase is described in /SKB, 2000b/. Note, surface based investigations and monitoring will continue also after tunnelling work has started. Also, in a general sense, site investigations, from the surface and from below, continue during all stages of repository development. They will only cease at some time in the future when a decision is made to stop further monitoring.

Construction and Detailed Investigation Phase (*Swedish: Bygg- och detaljundersökningsskede*). The construction and associated investigations of repository access routes and a number of underground rock rooms needed for the repository and all other activities needed to launch the Initial Operation Phase, when deposition of spent fuel is initiated. This phase requires a licence according to the Environmental Code (Miljöbalken) and the Act on Nuclear Activities (Lagen om kärnteknisk verksamhet). Other acts are also applicable.

Site Descriptive Model (*Swedish: Platsbeskrivande modell*): The Site Descriptive Model should be an integrated description of the site and its regional environments with respect to current state and naturally ongoing processes, covering geology, rock mechanics, thermal properties, hydrogeology, hydrogeochemistry, transport properties and ecosystems. The description is made in Regional and Local scale and should serve the needs for Safety Assessment, for Rock Engineering and for assessing Environmental Impacts (SKB, 2000b).

1.5 This report

The report starts with a re-assessment of the problem definition (Chapter 2). It is found that one important element of PLUSLUT is the decision perspective and that formal decision analysis tools may be useful. Chapter 3 discusses such tools. Another important aspect of the PLUSLUT problem is feedback from Safety Assessment and Repository Engineering. This is discussed in Chapter 4. In simple words, site investigations may stop when the knowledge obtained from the Site Description is sufficient. Consequently, Chapter 5 addresses our ability to assess uncertainty in critical aspects of the Site Descriptive Models. Chapter 6 demonstrates how formal decision analyses tools could be applied to the PLUSLUT problem. Chapter 7 discusses and provides recommendations.

2 Statement of the problem

Given the complexity of the task, it was found necessary to spend effort in more precisely defining the problem to be analysed. Various system analyses tools including organised brainstorm and decision analysis have been used for this purpose.

2.1 General premises

SKB plans to conduct site investigations at two sites. The site investigation phase will be concluded when at least one of the sites has been sufficiently investigated in relation to the overriding objectives (see Section 1.1).

SKB will need to select one of the sites and the selection needs to be justified. The basic premise is that the selected site must fulfil the stringent safety requirements. If this applies to both sites, there is no reason to make further ranking out of a safety perspective. Instead, other conditions may then determine the selection. Generally, the objective of the Site Investigations is to assess whether the investigated site is suitable.

SKB's ambition will be that the authority review of the licence application will lead to "minimal" requirements for complementing investigations. Furthermore, completing the Site Investigation Phase is a milestone towards a repository in operation. However, "full knowledge" is needed only when canisters actually are deposited. Only then is there potential for radiological hazards. In phases before that, the issue is if there is sufficient knowledge in relation to the commitment (economical, emotional, political,…) involved in the next phase. Specifically, the objective of the current project is to show how to assess whether hazards and uncertainties, both as regards safety and rock engineering, remaining after the Site Investigation Phase are reasonable in relation to the commitments involved in selecting one site and going underground.

2.2 A decision problem

After each site investigation step there are essentially three choices:

- discard the site,
- finalize and submit an application for the construction of the repository using the available information, or
- continue the investigations and obtain more information.

It should also be noted that deciding when to stop the investigations is essentially a subset of the more general question on how to optimise additional investigation activities (if any).

With each decision there is an associated expected cost as well as potential benefits. More investigations might change the expected cost (e.g. less probability of costly surprises during underground construction, higher probability to get application approved) but there are also costs involved in making more investigations! More information should thus be obtained only if we expect to gain more by obtaining the information than what it costs to obtain it. But at the time of decision we do not know how much the information will be worth.

The benefit of more investigations depends on how much is already known at the time of decision. Additional information will have less impact on a decision, the more that is known before (diminishing returns). The value also depends on how cost efficient the investigation is. No investigation is perfect, i.e. gives a complete picture, so there will always be uncertainties left, which means that the decision must be made under risk. In particular, if additional investigation on certain properties only slightly decreases uncertainty, they may not be worthwhile to pursue even if the uncertainty as such is judged to be quite large.

When to stop the site investigation is a decision problem. The objective of the investigations is not primarily to produce a scientifically "true" model – it is to provide a basis for good decisions. In simple words the site investigations should stop when the expected net gain of further investigations is zero or negative, where gain is related to the total cost and value, which includes several factors besides the direct monetary outlay. This means that there will always be remaining uncertainties, which eventually may or may not be a problem later on as "ground truth" will reveal itself, but that we accept these uncertainties at the time of decision.

Even if knowledge increases with more information, the needed knowledge depends on the user. It is thus necessary to understand who needs the knowledge, *the actors*, and for what purpose. Full scientific understanding may be unattainable whereas an engineer may only need knowledge to select suitable construction methods. To assess safety more knowledge is needed, but all aspects of the site are not necessary to understand.[1] Furthermore, the *cost* of increasing knowledge depends on the already existing knowledge (and the method of information gathering). The understanding will probably increase rapidly after a critical set of initial information is analysed, although initially real data may produce a confusing picture, but the increase in knowledge probably levels off for the later information gathering. Figure 2-1 illustrates these aspects.

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[1] There may also be instances where the engineer needs might more knowledge than the safety assessor. The engineer may need detailed information where the tunnels will be placed, whereas the safety assessor may rely on probability distributions.

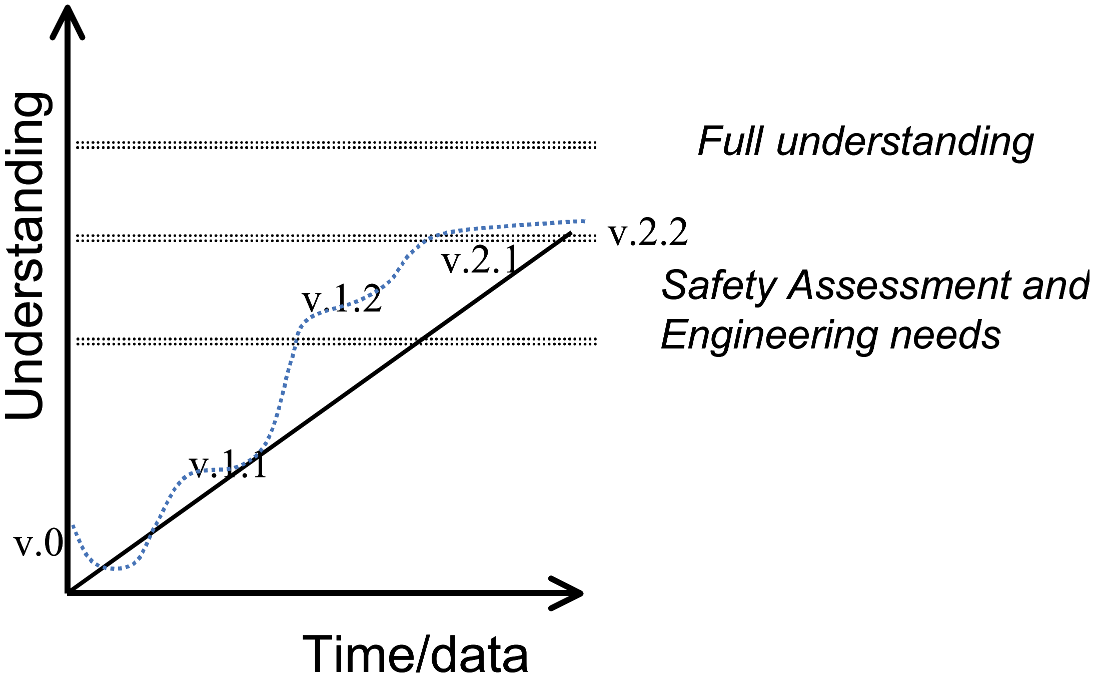

__Figure 2-1.__ For the site investigation it is likely that the knowledge increase in batches (dotted line) and then levels off after some campaigns. However, the needed knowledge depends on the user and the cost of increasing knowledge depends on the already existing knowledge (and the method of information gathering).

2.2.1 Actors

There are several different actors (or stakeholders) who will influence the judgment of when the Site Investigations are sufficient. It is thus important to identify these different actors, to understand their various reasoning and assess their influence on the ultimate decision.

All site investigation activities at SKB are organised into one project, the Deep repository project. The project includes the following main activities: Investigations at Forsmark and Oskarshamn, Site modelling, Engineering, Safety assessment and Environmental Impact Assessment, see Figure 2-2.

The Central Site Evaluation group “CPU” is the management group of the Deep Repository Project, with SKB top management as its the “steering committee”. CPU includes the project manager and leaders of the Site Investigations at the two sites, Site Modelling, Environmental Impact Assessment, Safety Assessment and Engineering. At its meetings CPU assesses strategic issues of common interest to the various activities in the project. The work focuses on oversight and co-ordination of the various activities, including the site modelling project, but also concerns interaction with authorities and municipalities. In practice, it will be CPU that at various stages would need to evaluate, for SKB, whether the site investigation phase is completed, even if the SKB management makes the ultimate decisions. Consequently, this report is to a large extent intended as guidance to the CPU function at SKB.

Site descriptive modelling is performed in projects, one for each site, with representation from all subject areas involved in building a credible site description. A forum for technical coordination oversees and coordinates these modelling projects and ensures that the

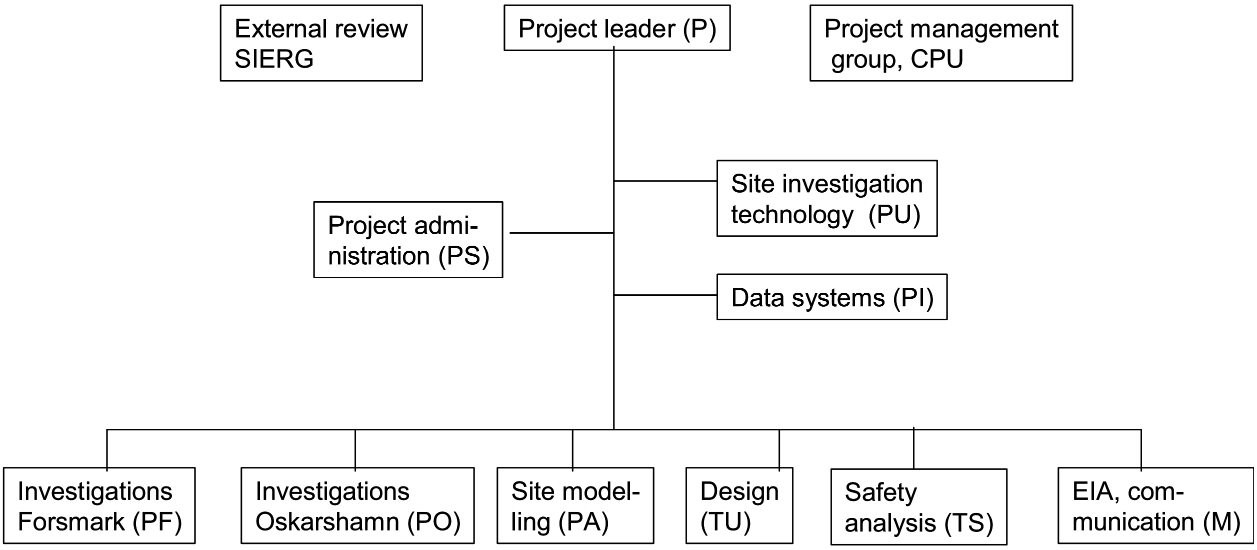

Figure 2-2. *The Deep Repository Project Organisation.*

methodology is applied as intended and developed if necessary. A site description presents collected data and interpreted parameters that are of importance both for the overall scientific understanding of the site and for the analyses and assessments that are made of design and safety assessment. The site description should furthermore present an integrated description of the site (geosphere and biosphere) and its regional environs with respect to current state and naturally ongoing processes.

Also within the SKB staff and among consultants working closely with SKB there are different perspectives. Some take a “scientific perspective”, where more knowledge “always” is needed and understanding is the key, whereas some take an “engineering perspective” and could readily accept making conclusions and decision without full understanding – as long as the information available seem sufficient in relation to the decision to make. In order to integrate all these perspectives into a co-ordinated Site Investigation Programme, the Deep Repository Project assesses its strategic decisions in the Central Site Evaluation group.

There are also critically important actors outside SKB. For the success of the programme, it is essential that the authorities with their reviewers as well as the local public attain confidence that the investigations have reached their goal. This does not mean that all actors need to agree on the sufficiency of the investigations. Possibly, there will always be some external experts, who from their perspective would argue that more information is needed.

As a summary Table 2-1 lists some of the actors influencing the sufficiency of the site investigations and assesses what could be their likely saying in this.

Table 2-1. Examples of actors with corresponding issues, influencing the decision on when the Site Investigations are completed.

Actor	Issues, perspectives, etc	Comments
CPU (Central Site Evaluation)	Suggests decision to SKB management.	Integrates different perspectives into a co-ordinated programme.
The sites	Hands on understanding. Resources and practicability.	"Data collectors".
Site modelling	Describe uncertainty and confidence.	Warning "self generated ambition increase".
Engineering	Can the repository be constructed in accordance with requirements set out by safety assessment and with reasonable environmental impact.	All details of the site not needed during Site Investigation.
Safety Assessment	Can safety be judged in light of uncertainty and confidence in the Site Description?	Essentially check conditions in requirements and preferences. Need to establish means of handling "lack of understanding All details of the site not needed during Site Investigation.
Environmental Impact Assessment	Overall Safety. Effects on the environment Public involvement.	Baseline conditions established for all relevant parameters. Reasonable safety assessment.
SKB-board of directors	Successful Implementation. Cost and time.	Decisions leading to successful implementation would overrule short term cost issues.
SKB expert review group (SIERG)	Is there scientific support for stated confidence?	Should help SKB judging completion.
Authority Expert review groups	Is there scientific support for stated confidence?	Should help SKI/SSI judging completion.
Authorities	Safety, Sufficient ground for licensing. Consultations ("Samråd"), decisions.	For SKB it would be preferable if authorities gained confidence in the SKB work and decision making already during the consultation phase. May require that SKB stick to various "promises" even if promises may not be important.
General public	Is it safe? Impact on neighbourhood.	Critical to keep public confidence and understanding when investigations are sufficient. Openness required.
External experts	Scientific review.	Important for general confidence building. However, risk for narrow expert perspectives. Comments may also be hostile with a purpose to show that investigations are insufficient. (There will always remain single issues where a case could be made for more scientific information.)

2.2.2 Value and costs of additional information

In deciding whether to continue the Site Investigation Phase it is necessary to assess the *value* of additional information. The following should be kept in mind:

- Additional information should, at least in theory, always reduce uncertainties[2]. However, at some point of existing information, the uncertainty reduction may be quite limited ("diminishing returns").
- The information has a value only as long as it affects the decision to be made. Some uncertainties concern factors that do not have a crucial bearing on the decision. Thus more information will not change the decision. However, it must also be remembered that the information gathered during the Site Investigation Phase may also be used for later decisions (e.g. decisions to expand repository, to close repository may include comparison between primary baseline conditions with the post-closure conditions).
- Information is not limited to data from boreholes. It concerns all knowledge and information, geological understanding, surface geophysics as well as surface mappings and monitoring (including ecosystems etc).
- Unexpected findings ("surprises") may affect our subjective view on how much additional information is needed to reach sufficient knowledge, see Figure 2-3, but such findings are not necessarily negative. They may show that a site is less complex or has even more favourable properties.
- Some new measurements are made to verify/validate previous prediction, i.e. to enhance understanding. The value of understanding must thus be factored into the analysis.
- Although flexible, there are practical limitations to the Site Investigation programme, in terms of elapsed time, practicality of investigations, some accessibility constraints and budget.
- All issues need not be resolved during the Site Investigation Phase. Some could be much better handled later, e.g. during the construction and detailed investigation phase.

Also there may exist previous commitments to authorities, landowners or other stakeholders made in various planning reports or at meetings, which needs to be addressed even if later assessment may show that these investigations contribute little to the overall value.

The *cost* of additional information may be divided into:

- direct cost of obtaining the information and,
- indirect costs as resulting from lack of completion of the Site Investigation Phase and the calendar time elapsed.

The direct costs include costs for drilling new boreholes, samplings, extra measurement campaigns, additional modelling etc. While these costs may be substantial, they are nevertheless controllable.

Indirect costs include loss of momentum, loss of attention (fatigue) and a developing "bad-will" to SKB. A too prolonged Site Investigation phase may develop a sense, both internally and externally, that the repository project may never be completed. In such a case, the entire SKB programme would be jeopardised.

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[2] Quantified subjective uncertainty may in fact increase if additional information contains surprises!

Generally the indirect costs of “failed application” or unexpected conditions resulting in a decision by SKB to abandon a site must be judged to be so high that it really is not worthwhile estimating this cost in order to optimise the investigation programme. If there is a risk that the project would be jeopardised in case an investigation is not performed it is usually always justified to carry out the investigation. Yet, this does not mean that all suggested investigations need to be conducted. There is always a need to assess whether an additional investigation really is reasonable and to what extent it really would reduce critical uncertainty.

