SKI Report 99:31

The Swedish Nuclear Power Inspectorate's Evaluation of SKB's RD&D Program 98

Review Report

April 1999

ISSN 1104-1374
ISRN SKI-R--99/31--SE

SKI

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1 Introduction

1.1 General

According to the Act (1984:3) on Nuclear Activities, the full responsibility for the safe management and final disposal of spent nuclear fuel and nuclear waste rests with the owners of the Swedish nuclear power reactors. In accordance with the Act (1992:1537) on the Financing of Future Expenses for Spent Nuclear Fuel etc., the owners are also responsible for ensuring that funds are set aside to cover the future expenses of the management and final disposal of spent nuclear fuel and nuclear waste. Furthermore, nuclear reactor owners must conduct, and every three years, submit a research and development programme for the management of the spent nuclear fuel and nuclear waste. The programme must also cover the measures which are necessary for the de-commissioning and dismantling of the nuclear installations.

The Ordinance on Nuclear Activities stipulates that the programme must be submitted to SKI for evaluation no later than on the last day of September, once every three years. SKI must submit the programme documents to the Government, along with its own statement. The owners of the nuclear power reactors have formed a joint company, the Swedish Nuclear Fuel and Waste Management Co (SKB) which, on behalf of the owners, fulfils the owners' statutory obligations with respect to the management and final disposal of spent nuclear fuel and nuclear waste and conducts related research and development.

The programme now submitted by SKB is the latest in the series which started with R&D Programme 86. However, as early as 1984, SKB's programme had been evaluated in connection with the presentation, for the first time, of the KBS-3 method as a basis for an application to start up the Forsmark 3 and Oskarshamn 3 reactors. The current programme was submitted in September 1998 and is called RD&D Programme 98 (programme for Research, Development and Demonstration).

In the Government's decision of December 19, 1996 concerning SKB's RD&D Programme 95, the Government stated that SKB must "carry out a system analysis of the entire final disposal system (encapsulation plant, transportation system and a re-pository). This system analysis shall allow for an overall, integrated safety assessment of the entire final disposal system, including how principles for safety and radiation protection are to be applied, in practice, in the safety assessment work. Furthermore, the system analysis shall include an account of the alternative solutions to the KBS-3 method described by SKB in previous research programmes or which have been described in international studies. Different variations on the KBS-3 method should also be described. In addition, the consequences which would arise if the planned repository is not constructed (zero alternative) as well as ongoing international work on transmuta-tion shall be presented".

In its decision on RD&D Programme 95, the Government stated that, before the site selection process can progress to the stage of site investigations at a minimum of two sites, "SKB's overall report on general siting studies, feasibility studies and any other

background and comparative information which, after consultation with the government-appointed National Co-ordinator for Nuclear Waste Disposal, SKB may wish to present, must be made available to the municipalities concerned." Furthermore, as regards the planned final disposal method, SKB should be able to specify criteria for the evaluation of candidate sites and specify which factors will determine whether a site will be excluded from further investigation". The Government also stated that, prior to the start of site investigations, SKB should consult with SKI and SSI concerning the conditions which should apply to the investigation work.

With respect to feasibility studies, the Government takes it for granted that "SKB, in consultation with the municipalities concerned, will be given the opportunity to carry out site-specific feasibility studies in such a way that an adequate basis for decision-making is available prior to SKB's consultation with SKI and SSI regarding the site investigations. SKB should make every effort to ensure that the municipalities concerned are given as adequate information as possible before different decisions are made in the siting work."

In RD&D Programme 98, SKB has stated that it particularly welcomes viewpoints concerning:

- Whether deep disposal[1] according to the KBS-3 method will continue to be the preferred method.

- The body of material that SKB is compiling in preparation for the selection of sites for site investigation.

- What is to be included in future Environmental Impact Statements (EIS).

Compared to previous programmes, RD&D Programme 98 is focused to a greater extent on method and site selection and on issues relating to the decision-making process. This is natural, since the programme is now approaching the stage where vital decisions will have to be made.

1.2 SKI s Work on the Matter

The RD&D Programme 98 report is supplemented by a background report "Detailed Programme for Research and Development 1999-2004" as well as a number of main references "System Reporting", "Alternative Methods", "Criteria for Site Evaluation" and the "North-South/Coast-Interior" report. In addition, a number of references are available in the form of county-specific general siting studies, feasibility studies etc.

[1] In order to emphasise that the final disposal system is not irrevocable, SKB now uses the term *deep disposal*. However, the term used in the legislation is *final disposal*. In acknowledgement of the legislation, SKI uses the term *final disposal* (except for the referenced text). Regardless of which term is used, different degrees of *retrievability* can be discussed.

Several of the reports were submitted to SKI at a fairly late stage ("North-South/Coast-Interior" was only submitted in January 1999), which made the evaluation work somewhat difficult for SKI and many of the reviewing bodies.

SKI has distributed RD&D Programme 98 to sixty-three reviewing bodies for comment. Forty-five responses were received. The reviewing bodies include universities and institutes of technology, local safety committees, municipalities hosting nuclear facilities and municipalities participating in feasibility studies as well as many authorities such as county administrative boards, the Swedish Environmental Protection Agency, the Swedish Board of Housing, Building and Planning and SSI.

During October 1998, SKI arranged a meeting for the reviewing bodies, where SKB was given the opportunity of presenting the programme and where SKI presented the evaluation and review process, including time-schedules.

The comments of the reviewing bodies mainly focus on the decision-making process, including issues relating to method selection and site selection and, in particular, on the selection of sites for site investigation. Several reviewing bodies, particularly universities and institutes of technology, have also submitted comments of a more technical-scientific nature.

SKI s Evaluation

SKI's evaluation has focused on determining whether SKB's programme can be considered to fulfil the requirements stipulated in the Act on Nuclear Activities that such a programme should be able to result in the implementation of solutions for the final disposal of the spent nuclear fuel from the Swedish nuclear power programme. Furthermore, SKI's evaluation has focused on the conditions that SKI considers should apply to SKB's future work.

In accordance with SKI's directive, SKI's statement to the Government must be dealt with by SKI's Board. SKI's statement to the Government includes the "Summary and Conclusions" of the Review Report. In the Review Report, SKI reviews SKB's RD&D Programme 98 and also deals with comments provided by the reviewing bodies. Furthermore, SKI has commissioned a separate report called "Comments by the Reviewing Bodies" (in Swedish). In addition, SKI and SSI have jointly prepared a report entitled "SKI's and SSI's Evaluation of SKB's System Report in RD&D Programme 98" (in Swedish).

2 SKI s Evaluation and Proposal for a Decision-Making Process

2.1 Introduction

SKB's programme is approaching the time when vital decisions, from the standpoint of SKB and the municipalities concerned, will have to be made concerning how SKB should proceed with the selection of site for a repository. This is reflected in the structure of RD&D Programme 98, where issues concerning the decision-making process have been given a considerably more prominent role than in previous RD&D programmes, which have been more focused on technical issues. This is also evident in the three issues that SKB considers should be addressed: site selection, the basis for the selection of sites for site investigation as well as the content of an Environmental Impact Statement (EIS). Moreover, it is evident that the reviewing bodies have focused on the decision-making process in their review.

SKB states its intention of conducting site investigations at a minimum of two sites, providing that the municipalities concerned give their consent. Before this stage, SKB would like the regulatory authorities and the Government to state clearly whether a geological deep repository of the KBS-3 type is the most suitable solution for Sweden. The municipalities involved in feasibility studies also emphasise that it is important that SKI, SSI and the Government should clearly state their opinion of the method. This is considered to be necessary in order for the municipal decision-making process to proceed. However, several of the environmental organisations are highly critical of SKB's work and are of the opinion that the site selection process should not continue until a method has been selected in a separate process.

2.2 SKI s Evaluation

2.2.1 Method Selection and System Analysis

SKI concludes, as does SSI, that some form of final disposal in deep geological formations appears to be the most suitable method for the final disposal of the spent nuclear fuel and long-lived waste from the Swedish nuclear power programme, taking into account established ethical principles and technical feasibility within the foreseeable future.

Storage above ground, for an extensive period of time, would entail a transfer of responsibility to future generations and this line of action cannot be defended from the ethical standpoint. Methods involving reprocessing and transmutation are still associated with significant technical and economic uncertainties which probably require decades of technical development to overcome. This method would also involve transferring responsibility to future generations. The facilities would also probably be so large and complex that Sweden would not be able to develop, construct and operate them on its own: a combination of a large accelerator, several reactors and a reproces-

sing plant would be required. It should also be emphasised that some form of final disposal would still be necessary, since all long-lived radioactivity cannot be eliminated.

SKI concludes, as does SSI, that an adequate system analysis is necessary in order to justify the selection of a method. In a memorandum (SKI dnr: 5.8 – 971083, SSI dnr: 6220/1994/97 from March 5, 1998), SKI and SSI have specified what should be included in a system analysis submitted by SKB. In summary, SKI and SSI consider that the system analysis which has been submitted has deficiencies, especially with respect to the justification of the method selected. SKB has not fully taken into account the instructions of the authorities. It is therefore necessary for SKB to conduct additional work on the system analysis.

SKI reiterates that the direction of the RD&D Programme, the method and site selection as well as the licensing of nuclear facilities in the final disposal system are all part of a process comprising many stages of decision-making which extend over a period of almost a century, if one takes, as the starting point, the date when the foundation was first laid for the Swedish strategy for the management and final disposal of spent nuclear fuel and nuclear waste through the AKA Inquiry and, as the finishing point, the time when a decision on the closure of the completed repository can be made. Figure 2.1 shows how far we have come in this process and some of the forthcoming stages where decisions will have to be made, as SKI described them in its Review Report on RD&D Programme 95.

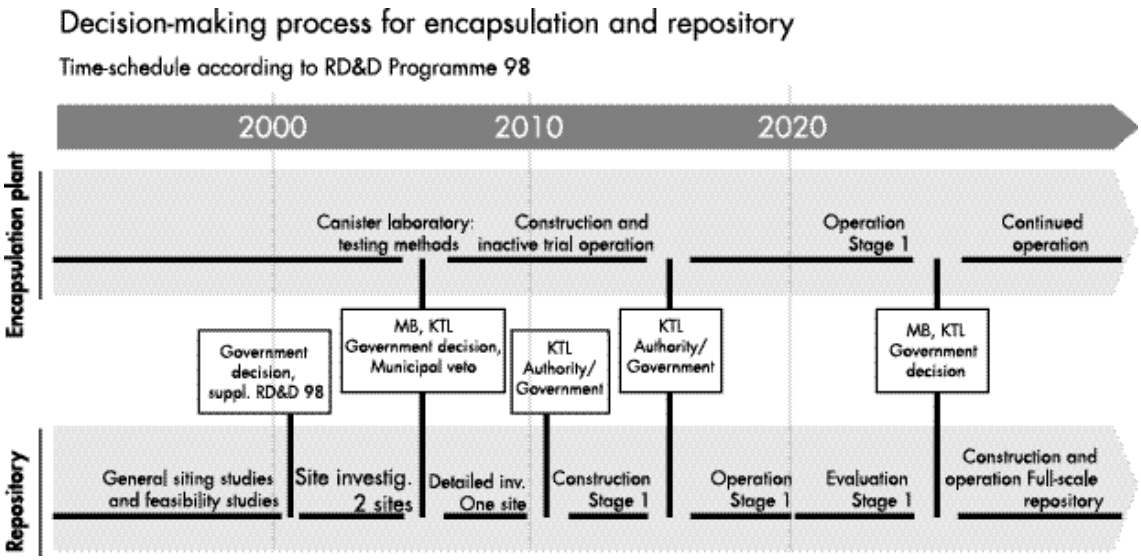

Figure 2.1
Overview of the decision-making process for the different stages of siting and construction of an encapsulation plant and repository. The laws under which licensing is to be conducted are specified for each stage where a decision is to be made (KTL stands for the Act on Nuclear Activities and MB, for the Environmental Code). The major stages, e.g. when SKB submits applications for permission to conduct detailed characterisations, to construct the encapsulation plant and to expand the repository from demonstration-scale disposal to full-scale disposal, will require decisions by the Government. At certain stages, licensing by a regulatory authority may be sufficient. In this review statement, SKI has proposed that SKB, as a condition for starting site investigations, should have to submit additional material to supplement RD&D Programme 98 (see Table 4.1) and that this material should be approved by the Government.