In the daily planning of investigation activities the cost/benefit perspective is more directly applicable. There the question is frequently asked whether a suggested investigation is worth its costs and efforts in relation to its expected outcome.

Figure 2-3. *Unexpected findings (surprises) may affect our subjective view on how much additional information is needed to reach sufficient knowledge.*

2.3 International guidance

There is some international guidance on site investigation. As already stated /OECD/NEA, 2001/ recognise the need to eventually proceed to the underground. Furthermore, /IAEA, 2003/ have submitted "Draft Safety Requirement" on Development of Geological Disposal Facilities. According to this draft document (Requirement 14: Site characterization):

> "The site shall be characterized at a sufficient level of detail to support both a general understanding of the site, its past evolution and likely future natural evolution over the period of interest for safety, and a specific understanding of the impact on safety of features, events and processes associated with the site and the disposal facility.
>
> A general understanding of the site and its regional setting is necessary in order to present a convincing scientific description of the disposal system, on which the more stylized descriptions that are used within safety assessments can be based. The focus should be on features, events and processes of the site that impact on safety and which must be addressed by the safety case and its supporting safety assessments. In particular, it is necessary to demonstrate sufficient geological stability, the presence of features and processes that contribute to safety, and demonstrate that other features, events and processes do not undermine the safety case.
>
> Characterization of the geological aspects will include activities such as investigation of long-term stability, seismicity and extent of host rock fracturing; confirmation of the volume of rock suitable for construction of disposal zones; geotechnical parameters relevant to design; groundwater flow regime; geochemical conditions and mineralogy. Investigation of the natural background radiation, radionuclide content in soil, groundwater and other media will contribute to a better understanding of the disposal site and to the evaluation of radiological impacts on the environment during development of the disposal facility."

It appears that these general requirements are in accordance with existing SKB plans, e.g. as expressed in the Site investigations Investigation methods and general execution programme /SKB, 2001/. A more specific answer to the question how much investigations are needed to e.g. "demonstrate sufficient geological stability, the presence of features and processes that contribute to safety, and demonstrate that other features, events and processes do not undermine the safety case" requires a more specific assessment of uncertainty in the site description in relation to safety assessment and repository engineering needs. In general, it seems that the suggested IAEA requirements are in line with the approach taken by the PLUSLUT project.

2.4 Which uncertainties may remain after the site investigation?

As stated above the Site Investigation Phase is not the final decision point, but uncertainties remaining after the Site Investigation Phase should be reasonable, in relation to the commitments involved in selecting one site and going underground. We need to better understand what can wait until the detailed investigation stage, at what level engineering work will be at the end of the Site Investigation Phase and where they will be when the underground excavation starts.

2.4.1 Safety assessment perspective

Even if the Construction and Detailed Investigation Phase does not imply potential radiological hazards, it would still be required that no essential safety issues may remain, which could not be solved by local adaptation of layout and design. During the Site Investigation there are several planned occasions when Safety Assessment will be able to provide organised feedback as regards the sufficiency of the site investigations. The SR-Can project /SKB, 2003a/ will deliver its first interim report in mid 2004. Early 2005 Preliminary Safety Evaluations /SKB, 2002/ of the investigated sites will follow. Quantitative feedback from safety assessment could thus not be obtained before these studies but the type of feedback to be obtained can still be assessed in relation to its potential impact on decisions on the site investigation programme.

2.4.2 Repository engineering perspective

When the site investigations are finished Repository Engineering shall, according to the general investigation and evaluation programme /SKB, 2000b/, have

- presented one site-adapted deep repository facility among several analyzed and proven its feasibility,
- identified facility-specific technical risks, and
- developed detailed design premises for the detailed characterization phase.

In order to meet these objectives Repository Engineering develops detailed procedures for the engineering planning. These procedures will also first be tested and then applied in order to produce a preliminary layout (D1) after the initial site investigation phase.

As with safety assessment, quantitative and site specific feedback from engineering to site investigations would come later (the time frame for this is similar to the time frame for planned safety assessments). Still, already now it should be possible to further explore the type of feedback to be expected.

2.4.3 Site characterisation perspective

There are at least three (major) issues that needs clarification from the Site Characterisation perspective:

- Establishing the level of uncertainty in the description of a parameter (the ones important for Safety Assessment and Engineering) at a given level of information.
- Understanding/quantification of how this uncertainty may be reduced by additional surface based investigations.
- Understanding/quantification of how this uncertainty may be reduced by the detailed investigations during the Construction and Detailed Investigation Phase, or later during repository operation.

The first two tasks are already given to the Site Modelling projects, but they would need help in achieving objectives (how, which)? The third task requires planning/assessment of the underground phase. Such activities need to be initiated.

2.5 Formulation of the problem

The discussion and assessment made within the project, has lead to the following problem definition:

- Demonstrate concretely how the assessed uncertainties in a Site Description based on a specific level of investigations, together with expected feedback from Safety Assessment and Engineering, can be used to decide whether the site investigations are sufficient – or need to continue. This demonstration will be based on a practical application of relevant aspects of decision analysis tools.
- Highlight and make concrete the type of feedback to be expected from Safety Assessment and Engineering and show how this feedback can be used in the decision whether and how to continue the investigation.
- Highlight uncertainty evaluation of aspects of the Site Description judged to be critical to the decision of investigation sufficiency ("uncertainty of key aspects") and to help substantiate how these uncertainties should be explored such that they can be used in the decision analysis.

Overall, the project should result in such concrete advice that the site investigation projects (and CPU in particular) could implement and apply in the future planning and evaluation. Furthermore, there are some important limitations in scope:

- The project should explore the need for further Site Investigations and not the entire amount of information SKB needs to supply in a licence application.
- The project should assist the Site Modelling projects – and should not carry out tasks already explored within these projects.

3 Some formal decision analysis tools

The overall question "when to stop the Site Investigation Phase", is a decision problem. Consequently, it may be useful to explore to what extent formal decision analysis techniques can be applied in addressing this overall question. It should be kept in mind that formal decision analysis and the actual decision-making are two distinctly separate activities. The formal analysis will never replace human decisions and will always be unable to capture all nuances behind real decisions. However, the formal analyses may still give important insights and will potentially help in more precisely identifying the various information and feedback between various actors.

3.1 Decision analysis

There are various decision analyses tools, which can be useful for formal decision analysis. A decision analysis requires the following:

- A person (or organisation) who is the decision maker.
- Alternatives to chose from (doing nothing is one alternative).
- Consequences connected to the decision. These depend on the real state of nature, which is not known at the time of making the decision.
- A rule for what constitutes a good choice.

Decisions can be made under different states of knowledge. A common notation is to separate between *decisions under risk*, in which case the probabilities for different outcomes are known and the more general case: *decision under uncertainty*, where the probabilities are unknown. There is need for a structured approach for making these kinds of decision, to help the decision maker, i.e. there is a need for decision support tools.

In the following we will discuss three different decision analysis methods and their possible application in the PLUSLUT project; decision tree, Analytic Hierarchy Process (AHP) and Weighted objectives analysis. They have different characteristics and different application areas. Decision analysis methods have also been used in some SKB studies, for example in the project on Alternative Systems /SKB, 1993/ or in a more recent evaluation on access routes to the repository /Bäckblom et al, 2003/.

3.2 Decision trees

Decision trees are useful for decisions under uncertainty in those cases where all possible outcomes can be expressed in the same quantity e.g. money and the goal of the decision is to minimise costs (or equivalent: to maximise profit). They are graphical methods to depict the decision situation with possible decisions, uncertainties and outcomes. (A practical example demonstrating the applicability of this technique is given in Section 6.1.)

A decision tree is built from the following components, see Figure 3-1:

- Decision nodes, where there exists a choice to be made.
- Chance nodes, where there is a possibility that events can follow one path or another, but the path followed is governed by chance.
- Terminal nodes which describe the outcome if a certain path is followed.

In order that the tree shall be useful for decision making, one must have a rule (criterion) for which decision is the best. One such criterion is called the "subjective expected utility" criterion (also known as the Bayes criterion):

- Probabilities are subjective.
- The value to be attached to a certain outcome must reflect the decision makers opinion of their desirability. Thus these values are subjective too.
- The best estimate is the expected value.

The decision tree in Figure 3-1 is very useful to graphically illustrate the general structure of the decision problem, but it cannot be used for decision analysis until both the probabilities connected to each unknown state and also the consequences have been enumerated. Such a quantified decision tree is shown in Figure 3-2.

The needed values for the probabilities can be found using statistical methods, often based on Bayes´ theorem, as one of the principles behind the method is that it is subjective (where "subjective" is necessarily connected to the decision maker). For assessing subjective probabilities, see the literature, /e.g. Olsson, 2000/ with references.

The consequences shall also reflect the decision makers´ subjective values and opinion of desirability. This means that there is often the case that a purely monetary description of the outcomes is not sufficient, as the decision maker might put a higher number on a large possible loss than the monetary value (the outcome might for instance mean ruin.) Large losses should thus be "exaggerated" in the calculations. Some values should be used that reflect his subjective preferences. These are usually called utilities and are assessed by the decision-maker.

For a description of the procedure /see e.g. Ang and Tang, 1984/. The conversion between monetary values and utilities is usually shown in a graph, a so called utility curve, see Figure 3-3.

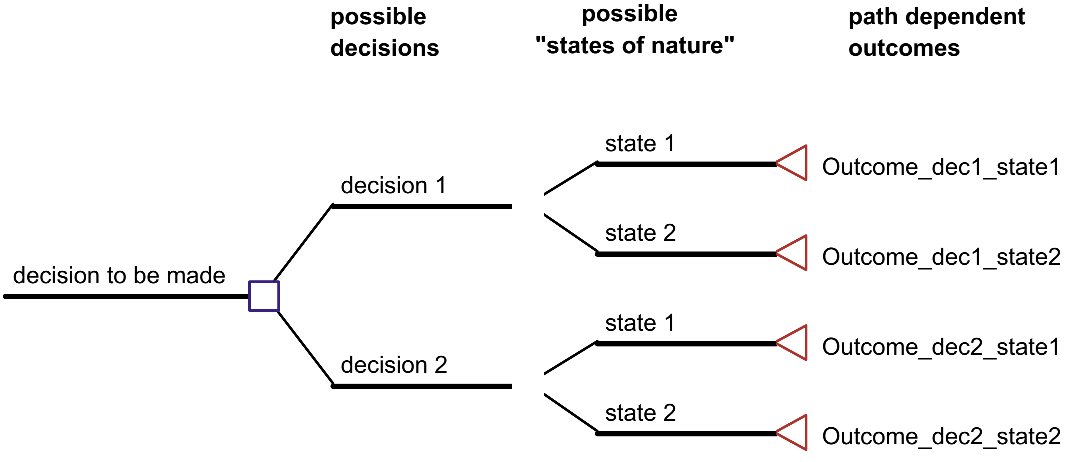


Figure 3-1. *Components of decision tree.*

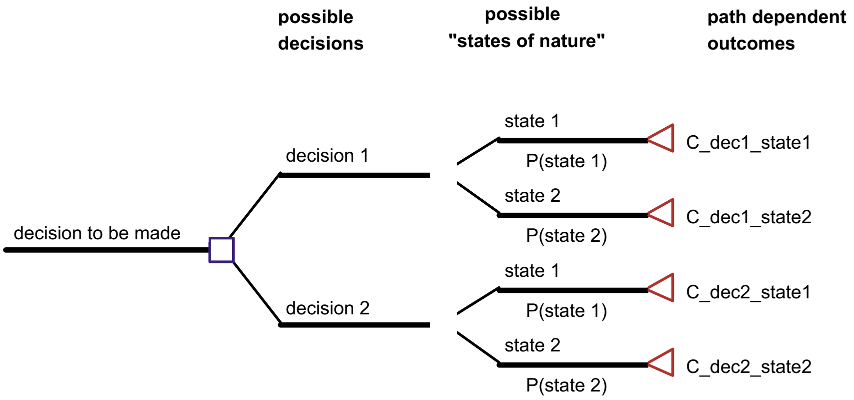


Figure 3-2. *Quantified decision tree, where P(state 1) is the probability of a state 1 and C_dec1_state1 is the cost given decision 1 is taken and the nature was in state 1 (etc).*

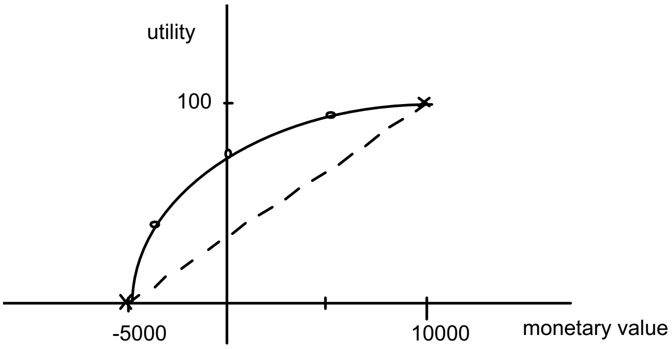


Figure 3-3. *Utility curve (example).*

A special case in the assessment of utilities is when one wishes to reach several goals at once with the decision, for instance at the same time minimise cost and minimise environmental impact. This is a case of *multi-objective* decision analysis. For such problems a special utility function is needed, a so called *multi-attributive* utility. For a discussion of this problem, /see e.g. Ang & Tang, 1984; Keeney & Raiffa, 1976/.

When both the (subjective) outcomes and probabilities have been assessed, the decision tree can be evaluated so that the alternative with the largest expected utility can be found. As utilities can be negative for losses, one normally searches for the largest expected utility. The calculation of the expected utility is normally done using what is called "roll back", i.e.

$$E(\cos t, decision_i) = \sum_{j=1}^{n} P(decision_i, state_j) \cdot Cost(decision_i, state_j)$$

where E (cost, $decision_i$) is the expected cost for decision i, P($decision_i$, $state_j$) is the probability that we will be in state j given the decision was i, Cost($decision_i$, $state_j$) is the cost of being in state j given decision n, and n is the number of possible states, see Figure 3-2. An optimal decision would then be the decision with the lowest expected cost. If probabilities of states or costs are hard to estimate – the following decision analysis may lead to poor decisions. However, surprisingly often the optimal decision can be quite robust to a wide range of probabilities of states or costs – even if the expected costs may vary. More detailed accounts for the construction and evaluation of decision trees can be found in the literature,

/see e.g. Ang & Tang, 1984; Olsson & Stille, 1980; Stille et al, 2003/. An SKB example is found in /Bäckblom et al, 2003/.

There might sometimes be the case that the decision process calls for decisions at different stages in the tree, for instance first choosing whether to make more investigations or not; and then at a later stage choose the investigation method to be used. This means that the primary decision to be evaluated will depend on decisions taken later on which thus are unknown at the first decision stage. This problem is handled assuming that the decision-maker is logical and follows the principles above, i.e. the later decisions are those that are optimal in the roll-back, which starts at the consequences.

In the PLUSLUT case the overriding decision is whether to gather more information or not. This decision depends on what we will know about the probabilities after we have done the investigation, but the decision will be made before the investigation!

In the examples above, the decision has been based on existing information, so called prior analysis. The decision depends on the possible consequences and on the probabilities of the branches. These probabilities might be based on a small amount of (prior) information. Often there is a possibility for gathering more information to be included in the decision process by updating the branch probabilities and repeat the analysis, a so-called posterior analysis. ("Posterior" refers to the gathering of additional data.) There is a possibility of assessing the value of gathering more information before it is really available (so called pre-posterior analysis). Thus it is possible to make a decision e.g. on whether an extensive soil investigation should be made or if a less extensive one is more cost effective. This is done by comparing the expected cost with only the original information (probabilities) with decisions made with the updated probabilities. A tree with the alternative to perform an investigation or not is shown in Figure 3-4.

In order to calculate the posterior probabilities one must estimate the precision of the investigation and state e.g. in a reliability matrix. Such a matrix might look like the example in Table 3-1.

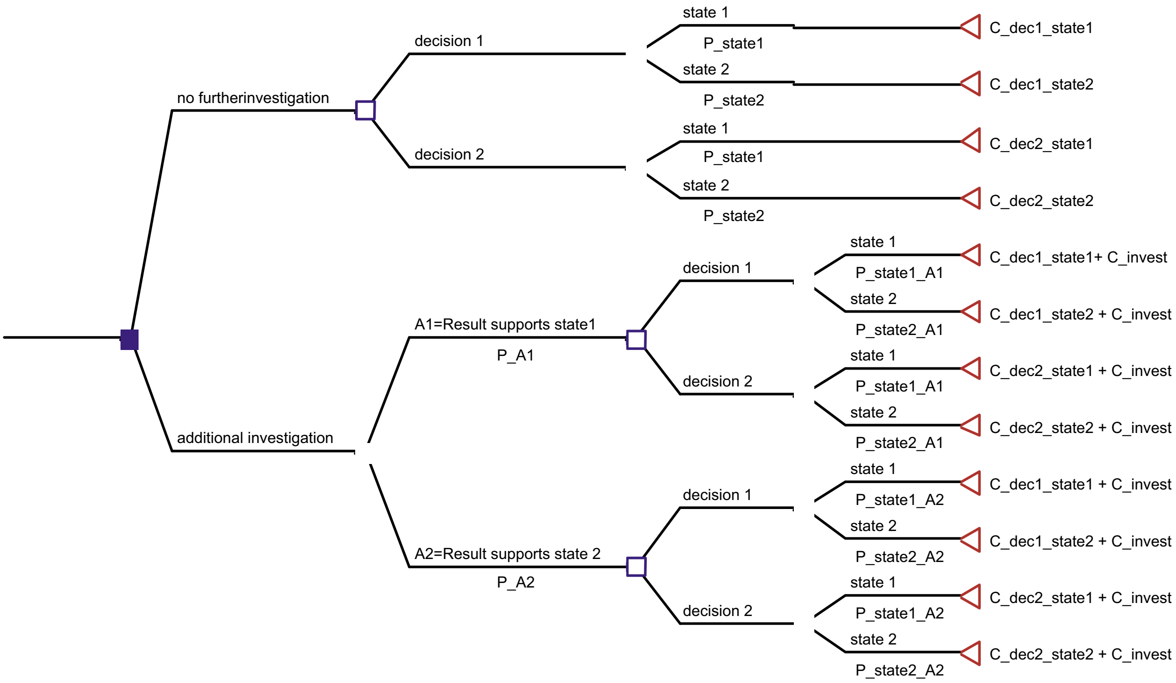


Figure 3-4. *Decision tree with the alternative to perform additional investigation.*

Table 3-1. Reliability matrix for rock investigation. Example.

Exploration result	State of nature	
	State 1	State 2
A1	0.8	0.3
A2	0.2	0.7

3.3 AHP – Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is used for decision under risk in cases where one cannot evaluate the possible outcomes in utilities, but where one is willing to *rank* them according to their desirability. AHP is a ranking method, where the different alternatives are compared to each other and ranked according to their judged desirability (without calculating the possible outcomes.) This judgement and the ranking should be made in a systematic and stringent manner in order to avoid psychological biases etc, /see Saaty, 1990/.

In the AHP the following steps are taken to solve the decision problem:

- Define the problem. Identify decision alternatives and criteria.
- Eliminate non-feasible alternatives.
- Build a structured AHP model.
- Make judgements.
- Evaluate.
- Examine, verify and document.

The *definition of the problem*, including the goal to be reached, and the identification of alternatives is a system analysis. The criteria to be used when judging the alternatives may also be seen as part of the system identification.

Some alternatives may not satisfy some minimum requirements. They should be *eliminated* to simplify further analysis.

In AHP the decision problem is *structured* in a hierarchic tree format using the elements GOAL, CRITERIA and ALTERNATIVES, see Figure 3-5. For example, the GOAL might "Chose best method to build a certain tunnel", the ALTERNATIVES might be: "TBM" or "Drill and Blast" and the chosen CRITERIA: "Construction time", "Environmental impact" and "Method reliability".

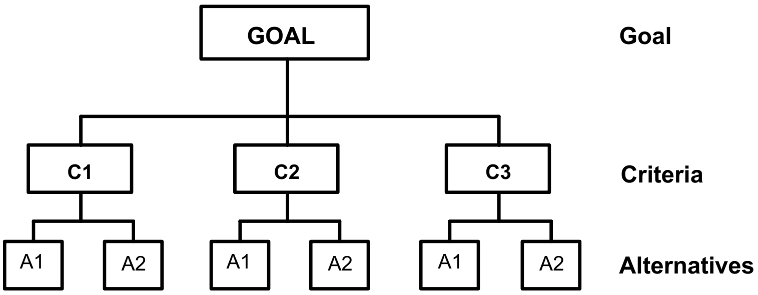


Figure 3-5. *Basic AHP structure.*

When using the AHP approach, all *judgements* are made in the form of pair-wise comparisons between the elements at one level of the tree. This comparison is made with regard to each element on the next level. In the example above the comparisons would be "Which alternative TBM or Drill and blast is preferable: With regard to Construction time? "With regard to Environmental impact?" and "With regard to Method reliability?". On the next level the comparison would be: "What is more important for the goal: Construction time or Environmental impact?", "Construction time or Method reliability", and "Environmental impact or Method reliability?" The preferences are described using verbal expressions that for computations are translated using a special scale, see Table 3-2.

Evaluation of the judgements is usually done using a computer with commercial software such as ExpertChoice. For the mathematical principles, /see Saaty, 1990/. As a result from the evaluation, one gets a ranking of the alternatives (with regard to the Goal) and also the importance of the various criteria. (These results are given on a ratio scale).

Table 3-2. Verbal expressions and corresponding numerical values used in AHP /Saaty, 1990/.

Intensity of importance	Definition	Explanation
1.0	Equal importance	Two elements contribute
3.0	Weak importance of one over another	
5.0	Essential or strong importance	Experience and judgement slightly favour one activity over another
7.0	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9.0	Absolute importance	The evidence favouring one activity over another is of the highest order of affirmation
2.0, 4.0, 6.0, 8.0	Intermediate values between adjacent scale values	When compromise is needed

3.4 Weighted objective approach

Weighted objectives analysis is a ranking method for decision under uncertainty, when it is difficult to assess the consequences as utilities. For a description of the method, /see Ang and Tang, 1984/.

The principle is to lists the various objectives (or goals as in AHP, see previous section) to be attained (by the decision) and to calculates relative weights for the outcomes. These weights should reflect the decision-makers preferences, like in the AHP. But unlike in the AHP it is not necessary to assume that the objectives certainly will be reached. Instead, the probability for reaching each objective as function of the decision alternative has to be estimated.

The best decision is then the one that maximises the overall relative utility, which is the sum of the (relative weight of the objective multiplied by the probability to attain it). This is shown in Table 3-3. /Ang and Tang, 1984/ describe a method for calculating these relative weights, but for the PLUSLUT case, it appears better to use AHP for this purpose.

Table 3-3. A weighted objective approach.

Relative weights	w_1	w_2	w_3	w_n	
Objectives	O_1	O_2	O_3	O_n	
Alternatives					**Overall relative utility**
$\mathbf{a}_1$ (no more tests)	p_{11}	p_{12}	p_{13}	p_{1n}	$U_1=\Sigma\, p_{1j}w_j$
$\mathbf{a}_2$ (further tests)	p_{21}	p_{22}	p_{23}	p_{2n}	$U_2=\Sigma\, p_{2j}w_j$

3.5 Suitability of the methods for PLUSLUT

The described decision analyses tools ought to be applicable to the PLUSLUT case, but there are several aspects to consider.

One aspect is that the decision to stop the Site Investigations is fundamentally a multi-objective one. Potential additional investigations will generally concern several objectives, i.e. the same investigation (like a new borehole) may be motivated by its capability to reduce uncertainty in the fracture zones, ore potential, hydraulic data or overall understanding. Also, the decision problem of stopping or not is just a subset of the more general problem of deciding the direction (if any) of the future characterisation efforts.

Another aspect is the complexity of the investigation programme, which may make it hard to estimate potential decrease in uncertainty for a given investigation and the potentially large costs of failing the investigation programme compared with the still rather moderate cost of e.g. drilling additional boreholes. This may make the cost/benefit or cost/utility perspective difficult to apply, since there is a risk that the resulting optimal decision will be very sensitive to numbers very hard to estimate.

Despite these concerns, it is still felt that application of decision analyses tools will be useful, if "handled with care". More specifically, the following judgements can be made:

- *Decision tree*. Although decision trees theoretically might be used for the overall PLUSLUT decision (i.e. to stop or continue), in practice they will not function. Main reasons for this are that the trees will rapidly grow very large and that there are difficulties especially in assessing all utility curves. However, trees are potentially quite useful for smaller decision problems that will be met in the process.
- *Analytic Hierarchy Process (AHP)*. Although this method avoids the problem of assessing utilities, its usefulness is restricted for PLUSLUT as it only considers decision under risk, i.e. in cases where the probabilities are known.
- *Weighted objectives decision analysis*. This decision analysis method seems to have a great potential, and the application has been tested in the project. This is described in Chapter 6.

4 Acceptable uncertainty and confidence

In order to judge the utility of additional information, it is necessary to specify the uncertainty and confidence acceptable in the Site Description. The needs of Safety Assessment and Repository Engineering were also key input when planning the Site Investigations and the selection of the currently investigated sites /see SKB, 2000a/. Clearly, most parameters are already defined in previous planning documents, and highly relevant studies like SR-Can and design exercises are underway. However, given the need for early feedback, the PLUSLUT project has tried to more clearly identify what feedback to expect from Safety Assessment and Engineering.

4.1 Feedback from safety assessment

This section discusses the expected feedback from Safety Assessment and to what extent this can be used for the PLUSLUT task.

4.1.1 General

Even if the Construction and Detailed Investigation Phase does not imply potential radiological hazards, it would still be required that no real safety issues remain, which could not be solved by local adaptation of layout and design. For example, it needs to be established:

- Are all critical site specific parameters identified, is a need to revise the list of preferences and requirements in /Andersson et al, 2000/ and do we understand how much uncertainty in these parameters would be acceptable after the Site Investigation phase?
- Detailed site properties and the detailed design can only be determined during the Construction and Detailed Investigation Phase. How should one reasonably factor this into the assessment without taking too much or too little credit for what could actually be achieved during this phase? For example, there may remain questions as regards performance of seals since or to what extent it is possible to take credit from clever layout and selection of disposal tunnels and deposition holes.

These and other issues will be explored in the planned Safety Assessments during the Site Investigation Phase, namely Preliminary Site Evaluations (PSE) and the projects SR-Can and SR-Site.

4.1.2 Expected feedback from SR-Can and PSE

As already noted in Section 2.4.1, SR-Can will deliver its first interim report in mid 2004 /SKB, 2003a/. Preliminary Safety Evaluations /SKB, 2002/ of the investigated sites will follow early 2005.

According to plan the Preliminary Safety Evaluation will review the plausibility of the confidence statements made on the Site Descriptive Model as a whole. Are the confidence statements well supported? If not how could they be improved? The following, more specific, feedback may be expected:

- Comparison with criteria as given in /Andersson et al, 2000/ and, based on this, a general recommendation of whether site investigations should continue.
- It is particularly important to have high confidence in the Site Description in the rock mass volume "enveloped" by calculated migration paths. The needed confidence could be compared with the current confidence and may thus lead to assessments of the need to increase borehole density etc. Similarly, the distribution of discharge points will indicate which portions of the surface environment are of most interest, at least for radionuclide turn-over modelling for present day conditions. However, uncertainty and evolution over time of actual migration paths needs to be considered.
- The transport calculations and sensitivity analyses will provide similar feedback of higher precision. They will also help in putting the site specific uncertainties in a broader perspective.
- Exploring the impact of different alternatives will suggest if there is a need to spend efforts (critical measurements and modelling) in decreasing the span of alternatives in the Site Description, both regarding geometry and properties.
- Assessing importance of (potential) heterogeneous rock type mixture will provide feedback to site investigations on the ambition level and approach for describing the rock type variability.
- Respect distances are introduced to take into account the effects of anticipated, future earthquakes on the barrier function of the repository. A set of research- and simulation projects are currently being undertaken to increase the understanding on how to confidently address this complex issue.
- Indication whether further attention is needed as regards colloid levels.
- If there is a problem with potential indications of mineral deposits found, this may equire a more careful assessment of the extent of the deposits.

4.1.3 Conclusions

The Safety Assessment planning suggests that only certain site properties are really important for assessing the safety. Generally, these are connected to the requirements already stated in /Andersson et al, 2000/. Consequently, there is a need to ensure that the site modelling is able to produce qualified uncertainty estimates of these properties. This is to be discussed in Chapter 5 "Uncertainties and confidence in the Site Description". Evidently, Safety Assessment would be able to produce updated feedback after the completion of currently planned assessments (e.g. PSE and SR-Can).

4.2 Feedback from repository engineering

This section discusses the expected feedback from Repository Engineering and to what extent this can be used for the PLUSLUT task.

4.2.1 General

Given the overall objectives of the repository engineering, as expressed in Section 2.4.2, it is still needed to more precisely establish the level of flexibility in design, which would be acceptable also after completed site investigations. In general, the layout developed by engineering at the end of the site investigation must be adaptable to findings made during underground excavation.

According to current thoughts within Engineering there are essentially three design issues to be addressed during the Site Investigation phase:

- Is there enough space?
- What is the degree of utilisation (i.e. a subset of the space issue)?
- Are critical passages properly assessed?

These issues are expanded in the following.

Space

The overriding issue whether there is enough space for the repository may be divided into determining the generally available space and the degree of utilisation within this generally available space. The latter will be discussed in the next subsection.

The factors controlling the generally available space are the regional and local major deformation zones. Deposition tunnels must not be placed closer than a certain respect distance from such zones. Working definitions of respect distances exist but there is still some refinement work going on what should be appropriate respect distances see e.g. /SKB, 2002/.

The final layout of deposition tunnels will not be made until the rock is explored from the underground, i.e. at the Construction and Detailed Investigation Phase. For the Site Characterisation phase it is much more important to assess whether there is place in general. The information needed for this is essentially

- information about the number of (or frequency) of deformation zones,
- assessment of the true width (including uncertainties, but not through unknown dip and strike) of the zones,
- assessment if there would be "regions" with such high frequency of zones that a large portion of rock would be unsuitable for deposition tunnels.

These points are illustrated in Figure 4-1. In practice this means that it is important to be able to confirm existence and non-existence of regional and local major zones, whereas information about dip and dip direction is of less importance. Clearly, information about possible occurrence of subhorisontal deformation zones is also important, but the detailed adaptation of design to subhorizontal features could anyway not be made before the Construction and Detailed investigation Phase.

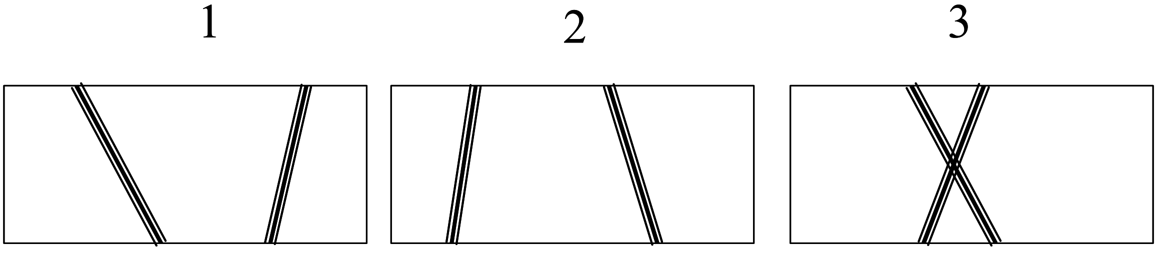


Figure 4-1. *The exact location of deformation zones is not crucial information to engineering as long as deposition panels would not be deemed too small (as in case 3).*

Degree of utilisation

The repository layout is not only controlled by the regional and local major deformation zones. For example, deposition holes connected to large fractures or holes with high inflows will not be used and the thermal rock properties affect the minimum allowable distances between deposition tunnels and deposition holes. During site investigations this is handled in the design by estimating a "degree of utilisation" for the deposition panels already adjusted to the regional and local major deformation zones. Final selection of deposition holes and tunnels will be made locally, underground, during the construction and detailed investigation phase.

Water is an important aspect of the degree of utilisation. There is a need to put a limit on how much water would be practically acceptable. Fractures with a high transmissivity need to be grouted for practically realistic working conditions. Such high transmissive fractures probably exist in all conceivable sites – and are not difficult to handle. However, it would not be practical to have to grout at every section of tunnel construction. This would be messy, uneconomical and would also imply a rock mass with undesired properties from a Safety point of view, both as regards hydraulic conductivity /see e.g. Andersson et al, 2000/ and the resulting grouts and grouting boreholes in the rock mass. Such reasoning could be used to set design rules based on the frequency of high transmissive fractures.

Apart from water, other factors affect the degree of utilisation. This includes heat conductivity and rock mechanics properties affecting bedrock stability and rock burst.

SKB also have ongoing studies (Christiansson pers. comm.) exploring the degree of utilisation in a rock volume described by a DFN description of fracture geometry and transmissivity resulting from various acceptance criteria in the form of maximum allowed size and maximum allowed total transmissivity in fractures intersecting a deposition hole. It is tentatively concluded that the tool developed would be applicable for such studies. The next step in this work is to develop a better basis for acceptance criteria for deposition holes, including considering whether such criteria should be based on more than fracture properties.

Critical passages

For the engineering planning and selection of the surface access point it is necessary to identify and characterise potentially difficult passages (i.e. deformation zones) in the rock. However, the information needed would be quite detailed, which means that the overall site description will be used to identify potential access locations. At these locations there will be a need to drill some additional exploration boreholes in order to assess the actual critical passages. There is no need to assess critical passages in the entire model domain.