With a general focus on final disposal in deep geological formations, it is obvious that the detailed design of the method must be evaluated at different stages. The focus of SKB's research and development work on the KBS-3 concept has been evaluated in previous RD&D review reports. As mentioned above, SKB, the municipalities involved in feasibility studies and SKI consider that it is necessary to once again evaluate the KBS-3 method prior to the next stage in the site selection process, namely the start of site investigations. The method must then be evaluated again in connection with the licensing of the relevant facilities (encapsulation plant and repository) under the Environmental Code and the Act on Nuclear Activities. Additional evaluations will be made before spent nuclear fuel is transported to a facility which represents the first stage of the repository and before this facility is expanded to a full-scale repository.

Before the facilities are licensed and constructed, the formal and economic commitments to a particular method are limited. Future changes in the choice of method would naturally entail a considerable delay in reaching the final goal – a completed repository. However, any additional cost can, to a significant extent, be compensated for by the interest on the capital in the Nuclear Waste Fund, which would be accrued over the extended period of time.

2.2.2 Focus of the RD&D Programme and the Feasibility of the KBS-3 Method

In SKI's opinion, the Swedish Nuclear Fuel and Waste Management Co (SKB) has presented a research and development programme which complies with the basic requirements stipulated in § 12 of the Act on Nuclear Activities. The owners of the nuclear power reactors have, thereby, through SKB and for the period of time in question, fulfilled their obligations under §§ 11 – 12 of the Act on Nuclear Activities.

On the whole, the programme is appropriate with regard to the development and evaluation of a method for the final disposal of spent nuclear fuel and nuclear waste in the Swedish bedrock. The quality of the supporting research programme is good. In comparison with other methods and on the basis of the body of material available, SKI considers the focus of the programme on the KBS-3 method to be suitable. In its own review of RD&D Programme 98, SSI also supports SKB's choice of method.

As described in Chapters 5 and 7, in SKI's opinion, considerable technical development and testing still remain to be carried out, both with respect to the canister (fabrication, sealing, control) and with respect to the bentonite and the final disposal technology in general. However, in SKI's opinion, the scope of knowledge is such that it should be possible to implement the KBS-3 method as a project, from the purely technical point of view. Similarly, it is essential that the method be subjected to critical evaluation, in stages, with the support of system analyses and safety assessments etc.

SKB's research in support of the development of the KBS-3 method is generally of adequate quality and has, to a large extent, focused on issues that have been identified as essential in connection with previous safety assessments. SKI finds that, also in the long term, there will be a need for further research, in order to gradually improve the body of material for future safety assessments. SKI assumes that a repository, during its

operating lifetime and up to the time of possible closure, will be subjected to periodic safety reviews in the same way as the existing nuclear power reactors. Consequently, it is essential for SKB to develop and maintain its competence over a sufficiently long time. In SKI's opinion, SKB should strive to, as far as possible, ensure that its research results gain the acceptance of the rest of the research community, e.g. by publishing particularly important results in scientific journals.

2.2.3 Safety Assessments

The assessment of the safety of all parts of the final disposal system (encapsulation plant, transportation, repository) and of the safety of the system as a whole must maintain a high level of quality. The methodology for this work must be developed, although it already exists to a large extent. It is particularly important to be able to assess the long-term properties of a repository and for this to be done in a way that inspires confidence in the safety assessment. System analyses and safety assessments should specifically examine issues relating to retrievability over different time ranges and how this can affect the safety of the system as a whole.

During an operational phase, there is the possibility of experience feedback and of immediately implementing corrective measures, if necessary. For example, this applies to the operation of the encapsulation facility, to the transportation system as well as to the operation of the repository (as long as the repository is kept open). In SKI's opinion, SKB has the necessary knowledge and experience to carry out safety assessments and safety management during the operational phase, from the operation of CLAB and SFR etc. as well as from the transport of nuclear fuel.

During 1998, SSI promulgated regulations concerning the protection of human health and the environment in connection with the final management of spent nuclear fuel or nuclear waste (SSI FS 1998:1). The regulations include requirements concerning the limitation of the annual risk exposure of an individual in the critical group. SKI is currently preparing regulations including criteria for how the long-term safety of a repository can be achieved through a combination of engineered and natural barriers as well as for how safety assessments should be structured in order to show how these criteria are met. SKI-PM 97-17, which is currently being reviewed by external bodies, contains a general description of the criteria in these forthcoming SKI regulations. SKI's forthcoming regulations are harmonised with the above-mentioned SSI regulations with respect to risk limitation.

For SKI to be able to evaluate the KBS-3 method, before the work proceeds to the stage of the selection of sites for site investigation, SKB must show, through an up-to-date safety assessment, that the necessary conditions exist to identify a site in the Swedish bedrock which meets regulatory criteria with respect to long-term safety and radiation protection (see also Section 6.2.2). SKB is currently developing methods for the assessment of the safety of the long-term properties of the repository (SR 97). According to SKB, the report will be presented in summer 1999 (August). SKI will arrange for an international review of the SR 97 report to be conducted toward the end of 1999. SKI will also conduct its own evaluation of SR 97.

In its review statement on RD&D Programme 98, SSI has emphasised that SKB must conduct more detailed studies of the biosphere as a basis for modelling and calculations in the safety assessment. Additional views on SKB's safety assessment work are presented in Chapter 6.

As is mentioned above, safety assessments will have to be presented as a basis for decision-making at different stages in the development of the final disposal system (Figure 2.1). The stages which can already be anticipated now are:

1. Decision (long-term safety) on the method prior to the selection of sites for site investigation.
2. Safety assessments in connection with licensing, under the Environmental Code and Act on Nuclear Activities, of the encapsulation plant, transportation etc.
3. Decision in connection with an application, under the Environmental Code and Act on Nuclear Activities, for permission to conduct detailed characterisations (excavation of shafts down to repository depth etc.) as the first stage in the construction of a repository.
4. Safety assessment in connection with the evaluation of an application for a licence, under the Environmental Code and Act on Nuclear Activities, to operate the first stage of the repository (demonstration-scale repository).
5. New safety assessment in connection with the licensing, under the Environmental Code and Act on Nuclear Activities, of the second stage of the repository (full-scale repository).
6. New safety assessment prior to a decision on repository closure.

2.2.4 Siting

According to SKB's plans, the siting of the repository will be conducted in stages. The basis for the selection of sites for site investigation includes general siting studies of Swedish geology, regional geological studies, a study of the advantages and disadvantages of siting in the north/south and coast/interior as well as the feasibility studies which SKB has conducted and is currently conducting in a number of municipalities as well as feasibility studies of other municipalities identified by SKB in the future. In addition, there are the earlier geological investigations which SKB previously conducted at a number of sites in Sweden.

In SKI's opinion, the scope of the reports which SKB plans to submit prior to the transition to site investigations appears to be reasonable and taking into account the findings of this review statement, can be expected to provide an adequate basis for review statements concerning the final disposal method and the selection of sites for site investigations.

Like Oskarshamn Municipality and the Local Safety Committee at Oskarshamn Nuclear Power Plant, SKI emphasises that it is important for SKB to account for how it balances the various siting factors (safety, technology, land, environment and society) in the selection of sites for site investigations. On the basis of an up-to-date safety assessment (SR 97), SKB must also reconcile and clearly account for the minimum criteria and

discriminating factors which determine whether a site can be judged to be suitable for a repository.

In summary, it is important that the additional material submitted by SKB before a decision is made regarding site investigations should include a clear account of measurement programmes for the site investigations, based on insights from the safety assessment and other studies, an integrated evaluation of implemented feasibility studies and other site selection material together with an evaluation of the suitability of the sites investigated in the feasibility studies which are included in the body of material for the selection of sites for site investigations, as well as SKB's plans for consultation at the different stages of siting.

2.3 Decision-making Process

2.3.1 Premises

SKB, like many other reviewing bodies, including the municipalities involved in the feasibility studies, considers that a clearer position on the KBS-3 method must be adopted, on a national level, before proceeding with site investigations. SKI shares this view. The start of site investigations marks an important stage of decision-making in the successive process which is to result in the implementation of a repository.

In that respect, adopting a positive position with regard to the KBS-3 method must not be viewed as a definite approval of the method, but as a stage in the gradual development of a process of evaluation, where the next stage would be the licensing of the various facilities in the system. As far as geological disposal is concerned, the next stage means the evaluation of an application for permission to conduct detailed characterisations (excavation of shafts down to repository depth).

Based on the comments of the reviewing bodies and SKI's findings, three main options can be distinguished in the future licensing and decision-making process:

- The presentation of additional material for decision-making prior to the selection of sites for site investigation.
- The initiation of a separate process, in parallel to SKB's RD&D programme, to conduct a Strategic Environmental Assessment (SEA) for the selection of a method.
- The discontinuation of SKB's site selection process and the transfer of the responsibility for developing a method for final disposal to a new organisation which will carry out work in an impartial manner.

As is mentioned above, SKI considers that the evaluation of SKB's RD&D programme shows that SKB and, thereby, the owners of the nuclear power reactors, has fulfilled its obligations under §§ 11 – 12 of the Act on Nuclear Activities. Therefore, SKI sees no reason for selecting the third option.

Several reviewing bodies, including the Swedish Board of Housing, Building and Planning and the Swedish Environmental Protection Agency, consider that a decision

with respect to the selection of a method should be based on some form of Strategic Environmental Assessment (SEA), as outlined in the second option above. However, neither the concept of SEA nor the process is defined in Swedish legislation. Since the concept of SEA is not yet defined in Swedish legislation, SKI concludes that, for example, if the Government were to charge an agency or special commission with the task of conducting such a process, this would render unclear the responsibilities towards SKB, and SKB's obligations, under §§ 11 – 12 of the Act on Nuclear Activities. A comprehensive and complex SEA, extending over a period of many years would also delay and, according to the municipalities involved in feasibility studies, render the site selection process which has already begun more difficult.

SKI emphasises, in this context, that the periodic, public evaluation and review process - stipulated in § 12 of the Act on Nuclear Activities and its precursor – which has been in progress for two decades, contains many of the elements that, according to ongoing discussions, are assumed to be included in a SEA, including public consultation. After all, the aim is to ensure that the basis for decision-making is sufficiently comprehensive and substantiated.

On the basis of the above discussion, SKI recommends that proposals to introduce new processes without the support of the existing Swedish legislation or EC legal acts should be rejected. In SKI's opinion, § 12 of the Act on Nuclear Activities gives the Government adequate opportunity to ensure, by requesting additional material, that a sufficiently comprehensive and substantiated basis for decision-making exists prior to decisions regarding method selection and the start of site investigations. SKI proposes that such a process should be structured as described below.

2.3.2 SKI s Conclusions concerning Future Action

The Possibility of Stipulating Conditions, under § 12 of the Act on Nuclear Activities, Provides the Legal Foundation

The legal foundation for SKI's proposal for future action is § 12 of the Act on Nuclear Activities. According to this Act, the Government, in connection with evaluations and decisions on the RD&D programme, may stipulate the necessary conditions for future research and development activities.

In SKI's opinion, a reasonable interpretation of the application of the law is that the Government can use the possibility of stipulating conditions to ensure that the municipalities involved in feasibility studies obtain a comprehensive and well-substantiated basis for their decision-making in the site selection process. After all, the consent of the municipalities is necessary for the siting process to continue and, according to SKB, the siting process is an important aspect of future work in the RD&D programme. Furthermore, there is a link between the Act on Nuclear Activities and the Financing Act. In SKI's opinion, it is therefore also reasonable for the Government to stipulate conditions concerning the body of material which must be available, in an evaluated and approved form, before the programme continues, in view of the fact that the programme is financed by funds which are administered by the state.

Additional Material for the Basis of Decision-making Prepared through a Review and Consultation Process

In SKI's opinion, the additional material that is necessary, as described above, for the Government and central authorities to make decisions and for the municipalities involved in feasibility studies to proceed to the site investigation stage, should be prepared through a review and consultation process. This process should reflect, to a reasonable extent, the provisions concerning extended consultation and environmental impact assessment, in Chapter 6 of §§ 4 –6 of the Environmental Code. In this context, it can be reiterated that according to Article 2.7 of the Espoo Convention, which was ratified by Sweden, "to the extent appropriate, the Parties shall endeavour to apply the principles of environmental impact assessment to policies, plans and programmes." On the basis of the proposed process, it could be maintained, with good reason, that the requirements of the Espoo Convention are met to a reasonable extent, especially if all of the previous public evaluations and reviews of the RD&D programme are considered in the light of § 12 of the Act on Nuclear Activities.

2.3.3 SKI s Proposal for the Position to Be Adopted by the Government on Method Selection

SKI proposes that a government decision on RD&D 98 should be made in early autumn 1999 and should contain the following elements in order to satisfy different views on the future process which have emerged during the review of the programme.