Sensitivity analyses

Sensitivity analyses is one way of assessing whether the points made here needs further elaboration. Some sensitivity analyses are already underway (see Section 4.2.2), but follow up studies may be needed. Especially since conclusions may be rather site specific. For many parameters it is likely that rather high uncertainties are acceptable, but there may be some critical threshold values, where site modelling needs to assure that these are not reached.

4.2.2 The design D1 exercise

Rock engineering will develop design and layout in stages. Layout D1 will be produced based on Site Model version 1.2 and Layout D2 will be produced based on the final Site Model. As with safety assessment a test will be conducted using the Site Descriptive Models as input.

Handling uncertainty in design work is a developing area within rock engineering /see e.g. Stille et al, 2003/. For this reason a first design test exercise focused on uncertainty in "deterministic" deformation zones and how this would impact the available space. To conduct this test, *each deformation zone in the model* should have an uncertainty description with the following characteristics

- Judgement on confidence in *existence* expressed in a relative scale (such as high, medium, low).
- Quantified uncertainty in dip (e.g. estimated from k in a Fisher distribution) with special attention to whether the expected dip deviates from perfectly vertical.

More generally, the uncertainty description should also consider:

- Identification of areas where there is no (or very poor) information (i.e. where the non-existence of deformation zones at the surface could not be considered as an indication of actual non-existence. This is however not crucial for the planned engineering exercise, since the area designated for the exercise is equally well characterised.)
- Quantified uncertainty (e.g. range or mean ± standard deviation) of actual width of the deformation zone. However, this information is not critical if the widths are much less than the respect distance to the zone (e.g. a width and associated uncertainty of a few m, for a local major zone does not have a direct consequence for the available space).

More specific feedback, than this could not be expected in the spring of 2004.

4.3 Conclusions

The Repository Engineering planning suggests that only some site properties are really important for assessing the design work during the site investigation phase. Consequently, there is a need to ensure that the site modelling is able to produce qualified uncertainty estimates of these properties. This is to be discussed in Chapter 5 "Uncertainties and confidence in the Site Description". Evidently, Repository Engineering would be able to produce updated feedback after the completion of currently planned tests – or at least after producing Layout D1.

As regards degree of utilisation it is clear that a reasonably high confidence would be required in the DFN descriptions of the Site Descriptive Model. More specific feedback would not be possible before the anticipated further development steps, see above, are taken.

5 Uncertainties and confidence in the site description

Another necessary component in order to make a decision on when to stop the Site Investigation phase is to substantiate uncertainties and confidence in the Site Description for a given level of Site Specific information. This is a general task for the Site Modelling work, but the evaluation of the needs of Safety Assessment and Repository Engineering in Chapter 4 shows that only a few site properties really are important for the decision whether site investigations are completed. This chapter assesses these issues.

5.1 Key aspects of the site description

The needs of Safety Assessment and Repository Engineering were key input when planning the Site Investigations and the selection of the currently investigated sites /see SKB, 2000a/. These needs were also compiled in the report "What requirements does the KBS-3 repository make on the host rock? Geoscientific suitability indicators and criteria for siting and site evaluation" /Andersson et al, 2000/. These judgements, made at the planning stage, are still relevant and generally valuable, and need thus be reiterated here. However, the ongoing work of Safety Assessment and Repository Engineering, as reported in Chapter 4, also implies that some of the aspects of the Site Description require additional focus.

5.1.1 Requirements and preferences

Among other things /Andersson et al, 2000/ presented:

- The requirements and preferences made on the bedrock on the site for the deep repository.
- How these requirements and preferences can be translated into measurable parameters and criteria that provide guidance, especially during the site investigation phase.

Requirements are absolute conditions that must be satisfied. They refer to actual conditions and remain the same throughout the siting process. If it is found at any point that a requirement cannot be satisfied on a site, the site must be judged to be unsuitable.

Preferences are conditions that ought to be, but do not have to be, satisfied. Many preferences can be formulated, and satisfying all of them is not realistic. A satisfied preference can offer advantages such as larger safety margins, simplified repository construction, lower environmental impact or lower costs. It is important to distinguish between the above concepts, particularly when it comes to the rock and the prospects of long-term safe disposal. The requirements on the rock are absolute; if they are not met at a site, the site cannot be considered for the repository. But many of the factors that have to be taken into account with regard to the rock have the character of being"advantages/ disadvantages", and can be translated into preferences of differing weight.

5.1.2 “Showstoppers”

Based on the requirement and criteria presented by /Andersson et al, 2000/ SKB has also presented /SKB, 2000a/ under what circumstances should investigations on a site be discontinued. Generally, the site is only accepted if it is possible to show in the safety assessment that the deep repository can satisfy the regulatory authorities’ safety requirements. During a site investigation, when measurement data have been obtained from repository depth but before the overall assessment has been carried out, criteria are used to check whether the above requirements and preferences can be satisfied. A group of these criteria are judged so important that the site investigation should be discontinued and another site chosen if they cannot be met. These criteria concern:

- If large deposits of ore potential minerals or valuable industrial minerals within the repository area are encountered.
- If the repository cannot be positioned in a reasonable manner (if it would have to be split up into a very large number of parts) in relation to regional or local major deformation zones.
- If the repository cannot reasonable be designed in such a way that extensive and general stability problems in rock facilities can be avoided.
- If oxygen-free conditions, i.e. no dissolved oxygen in the groundwater at repository depth, cannot be proven.
- If measured total salinities (TDS = Total Dissolved Solids) at repository level are higher than 100 g/l.

Besides these directly disqualifying criteria, the suitability of the site can be questioned if a large fraction of the rock mass between fracture zones has a hydraulic conductivity greater than 10^{-8} m/s.

5.1.3 Key uncertainties

A Site Description comprises many different parameters. However, the already identified key aspects of the Site Descriptive Models as described above, the additional input from Safety Assessment and Repository Engineering, as reported in Chapter 4, together with experiences gained during the ongoing site investigations suggest that there are some aspects of the Site Descriptive Model, where it is especially crucial to get good uncertainty estimates. The PLUSLUT project has studied the *relation between wealth of data and our ability to assess* the following:

- baseline conditions,
- ore potential,
- fracture statistics as well as individual fracture zones,
- long term mechanical evolution (earthquakes, etc),
- current distribution of the groundwater composition as well as its past and future evolution,
- confidence, including surprises in conceptual model (e.g. porous granite, fracture zones of unexpected dips,…)?

The following question has also been raised:

- Can an excessive amount of investigations (like many boreholes) impair the site properties?

The list may be expanded. It should also be noted that all these issues already are at focus in the ongoing site modelling work. Nevertheless, additional special studies on these difficult issues are warranted.

5.2 Temporal variation and baseline

Many of the investigated parameters will show a pattern of more or less pronounced temporal variation. One apparent reason for such variation is the seasonal fluctuations in temperature and precipitation. There may, however, also be other and more unpredictable reasons, such as long-term variation or trends in meteorological parameters as well as any kind of stochastic events, which can cause variation in one or several of the parameters. Furthermore, investigations and underground activities themselves may give rise to changes or variation in some parameters.

Understanding the temporal variation is important when establishing the Primary Baseline conditions of the site. As set out in the overall SKB strategy for monitoring /Bäckblom and Almén, 2004/, the general idea with establishing the Primary Baseline conditions during the site investigations from surface is to get a reference against which the changes caused by the repository development can be recognised and distinguished from natural and other man-made temporal and spatial variations in the repository environment. These changes observed are useful for many purposes as the observed anomalies may be compared to predicted responses to accept or reject scientific models of the site or of the repository, to adapt and refine repository design to the geological conditions at hand and to calibrate models included in the safety assessment. However, this does not imply that all aspects of the natural time variation needs to be captured. Monitoring results themselves are indicators only and that there should be very few implementation decisions based on monitoring results only. The reason is that major decision points in the programme are preceded by comprehensive, updated safety assessments where the importance of a monitoring result as well as other data is put in a holistic perspective.

5.2.1 Need for time series data

The occurrence of temporal variation means that there will be a demand for time series data for at least two reasons. Firstly, for many parameters the site characterization will involve estimation of “typical” values (mean, median, etc) or extreme values (min, max, etc), as well as a measure of variation of these values. Knowledge of the pattern and amount of temporal variation may be critical for our ability to accurately describe site-specific conditions and processes and to model important processes at the site. Secondly, many site-specific conditions and processes will change during site investigations and construction of the repository, both due to natural causes and to activities at the site. To be able to detect and quantify any changes, it is necessary to have a clear picture of the “undisturbed” baseline conditions at the site. Furthermore, knowledge of baseline conditions, together with good reference data, will considerably increase our possibility to differentiate between natural changes and changes caused by activities at the site.

Site investigations should therefore include the collection of time series data for all important parameters showing significant temporal variation, i.e. those for which a single snapshot will not be enough to characterize undisturbed conditions or processes. This kind of natural temporal variation will be an issue mainly for ecological, hydrological, hydrogeological and hydrogeochemical parameters measured near the ground surface. There may, however, be some, mainly hydrogeological, parameters showing significant temporal variation also at considerable depths.

A crucial question for the Site Investigation Phase is how long time series are needed to enable an acceptable characterization of site-specific conditions and processes. For most parameters showing temporal variation with a seasonal component, the within-year variation will be much larger than the longer-term variation. This means that the detection and description of any longer-term variation requires considerably more effort than what is needed for the characterization of within-year variation. A relevant description of the between-year variation, based solely on site-specific data, would in most cases require longer time series (probably > 10 years) than what is realistic to attain during the Site Investigation Phase. The characterization of within-year variation would certainly also benefit from longer time series, however, the direct and indirect costs (cf Section 2.2.2) of extending baseline monitoring over several years will probably not be in proportion to the value of the additional information gained for each new year of monitoring. The best approach for the site investigations seems therefore to be to carefully capture the within-year variation during initial, "undisturbed" conditions for one or a couple of years, and then relate these measurements to good reference data for a description of the between-year variation. Accordingly, it is almost equally important to ensure the access to good reference data as is the establishment of baseline monitoring itself.

Arguably, the extreme values are important for some parameters. Information on extreme values will to some extent be provided by a careful description of the within-year variation for a given parameter. Some additional years of baseline monitoring would however not provide significantly more information on longer-term extremes, and arguments on extreme values need anyway to be derived from long-term measurements on reference sites, combined with a mechanistic understanding of the processes potentially inducing extreme values.

5.2.2 Long-term monitoring

Even if extensive sampling programmes for the collection of time series data is restricted to one or a couple of years, the programmes would not be terminated after this period. Instead, a reduced number of carefully selected sampling points will, together with equally carefully selected reference sites, and monitoring underground be included in long-term monitoring programmes. Data collected in these monitoring programmes will, together with the initially collected baseline data, form the reference against which any changes caused by repository construction can be recognised and distinguished from natural and other man-made temporal and spatial variations in the repository environment.

The detailed characterization of site-specific conditions and processes planned to be carried out during the Site Investigation Phase will for most parameters ensure the establishment of undisturbed baseline conditions with sufficient accuracy. However, care should be taken to ensure that baseline conditions are established for all those features of the system that are likely to be significantly affected by investigations and construction activities. These features are generally concerned with the rock stress, as well as the hydrological and hydrogeochemical regimes in the subsurface /Miller et al, 2002/. This means that a considerable amount of baseline information is needed, including features that may vary naturally over time, as well as features that may change due to human activities at the site.

Table 5-1 shows a compilation of features (parameters or group of parameters) for which natural temporal variation may be significant and/or which are more or less likely to change due to investigations or construction activities. For all the features in the table showing temporal variation, this variation is dominated by the seasonal component. As discussed above, a relevant description of the between-year variation, based solely on site-specific data, would require longer time series than what is realistic to attain during the Site Investigation. Accordingly, the availability of good reference data will be critical for the establishment of site-specific baseline data for all parameters showing significant temporal variation. For parameters with minor temporal variation, baseline conditions may be established by a "single" time, i.e. data collected in a single sampling campaign.

Baseline data may be of different importance for different aims, and Table 5-1 also includes an estimation of the importance of site-specific baseline data for repository design, safety analysis and environmental impact assessment respectively.

5.2.3 Conclusions

Baseline conditions have to be established for a substantial number of parameters. The data needed is either in the form of time series or "single" time data, depending on the degree of temporal variation of the parameter.

Certainly, there will always be a scientific desire for long time series of temporally varying parameters. However, the Site Investigations should focus on the needs for license and associated control programme, i.e. to capture changes of importance for repository design, safety analysis and environmental impact assessment. It is sufficient to carefully capture the within-year variation during undisturbed conditions by extensive monitoring programmes for at least one complete year for the parameters indicated in Table 5-1. After that, a reduced number of carefully selected sampling points would be included in long-term monitoring programmes, which, together with long-term measurements on reference sites, can be used to describe the longer-term variation.

5.3 Ore potential

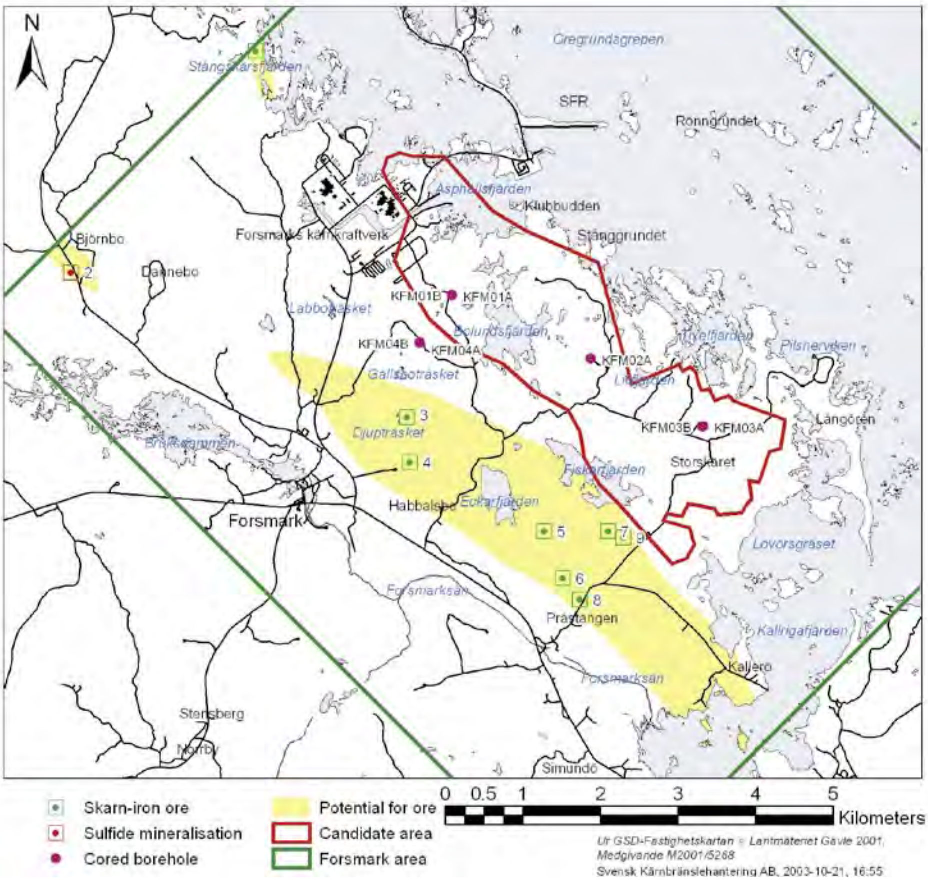
It is a requirement that the rocks in the deposition area do not possess any ore potential, i.e. contains valuable minerals that could justify future mining at a depth of hundreds of metres /Andersson et al, 2000/. Understanding the relation between wealth of information and uncertainty and confidence in the assessment of ore potential is thus essential for judging the state of progress of the Site Investigation and associated descriptive modelling.

A special project /Lindroos et al, 2004/ outside PLUSLUT has engaged an ore exploration company (MIRAB). The following was considered:

- The evaluation concerned the Forsmark site (see figure Figure 5-1), but the general approach of handling ore potential seem appropriate – not only the final conclusion as regards ore potential at Forsmark.
- The work should avoid trying complex definitions of ore *potential* but use more straightforward ones, such as (i) what is considered worthwhile in today's ore exploration, (ii) what has been considered worthwhile over a longer period.

Table 5-1. Features or types of data which show significant temporal variation and/or which are likely to change due to site investigations or repository construction. For each feature/type of data, the table also includes an estimation of the importance of site-specific baseline data for repository design, safety analysis and environmental impact assessment, respectively, and also a judgement of the type of baseline data needed (“single” time measurement or time series). For surface ecosystems, a more detailed compilation of variables for which there is a need for time series data for the characterization, understanding and monitoring is given in /SKB 2000c/.

Feature / type of data	Significance of natural temporal variation	Likelihood for changes due to investigations / construction	Importance of site-specific baseline data for			Type of baseline data needed	Comment
			Design	Safety Analysis	Env. Impact Assessment		
Geology							
Seismicity, see e.g.	–	(+)	+	+	−	Time series	Changes during construction refer to small events – tightly coupled to stress field in the rock mass
Rock mechanics							
Stress field in the rock mass	−	(+)	+	+	−	“Single” time	Only local impact from investigations / construction
Hydrology							
Meteorological and climatic data	+	−	+	+	+	Time series	
Precipitiation	+	−	−	+	+	Time series	
Surface hydrology (including surface water run-off, infiltration and water level in lakes and the sea)	+	+	−	+	+	Time series	
Hydrogeology							
Hydraulic heads and gradients	+	+	−	+	+	Time series	.
Groundwater flow rates and directions	+	+	+	+	+	“Single” time	
Hydraulic conductivity	−	(+)	+	+	−	“Single” time	Potential changes only in vicinity of tunnels
Temperature (groundwater / rock mass)	−	+	+	+	−	“Single” time	
Hydrogeochemistry							
Groundwater chemistry (redox, salinity, major and trace elements, radionuclides, dissolved gases etc)	−	+	+	+	+	“Single” time	
Surface ecosystems							
Surface water chemistry (major and trace elements, salinity, radionuclides etc)	+	+	−	+	+	Time series	
Species composition of animal and plant communities on land and in water	+	+	−	+	+	“Single” time	
Levels of radioactivity in the air, water, soil, animals and plants	−	−	−	+	+	“Single” time	
Noise	−	+	+	−	+	Time serie	
Air quality and particle fallout	−	+	−	−	+	Time serie	Good regional reference data exist



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Svensk Kärnbränslehantering AB, 2003-10-21, 16:55

Figure 5-1. *Map showing areas with an ore potential in the Forsmark area.*

/Lindroos et al, 2004/ conclude that the Forsmark candidate area is virtually sterile with respect to ore, although some additional assessments and measurements might be advisable to completely rule out the possibility. Furthermore, the general approach should be applicable to other sites although adjustment to the local conditions may imply changes in what to look for and which data are needed. Nevertheless, it appears clear that ore potential can be assessed within the framework of decided investigations using only limited additional interpretation efforts and with modest additions to existing sampling schemes.

5.4 Uncertainty in deformation zones and fractures

As is evident from Section 4.2 deformation zones and large fractures directly influence the design of the repository due to the following:

- The size and location of disposal panels is governed by the location and geometry of deformation zones.
- Canisters can only be located at certain respect distance from regional and local major deformation zones.
- Deposition holes may not intersect too large fractures.

These design rules depend to a large extent on Safety Assessment consideration on earthquake impacts. Currently used respect distances may be re-assessed in coming safety assessments, see Section 4.1.2, but fractures and fracture zones will nevertheless be highly important features. This puts direct demands on how to assess uncertainty in the deformation zones and in large fractures.

Not strictly related, but still of potential importance, are the lithological boundaries. They are exceptionally difficult to determine in three dimensions due to their, commonly, irregular (sometimes highly irregular) shapes. If high accuracy is needed, an unrealistic number of boreholes would be required. On the other hand, by the proper use of rock domains, the properties of small-scale lithological units can be averaged and described in statistical/stochastic terms. The boundaries of the domains still impose a challenge to determine but the relatively strong lithological anisotropy of e.g. the Forsmark site /SKB, 2004/ aid to model the boundaries with relative confidence despite the limitations in drilling efforts. Furthermore, the problem is strongly depending on the modelling scale. Uncertainties concerning lithological boundaries remaining after the Site Investigation will be dramatically reduced, at least close to the tunnels, during the detailed investigation.

5.4.1 Regional and local major deformation zones

Regional and local major deformation zones to a very large degree govern the size, shape and location of disposal panels. Uncertainty in the position and orientation of such structures can consequently induce substantial uncertainty in the position and geometry of the disposal panels. In this context it is important to separate between:

- Uncertainty in geometry and position of a structure that has been shown to exist, i.e. classified as “certain”, or in words with similar effects, in the geological model and its description.
- Uncertainty in geometry and position of a structure that is suspected but not proven to exist, i.e. classified as “probable” or “possible” (still weaker indications) in the geological model.
- Uncertainty regarding position, geometry etc of small (minor local) deformation zones and large fractures i.e. structures that generally are too small to intersect the ground surface in sufficient amount to be able to properly deduce their density and properties. These are only rarely modelled deterministically.
- Uncertainty due to the unknown, i.e. due to lack of information or conceptual misunderstanding.

Given the already executed or definitely planned surface investigations (e.g. geophysics) it is possible to advocate that virtually *all steep regional- and major local deformation zones will be detected* by surface investigations. Also, the uncertainties in position and orientation of regional and local major deformation zones (e.g. as advocated in Section 4.2.2) are relatively easy to relate to available information from surface investigations, existing boreholes and generic knowledge, regardless of whether the structure is classified as “certain”, “probable” or “possible”. Such estimates are provided already in the first versions of the site model /see e.g. SKB, 2004/.

Furthermore, those structures that are anticipated to intersect the planned repository volume can have their geometric uncertainty substantially reduced with limited boring campaigns. With regard to PLUSLUT, the decision of whether such additional sampling is necessary and, if so, to what extent, could thus be weighted against the impact of already assessed uncertainty on the Safety Assessment or Repository Design – as envisaged (see Sections 4.1 and 4.2).

Generally, all linear geophysical anomalies will be regarded as possible deformation zones, but if the indications are poor the confidence in existence will be classified as “low” or “very low” (e.g. Figure 5-2). Lineaments with firmer indications are classified as “probable”. The upgrading of a “possible” deformation zone to “medium” or “high” confidence in existance can be achieved with additional sampling at the site. For most cases, it can be anticipated that it will suffice with a limited amount of carefully placed percussion boreholes to determine the nature of the interpreted structures, by means of BIPS and other surveying methods, but the uncertainty at depth needs to be considered. For larger deformation zones, interpreted to intersect the repository volume, it might be necessary to intersect with cored boreholes. It might, further, be advisable to dig and map trenches across major lineaments to get further evidence on existence and to obtain information on the zone properties.

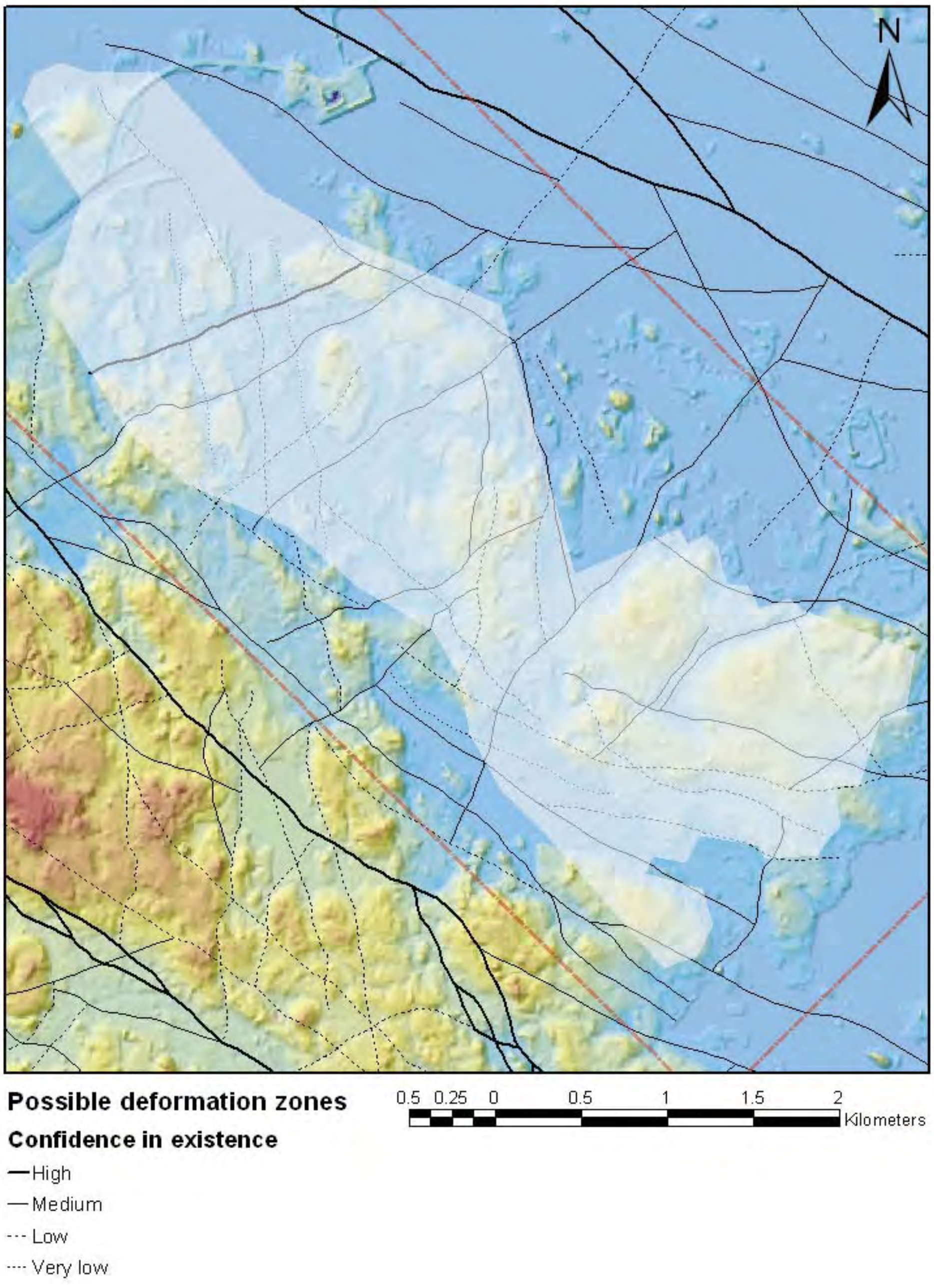

***Figure 5-2.** Interpreted deformation zones at Forsmark classified according to confidence (for details see SKB 2004).*

Horizontal and gently dipping zones impose a particular challenge because they are rarely detected by traditional surface investigations. Seismic measurements and boreholes are needed. Consequently, many of the potential subhorizontal zones will presumably be intersected by the planned boreholes. On the other hand, it is very hard to determine their extension, eventual truncation against other (steep?) zones, etc. A pragmatic approach is to determine the "acceptable" maximum size of a gently dipping or horizontal zone, and optimise boring campaigns so that the borehole spacing reflects the size of the structure to be targeted. In Forsmark however, subhorizontal reflectors appear (November 2003) to be ubiquitous and near-surface, highly conductive subhorizontal fractures are known from e.g. SFR. It is not reasonable to expect to find all, or even most, such structures within the regional model volume using realistic drilling efforts. However, drilling within the volumes most likely to host the repository, i.e. within the local model volume, can be optimised such that the uncertainty regarding the existence, geometry and, to a lesser extent, properties of these structures can be sufficiently well depicted.

Uncertainties regarding large fractures and minor local deformation zones, i.e. zones that are not generally modelled deterministically, are discussed in the next section.

5.4.2 Statistical description of minor local deformation zones and in large fractures

Minor local deformation zones and large individual fractures affect the degree of utilization, see Section 4.2.1, and thereby also the size of the panel(s). Though we are optimistic in the possibilities of being able to depict affected canister holes, more method development is needed concerning underground mapping/modelling in this context. This aspect of the degree of utilization is, however, beyond the current scope of PLUSLUT, but will be an important part of the planned underground characterisation programme, see Section 5.9.

Nevertheless, a critical issue is the determination of an adequate stochastic fracture array. The fractures of interest and the local minor deformation zones are too small to be modelled deterministically, at least during the Site Investigation, and are therefore predominantly modelled as stochastic discrete fracture networks (DFN).

Previous work /Holmén and Outters, 2002/ has shown that, under reasonable assumptions, the parameters describing the DFN statistics can be estimated with reasonable estimation variance using realistic investigation efforts. In short, the study of /Holmén and Outters, 2002/ showed that an accumulated borehole length of about 800 m and outcrop area of about 4000 m^2 is sufficient to accurately determine a the DFN statistics within a rock domain with statistically homogeneous DFN. However, it is suggested that statistical homogeneity is hard to prove, and it would require an unrealistic amount of investigation (drilling) efforts if the assessment was to be based solely on borehole statistics. However, we advocate that this apparent flaw can be, at least partly, compensated by proper understanding of the geological history and ancient or ongoing geological processes.

From the perspective of PLUSLUT, it is therefore regarded sufficient to evaluate if the following prerequisites and assumptions are fulfilled in the studied rock volume:

- The sampled rock domain can be regarded as statistically homogeneous.
- Only the orientation, length and density distributions of fractures are regarded. Further assumptions might, however, expand the applicability to other, e.g. hydraulic, properties.

- The dispersion (i.e. spread) of the orientation distribution is not too large. Larger dispersion requires both longer boreholes and larger outcrops.
- The fracture density is not too low. Lower density requires both longer boreholes and larger outcrops.
- No spatial correlation between fractures – a Poissonian spatial distribution (i.e. existence of one fracture does not affect probability of occurrence other fractures). If the spatial correlation is non-Poissonian, both longer boreholes and larger outcrops are required. However, to some degree, strong spatial correlation can be handled by the careful use of domains. /Holmén and Otters, 2002/ indicate that more and shorter boreholes or many small outcrops is more effective than few and long boreholes or very large outcrops.

Finally, there is an information gap regarding structures (fractures and small deformation zone) in the size-range ≈ 50 m to ≈ 500 m. Currently, this gap in information is handled by statistical interpolation between small scale fractures, as inferred from outcrop mapping, and larger scale deformation zones as inferred from lineament maps. It is judged that more boreholes will not provide any valuable information, in this context, although we recognise that hydraulic interference tests etc might be of use.

5.4.3 Conclusions

In conclusion, there are already implemented techniques, in the Site Modelling, for assessing uncertainty in deformation zones and fractures. This uncertainty description could then be used by Safety Assessment for assessing its impact on e.g. mechanical stability and radionuclide migration and by Engineering for assessing space and degree of utilisation as outlined in Section 4.2.1. However, it is also clear that investigation efforts to fully verify existence of zones and to assess their properties are relatively resource demanding. To keep the investigation efforts reasonable different exploration strategies may be contemplated, for example;

- reduce the current size of the local model areas,
- direct exploration to various sets of deformation zones or geophysical signals, thereby improving the foundation for extrapolation and interpretation of already existing data,
- combination of these two strategies.

This demonstrates that PLUSLUT is not only a matter of yes and no, but also concerns what the remaining strategy of the investigations should be. The decision analysis should adapt to this observation.

5.5 Mechanical evolution – earthquakes

According to current plans safety assessment will handle the issue of mechanical evolution and earthquakes through respect distances, see Section 4.1. This also means that, the geological model apart, there is not an anticipated need to incorporate other site-specific data for this aspect and the issue would then not be a factor to consider whether there is a need for more Site Investigations. Furthermore, also assessment of (the very low) probability of earthquake events is only to some extent based on site specific observations and much more on the existing regional and general understanding of the tectonic past.

5.6 Evolution of groundwater composition

Another critical issue is to explore the relation between wealth of data and our ability to describe the current distribution of the groundwater composition as well as its past and future evolution. Current understanding suggest that the present day groundwater composition is a result of mixing/reactions and possible diffusion processes (this process dominates in low conductive rock and in deep groundwaters i.e. > 1000 m) such that it mainly reflects past changes in groundwater flow boundary conditions – the mixing processes essentially being controlled by climate and shore line displacement. This hypothesis has strong implications for Safety Assessment as it suggests that future changes in groundwater composition would be essentially controlled by future changes in groundwater flow.

5.6.1 Main processes

There is quite strong support /e.g. Laaksoharju et al, 1999; Puigdomenech ed 2001/ for the hypothesis that mixing (and possible diffusion) are the main processes affecting the salinity distribution, whereas additional processes may affect other components of the waters (for at least several 10^4 years):

- Past attempts to explain composition as a result of weathering reactions alone were far less successful.
- Water samples appear to have strong imprints of "historical waters" (Litorina sea water, glacial melt water).
- Most equilibrium reactions take very long (almost infinite) time at prevailing temperatures (some ion exchange reactions are very fast, but this is also considered when estimating future groundwater composition).
- It seems difficult to explain observations in any other way.

Still, many uncertainties remain to be addressed properly:

- Proper integration between hydrogeochemistry and hydrogeologic modelling, although promising, is still at its infancy.
- Representativity of water samples can be questioned (is some mixing produced in the boreholes, do we get proper initial water samples, how to get water composition of low conductive parts of the rock).
- Simulations suggest that both mixing, some reactions and possibly matrix diffusion need to be considered. This calls for integration, not only with hydraulic modelling, but also with transport modelling and sampling of matrix transport properties.

However, even if uncertainties remain, it can be questioned to what extent these are resolved by site specific data and modelling. The main argument, for the process understanding, stems from the essentially consistent picture obtained from 20 years of sampling from more than 10 different sites in the Fennoscandian shield /see e.g. Laaksoharju et al, 1999; Puigdomenech ed. 2001/. There are also observations from outside Fennoscandia in support of this claim.