1. SKI proposes that the Government should state that SKB, and thereby the reactor owners, have so far fulfilled their obligations under § 12 of the Act on Nuclear Activities.

2. As a condition for starting site investigations, SKI proposes that the Government stipulate that the additional material which, in this statement, SKI considers should be presented, should have obtained government approval prior to the start of site investigations (Figure 4.1), namely:

- A supplement to the analysis of alternative system solutions, including the "zero alternative". The aim is to verify, more clearly, that there is no method which is essentially more suitable than the KBS-3 concept, from the Swedish standpoint.
- An in-depth safety assessment of the KBS-3 method. The aim is to show, in a credible manner, that the KBS-3 method has the necessary conditions to comply with the safety and radiation protection criteria that SKI and SSI have stipulated in recent years. The safety assessment must be subjected to international peer review.
- A clear account of measurement programmes for the site investigations, based on insights from the safety assessment and other studies,
- Other material which, according to SKB, will comprise the basis for the selection of sites for site investigation and SKB's plans for achieving consultation in the different stages of siting.
- An integrated evaluation of implemented feasibility studies and other site selection material together with a judgement of the suitability of the sites investigated in the

feasibility studies which are included in the body of material for the selection of sites for site investigation.

The Government's approval of this additional material would entail approval, as a matter of principle, of the KBS-3 method as a basis for future technical development and site selection work. However, at the same time, it should be emphasised that such approval does not, in any way, anticipate or restrict the full evaluation and licensing of future facilities, under the Act on Nuclear Activities and the Environmental Code.

3. SKI proposes, as an additional condition, and in accordance with the intentions concerning extended consultation and environmental impact assessment provided in Chapter 6, §§ 4-5 of the Environmental Code, that the Government should stipulate that SKB must consult with the municipalities concerned (i.e. the municipalities involved in feasibility studies), county administrative boards, authorities and other bodies with respect to the additional material that SKB must provide. The EIA forums established in the counties and municipalities concerned should be used as far as possible. An account of this process of consultation and what has emerged from it should be included in the additional material that SKB is to provide.

4. SKI proposes that the Government charge SKI with the task of evaluating the additional material presented. This will include an evaluation of how viewpoints emerging from the consultation process have been taken into account. SKI's evaluation should include comments from reviewing bodies. SKI should – as in the case of the licensing of the construction of Stage 2 of CLAB (Central Interim Storage Facility for Spent Nuclear Fuel) – arrange public meetings in the municipalities concerned in order to further ensure that all relevant viewpoints and issues are taken into account in SKB's material as well as in the review statements of SKI and other authorities.

The Government does not necessarily have to set a time limit for the additional material which is to be submitted by SKB. As shown above, it is in the interest of SKB and the municipalities concerned that the process does not take too long. On the other hand, one reason for setting a time limit is that this would be a way for the Government to clearly demonstrate to the municipalities that it feels responsible for ensuring that the process makes progress. In such a case, the aim should be to announce a government decision by no later than June 30, 2001 (Figure 2.2).

In SKI's view, the Government should particularly emphasise, in its decision, that previous RD&D programme reviews have entailed more opportunities for consultation than those touched upon in points 3 and 4 above, and that this process is not a new one, but rather an opportunity for ultimate reconciliation and for adding material prior to an important stage in the decision-making on site selection and the future RD&D programme.

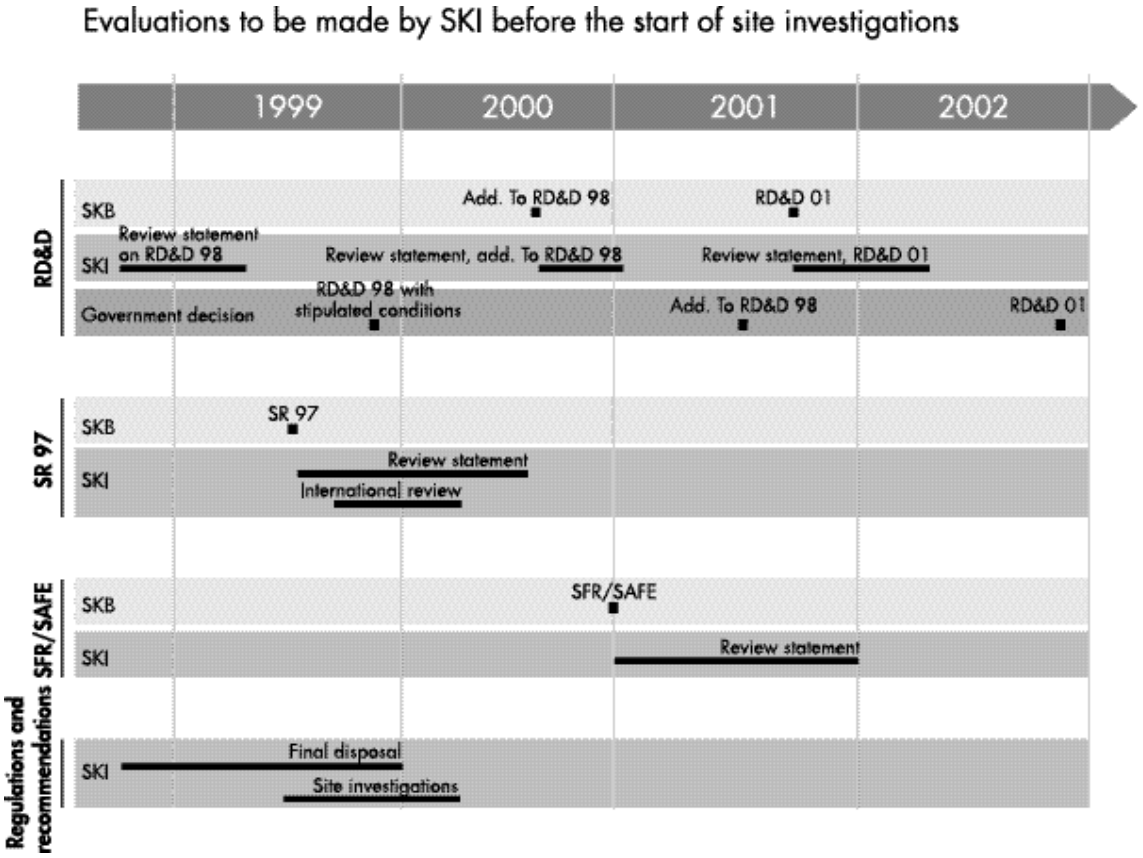

Figure **2.2**
Overview of major evaluations of SKB's work which SKI will have to conduct over the next four years. The figure is based on the assumption that SKB, in accordance with the proposal in this review statement, will be required by the Government to submit additional material to supplement RD&D Programme 98, prior to the start of site investigations. In addition to SKB's RD&D Programme reports and the new safety assessment study for the repository (SR 97), during the period, SKI must also evaluate SKB's new safety report (SAFE) for the repository for radioactive operational waste at Forsmark (SFR).

2.3.4 SKI s Proposal for the Clarification of Certain Issues Relating to Future Work in the Decision-Making Process, Including the EIA

The Environmental Code entered into force as of January 1, 1999. The Environmental Code requires SKB to submit an Environmental Impact Statement (EIS) as a basis for decisions concerning planned nuclear facilities (repository and encapsulation plant). The Environmental Code regulates the content of the document (EIS) and the process of preparing the document (EIA) which, in the case of nuclear facilities, must be achieved through an extended consultation, in accordance with Chapter 6 § 5 of the Code.

In their review comments, municipalities concerned state that they would like to have greater clarity with respect to when a formal EIA actually starts. For several years, a process, which is similar to an EIA, has been in progress in Oskarshamn Municipality, under the leadership of the County Administrative Board of Kalmar County (cf. government decision of May 18, 1995). This process has been conducted on a voluntary basis and without any legislative requirement. Through this process, it has been possible for

representatives from SKB, the municipality, the county administrative board, SKI and SSI to constructively discuss issues relating to the content of future EIS. Similar groups have also been established in connection with SKB's other feasibility studies. This has made it possible to lay an adequate foundation for conducting extended consultation in accordance with the Environmental Code.

According to Chapter 6, §§ 4-5 of the Environmental Code and the Ordinance on Environmental Impact Assessment (1998:905), a formal process involving extended consultation and environmental impact assessment is to be initiated through a decision made by the county administrative board concerned when SKB announces its intention to make preparations to submit an application for permission to site a facility for the management or final disposal of spent nuclear fuel in a municipality in the county. In SKI's view, this should be interpreted to mean that extended consultation should be initiated when SKB starts site investigations, since the aim of these investigations is to prepare an application for siting permission in one of the municipalities. Through the extended consultation, municipalities concerned, SKI, SSI and other competent authorities have the opportunity to influence the content of the EIS which is to be appended to a licence application under the Environmental Code and Act on Nuclear Activities.

SKB's proposed table of contents for an EIS comprises the compulsory issues stipulated in the Environmental Code which have been adequately adapted to the final disposal issue. In SKI's opinion, SKB's proposed table of contents can comprise a basis for further discussion with actors concerned within the framework of the extended consultation, in accordance with the Environmental Code.

One issue which is unclear at present is how to co-ordinate the licensing of allowability, in accordance with the Environmental Code, with the licensing, in accordance with the Act on Nuclear Activities, of future facilities in a final disposal system. It is important that the Environmental Court, municipalities involved and the Government should have access to the complete review statements of the competent authorities – SKI and SSI – on the Act on Nuclear Activities when these bodies make decisions on allowability, in accordance with the Environmental Code. This is particularly important for municipalities which can then exercise their veto right. One possibility is for the Government to make a decision on allowability, under the Environmental Code, at the same time as it makes a decision on whether to grant permission for final disposal facilities under the Act on Nuclear Activities. Like many of the reviewing bodies, SKI would like to have clarification from the Government with respect to how this co-ordination will take place. In SKI's opinion, clarification is necessary in order to direct the co-ordination of licensing, which has been desired by the Government in previous decisions, even at a lower level, since the question of allowability is now to be prepared by the Environmental Court and not by authorities and ministries. Several municipalities have also expressed a desire for greater clarity with respect to how the Government's right to override a municipal veto can be applied.

SKI s Proposal

In order to clarify the regulations regarding future work in the decision-making process - as requested by several of the reviewing bodies - SKI proposes that the Government, in addition to the position that it has adopted in previous government decisions should:

- Propose to the Swedish parliament to amend the Act on Nuclear Activities by including a provision whereby the Government's licensing, under the Act on Nuclear Activities, of the construction of nuclear facilities is to be co-ordinated with the licensing of allowability, in accordance with the Environmental Code.
- Furthermore, clarify the criteria on the basis of which the Government's right to override a municipal veto is to apply.
- Stipulate that the start of site investigations is to be viewed as the first stage in SKB's preparation of an application for permission to construct a repository under the Act on Nuclear Activities and the Environmental Code. Thus, extended consultation and environmental impact assessment prior to licensing under Chapter 6, §§ 4-5 of the Environmental Code, are to be initiated at that time.

3 Method Selection and System Analysis

This chapter deals with issues relating to method selection, presented in Chapter 2 of RD&D Programme 98 and in the Alternative Methods report (Ekendahl and Papp, 1998) as well as issues relating to system analysis, primarily reported in Section 3.2 of RD&D Programme 98 and the System Report on Deep Disposal Based on the KBS-3 Method (SKB, 1998). A number of background reports belong to the latter report: Safety during the Operation of the Encapsulation Plant (Gillin, 1998), Safety during the Transport of Encapsulated Fuel (Ekendahl and Pettersson, 1998), Safety during the Operation of the Deep Repository (Lönnerberg and Pettersson, 1998) and Design Premises for the Canister for Spent Nuclear Fuel (Werme, 1998). Furthermore, monitored storage is reported by SKB in the Background Report, Monitored Long-term Storage in CLAB (Söderman, 1998).

3.1 Introduction

SKI's evaluation of SKB's selection of a method for the final disposal of spent nuclear fuel and long-lived nuclear waste is presented in this chapter. In SKI's opinion, which is also shared by SSI (see below), such an evaluation should be based on the government decision concerning RD&D Programme 95 (December 19, 1996). The Government stipulated that SKB, in its future work, should conduct a system analysis of the entire final disposal system, and that the system analysis should include a description of alternative methods. The idea that an account of the method selection should be included in SKB's system analysis report has subsequently been developed and clarified in a memorandum which was jointly written by SKI and SSI (SKI dnr: 5.8-971083, SSI dnr: 6220/1994/97 from March 5, 1998). The evaluation of the method selection and the system analysis should, therefore, be conducted within the same context.