5.6.2 Conclusions

The following implications for site-specific work and analyses can be stated:

- There is a need to “confirm” that the overall hydrogeochemical concept also is valid at the local site. However, this does not require measurements at a very high number of locations at the site.
- The focus should be on integration with flow and transport modelling. Hypotheses on the regional flow pattern may have implications on where to make sampling (potential need for regional boreholes) and understanding of boundary conditions.
- Coupling with transport modelling implies a need for sampling of “water chemistry” of matrix water and consistency in diffusivities used in chemical modelling and in transport modelling.
- There is less need to accurately match results from specific sampling points with local fracture minerals.

The current approach within Site Modelling to handle this issue is to conduct coupled flow and salinity transport simulations covering the period from the last de-glaciation /SKB, 2004/. The analysis aims at demonstrating that mixing alone, in this time perspective, is sufficient to explain the current salinity distribution. It covers a set of assumptions regarding initial and boundary conditions. This modelling will subsequently be used as input to Safety Assessment for constructing a chain of arguments for the future evolution of the groundwater composition. This will first be tried in SR-Can, see Section 4.1.2.

It seems clear that there will be remaining uncertainties in the hydrogeochemical description. Compared to the investigation level at “data freeze 1.1”, /see e.g. SKB, 2004/ there are some potentially useful additional characterisation efforts like a “fair amount” of characterisation points at depth, a better understanding of the chemical composition of the rock matrix and potentially an example of the groundwater composition in a regionally placed borehole. However, it also seems evident that there will be a point where additional site specific information would add very little to resolve remaining uncertainties. These would rather be handled on a general level and should not be used as arguments for additional site measurements. Both the site modelling projects and the Safety Assessment handling of this information in SR-Can, would need to consider these aspects carefully.

5.7 Investigations impairing site properties?

The question may be asked whether an excessive amount of investigations (like many boreholes) impair the site properties? Boreholes are the obvious example, as unsealed boreholes constitute significant high conductive pathways in the rock. Evidently, even if the boreholes will be sealed, some kind of ‘respect distance’ to boreholes from the underground facilities are needed. Direct intercepts should certainly be avoided, even if holes are sealed.

According to the general investigation programme /SKB, 2000b/ it is sufficient to carefully note exactly where boreholes are located in three dimensions. Furthermore, practical tests of sealing technology are underway within the Äspö HRL project “Cleaning and sealing of investigation boreholes” /SKB, 2003b/.

A simplistic approach is to assume that properly sealed boreholes should not be a problem in the safety assessment. Nevertheless, at some point there will be an upper limit of boreholes that can be drilled, and also safety assessment would need to consider the impact of improperly sealed boreholes.

Theoretically, a too high borehole density would put an upper limit to the number of allowable boreholes. However, from a practical point of view the envisaged number of boreholes at the site are unlikely to come close to such a number and the issue does not really warrant further consideration within PLUSLUT in addition to the already ongoing study at Äspö HRL.

5.8 Confidence, uncertainty and surprises

A general question concerns how to quantify confidence and understanding. In general, there is a need to avoid being too theoretical. SKB cannot take on to solve general problems of knowledge theory. The concrete results of the Site Modelling work are the foundation of the confidence assessment.

Currently, the Site Descriptive Modelling /see e.g. SKB, 2004/ handles confidence by addressing a set of questions (protocols) based on the general format described by /Andersson, 2003/. Thereby there is a means to qualitatively describe the overall confidence and level of understanding at each model version. Still, the question remains on how this qualitative information may be used for assessing the need for additional characterisation efforts.

Confidence in itself cannot be exactly defined and it is thus not possible to quantify it "objectively". This means that the confidence will be assessed subjectively. What we are interested in is to show that we are confident enough in the model chosen, rather than in giving an exact "confidence number". Two possible, practical approaches are

- *Direct overall assessment*. The confidence is assessed from the overall picture when comparing the model with the list of important factors.
- *Ratings approach*. Using a previously determined scale of weights for ratings of the listed factors, each factor is deliberated in turn and given a rating, which can be verbal ("Good, sufficient, unsatisfactory") or expressed in other ways. Each such rating will thus correspond to a weight. If the weights are determined e.g. by using an AHP-approach, the weights are given on a ratio scale and can be added (This is a proven method in AHP, /see Expert Choice, 2000/. One advantage is that the pair-wise comparison in AHP also gives the correct relation between the different factors).

Both approaches have in common that there is a list of important factors that influence the model confidence, /see Andersson, 2003/. This means that the confidence assessment made within the framework of the Site Descriptive Modelling also can be used within the decision frameworks as outlined in Chapter 6.

5.9 The construction detailed investigation phase

Crucial to the decision whether to continue the Site Investigation is what will/could be determined from the Underground Characterisation during the Construction and Detailed Investigation Phase. Currently the SKB planning for the underground characterisation programme lies within the framework of repository engineering.

A wide perspective on the coming underground characterisation programme is needed to get a reasonable understanding on what the programme would cover and what uncertainties it would and would not resolve. Given the relatively early stage of the Site Investigation Programme, it is understandable that the underground programme is relatively undeveloped. However, for the “real” PLUSLUT decision, such an ambiguity regarding the coming Underground Characterisation Programme needs to be resolved. This calls for substantial resources to be put in this direction in coming years.

6 Application examples

Preceding chapters have assessed the needed input from the Site Investigation (Chapter 4) and uncertainties in the site description at a given level of investigation (Chapter 5). This chapter explores some examples of how to use the decision analyses tools outlined in Chapter 3, for combining this information into a decision support regarding the possibility to stop or continue the Site Investigation Phase. It needs to be understood that the examples given are illustrations of the techniques – not very well thought through judgements on the current state of the ongoing investigation programme.

6.1 Conventional decision analysis

Before filing an application and going underground, the site under study must be approved both from a safety and from an engineering point of view. Each of these considerations will be based on the information that has been collected. A logical time for stopping the explorations is when one estimates that the information is sufficient, both in quantity and quality so that the safety assessment team and the repository engineering team can perform their tasks and be reasonably sure of the results. (The simplifying assumption is made that if the SKB teams approve of the site, so will the authorities). However, there are both costs and uncertainties involved in the decision, so a "conventional" decision analysis model can be helpful, e.g. for sensitivity analyses. To illustrate this the PLUSLUT project team have set up a simple decision problem.

6.1.1 Illustrative example

The decision under study is governed by the two main objects of the investigation to gather enough information for Safety Assessment and for Engineering Feasibility Analysis. The studied decision alternative is to choose between stopping the Site Investigation already now (i.e. at "data freeze 1.1") or to carry out the generic investigation programme as envisaged in /SKB, 2001/.

If the decision is to stop with data freeze 1.1 but Safety Assessment or Engineering finds the information to be insufficient, the resulting consequence would be to carry out the generic program (i.e. as set out in /SKB, 2001/), but with the added cost of postponing the investigations during the time for assessing whether data freeze 1.1 was sufficient. Furthermore, if Safety Assessment or Engineering finds the information insufficient even after the generic programme; it is (in this example) assumed that the site needs to be abandoned, with its associated costs. Figure 6-1 displays the resulting decision tree.

Furthermore, the assumption is made here that the "generic programme" can be modified during the testing so that it is not considered to further extend the testing with another investigation step. Or in other words, the "generic programme" is comprehensive enough for all involved to be reasonably confident in their judgements. The possible outcomes show if both necessary objectives are attained. The variables and probabilities in the tree have been assessed by members of the PLUSLUT project group – for illustration purposes. Table 6-1 shows the values selected. It should be noted that straight monetary values have been used for the consequences, without transformation to utilities.

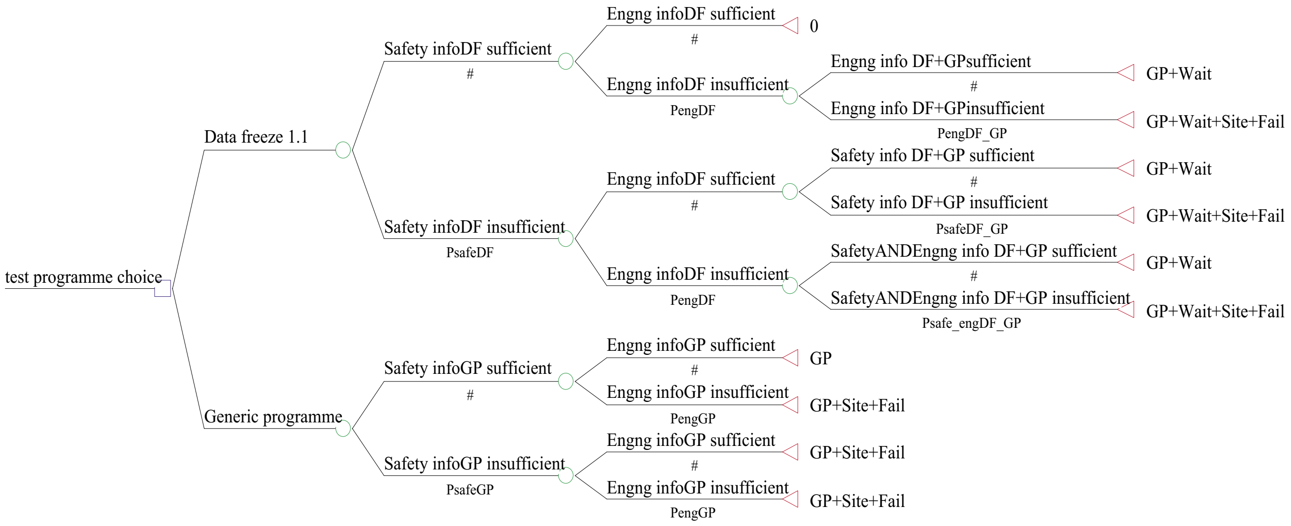

Figure 6-1. *Decision tree in illustrating example.*

Table 6-1. Variables used in decision tree analysis.

Variable	Description	Value[3]
Consequences [MSEK]		
GP	Cost for performing Generic programme site investigation (at one site)	350
Wait	Cost for waiting if GP is done after first exploring suffciency of DF	50
Site	Cost for abandoning site	600
Util	Cost for limited utilisation of repository	200
Fail	Cost for "failing "in producing suitable site	0
Probabilities		
PsafeDF	Information obtained at data freeze is insufficient from safety aspect	0.90
PsafeGP	Information obtained in Generic Programme is insufficient from safety aspect	0.05
PengDF	Information obtained at data freeze is insufficient from engineering aspect	0.90
PengGP	Information obtained after Generic Programme is insufficient from engineering aspect	0.05
PengDF_GP	Information obtained after Data freeze + Generic Programme is insufficient from engineering aspect	0.1
PsafeDF_GP	Information obtained after Data freeze + Generic Programme is insufficient from safety aspect	0.05
Psafe_engDF_GP	Information obtained after Data freeze + Generic Programme is insufficient from both safety and engineering aspects	0.5

Using these values the roll-back result shown in Figure 6-2 is obtained. From the tree can be seen that the best decision, based on the assumptions in Table 6-1, is to carry out the generic programme.

The decision should always be assessed by a sensitivity analysis, to check that the decision is robust. One such analysis is the Tornado Diagram, see Figure 6-3, where a horizontal bar is generated for each variable being analyzed. Each bar represents the selected node's range of expected values generated by varying the related value.

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[3] The costs are probably very much underestimated – the table should only be seen as an example.

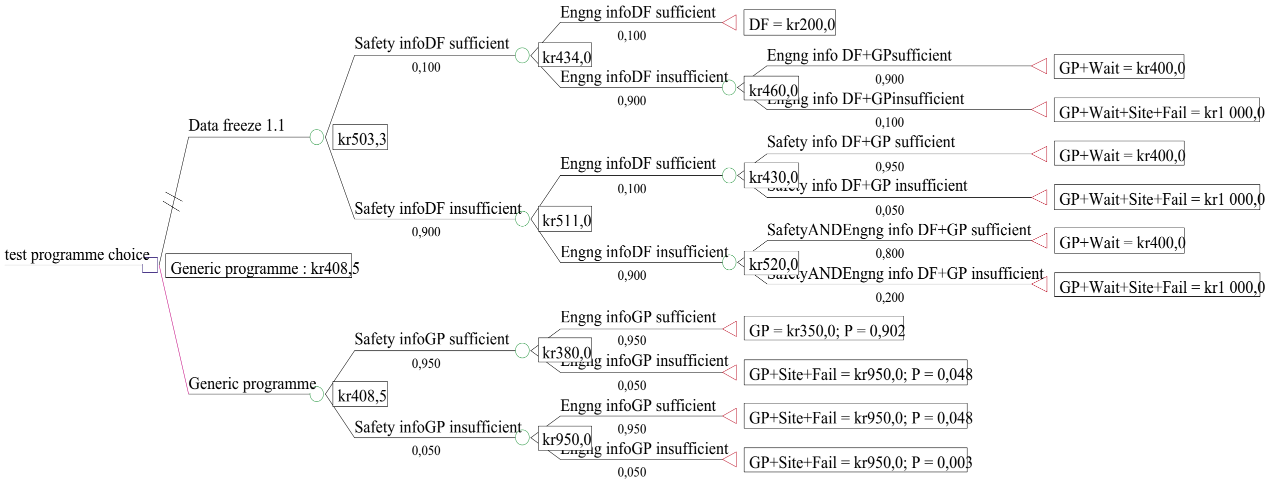

Figure 6-2. *Rolled-back decision tree.*

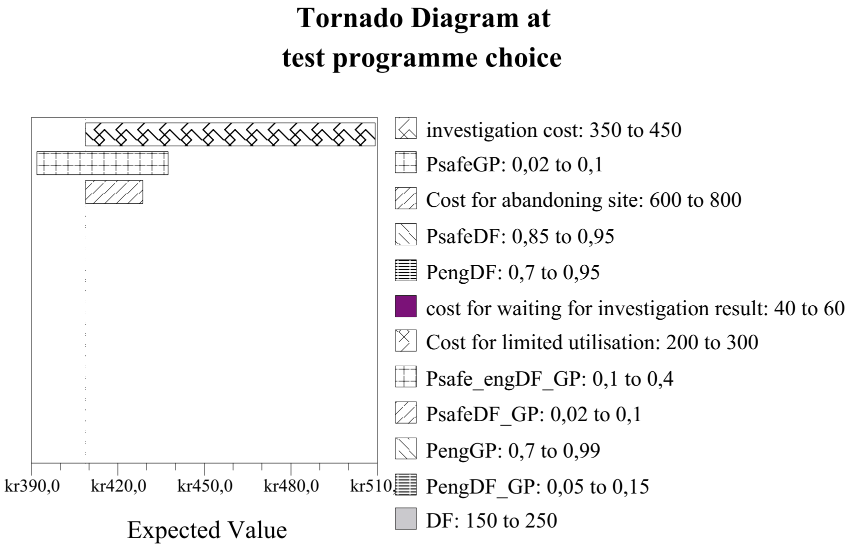

Figure 6-3. *Tornado Diagram.*

From the Tornado Diagram it can be seen that the investigation cost, the cost for abandoning site and the probabilities that the Generic programme is not sufficient are the most important uncertainties for the Engineering Feasibility study. These factors can be studied further, for instance using two-way sensitivity analyses. Several more sensitivity analyses have been performed and all support the robustness of the decision.

6.1.2 Discussion

The above example shows that a decision tree analysis can be quite useful for simple decisions like the above, with few alternatives and possible outcomes. It should be observed that in the example there was no conversion from monetary cost to utilities and that the probabilities were assessed for the investigation programme as a whole, which is very difficult to do.

6.2 Weighted objective analysis approach

A weighted objective analysis has been performed as part of the study. It was made using the AHP approach, outlined in Section 3.3, to find the relative weights. The study was made for illustrative purposes by individuals of the PLUSLUT project group. For real application, a more careful analyses and a broader spectrum of expertise would be needed.

6.2.1 Decision alternatives and AHP structure

The example examined the following two decision alternatives:

- a1: no further testing, i.e. accept the test results available after data freeze 1.1,
- a2: more tests and carry out the generic test programme.

The decision alternatives should be explored in relation to the objectives of the study. This means that the objectives need to be formulated such that they are dependent on information that can be obtained. Furthermore, when using AHP the objectives shall be given in a hierarchic structure. For this first modelling of the hierarchic structure, some simplifications have been made, as the purpose is to test the suitability of the decision methodology.

The factors used in the structure must be clearly defined. When defining them, one must be careful to do so in the light of PLUSLUT, i.e. the information gathering aspects. This means that questions should always be phrased in an information gathering context.

For the test the main factor was selected to be: “Most important factors governing PLUSLUT”, which should be read as: “For which factors is it most important that we gather information before ending the PLU?”. At the second level there are three different factors affecting the main factor:

- “Safety evaluation”, i.e. “For which factors is it most important to have enough information, when it comes to performing an approved safety analysis?”
- “Engineering feasibility”, i.e. “For which factors is it most important to have enough information, when it comes to performing the feasibility of design analysis?”
- “Investigations jeopardising site properties”, where the relevant question is: “Is it more important to gather information, than to avoid jeopardising the site properties with the investigation bore-holes?”