With reference to the above-mentioned memorandum, SKI would like to emphasise that the system analysis should be viewed as a tool for:

- justifying the selection of a strategy and method for the disposal of spent nuclear fuel and nuclear waste,
- showing how safety and radiation protection criteria are satisfied by the selected method.

The fact that the method selection is viewed in this way, as a part of the system analysis, should improve the clarity of reporting. However, SKB has not been able to make full use of these possibilities in its RD&D Programme 98. Already in early 1998, it became clear that it would not be possible for SKB to present a complete system analysis in RD&D Programme 98, i.e. the essential safety assessment study of the final disposal system for spent nuclear fuel, SR 97, has not yet been completed.

SKI's and SSI's view of the content of a system analysis report has, in spite of this, been used as a basis for the evaluation. One important reason for this is that SKB's system analysis will have to be presented several times during the decision-making process. For example, it will also be needed as a basis for an application to construct

planned facilities. Therefore, it is essential that the opinions of the authorities should be taken into account, already at this stage, by SKB, in its future work. An additional reason is the requirements regarding adopting a position on method selection which have emerged in recent years and which are evident from the comments by the reviewing bodies. SKI is of the opinion that the system analysis and system analysis reporting, as defined in the authorities' joint memorandum, should be used as a tool to clarify and justify the selection of a method.

Besides evaluating the suitability of SKB's selection of a method in the light of existing knowledge, one of the main purposes of this review has been to assess and comment on the comprehensiveness of SKB's system report. This has been done, in spite of the fact that it was clear from the outset that SKB would not present a comprehensive report in RD&D Programme 98.

For the sake of clarity, it should be added that a system analysis which is conducted in order to select the most suitable method does not necessarily have to show that safety and radiation protection objectives are fulfilled for all alternatives. On the other hand, a system analysis of the alternative which is ultimately chosen, and upon which the rest of the decision-making process will be based, e.g. the selection of sites for site investigations, must be based on safety reports for system parts which, together, show that the safety and radiation protection objectives can be fulfilled by the selected system. This is in agreement with the government decision on RD&D Programme 95.

In their previous statements concerning SKB's programme, regulatory authorities, i.e. SKI and previously SKN (National Board for Spent Nuclear Fuel), and the Government have seemed to adopt a "wait-and-see" approach to the method selection and the studies of alternative methods. This is partly due to two reasons:

- the Act on Nuclear Activities contains stipulations concerning the comprehensiveness of the research programme, also stipulated in the Ordinance to the Act, which contains explicit requirements on the evaluation of alternative methods,
- SKI also wished to avoid adopting a position and, consequently, committing itself, to a method, which it would subsequently have to evaluate in connection with licence applications.

This cautious approach may have been misinterpreted to mean that it has been unclear whether the KBS-3 method has been considered, all along, to be the most suitable alternative for further development work.

3.2 SKB s Report

SKB's report on method selection is independent of the system report. However, in the Alternative Methods report, SKB refers to the government decision concerning RD&D Programme 95, which states that the system analysis must "include a report of the alternative solutions to the KBS-3 method which SKB has reported in previous research programmes or which are the subject of international studies". Since SKB has, so far, not opted to link the system analysis and method selection, apart from in this respect,

the presentation of SKB's work provided below, is divided into two parts: method selection and system analysis. However, the evaluation (3.4), does not follow this structure.

Method Selection

SKB starts its report on method selection (Chapter 2 of RD&D Programme 98) with an overview of proposed alternative methods or strategies. (However, the section is somewhat confusingly entitled, "Different Modules in Waste Management". SKB reaches the conclusion that "four main modules or methods" can be distinguished. A brief description of these modules is followed by two sections (2.3 Selecting a Main Alternative and 2.4 The Swedish Main Alternative) of which the latter is the actual report on method selection.

SKB defines four possible "programmes or strategies" which correspond to the "modules or methods" mentioned above:

- monitored storage, where a decision on subsequent handling is postponed,
- direct disposal in a deep repository,
- reprocessing (possibly followed by transmutation) and deep disposal,
- ultimate removal.

SKB selects the KBS-3 method by first eliminating reprocessing on the basis of the argument that Sweden has decided to exclude this option on account of the risk of nuclear weapons proliferation and other reasons. SKB then states that, in Sweden, the intention is to implement geological disposal. This is based on the view that it is the responsibility of the present generation to dispose of the waste since it is the current generation which has benefited from nuclear power. Furthermore, uncertainty concerning the development of society in the future means that it would be better not to postpone implementing a final disposal solution.

SKB then opts for the geological environment on the basis of the fact that crystalline bedrock is most prevalent in Sweden and based on the argument that it is more suitable from a technical-scientific standpoint. The selection of the final disposal concept – the KBS-3 method – is briefly justified by referring to investigations and comparisons which have been conducted with other alternatives in terms of feasibility, short and long-term safety and cost.

The subsequent section of RD&D Programme 98 on the historical background (Section 2.5) provides an overview of developments over a period of just over 25 years. The AKA Committee Inquiry (1972-76) which laid the foundation for subsequent work, and the KBS-1, KBS-2 and KBS-3 Inquiries are briefly described. The R&D and the RD&D programmes in 1986, 1989, 1992 and 1995 are described in greater detail, focusing on alternative studies and regulatory and government decisions.

According to SKB, the purpose of the Alternative Methods report (Ekendahl and Papp, 1998) is to compile technical and safety-related material for the discussion on alternatives and method selection which is presented in RD&D Programme 98 and the KBS-3 system report (SKB, 1998). After starting off with almost the same content as Chapter 2 of the main report on method selection, the report then gives a more detailed description

of alternative methods for final disposal in crystalline bedrock (Chapter 4). A general description is also provided of studies conducted in other countries. SKB distinguishes between, on the one hand, KBS-3-type concepts such as "two canisters per hole and "short horizontal holes", and on the other hand, designs based on Medium-Long Holes (MLH). In a separate chapter (5), other final disposal concepts are described: Very Deep Holes (VDH), Very Long Holes (VLH) and hot dry disposal (WP-Cave and Dry Rock Disposal, although the latter should be considered to be a form of interim storage). The report also contains a description of foreign alternatives based on other geologies than crystalline bedrock (non-water saturated rock, salt formations, clay sediment). The report concludes with an appendix describing partitioning and transmutation (P&T). The appendix is more or less a reproduction of the section on this topic in SKB's Detailed Programme for Research and Development 1999-2004.

System Analysis and System Reporting

SKB presents the system analysis in Section 3.2 of RD&D Programme 98. SKB refers to the government decision on RD&D Programme 95 which states that SKB "must conduct a system analysis of the entire final disposal system (encapsulation plant, transportation and repository). This system analysis shall allow an overall, integrated safety assessment of the entire final disposal system to be made, including how principles for safety and radiation protection are applied, in practice, in the safety assessment work. SKB states that the main purpose of the system analysis is to show that operational safety is ensured in all parts of the system. According to SKB, another purpose is to show that the system provides a reasonable balance between the measures at different stages in the process and the resulting safety of the repository after closure. The system analysis also aims to examine the degree of flexibility and freedom of choice in the system with respect to factors such as detailed design and time-schedules.

SKB's system analysis is presented in the deep disposal system reporting according to the KBS-3 method (SKB, 1998).

3.3 Comments by the Reviewing Bodies

Nyköping and Oskarshamn Municipalities and the local safety committees at the nuclear facilities in Studsvik and at Oskarshamn nuclear power plant mainly express the same views in their statements. (These bodies are referred to as "the municipalities" in this section). The municipalities consider it necessary for the Government, Ministries and the regulatory authorities to state clearly, prior to the start of site investigations, whether they consider the KBS-3 method to be a safe and feasible method. Furthermore, the municipalities maintain that the method and alternative issue has been considered to be unclear by many during the work on feasibility studies and that this lack of transparency must be resolved before a decision is made concerning site investigations. A decision to say yes to a site investigation implies a considerable moral and political responsibility which must be taken by both the decision-makers and the inhabitants of the municipalities. In short, three positions on this issue are possible:

- that the KBS-3 method is considered to be the most suitable method for the siting of the necessary facilities and, therefore, the authorities, on the basis of current knowledge, evaluate this system to be feasible and consider that it can be made to be safe,
- that the KBS-3 method is promising but that, due to a lack of clarity in one or more areas, other methods must also be studied in further detail,
- that the lack of clarity with respect to the KBS-3 method is so significant that other methods may be equally as good or better, which means that it is too early to select a method.

Oskarshamn Municipality bases its statement on comments from various municipal working groups. These groups maintain that SKB should more clearly report both the facts and values upon which the selection of KBS-3 is based. According to the working groups, an incorrect impression is being given that the selection of KBS-3 is solely a technical decision. The groups also raise the question of whether SKB has selected KBS-3 because all other methods are worse, i.e. through a process of elimination.

Östhammar Municipality and the Local Safety Committee at Forsmark Nuclear Power Plant consider that SKB has adopted a definite position on the method selection issue and that research into alternatives is being conducted in order to comply with legislative requirements concerning the comprehensiveness of research and development work. The Municipality and the Committee also point out that SKB itself is remaining open to changes in the programme for a long time, possibly for ten years.

According to Malå Municipality, the current time-schedule for the start of site investigations is somewhat optimistic, in view of the fact that no decision has been made selecting KBS-3 as the ultimate method. The Municipality also believes that as soon as the additional material has been provided, the Government should be able to either definitely adopt KBS-3 as the method for final disposal or reject KBS-3 in favour of another method.

Tierp Municipality considers it understandable that the authorities cannot definitely approve a method before the method has been fully evaluated. Furthermore, it is not possible for a municipality, on its own, to approve of further investigations within its borders if the Government has not explicitly stated that it is the KBS-method which is to be further investigated. The Municipality also states that the material presented by SKB does not make it clear that a transmutation facility is a huge and complex industrial nuclear facility.

The Swedish Association of Municipalities with Nuclear Reactors (KSO) shares the critical view adopted by the feasibility study municipalities with respect to the method issue. KSO believes that those municipalities that are selected for site investigations, in particular, must have both the Government's and the competent authorities' unambiguous support that the proposed method is both safe and feasible. KSO would therefore like clarification of the method issue.

The Swedish Anti-Nuclear Movement (FMKK) reaches the conclusion that SKB's R&D activities do not aim to achieve a safe final disposal of spent nuclear fuel stipulated by the Act on Nuclear Activities. FMKK states that this view is based on the

impression that SKB seems to believe that the point of the [deep disposal] project is to construct a temporary interim storage facility and not a repository. Another reason, according to FMKK, is that SKB has explained that its investigations of alternatives are characterised by "sceptical curiosity" and that it is clear from the Alternative Methods report (R-98-11) that SKB's intentions go no further than that. As regards the system analysis, FMKK considers that the content of the report (SKB, 1998) does not allow any definite conclusions to be reached regarding whether or not definite safety requirements are fulfilled. In short, FMKK also presents the following views concerning alternative methods:

- Very Deep Holes should be the focus of greater attention since there is much to indicate that this alternative has a greater safety potential than the KBS-3 method,
- final disposal above groundwater level should be investigated,
- SKB should investigate dry interim storage as a zero alternative in comparison with storage in CLAB.

Friends of the Earth (MJV) does not believe that any method is totally satisfactory. MJV has two basic criteria for the selection of a method: that future generations should have as little responsibility to bear as possible and that the waste should not be an easy-to-access source of plutonium for future nuclear weapons. Furthermore, MJV expresses concern that official approval of a particular method before the phase-out of nuclear power could be used as a "weapon" in an attempt to revive the nuclear power programme "(now that the waste problem is solved!)".

The Geological Survey of Sweden (SGU) supports the KBS-3 concept on condition that the geological aspects carry significant weight during repository site selection.

The Swedish Geotechnical Institute agrees with the direction adopted by SKB and has no geotechnical comments.

The County Administrative Board, Kalmar believes that it is difficult to make comparisons between different methods on the basis of RD&D Programme 98. In order to make a correct comparison, an equivalent and comparable system analysis and environmental impact statement is required for the different alternatives. The County Administrative Board would like the Government and authorities to adopt a more definite position with respect to the KBS-3 method so that progress can be made in the siting work.

The Swedish Board of Housing, Building and Planning considers that method selection should be handled in a "strategic environmental assessment", with the different alternatives clearly described, along with advantages and disadvantages.

The Green Party, Tierp, is of the opinion that RD&D Programme 98's approach to the alternatives is unprofessional, and that the alternatives to KBS-3 that are given mainly comprise ultimate removal and transmutation. The Green Party would also like to see a discussion of deep disposal and of disposal under caprock as well as in gabbro. Furthermore, the Green Party would like a discussion of different methods of this type of

storage since interim storage will have to be extended if the repository does not ultimately comply with the safety criteria established by the regulatory authorities.

The Waste Network does not consider that SKB has justified method selection or site selection in a scientifically acceptable way: instead of first selecting a method and then concentrating on showing that the method chosen in this way is acceptable, a method is to be selected on the basis of performance criteria which it is believed a repository should meet. The Network states that, before that the method selection is approved, it is meaningless to pursue work on siting, apart from with respect to principles and the structure of the process.

The Opinion Group against Nuclear Waste in Malå believes that SKB has made an irrevocable commitment to the KBS-3 method and states that it experiences a definite unwillingness on the part of SKB to investigate in detail alternative methods to KBS-3. In support of this, the Opinion Group quotes the following from RD&D Programme 98: "it can be said that 'sceptical curiosity' characterizes our own investigations of the alternatives." Consequently, the Group recommends that work on KBS-3 should be toned down during the coming years and more research conducted on alternative methods.

Greenpeace summarizes its comments concerning the selection of a method by stating that it is desirable to ignore SKB's request for acceptance of the KBS-3 method by the Government and the authorities. Furthermore, Greenpeace considers that the authorities should state their opinion on the method selection before siting continues. Such a statement would have to be based on a comprehensive safety assessment and environmental impact statement for the method without any link to a particular site as well as on a completed and reported full-scale deposition and retrieval test and completed research on other alternatives. Furthermore, Greenpeace believes that SKB should not conduct siting work but should concentrate on method development and that the Government should formally approve of the method before an EIA is initiated with respect to a specific site. Furthermore, Greenpeace maintains that the intention to avoid transferring responsibility to future generations when proposing a method should be abandoned since this is incompatible with the principle of retrievability and the requirement concerning physical protection. Finally, Greenpeace states that SKB should conduct a much more detailed analysis of the possibilities of long-term interim storage of spent nuclear fuel in case the proposed method is not approved.

In the opinion of Uppsala University (UU), it is very satisfactory that SKB is now talking about deep disposal rather than final disposal, in the sense that retrieval should be possible. According to UU, this is a significant change of strategy which gives scope for the application of future advancements in technology. This would make it possible to ensure that future generations are not limited, in terms of technical, political, economic and environmental conditions, to the level of present-day knowledge. Furthermore, UU is surprised that SKB does not devote greater attention to alternative methods, especially methods which would result in reduced requirements on the deep repository [meaning partitioning and transmutation].

The Swedish Society for Nature Conservation (SNF) states, in its conclusions on the selection of a final disposal method, the importance of SKI and the Government both

rejecting SKB's wish for approval of the KBS-3 concept as a final disposal method since RD&D Programme 98 is not a basis for decision-making, but is only a report on the status of the waste issue, in compliance with the Act on Nuclear Activities. SNF also emphasises the need for assessing and balancing the partly conflicting requirements regarding difficulty of access to and retrievability of the waste. Furthermore, SNF believes that a relevant basis is lacking for comparison between a KBS-type repository and a repository at a greater depth or deep disposal under caprock and final disposal in deep boreholes.

SSI supports SKB's selection of a strategy – geological disposal – and also considers that SKB's selection of KBS-3 as a method is reasonable in the light of the material that SKB has presented. However, in SSI's opinion, SKB should develop its system analysis for different strategies and alternatives in a supplementary RD&D programme. Furthermore, SSI is against reprocessing and transmutation as a strategy. SSI justifies this position on the basis of the uncertain feasibility of implementation, for radiation protection reasons and refers to the delay in the programme which such a strategy would involve. Furthermore, SSI believes that SKB should continue to conduct research into and improve its knowledge of the deep boreholes alternative.

3.4 SKI s Evaluation

The viewpoints expressed by SKI below coincide with the viewpoints which are presented in SKI's and SSI's joint evaluation of the system analysis and method selection (SKI and SSI, 1999). Most of the text is also taken from this memorandum, although it is in a considerably reworked and abbreviated form.

System Analysis and Method Selection Model
The authorities' evaluation is based on the viewpoints presented in SKI's and SSI's joint memorandum from March 1998 (SKI and SSI, 1998). The model for system analysis and method selection which is presented in the memorandum is described in this section in a somewhat more developed form.

Definitions of certain concepts within system analysis are provided in the box below.

According to the terminology used here, the term *strategy* should be reserved for a general direction, as a matter of principle, for the management of the waste. Strategies include ultimate removal, monitored storage, reprocessing/transmutation and geological disposal. Each strategy can be realized by using *alternative methods*, which is a technically more detailed selection within a certain strategy. The KBS-3 method is there-fore a method within the geological final disposal strategy. Furthermore, each method can be implemented in a number of variations which may comprise a number of sub-variations.

As shown in Figure 3.1, it is appropriate to select a method in stages. It can be assumed that the selection of a strategy does not have to be based on more than general system descriptions and that this can primarily be done on the basis of principles other than

*"**system analysis**, analysis of complex systems as a basis for decisions, often using mathematical tools. Such systems include industrial manufacturing systems, transport systems etc as well as ecological systems. The aim of a system analysis is to determine how the resources at one's disposal should be used to achieve the specified goals in the best possible way".*
(Swedish National Encyclopaedia)

SKI and SSI propose the following definitions for the concepts occurring in this context:

System analysis: the implementation of an analysis of an overall system for the disposal of spent nuclear fuel and nuclear waste. The analysis should comprise a study of how the objectives of safety and radiation protection are fulfilled on different time scales and for different facilities. The term can also refer to a comparative study between different system alternatives. In principle, the system analysis can be said to consist of two parts: system description and system evaluation.

System description: A description of one (or several alternative) system(s) as a basis for the system evaluation.

System evaluation: The part of the system analysis where (in this case) an overall assessment of safety and radiation protection is made with respect to the various stages of the final disposal system and which covers different time periods.

System analysis reporting: One or several reports/background reports comprising the presentation of a system analysis.

safety and radiation protection. In the case in question, the three latter strategies for further analysis remain, but for different reasons:

- *Monitored storage* cannot be considered to be a permanent solution, mainly due to the fact that this would mean transferring the problem to future generations. However, continued storage in CLAB is an alternative which must be reported according to the EIS requirements ("zero alternative").
- *Reprocessing (and possibly transmutation)* is in conflict with current Swedish policy. However, since the public and the research community are now showing considerable interest in transmutation, the Government has decided that this alternative must also be reported in detail.
- *Geological final disposal* is the strategy which seems to be most suitable and which § 10 of the Act (1984:3) on Nuclear Activities also assumes will be adopted. Requirements on the final disposal of radioactive waste are also stipulated in § 13 of the Radiation Protection Act.

In the case of the above strategies, it may be necessary to discuss several alternative methods in detail. One or more of these alternatives from each strategy can then be selected for the comparative system analysis. There must be a system description for each of these alternative methods and the degree of detail in the descriptions should be comparable. The system evaluation which is then conducted must result in a justification of the selection of a main alternative.

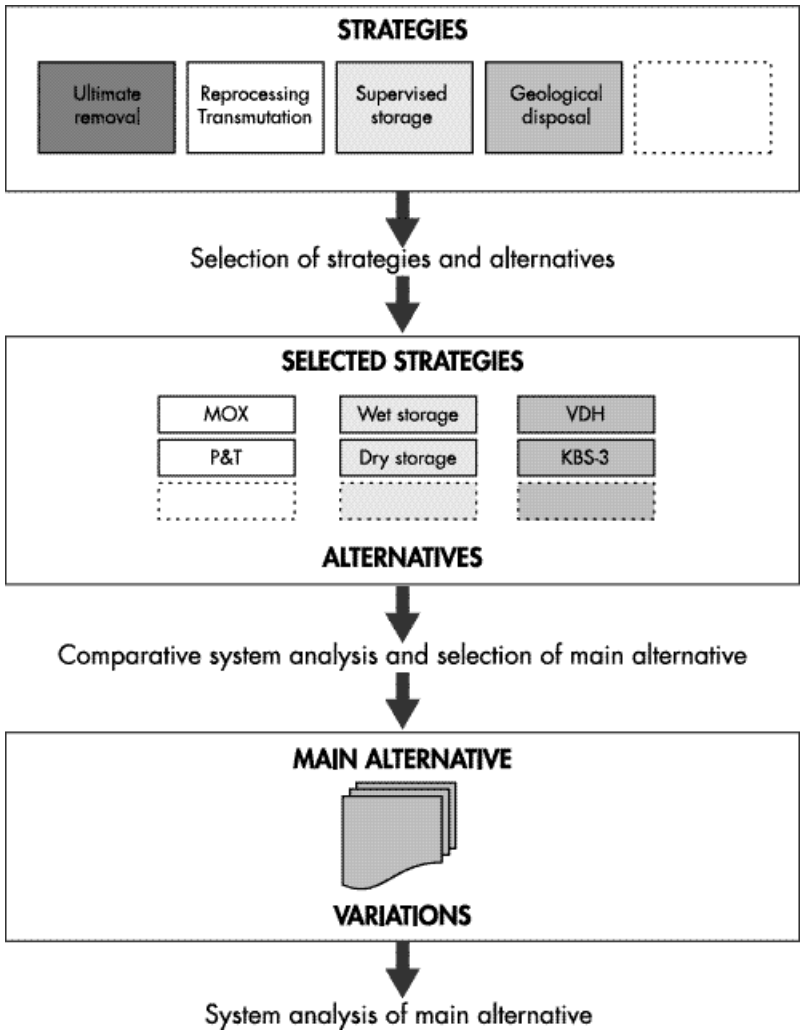

Figure 3.1
SKI and SSI's proposed model for interrelationships between system analysis and method selection.

In the first stage (box at the top: STRATEGIES) a number of strategies are defined. Although these strategies are described in general terms, the description is so complete that an initial, well-founded selection of strategy/strategies and alternatives can be made.

This stage is then followed by "Selection of Strategies and Alternatives", which, in fact, comprises two sub-stages: First the selection of a strategy/strategies and then the selection of alternatives within one, or several, strategies so that work can proceed to the next stage. Several strategies can exist at this stage due to the fact that different types of criteria are used: Technical, economic, ethical, legal and societal criteria. In the case in question, the strategy of "Ultimate Removal" is excluded on the basis of being unrealistic.

In the third stage (middle box: SELECTED STRATEGIES AND ALTERNATIVES), the selected alternatives are defined and described as completely and in such detail that a comparative system analysis is possible.

In the fourth stage ("Comparative System Analysis and Selection of Main Alternatives"), the consequences of the different alternatives are assessed so that a comparison on the basis of various criteria, including safety and radiation protection, can be made.

In the next stage (box at the bottom: MAIN ALTERNATIVE WITH VARIATIONS) the main alternative is defined and described, largely along the lines of SKB's system analysis report for KBS-3, including safety reports for the various facilities within the system.

In the final stage, the system analysis focuses on the main alternative. The analysis must show that the safety and radiation protection criteria for all of the parts of the system are fulfilled and that safety and radiation protection is reasonably distributed among the different facilities and over different time periods. This system analysis must also provide the justification for selecting or prioritising variations (e.g. horizontal or vertical tunnels in the case of the KBS-3 method) within the main alternative.

The last stage in the system analysis is a detailed system evaluation of the main alternative, with the purpose of showing that the different parts (facilities) are adapted to each other, the degree of freedom allowed and that the system is optimised with respect to safety and radiation protection as far as reasonably achievable. With respect to this stage the regulatory authorities and SKB share the same view concerning the content of the system analysis.

Comments on SKB s Presentation of Method Selection

In the introduction to Chapter 2 of RD&D Programme 98, SKB specifies certain important premises for the handling of spent nuclear fuel:

- that selecting a method is not just a technical question
- that the main focus is that "spent nuclear fuel, after a period of monitored storage, should be deposited deep down in the bedrock" and that "it means that the present-day generation should assume concrete responsibility for waste disposal"
- that it must be recognised that future technical advancements may lead to a re-evaluation of the method that is selected at the present time.

SKI and SSI agree with these principles. However, it would have been appropriate to reiterate the stipulations of the Act (1984:3) on Nuclear Activities regarding ensuring that the necessary measures are adopted to "safely handle and finally dispose of nuclear waste arising in the activities or nuclear material arising therein that is not re-used."