The level 3 and level 4 factors are listed in Table 6-2 (Safety evaluation), in Table 6-3 (Engineering feasibility) and in Table 6-4 (Investigations jeopardising site properties). The selected factors are essentially based on the requirements and preferences as presented by /Andersson et al, 2000/.

This hierarchic structure was developed based on discussions in the group and is shown in Figure 6-4. In the tree no alternatives are shown. This is because we are only interested in the relative importance of the different decision criteria. Also, the complete tree structure is not shown as that would make it immense and very difficult to read. Instead the lowest level branches are shown below each other. This is illustrated in Figure 6-5 for part of the structure.

Table 6-2. Safety evaluation factors.

Factor	Level
Overall site understanding (safety view)	3
Conceptual understanding	4
Site information	4
Ecosystem	3
Length of time series	4
Basis for EIA	4
Understanding matter (carbon) transport	4
Deformation zones	3
Sufficient respect distance	4
No large variation in site model	4
Hydrogeology	3
DFN statistical model	4
Transmissivity given joint model	4
Thermal properties	3
Heat transfer properties	4
Spatial distribution of properties	4
Ore potential	3
Ore minerals	4
Not common rock type	4
Water chemistry	
Dissolved oxygen	3
TDS	4
Understanding of long time processes	4

Table 6-3. Engineering feasibility factors.

Factor	Level
Space	3
Frequency of deformation zones	4
Dip variations causing large unsuitable volume	4
Existence of large low information areas	4
Critical passages	3
Existence of difficult passages at potential access	4
Number of suitable access points	4
Degree of utilization	3
Frequency of high T fractures	4
Statistical homogeneity	4
Heat conductivity	4
Stability	3
Rock stresses	4
DFN geometry	4
Overall site understanding (engineering view)	3
Conceptual understanding	4
Site information	4

Table 6-4. Whether investigations jeopardising site properties factors.

Factor	Level
Investigations jeopardising site properties	3
Too high bore-hole density	4
Bad selection of access point	4

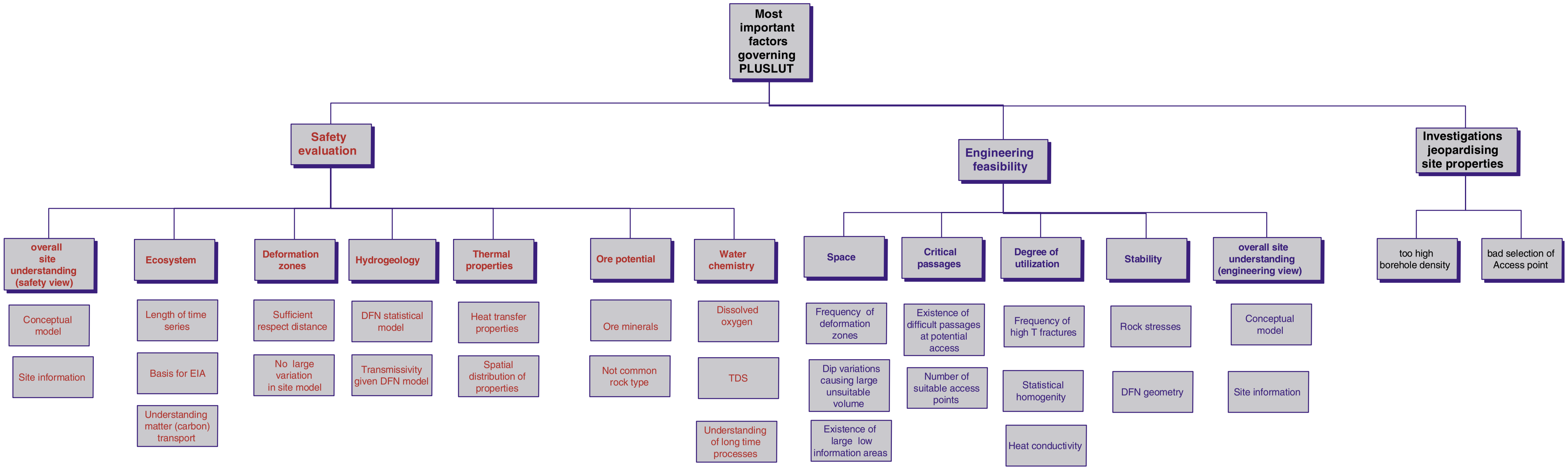

***Figure 6-4.** AHP structure used in weighted objectives approach.*

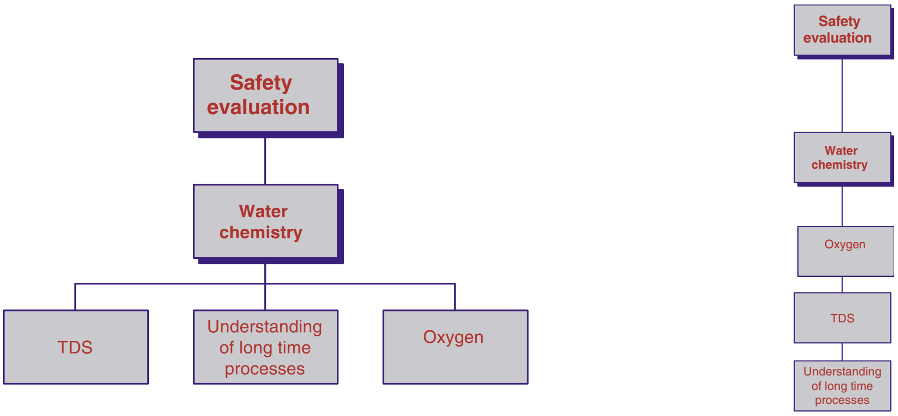

Figure 6-5. *Expanded tree structure (to the left) and simplified (to the right).*

6.2.2 Weighting and probability assignment

Input of preferences to the AHP structure was made by one member of the PLUSLUT team. This was under time stress and it must therefore be observed that the analysis is only aimed at demonstrating the method, not to be used in a real decision. The input was obtained using the forms shown in Appendix 1.

After the AHP preferences were input, the probabilities of obtaining each objective were assessed by the same PLUSLUT team member. The AHP weights were calculated using ExpertChoice and were used together with the probabilities to calculate the overall relative utilities. The weights and the probabilities are provided in Table 6-5.

Table 6-6 and Figure 6-6 display the resulting relative utilities for the explored decision alternatives. The Table also shows the gain in relative utility for the various factors.

Several observations could be made from the results of the analysis. Apart from the trivial observation that utility increases with additional investigations (which always is true) one could compare the utility gain with the relative utility of not carrying out more investigations. For the example, the relative utility gain still appear quite large, but the method gives little guidance if this gain is large in relation to the costs of carrying out more investigations. Nevertheless, if the relative utility gain had been marginal, this would have been an indication that more information would not be needed.

Table 6-5. AHP weights and assessed probabilities of each factor resolving its objective after investigation a1 and a2 respectively.

Factor	AHP weight	Prob if a1	Prob if a2
Conceptual model(S)	0.024	0.50	0.60
Site information	0.008	0.30	0.90
Length of time series	0.001	0.60	0.90
Basis for EIA	0.008	0.70	0.85
Understanding matter (carbon) transport	0.004	0.30	0.40
Sufficient respect distance	0.029	0.50	0.50
Knowledge of variations in site model	0.086	0.40	0.90
DFN statistical model	0.02	0.40	0.70
Transmissivity given DFN model	0.046	0.05	0.60
Heat transfer properties	0.014	0.50	0.80
Spatial distribution of properties	0.005	0.30	0.60
Ore minerals	0.145	0.70	0.90
Not common rock type	0.021	0.70	0.95
Dissolved oxygen	0.134	0.90	0.95
TDS	0.055	0.70	0.95
Understanding long time processes	0.022	0.20	0.50
Frequency of deformation zones	0.055	0.50	0.95
Dip variations causing large unsuitable volume	0.009	0.10	0.95
Existence of large low information areas	0.022	0.20	0.50
Knowledge about difficult passages at potential acc. point	0.015	0.10	0.95
Number of potential access points	0.003	0.40	0.95
Frequency of high T fractures	0.008	0.05	0.60
Statistical homogeneity	0.003	0.20	0.60
Heat conductivity	0.021	0.30	0.60
Rock stresses	0.052	0.50	0.95
Conceptual model(E)	0.003	0.70	0.75
Site information(E)	0.008	0.40	0.90
Too high borehole density	0.03	0.001	0.01
Bad selection access point	0.149	0.60	0.80

Table 6-6. Resulting relative utilities for the explored decision alternatives.

Factor	Relative utility		Per cent rel.Utility		Δ utility
	a1	a2	a1	a2	%
Conceptual model(S)	0.012	0.0144	2.25%	1.79%	1.0%
Site information	0.0024	0.0072	0.45%	0.89%	2.1%
Length of time series	0.0006	0.0009	0.11%	0.11%	0.1%
Basis for EIA	0.0056	0.0068	1.05%	0.84%	0.2%
Understanding matter (carbon) transport	0.0012	0.0016	0.23%	0.20%	0.0%
Sufficient respect distance	0.0145	0.0145	2.72%	1.80%	0.0%
Knowledge of variations in site model	0.0344	0.0774	6.46%	9.60%	18.5%
DFN statistical model	0.008	0.014	1.50%	1.74%	1.2%
Transmissivity given DFN model	0.0023	0.0276	0.43%	3.42%	10.9%
Heat transfer properties	0.007	0.0112	1.31%	1.39%	1.2%
Spatial distribution of properties	0.0015	0.003	0.28%	0.37%	0.6%
Ore potential	0.1015	0.1305	19.05%	16.19%	12.5%
Not common rock type	0.0147	0.01995	2.76%	2.48%	2.3%
Dissolved oxygen	0.1206	0.1273	22.64%	15.79%	2.9%
TDS	0.0385	0.05225	7.23%	6.48%	1.2%
Understanding long time processes	0.0044	0.011	0.83%	1.36%	2.8%
					0.0%
Frequency of deformation zones	0.0275	0.05225	5.16%	6.48%	1.2%
Dip variations causing large unsuitable volume	0.0009	0.00855	0.17%	1.06%	0.2%
Existence of large low information areas	0.0044	0.011	0.83%	1.36%	2.8%
Knowledge about difficult passages at potential acc. point	0.0015	0.01425	0.28%	1.77%	5.5%
Number of potential access points	0.0012	0.00285	0.23%	0.35%	1.1%
Frequency of high T fractures	0.0004	0.0048	0.08%	0.60%	1.9%
Statistical homogeneity	0.0006	0.0018	0.11%	0.22%	0.5%
Heat conductivity	0.0063	0.0126	1.18%	1.56%	2.7%
Rock stresses	0.026	0.0494	4.88%	6.13%	10.1%
Conceptual model(E)	0.0021	0.00225	0.39%	0.28%	1.7%
Site information(E)	0.0032	0.0072	0.60%	0.89%	0.1%
					1.7%
Too high borehole density	0.00003	0.0003	0.01%	0.04%	0.0%
Bad selection access point	0.0894	0.1192	16.78%	14.79%	0.1%
	0.53	0.81			

Factor	Relative utility		Per cent rel. Utility		utility
	a1	a2	a1	a2	%
0,53		0,81			

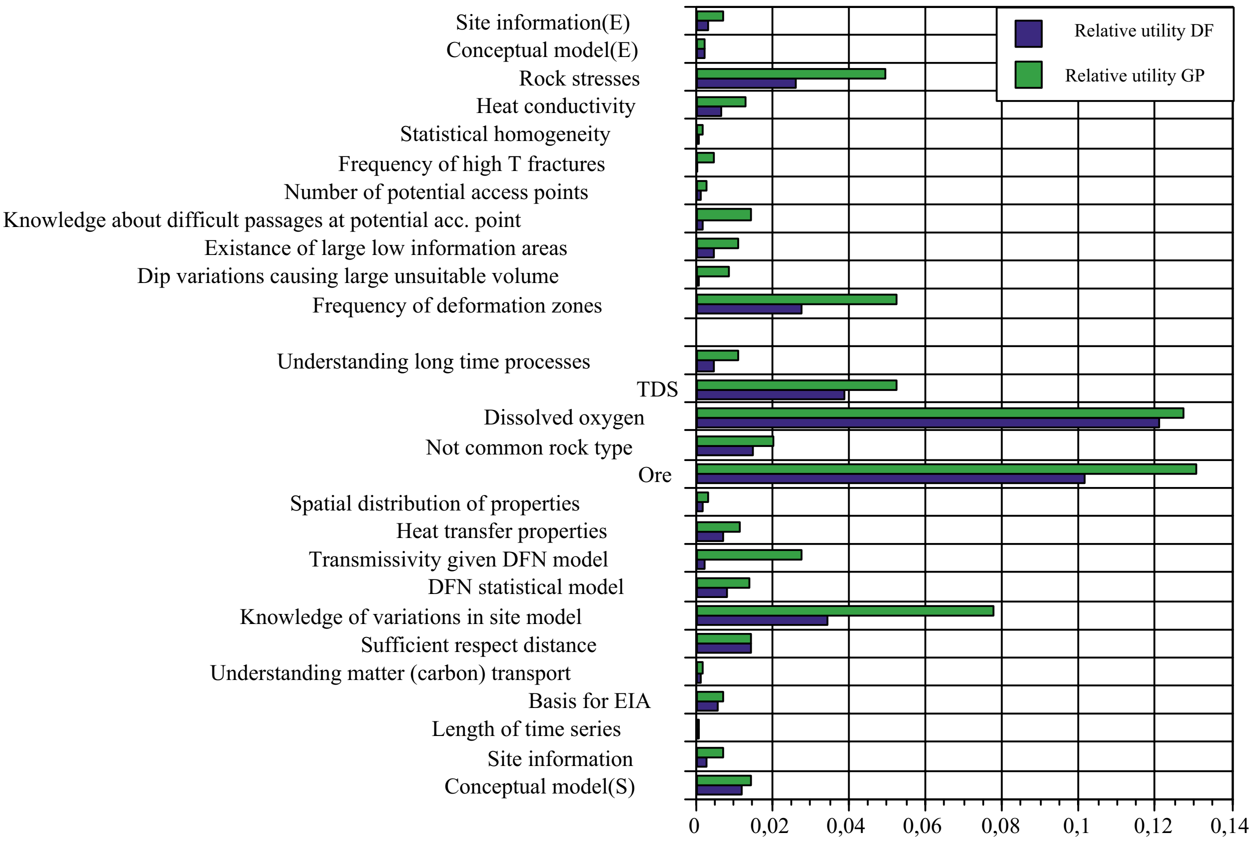

***Figure 6-6.** Results from Weighted objective decision analysis.*

However, more interesting is that the analyses also finds the objectives (factors) where more information would contribute most to increasing the relative utility as displayed in the last column of Table 6-6 and illustrated in Figure 6-7. For the example studied these factors include Knowledge of variations in site model, Transmissivity given DFN model, Ore and Rock Stresses, whereas the very important factor Oxygen really is not an issue for the further investigations, since lack of dissolved oxygen credibly could be assessed already using the information after the data freeze. (Again please note that weights and probabilities are given as examples and that these specific conclusions may well change if the analysis was remade). Nevertheless, such considerations can be used in the detailed design of the investigation programme, as such a complex investigation will require some “give and take” between different disciplines.