In SKI's and SSI's opinion, SKB's description of method selection in Chapter 2 of the RD&D Programme is not sufficiently logical and pedagogical and it, consequently, does not fulfil the purpose of clearly justifying the selection of a method for broad range of groups in society. SKI does not have many objections to make regarding the factual content of the description. However, SKI finds that the structure is difficult to grasp and that the terminology is inconsistent. One example of this is the above-mentioned confusion of concepts: "module" (in waste management) with "method" or "alternative". SKI can understand SKB's intention to start from a general overview of different stages in the waste management process, which can each be performed using different methods. However, the result is confusing and means that the same question, e.g. whether SKB means reprocessing or transmutation, must be raised unnecessarily and in an irritating manner, time and time again. Figure 2-1 in RD&D Programme 98 is probably also very difficult for a layman to understand. However, in terms of detailed and factual information, SKI has no major objection to make regarding this section, even if, from a pedagogical standpoint, it would have been better to deal with transmutation together with reprocessing and recycling.

The actual description and justification of the selection of a method (the main alternative) are provided in Section 2.3 and 2.4 of RD&D Programme 98. Also in this case, there is room for improvement from a pedagogical standpoint. However, Table 2-1, presenting the advantages and disadvantages of strategies, provides a good overview and is actually better than the text, from a pedagogical standpoint.

The Alternative Methods report (Ekendahl and Papp, 1998) contains much of the reasoning which can be demanded of a systematic description of method selection.

However, the structure of this presentation also needs to be improved. SKB has focused on describing alternative methods for geological final disposal. SKB has also dealt with the development of methods by other countries which, purely for geological reasons, cannot be applied in Sweden. Such an international overview is certainly of value (and has been requested by the Government in its decision on RD&D Programme 95), since it shows that Sweden and SKB cannot, on their own, develop methods for final disposal and that much of the development work is accomplished through international co-operation. However, in a section which aims to describe strategy and method selection, this may appear to be somewhat confusing.

History

The history of Swedish work on nuclear waste issues which SKB presents in Section 2.5 of RD&D Programme 98 provides a clear and concise view of developments. SKI and SSI consider that the presentation is a good start, but that it should be made more detailed and expanded to include developments in society which are of importance in terms of related issues. This probably means that the history should be provided in a separate report. A history which includes regulatory review statements, government decisions, technical developments and the political and economic background is necessary in order to provide an accurate view of method selection.

Comments on SKB s Selection of Strategies and Alternative Methods

SKB defines four strategies for the final disposal of spent nuclear fuel: ultimate removal, reprocessing/transmutation, monitored storage and geological disposal.

Like SKB, SKI considers that ultimate removal, e.g. launching the waste into outer space or disposal in deep sea sediments, can be excluded from further discussion as an unrealistic strategy.

SKB should have made it clear that reprocessing and transmutation are specified as a remaining alternative strategy solely for the reason that it is required in accordance with a government decision, but that it otherwise would have been disqualified on the grounds of being against Swedish policy, which is against reprocessing and long-term continued use of nuclear power. Furthermore, SKI and SSI consider that the treatment given to systems with reprocessing/transmutation is far too cursory for readers to understand what the strategy is about. Tierp Municipality also shares this view. The appendix provided in Ekendahl and Papp (1998) (also in Section 9.4 of RD&D Programme 98 and in Section 13.1 in the Background Report, Detailed Programme for Research and Development 1999-2001) gives a concise presentation of the status of research and future prospects but is not a pedagogical description of possible systems.

SKI shares SSI's view that this strategy can be excluded from SKB's programme as a realistic alternative to geological final disposal. Full-scale transmutation is associated with considerable technical and economic uncertainties which probably require decades of technical development to overcome. Such a delay would probably result in the transfer of responsibility to future generations and it would still not be certain whether the method can be realised. The facilities would be large and complex and, in practice, cannot be realised without the further use and expansion of nuclear power: a combination of a large accelerator, several reactors (including one fast-breeder) and one (or

more) facilities for reprocessing, partitioning and fuel fabrication. It should also be emphasised that some form of final disposal would still be needed since it is not possible to eliminate all long-lived radioactive waste. However, in connection with the next system analysis report, SKB must describe the implications of transmutation so that this can be understood by a broader audience than the regulatory authorities, and explain why this strategy is not suitable for Swedish conditions. (Nevertheless, like SSI and the Royal Institute of Technology, SKI believes that research in this area should be maintained at the same level as before, see Section 7.11).

Monitored storage is not considered by SKB to be a separate strategy but a stage in other strategies. In SKI and SSI's opinion, this may be technically correct, but taking into account that monitored storage has been presented as an alternative, also for an indefinite period of time, e.g. in the form of a zero alternative, this strategy should be dealt with and described separately. (See below).

To summarise, SKI and SSI have no objections to SKB's selection of strategy on factual grounds. However, SKB's presentation has a number of shortcomings which should be corrected in future, see below.

Prior to the comparative system analysis which is to be reported no later than in connection with the selection of sites for site investigation, it is reasonable that a selection should be made on the basis of those methods which have been discussed over the years. This selection must be justified on the basis of general system descriptions. The Alternative Methods report (Ekendahl and Papp, 1998) is a good start in terms of describing such a selection.

The alternatives to the KBS-3 main alternative which SKB presents include, "Disposal in Very Deep Holes" (VDH), "Disposal in Very Long Holes (VLH) and "Hot Dry Disposal" (WP-Cave). SKB does not make a definite statement on the selection of one of these alternatives for further analysis. However, in the case of VDH, SKB states that technical advancements will be monitored on a continuous basis and that a "separate study is being planned to look into the feasibility and long-term safety of a VDH repository". SKI and SSI consider that this, from all accounts, seems to be a correct choice, which is justified by the theoretical possibilities for a more complete isolation of the spent nuclear fuel than can be provided by this method. On the other hand, it is important to also investigate the disadvantages such as the considerable difficulty of retrieval and the uncertainties and technical difficulties associated with disposal at great depths.

SKI interprets the review statement from Oskarshamn Municipality and others concerning the necessity of adopting a position on the method issue as a need for reassurance that the selected method is the best available technique and that it is sufficiently well developed to be used as a basis for further work in the siting and decision-making processes. In turn, this process comprises stages and, therefore, the approval of a method should be considered to be a stage-by-stage process. At each stage – and a decision to conduct site investigations is a stage – it must be confirmed that the selected method meets the requirements which may be specified each time a decision must be made. The approval which may be necessary for a particular stage in the process may be

valid for that stage alone. Even if permission to construct facilities can be perceived as final approval in a certain sense, safety reporting will be necessary on a recurrent basis and re-evaluations required against new knowledge for as long as the system in question is in operation.

The Oskarshamn Municipality and others consider that, before moving on to the site investigation stage, the KBS-3 method must be evaluated "as the most suitable method for siting the necessary facilities and, thereby the regulatory authorities, with the current level of knowledge, should also judge the system as feasible and possible to make safe." Such an evaluation prior to a decision on site investigations cannot be made on the basis of the material presented in RD&D Programme 98. The system report must be supplemented, mainly by the safety report for the repository, SR 97. On the other hand, SKI considers that, with the current level of knowledge, that the KBS-3 method, in relation to other alternatives, is still most suitable for the main direction of further work.

Even if systematic and comprehensive justification for the selection of alternatives prior to continuing a system analysis is lacking in RD&D Programme 98, SKI considers that the line of reasoning presented by SKB, including the selection of KBS-3 as a main alternative, is correct. This opinion is not only based on the material presented in connection with RD&D Programme 98, but also on reports and discussions of method selection in connection with previous evaluations of SKB's programme.

Finally, SKI and SSI consider that SKB should make the following improvements in its presentation of method selection:

- The overall structure of the system report must be improved. In the same report and/or same chapters, arguments are presented and systems described on several different levels, e.g. strategies, methods (alternatives) and variations (e.g. within a main alternative). Consequently, repetitions make it difficult to obtain a good overview.
- More comprehensive justification is necessary in future system analyses, both with respect to the selection of strategies and with respect to the selection of alternatives.
- The selection of a strategy should be dealt with separately from the further, more detailed analysis of selected alternatives.
- The international and historical developments should be described separately in separate reports.

System Descriptions and Comparative System Analysis

The system descriptions which are necessary prior to a comparative system analysis are largely lacking except for the main alternative. The other descriptions which are given are incomplete in that they only focus on one or on a couple of the stages or facilities included in the method when the entire system for final disposal should be described. These deficiencies have already been pointed out above in the case of transmutation. This system description of each of the alternatives must be comparably comprehensive and detailed. Such a presentation of the systems would also be of considerable pedagogical value in terms of explaining and justifying the selection of a method.

SKB has chosen to deal with the zero alternative, i.e. extended interim storage of spent nuclear fuel in the event final disposal cannot be implemented or is considerably delayed, within the framework of the system report on the KBS-3 method (SKB, 1998). The methods which are discussed are wet storage, in practice, continued storage in CLAB, and dry storage. SKB discusses principles and problems in connection with extended interim storage. Furthermore, the analyses which have been conducted with respect to continued monitored operation and the consequences of abandoning the facility are summarized. In SKI and SSI's opinion, SKB's reporting of the zero alternative is adequate and well-supported by background reports.

However, SSI and SKI consider that SKB should compile a separate report on the zero alternative, which combines relevant parts of the current system report with summaries of the background reports: Monitored Long-term Storage in CLAB (Söderman, 1998), Consequences of Abandoning CLAB (Birgersson et al., 1998) and Comparison between Wet and Dry Storage of Spent Nuclear Fuel (Söderman, 1998b). Such a combined report is not a prerequisite for regulatory evaluation but should be useful to a wider audience since interim storage is often discussed and sometimes presented as an alternative to final disposal.

The comparative system analysis which is to justify the selection of the main alternative is more or less missing from RD&D Programme 98, even though reasoning along these lines is presented by SKB in the Alternative Methods report (Ekendahl and Papp, 1998).

Thus, in terms of alternative strategies and methods other than the main alternative, the reporting of consequences is considerably limited. To facilitate an evaluation of the different alternatives, SKI, like SSI, considers that a qualitative assessment and comparison of consequences, in the short and long term, would be valuable for the different alternatives. SKB states that it will continue to evaluate alternatives such as reprocessing and transmutation as well as disposal in deep boreholes. It is therefore, particularly important that the reporting of consequences should be expanded for these methods.

System Description and System Analysis of the Main Alternative

The system description and system analysis of the main alternative, i.e. the KBS-3 method, is described in detail in SKB's system analysis report (SKB, 1998). SKI, like SSI, considers that the system description in this report along with the separate safety reports for the parts of the final disposal system are adequate in scope, even if the degree of detail is expected to increase at each new stage of programme implementation.

A relatively large part of the report is devoted to the description of freedom of choice with respect to questions concerning siting and time-schedules as well as the technical design of sub-components. The regulatory authorities consider it to be important that SKB should pursue this line of reasoning and that it should be updated as progress is made. Before the next revision, SKB should take the following into account:

- A system analysis must start with a definition of the system which is to be analysed. However, in SKB (1998), Ekendahl and Papp (1998) and RD&D Programme 98, it is not quite clear if, for example, Medium-Long Holes are included in the KBS-3

method or whether this should be considered to be an alternative disposal method. This question should be clarified by SKB. The question is related to the scope of freedom of choice, i.e. the breadth of alternatives with respect to technical design, that SKB considers necessary in connection with different licence applications at different times.

- The advantages, disadvantages and consequences of the different variations are dealt with in general terms in the Alternative Methods report. To a certain extent, this also applies to variations on the system analysis report. Therefore, the authorities would like to see an in-depth presentation and a consequence analysis which shows the impact of different selected variations of the sub-systems on each other.

In the system analysis report, SKB discusses the retrieval of deposited canisters at different times during the disposal process. Several retrieval methods are also reported and a general description of the layout of an interim storage facility for retrieved canisters is given. Consequences to the canisters in the event of retrieval are also described. In its further development work, SKB will develop the technique for retrieving deposited canisters. In the opinion of the authorities, this is a necessary measure.

It is also important for SKB to report the consequences of different facilities and activities. In the case of the KBS-3 method, SKB has reported estimated consequences (radiation doses) and possible mishaps during the different stages of final disposal. An important objective in terms of radiation protection, which is stipulated in SSI FS 1998:1, is optimised radiation protection for the entire system (i.e. CLAB, encapsulation, transportation and repository). SKB does not present a lengthy discussion on this topic, and only states that “a good balance can be achieved between the different stages. ” SSI and SKI understand that it is difficult to conduct an in-depth discussion of optimisation at present, e.g. SR 97 is not yet available and the experience from the Canister Laboratory and from full-scale deposition tests at Äspö should also be of value. However, SSI and SKI would like to emphasise the importance of SKB updating the system report in this respect as experience is obtained.