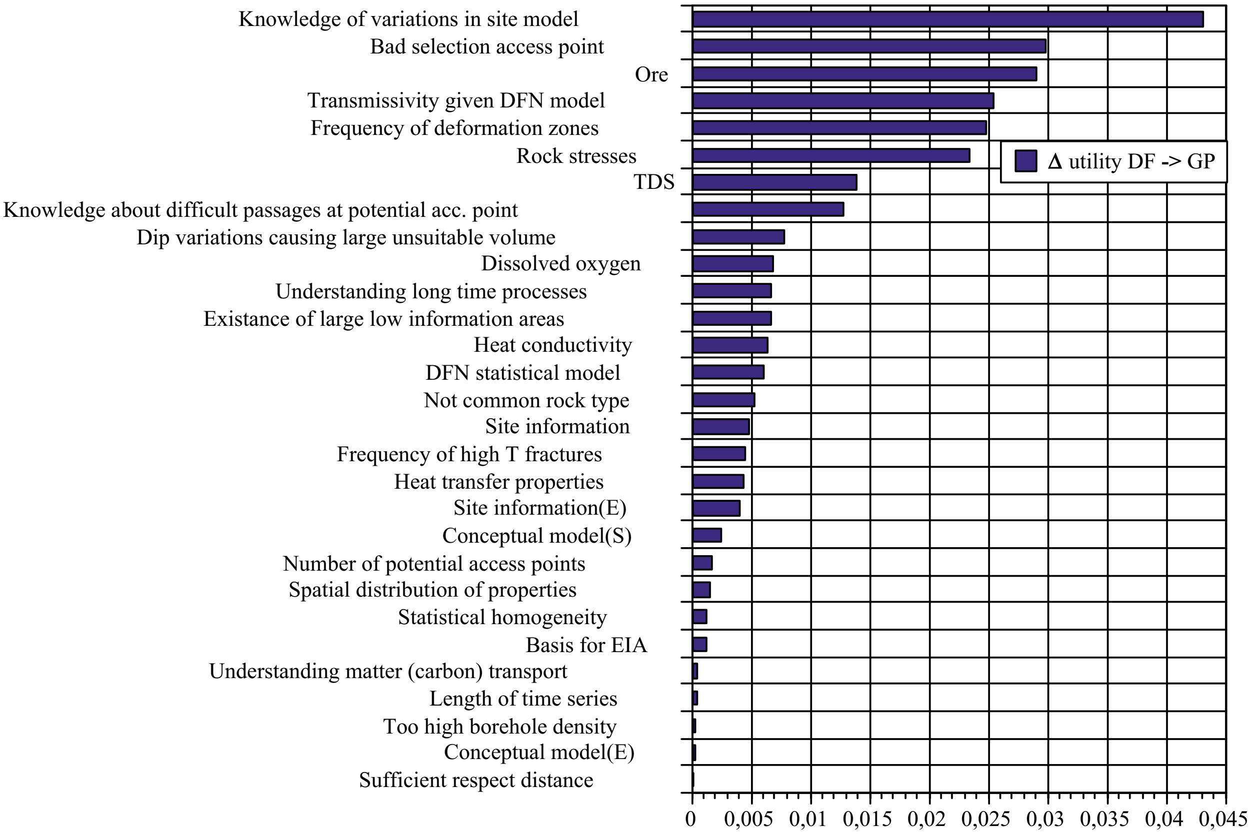

***Figure 6-7.** Relative change in utility with investigation.*

6.3 Testing the methodology

Among other things the Central Site Evaluation Group ("CPU", see Section 2.2.1) has the responsibility to develop a concrete plan for the completion of the Site Investigations (the "Complete Site Investigation Phase", /see e.g. SKB, 2000b/). In order to tests the methodology, the AHP/Weighted Objective Analysis technique, as outlined in the previous section, has also been tried in a workshop, conducted by the CPU group. The aim of this test was to provide insight into how to define the scope and focus these investigations by

- raising questions and provide overview and a structure of thought for the decision maker,
- raise strategic questions regarding the objectives and scope of the concrete plan for the completion of the Site Investigations.

From a somewhat modified AHP tree structure, compared to Figure 6-4, the group carried out the weighting and set probability of fulfilment for three different approaches, "the generic programme", "a focused programme" and "a statistical approach" to the continued site investigations.

Due to the preliminary nature and significant learning element involved in this test – the actual results have little significance – and are not reported here. However, several general observations were made:

- The workshop and the methodology itself triggered “the right type” of discussions in the rather heterogeneous group comprising the CPU. The test provided structure to the discussion and the test was a step on the road for reaching internal understanding and consensus on which strategy to adopt for the further programme.
- It is not trivial to set up a good AHP structure. Different people interpret terms differently, and with many levels and objectives the number of combinations in the tree also tend to increase to almost unmanageable proportions.
- The weighting is difficult and include many ambiguous and judgmental aspects. It was concluded, that the importance weighting should concern the actual conditions at the site – rather than generically address what is important. Treating all objectives with the same logical reasoning is difficult. Evidently, the weighting requires multiple and specific expert input and it could be argued that it should have been done prior to the test. The weighting, on the other hand, is as important input to the decision analysis as the probability assignments.
- Subjective probability estimation is never easy.
- The test also showed that it is required to clearly define alternative strategies for the further investigations and also to make sure that the details of these strategies actually live up to their ascertained objectives. (These latter conclusions are of course essential even if the specific AHP Weighted Objective analysis had not been conducted).
- As with any group and “consensus” striving exercise, strong persons may influence its results. However, this would certainly be true also if other decision making techniques (including less formal ones) would be used. In fact, one of the strong points of the formal decision making is that the input of “strong people” could be mapped and the sensitivity of the decisions to their judgments could be tested. Furthermore, there are means of obtaining a more “objective” input using “formal expert elicitation techniques”, /see e.g. Hora and Jensen, 2002/.

From the test described above, it seems that the Weighted objective decision process could provide insights to the PLUSLUT problem. However, like in all problems calling for the subjective assessment of some data, it is absolutely necessary to formulate all descriptions and questions in an unambiguous way. This became very clear during the CPU test!

Furthermore and more important, the formal decision making is conducted to assist the decision maker – *not as a means to motivate decisions* for others. For this, the formal methods are judged *unsuitable*. There is unavoidable arbitrariness and interpretation difficulties in setting up the structure and in assigning weights and probabilities. It could be very hard to formulate all factors, which actually impacts a decision. Eventually, it is *the arguments themselves* (level of knowledge related to needed knowledge), which will make up the motivation for the decision. Even if formal decision methods are used as support, it is these arguments, which should be made and presented.

Finally, the test was only the starting point of the work in developing the programme for the completion of the Site Investigations. Apart from the general focusing of this work, the test showed the need to clearly define alternative strategies for the further investigations and also to make sure that the details of these strategies actually live up to their ascertained objectives.

7 Recommendations

The information presented in previous chapters has allowed the project group to reach some recommendations and conclusions. They are presented here.

7.1 Decision perspective in the central site evaluation

When to stop the site investigation is a decision problem. The objective of the investigations is not primarily to produce a scientifically "true" model – it is to provide a basis for good decisions. In simple words the site investigations should stop when the expected net gain of further investigations is zero or negative, where gain is related to the total cost, which includes several factors besides the direct monetary outlay. Evidently, it is not a trustworthy approach to simply resort to cost arguments when deciding "when to stop" and e.g. scientific credibility is an essential part of the utility strived for. On the other hand, resources are not unlimited and the question on when sufficient knowledge is obtained depends on who is answering.

Sufficiency in information also needs to be understood in the step-wise repository implementation approach. At some stage surface based investigations needs to be supplemented by information from the underground. This is also internationally recognised. In an assessment of the role of Underground Research Laboratories, the OECD Nuclear Energy Agency conclude that /OECD/NEA, 2001/, "...at some point, performance-assessment modelling, engineering design, and other aspects of a repository programme require detailed information that can only be obtained underground at the repository site."

It is generally recommended that the Central Site Evaluation (CPU) applies a decision perspective. Furthermore, this decision perspective should be applied not only in determining the sufficiency of the programme, but also when optimising the remaining parts of the ongoing programme.

More specifically, it is recommended to:

- actively solicit feedback from Safety Assessment and Repository Engineering,
- keep track of the uncertainty evaluation of the key aspects of the Site Descriptive Models,
- develop the Underground Characterisation Programme as this is the next step against which to evaluate whether the surface based investigations should continue and,
- occasionally apply formal decision aiding tools as a means to provide further insights into the decision problem, but not as the main mechanism of reaching and motivating decisions.

These specific recommendations are further explored below.

7.1.1 Solicit feedback from safety assessment and repository engineering

It is essential that Safety Assessment (in PSE and SR-Can) and Repository Engineering (in the Design D1 exercise and beyond) actually deliver feedback on the site description and its assessment of uncertainty. Already now, it is clear that there only are a limited set of site specific issues that are of importance for the users. However, the coming assessments and engineering exercises include several novel activities not really carried out before. Specifically,

- the Safety Assessment focus on the initial state and the impact from the repository on the rock and
- the Design exercises exploring the impact from uncertainties in the site description

may provide new insights on what are important site properties and uncertainties. Consequently, once the ongoing Safety Assessment and Engineering activities have completed there first new analyses, there is a need to re-assess what really are the critical site specific issues. Furthermore, the answer to this question may well vary between the explored sites.

7.1.2 Make sure site descriptive modelling delivers uncertainties

In order to assess the need for further characterisation efforts, it is essential that the Site Descriptive Modelling project really deliver uncertainties in their estimates. The uncertainty estimates delivered in early phases /e.g. SKB, 2004/ needs to be assessed by the Central Site Evaluation Group (and by Safety Assessment and Repository Engineering, see below) in order to judge whether they are useful.

Assessing the uncertainties in key aspects of the Site Descriptive Models suggests:

- Baseline conditions have to be established for a substantial number of parameters. However, a realistic approach for the Site Investigation seems to be to carefully capture the within-year variation during undisturbed conditions by extensive monitoring programmes for at least one complete year. After that, a reduced number of carefully selected sampling points should be included in long-term monitoring programmes, which, together with long-term measurements on reference sites, can be used to describe the longer-term variation.
- /Lindroos et al, 2004/ conclude that the Forsmark candidate area is mineralogically sterile, although some additional assessments and measurements may still be worthwhile. Furthermore, the general approach of /Lindroos et al, 2004/ should be applicable to other sites although adjustment to the local conditions may imply changes in what to look for and which data are needed. Nevertheless, it appears that ore potential can be assessed with limited efforts and with modest additions to already decided investigations.
- There are already implemented techniques for assessing uncertainty in deformation zones and fractures. However, it is also clear that investigation efforts to fully verify existence of zones and to assess their properties are relatively resource demanding and different strategies for the further exploration needs to be considered. For example, one strategy could be to reduce the current size of the local model areas another could be to focus on various sets of deformation zones or geophysical signals.

- It seems clear that there will be remaining uncertainties in the hydrogeochemical description. Compared to the investigation level at "data freeze 1.1", there are some potentially useful additional characterisation efforts like a "fair amount" of characterisation points at depth, a better understanding of the chemical composition of the rock matrix and potentially an example of the groundwater composition in a regionally placed borehole. However, it also seems evident that there will be a point were additional site specific information would add very little to resolve remaining uncertainties.
- It is possible to put the qualitative assessment of the "understanding of site" into a decision framework as outlined in Chapter 3.

These examples also demonstrate that PLUSLUT is not only a matter of yes and no, but also concerns what the remaining strategy of the investigations should be. The decision analysis should adapt to this observation and also identify various potential investigation strategies. The Site Descriptive modelling addresses the potential for resolving identified uncertainties in a format exemplified by Table 7-1, taken from version 1.1 of the Site Descriptive Model of the Forsmark Site. This input should be further assessed by the Central Site Evaluation (and the site) on order to formulate possible investigation strategies.

Table 7-1. Example of feedback from SDM to Investigations /extracted from SKB, 2004/.

Discipline	**Model version 1.1**		**Will 1.2 data reduce this uncertainty?**		**Can remaining uncertainty in SDM v 1.2 be reduced by more field data?**	
	Uncertainty	**Cause**	**Much/To some extent/ Little**	**How**	**Much/To some extent/ Little**	**How**
Geology – rock domain model.	Extension of rock domains at depth.	Limited sub-surface data.	To some extent, pre-dominantly in the candidate area.	Observations in additional cored boreholes. Assessment of borehole and tunnel data around NPP and SFR (predominantly shallow depths).	To some extent.	Observations in additional cored boreholes. Modelling of geophysical data.

7.1.3 Develop the underground characterisation programme

As already stated in Section 5.9, crucial to the decision whether to continue the Site Investigation is what will/could be determined from the Underground Characterisation during the Construction and Detailed Investigation Phase. Underground characterisation would enable acquirement of much higher resolution data, but in a limited domain. Furthermore, mistakes made underground may have much wider consequences than mistakes made during the surface based investigation phase. It is necessary to widen the perspective on the coming underground characterisation programme in order to get a reasonable understanding on what the programme would cover and what uncertainties it would and would not resolve. This calls for input from the Site Characterisation side of SKB in this work.

7.1.4 Formal decision aiding tools for additional insight

It is recommended that the Central Site Evaluation group occasionally applies formal decision aiding tools as a means to provide further insights into the decision problem, but not as the main mechanism of reaching and motivating decisions.

Even if applying formal decision methods require an effort and although they are just an aid to the real decision-maker, they have some very important advantages: The decision is broken down into elements so they give a clear (often graphic) picture of the decision problem and the decision process. This means that it is possible to follow the reasoning and to discuss each part so that communication between the persons involved is greatly facilitated. Furthermore, sensitivity analyses, e.g. by changing weights and probabilities, or even structure, may provide important insights on the robustness of a decision.

It appears that both decision trees and Multiple Attribute Analyses, like the AHP Weighted Objective Analysis could be useful for assessing various aspects of the further planning of the Site Investigations. Also other Multiple Attribute Analysis tools could be considered. However, even if formal decision analyses techniques are applied, they are judged unsuitable for actually motivating decisions. There is unavoidable arbitrariness and interpretation difficulties in setting up the structure and in assigning weights and probabilities. It could be very hard to formulate all factors, which actually impacts a decision. Eventually, it is the arguments themselves (level of knowledge related to needed knowledge), which will make up the motivation for the decision. Even if formal decision methods are used as support, it is these arguments which should be made and presented.

7.2 Final remarks

As a final remark it must be stated that there is no unique answer to the question when to finish the site investigation and to proceed with underground exploration. The issue is to decide a point in time in the step-wise implementation of a repository when surface based information is considered sufficient in relation to the information that will be obtained from investigations underground. Different perspectives, available resources, appraisals of risk and to whom the question is raised affects the answer. This also means that a pragmatic approach is needed. The decision perspective is such an approach.

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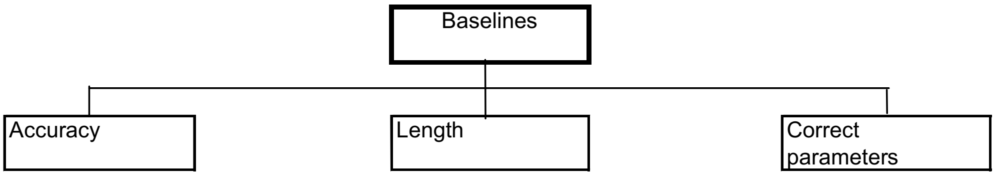
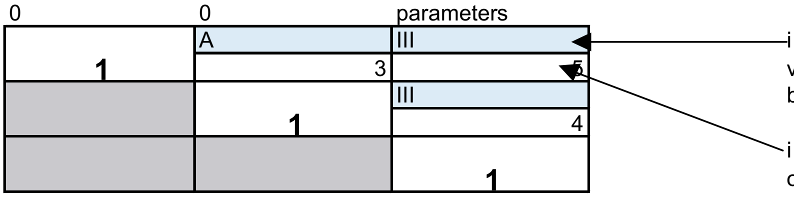
Appendix 1

Input forms for weighted objective analysis

Instructions for filling in AHP forms





		I Accuracy 0	II Length 0	III Correct parameters
A Accuracy			A	III
	0	1	3	5
B Length				III
	0		1	4
C Correct parameters				1

What information is important when establishing baselines?

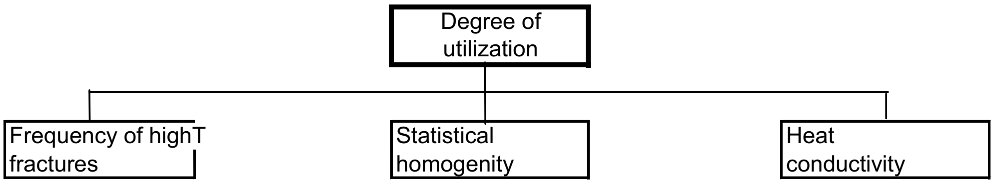
i turkos fältet markeras vilken faktor som är viktigast med resp bokstav eller romersk siffra

i vita fältet anges faktorns betydelse omkodat till numerisk skala

Skala för tolkning av verbal skala för preferenser till numerisk skala

Verbal skala	Förklaring	Numerisk skala
Båda elementen har samma betydelse	Två element bidrar lika mycket till egenskapen	1,0
Ett element har ett något större betydelse än det andra	Erfarenhet och bedömningar favoriserar ett element något över det andra	3,0
Stor övervikt för ett element	Erfarenhet och bedömningar favoriserar ett element starkt över det andra	5,0
Mycket stor övervikt för ett element	Ett element är starkt gynnat och dess dominans kan visas i praktiken	7,0
Extrem övervikt för ett element	De belägg som talar för ett element har starkast möjliga bekräftelse	9,0
Värden mellan två närbelägna omdömen	Kompromiss erfordras mellan två bedömningar	2,0;4,0;6,0; 8,0

Example AHP form



	I Frequency of highT fractures	II Statistical homogenity	III Heat conductivity
Frequency of highT fractures	1		
Statistical homogenity		1	
Heat conductivity			1

What information is important when estimating the degree of utilization?

Assessed probabilities that each investigation alternative will give enough information on each factor so that we can say that the factor will not be a problem.

Factor	**Prob. given Data freeze**	**Prob. given Generic progr.**
Conceptual model (safety view)		
Site information (safety view)		
Length of time series		
Basis for EIA		
Understanding matter (carbon) transport		
Sufficient respect distance		
No large variation in site model		
DFN statistical model		
Transmissivity given joint model		
Heat transfer properties		
Spatial distribution of properties		
Ore minerals		
Not common rock type		
Dissolved oxygen		
TDS		
Understanding of long time processes		