The safety reports for different facilities which are included in the material for the system report are necessary both in terms of the evaluation of the main alternative and as a basis for licence applications. These reports are also part of the material which will be used to prepare the EIS that is to be included in the licence applications. The evaluation of the safety reports which has now been made has focused on the comprehensiveness of the material presented. The general quality of the material is of secondary importance. At this stage, it is not meaningful to evaluate safety and radiation protection issues. This can only be done once the material has been supplemented so that the next report can be made and once the essential post-closure safety report for SFL 2 is available and has been subjected to international peer review.

SKI’s and SSI’s impression of work so far conducted by SKB on the safety reports is that it is of a generally high and consistent quality.

3.5 SKI s and SSI s Joint Evaluation

The overall evaluation from SKI's and SSI's joint memorandum on SKB's system report (SKI and SSI, 1999) is largely presented below.

SKI and SSI maintain, as stated in the memorandum of March 1998, that method selection and system analysis should be seen as two interrelated activities and that the description of method selection should therefore be part of the system report. This opinion has been the basis of the joint evaluation carried out by the authorities.

In SKI's and SSI's view, SKB has made a good start on the work on a complete system analysis. In early 1998, it became clear that the system analysis report would not be complete in connection with RD&D Programme 98.

SKB has clearly described method selection in the main report of RD&D Programme 98 and in the Alternative Methods report (Ekendahl and Papp, 1998). SKI and SSI have no essential objections to make to SKB's selected strategy. On the other hand the account of the selection of strategies must be justified and improved from a logical and pedagogical standpoint.

On the basis of the material presented by SKB, it is difficult to determine how the alternative methods, prior to a system analysis, have been selected. It would be desirable to have a more systematic comparison, based on a somewhat more detailed assessment of the advantages and disadvantages of the alternatives presented in Ekendahl and Papp (1998).

Apart from the main alternative (KBS-3), the system descriptions for the alternatives which must be compared in the system analysis are inadequate. Furthermore, the actual comparative analysis, based on the assessment of consequences in terms of safety and radiation protection is lacking. However, as in all previous presentations of SKB's programme, SKI and SSI consider that the selection of geological disposal as a main strategy is correct. Furthermore, the authorities also consider that, in view of the material available, SKB's selected main alternative, the KBS-3 method, is a reasonable choice. However, the authorities will have the important task of evaluating SKB's forthcoming system analysis and of deciding whether or not this opinion can be confirmed.

The reporting of the system analysis of the main alternative is largely complete and well-structured. However, SR 97, the essential safety report for SFL 2 and the separate safety report for SFL 3-5, are still not available. A detailed discussion of how balance, in terms of safety and radiation protection, is achieved in the system is also necessary. The structure and content of the safety reports presented in connection with RD&D Programme 98 are generally adequate. However, it is not possible – and it is not the intention – at this stage to state an opinion on the extent to which these reports show how existing safety and radiation protection criteria can be fulfilled.

In their overall evaluation, SKI and SSI also state their opinion on SKB's continued work. This is presented at the end of Section 3.6 below.

3.6 SKI s Overall Evaluation

The selection of a method comprises several stages. In the first stage, a strategy is selected, i.e. the main principle for the disposal of spent nuclear fuel and long-lived low and intermediate level waste. With respect to this stage, SKI, like SSI, is of the opinion that SKB's choice of geological disposal is correct. In SKI's opinion, the selection of the KBS-3 main alternative appears to be the most suitable, compared to other alternatives. This conclusion is primarily based on the application of basic ethical principles concerning what is known about the technical feasibility of the different alternatives as well as about the possibility for the retrieval of deposited spent nuclear fuel.

SKI shares SSI's view that the strategy of transmutation can be excluded from SKB's programme as a realistic alternative to final disposal. Transmutation as a method is associated with significant technical and economic uncertainties which probably require decades of technical development to overcome. This method would also involve transferring responsibility to future generations. The facilities would also probably be so large and complex that Sweden would not be able to develop, construct and operate them on its own: a large accelerator would be required, several reactors and a reprocessing plant. It should be emphasised that some form of final disposal will still be necessary, since all long-lived radioactivity cannot be eliminated. However, in connection with the next system analysis report, SKB must improve its description of the implications of transmutation, so that it can be understood by a broader audience than the regulatory authorities, and justify why this strategy is not suitable for Swedish conditions.

SKB's system analysis is not yet complete. However, the material presented in RD&D Programme 98 can be viewed as a good start. Even if SKB's presentation of the system analysis and method selection is incomplete within the framework of RD&D Programme 98, this does not mean that the justification for the selected method has been lacking in the material presented by SKB ever since SKB started reporting on its programme in 1984. It is important that all of this material should now be compiled and reported within the same context, in a way that makes it easily accessible to a broader audience than the competent authorities. It is also important that SKB should present its method selection on the basis of system analyses.

Above all, RD&D Programme 98 lacks complete system descriptions and system analyses for the other alternatives that it may be necessary to pursue in the system analysis, for various reasons: partitioning/transmutation, monitored storage, and a geological alternative to KBS-3, e.g. deep boreholes. Safety reports for the SFL 2 (SR 97) and SFL 3-5 repositories are also lacking.

In SKI's opinion, the demands made by the reviewing bodies with respect to method approval should be interpreted as a need for reassurance that the selected method is the best available technique and that it is sufficiently well developed to be used as a basis for further work in the decision-making process. This should also mean that the approval of a method is a stage-by-stage process where the fact that no better alternative exists must be confirmed at each stage and where the selected method fulfils the requirements which may be made.

The next stage in the process is when SKB wishes to initiate the site investigation stage. SKB must supplement its reporting no later than in connection with the selection of sites for site investigation and the authorities must evaluate the new material that SKB has presented. The approval which may be necessary for a particular stage in the process may be valid for that stage alone. In a certain sense, “ultimate approval” can only be given after the evaluation of an application for a licence to conduct detailed characterisations (see Chapter 2). However, periodic judgements of the compliance of the repository and system will be required as long as they are in operation, including prior to the planned full-scale operation and prior to the closure of the repository.

SKI, like SSI, is of the opinion that it is important that SKB, during the coming period and in dialogue with the authorities, should examine and define its view of the safety analysis. SKB should clarify how it intends to report its justification of the method selection and the selection of variations on the main alternative. SKB should also state how detailed it intends its account of the consequences of choices to be and how the scope for freedom of choice which is provided within different subsystems will affect these systems and the system as a whole as well as how this will change with time.

A detailed and broad history of the method selection and its evaluation by the authorities should be published in a separate report which provides a pedagogical explanation of the process for the benefit of a broader audience. International developments should be presented in a similar way, in a separate report.

In connection with the selection of sites for site investigation, SKB should:

- Present a complete system analysis, including an overall assessment of the radiation protection and safety aspects of the various strategies for the management of spent nuclear fuel (reprocessing/transmutation, monitored storage, geological disposal) as well as of selected alternative methods within these strategies. The report should clearly specify the basis used for the selection of the different alternatives.

- Present a complete system analysis of the main alternative.

4 SITING

In this chapter, SKI presents its opinion on SKB's work on siting, as described in Chapter 6 of RD&D Programme 98.

4.1 Introduction

Issues concerning the siting of the facilities required for the final disposal of spent nuclear fuel and nuclear waste have received considerable attention from both SKB and the reviewing bodies. At present, the major issues concern the body of material which will provide a basis for SKB to select two sites for site investigation as well as how this site selection process should be carried out.

The municipalities involved in feasibility studies, SKB and others have stated that site investigation is such a major step that the authorities and the Government should clearly state their opinion on the method and site selection. SKI shares this view, and consequently, SKI's evaluation in this chapter largely concerns the body of material which should be available before the start of site investigations. The points of view of both the reviewing bodies and SKI on a number of issues related to the EIA are presented in Section 4.2.

Considerable attention has also been devoted to various aspects of siting in previous research programmes, reviews by external bodies and government decisions. For example, in its decision on RD&D Programme 95, the Government required that SKB should, no later than in connection with RD&D Programme 98, account in greater detail for the factors which should determine the selection of a suitable site for a repository. Such reports, e.g. the comparative study of siting in north or the south of Sweden and of siting along the coast of Sweden or in the interior, have been submitted and are evaluated in greater detail below. The Government has also particularly emphasised the importance of the municipalities concerned having access to SKB's entire body of material on this issue before they make a decision on whether or not to allow SKB to conduct site investigations within their municipalities. SSI's views on the body of material which should be available in connection with the selection of sites for site investigations are presented in Section 4.4.2.

The Government has also stated its opinion on EIA and the site selection process. The Government's decision of May 18, 1995 on RD&D Programme Supplement 92, was an important starting point for the consultation processes relating to the content of Environmental Impact Statements (EIS), conducted on a regional level. The decision emphasises the task of the county administrative boards in co-ordinating liaison between municipalities, authorities etc. in connection with SKB's feasibility studies, site investigations and detailed characterisations. In SKI's opinion, the importance of these various "Environmental Impact Assessments" (EIAs) must be viewed in the light of the Government's unambiguous statement of opinion.

4.2 Environmental Impact Statement (EIS) and Consultation

SKB s Report
SKB's report on EIS-related issues in RD&D Programme 98 can be divided quite simply into two sections – one section being the contents of EIS and the other being the description of the ongoing consultations relating to EIS. The description of the ongoing consultations, which are presently taking place on national, regional and local levels, is a clear site characterisation without any thorough analysis. An important assertion SKB makes concerning local consultation, i.e. the consultations which take place in feasibility study municipalities, is that they have been and henceforth ought to be drawn up in such a way that they meet both the needs and the requirements of the municipalities.

As regards the EIS, SKB has presented, in an attachment to RD&D Programme 98, a proposal for a "table of contents of the environmental impact statement for siting of deep repository". SKB emphasises that the purpose of the proposal is not to establish a structure for the EIA but to initiate a discussion with the parties concerned. By this, SKB is implying that the review by a wide range of external bodies which RD&D Programme 98 is undergoing is an appropriate opportunity to gather opinions about the proposal at an early stage.

Comments by the Reviewing Bodies
Many reviewing bodies discuss issues relating to EIA (consultation) and EIS (statement) in their statements. In the majority of statements, EIA issues are closely related to the selection of a method for the disposal of the spent nuclear fuel and/or to the siting process which will enable the facilities needed for final disposal to be sited, built and operated.

Some bodies (municipalities in which feasibility studies are to be carried out, county administrative boards, Greenpeace, etc.) discuss in general terms the importance of well-defined procedures for the EIA, e.g. that there should be a definite starting date and that the parties participating in the process need to be defined. There has also been particular criticism that SKB has been interpreting the EIA far too generously and that SKB may run the risk of undermining the EIA's importance. For instance, Oskarshamn Municipality states that SKB's municipality information can not be regarded as constituting part of a systematic EIA consultation. Greenpeace is also critical primarily of the "national EIA consultation", which it does not consider to be an EIA.

SSI (the Swedish Radiation Protection Institute) states that the "National EIA Forum", which operated for some time under the chairmanship of the National Co-ordinator for Nuclear Waste Disposal, must not be seen as a formal consultation according to the intentions of the Environmental Code, which may be the impression given from the descriptions in RD&D Programme 98.

SSI also discusses the EIA and suggests that SKB must report its plans for how different consultations will take place at different stages of the siting process, before the site investigations have taken place. SSI means, therefore, that SKB must proceed from the requirements of the Environmental Code.

SSI is of the opinion that the Government should clarify the methods which could be regarded as providing environmental organisations with the opportunity to assimilate and to evaluate bases for decision-making. In this context, SSI indicates that feasibility study municipalities will receive compensation from the Nuclear Waste Fund for providing information and competence development while, usually, neither municipalities nor organisations receive contributions in connection with the siting of industrial facilities. Several environmental organisations also mention the need for resources in order to be active in connection with SKB's site selection process.

Several organisations (Greenpeace, Opinion Group against Nuclear Waste in Malå, Waste Network) recommend that the method selection and site selection should be separated, i.e. first a method should be developed, tested and approved, and after that the site selection can begin. In this case, the decision about the method will be made on the basis of, among other things, a non-site specific EIA. To this group of statements can also be added those organisations (the Swedish Board of Housing, Building and Planning, the Swedish National Environmental Protection Agency) which propose that a strategic environmental assessment should provide the basis for the selection method.

SSI also mentions strategic environmental assessments and means, in summary, that it is hesitant to develop such a process. SSI claims that the strategic environmental assessments mentioned in the Espoo Convention (SÖ 1992:13) are not applicable to civil law organisations such as SKB. SSI emphasises the fact that the provisions of the Environmental Code must form the basis for the EIA. SKB has established collaboration between municipalities and county administrative boards in connection with feasibility studies which provide the opportunity for regional and local bodies to gain an insight into SKB's operations. "SSI sees that SKB's work is carried out in such ways as to give county administrative boards and municipalities concerned a satisfactory starting point for making a subsequent evaluation as expected in the Environmental Code".

SSI further points out that there is considerable doubt concerning the formal status of the consultations which are currently being carried out. According to SSI, "the way in which a consultation should be carried out should be reported in detail as soon as possible, and it is important that this issue is further elucidated before starting the site selection for site investigations". Furthermore, SSI states that " SKB – in agreement with the proponent's responsibility to ensure that a suitable consultation has been performed – provides an early account of the systematics, structure and extent of the planned consultation in the forms (information, early consultation, extended consultation) and with all the interests which have been included in the Environmental Code. This can take place adequately in connection with a comprehensive RD&D Programme, which will be submitted broadly, to authorities, feasibility study municipalities concerned, and other organisations. SSI understands that considerable importance is given to the EIA by many interest groups in society and it therefore believes that a clear and transparent structure in the EIA is of the utmost importance, whereby the parties can foresee the various stages and can have a real opportunity for consultation. A lack of faith in the EIA will have an effect on the faith in the entire final disposal programme".

A few reviewing bodies (Waste Network, Opinion Group against Nuclear Waste in Malå and the Green Party, Tierp) recommend that an independent body be given responsibility for the development of the EIA.

Some statements also suggest that the decision concerning which organisation should manage the site selection process ought to be made after the decision concerning selection method has been made, or that SKB should not have this task.

Many reviewing bodies (e.g. Oskarshamn Municipality, the County Administrative Board, Västerbotten, the Swedish Anti-Nuclear Movement and KTH) stress that the EIA should consider the entire final disposal system. i.e. all the activities and systems which are required.

The importance of considering various alternatives in the EIA, concerning both different methods and siting, is also taken up by several reviewing bodies.

The reviewing bodies (SSI, Oskarshamn Municipality, the County Administrative Board in Kalmar, the Swedish Environmental Protection Agency) which discuss SKB's proposed table of contents for an EIS are, on the whole, cautiously optimistic. They believe that the proposal fulfils the criteria of the Environmental Code, for instance, but at the same time stress that the content and form of the EIS will be determined through consultation. Greenpeace, however, considers the table of contents irrelevant, as it does not satisfy its request for separate method and site selections.

SKI s Evaluation

Issues which concern the EIA have given rise to many viewpoints from various reviewing bodies. The EIA is closely linked to the decision-making process discussed in Chapter 2. SKI's evaluations in this section should therefore be considered together with the evaluations of Chapter 2.

A new condition compared with previous RD&D programmes is that the Environmental Code came into force on January 1, 1999 and contains new rules for the EIA. This means that SKB's RD&D Programme 98 does not fully reflect the criteria of the Environmental Code. The comments by the reviewing bodies, to a certain extent, also concern the importance of the Environmental Code for the EIA and the decision-making process. SKI also has several questions regarding the contents and application of the Environmental Code. These concern the EIA, but also how co-ordination will take place between future licensing actions under the Code and under the Act on Nuclear Activities, respectively.

SKI concludes, as do several reviewing bodies, that it is important for the Government, in its decision on RD&D Programme 98, to state its opinion on the application of the Environmental Code in connection with SKB's ongoing site selection process and prior to future licensing actions.

Some reviewing bodies question SKB's description of the local, regional and national EIA consultations. SKI will therefore explain its viewpoints on these different consultations.

SKI, like the reviewing bodies, considers it necessary for the various actors to be given a clear and distinct allocation of roles and responsibilities. According to both the Act on Nuclear Activities and the Environmental Code, it is evident that the responsibility of preparing an EIS and initiating and carrying out various consultations rests with SKB. An issue which is mentioned in the statement and which is regularly discussed at various meetings concerns when the EIA starts. With previous legislation (Act on the Management of Natural Resources, etc.) this issue was essentially undefined. Previous legislation only required an EIS to be prepared and to constitute one of the bases for decision-making for licensing. The initiative was therefore taken for various consultations in different feasibility study municipalities and county administrative boards, with the aim of fulfilling the intentions behind the EIA.

SKI considers that the consultations which are being carried out in connection with feasibility studies are generally going well and are being performed in accordance with the intentions of the EIA. However, in SKB's opinion the Environmental Code will need a more stringent application of the EIA concept in the future so as to avoid any uncertainty. Oskarshamn's opinion that SKB's information activities in feasibility study municipalities cannot be regarded as a part of a systematic EIA illustrates this risk of uncertainty. SKI agrees with this criticism and says that SKB should make a better distinction between EIA and information activities in its reporting.

The National Co-ordinator for Nuclear Waste Disposal has been running a "National EIA Forum on nuclear waste disposal" since 1997. According to SKI's opinion, which corresponds with that of SSI, this forum must be considered against the background of the co-ordinator's task of promoting the co-ordination of the information and investigation work which the feasibility study municipalities deem necessary and of proposing forums for information exchange as well as being prepared to co-ordinate liaison between municipalities and county administrative boards. This forum has thus not been established for the purpose of fulfilling the formal criteria of the legislation for the EIA. However, it must be emphasised that the participants in the National EIA Forum endeavoured to work in the "EIA spirit" and that EIA issues have had a major influence on the discussions which were conducted.

There are certain guidelines for the EIA now that the Environmental Code has entered into force. According to the Environmental Code, SKB must conduct consultations at an early stage with the county administrative board and individuals who assumed to be particularly affected by the issue (Chapter 6, § 4). The county administrative board must then reach a decision regarding extended consultations (Chapter 6 § 5). Such a decision must be reached, because it will always be assumed that facilities for the handling, treatment, storage or final disposal of spent nuclear fuel or nuclear waste will result in considerable impact on the environment (Ordinance (1998:905) on Environmental Impact Statements). Prior to this early consultation, SKB is to submit information concerning the siting, scope and design of the activity and the anticipated environmental impact. This information will be included in the reports which will provide the basis for the justification of the selection of sites for site investigations. The feasibility study municipalities will decide on potential site investigation based on these reports and the authorities' evaluations.

SKI is of the opinion that SKB's early consultation with county administrative boards could be conducted in connection with municipalities concerned deciding whether or not to participate in site investigations. Since early consultation is to be followed by a decision by the county administrative board, this will ensure that there is a clear and formal start to the extended consultation and EIA stipulated in the Environmental Code. An overview of SKI's proposal for a possible decision-making process prior to site investigations is provided in Figure 4.1. In SKI's opinion, it is advantageous that such a decision should be made in conjunction with the vital stage of site investigation within SKI's programme. A process for SKB's planned encapsulation plant can be conducted in a similar manner.

SSI has proposed that SKB should be instructed to report their planning of how different consultations will take place in different phases of the siting, together with other material which will form the basis of SKB's selection of sites for site investigations. SKI supports this proposal and suggests that the Government stipulate terms for SKB's continued work with this purport.

As mentioned above, several reviewing bodies have proposed the introduction of a process for strategic environmental assessment. These bodies share the view that the selection of a method for final disposal can be based on such an assessment. SKI shares the view that the issue of nuclear waste disposal covers many issues of a strategic nature, and primarily that of method selection. Method selection is discussed thoroughly in Chapter 3 above and will not be repeated here. Strategic issues are frequently discussed today in the EIAs in connection with SKB's feasibility studies. Such issues have also been the focus of attention in previous RD&D programmes, programme reviews and particularly in government decisions. For instance, SKI considers that the Government's demand for a system analysis of the entire final disposal system,

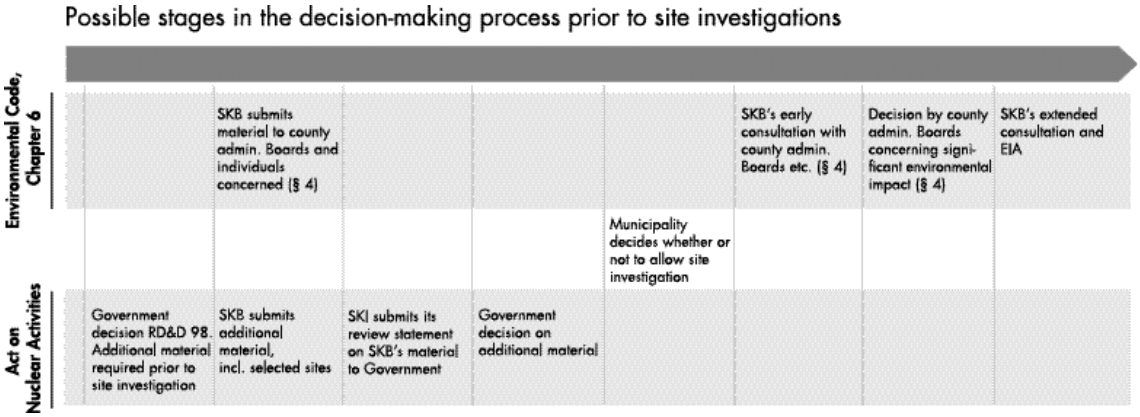

Figure 4.1
SKI's proposal for a decision-making process prior to commencing site investigations. The figure shows how various activities and decisions could be co-ordinated to comply with the requirements of the Act on Nuclear Activities and the Environmental Code as well as satisfy the desire for a transparent decision-making process. SKI is of the opinion that SKB's early consultation with county administrative boards could be conducted in connection with municipalities concerned deciding whether or not to participate in site investigations. This will provide a clear, formal starting point in the EIA for the repository since, according to the Environmental Code, this early consultation must be followed by the county administrative board's decision concerning extended consultation and environmental impact assessment.

including a report on alternative solutions to the KBS-3 method, must be seen to constitute an important basis on which to make a decision if SKB's programme has the correct strategic aim (see Chapter 3 above). SKI assumes and recommends that SKB, in future EIAs, will ensure that both method selection and system analysis also constitute part of the background material for the EIS.

A couple of reviewing bodies refer to the work which has been in progress for several years within the European Commission on preparing a directive on strategic environmental assessment. A revised proposal for the directive was presented by the Commission in March 1999 (European Commission, 1999). The proposal will subsequently be handled in the usual way. It will require a long process before such a directive can be approved and an even longer time before it can be introduced into Swedish legislation. SKI considers that there are many issues concerning the directive and its application. In SKI's opinion, it is not reasonable, at present, to develop a Swedish process for the nuclear waste disposal issue on the basis of the directive proposal. However, SKI considers that the proposal may be a source of assistance and inspiration to SKB, authorities, municipalities and other parties involved in the work of developing the Environmental Impact Assessment process (EIA).

Closely related to the issue of strategic environmental assessment are the proposals for the establishment of a separate body, the purpose of which is to monitor and/or be responsible for the EIA. SKI does not support this proposal. In SKI's view, the most important factor is that the various actors in the nuclear waste disposal issue should have transparent and unambiguous roles and responsibilities. At present, these roles are sufficiently unambiguous in both the Act on Nuclear Activities and the Environmental Code. It is clear that SKB is responsible for preparing the EIS and any other basis for decision-making before submitting a licence application. The Environmental Code has also made it clear that SKB is responsible for initiating, implementing and documenting the necessary consultations with authorities, the municipalities, the general public and the organisations which may be regarded as being affected.

In SKI's opinion, the authorities which are responsible for supervision and review, under various acts and ordinances, of the planned activity are also responsible for monitoring the EIA to ensure that it is adequate. SKI considers that the feasibility study municipalities' increasing demands on the safety and radiation protection authorities support the fact that it is precisely the inspection and supervision authorities' assistance and support for the municipalities, etc. that are required. The Swedish Association of Municipalities with Nuclear Reactors (KSO) agrees with this, stating that the authorities should be responsible for the decision-making process, the EIA etc. In conclusion, SKI considers that there is no need for an EIA commission for nuclear waste disposal, and that, on the contrary, such a body would give rise to uncertainties concerning the legislated and established allocation of responsibilities.

An active participation in the EIA presupposes that parties concerned have sufficient resources. When SKB started conducting feasibility studies, the municipalities' need for resources to provide information to the general public came to the fore. This resulted in changes to the Act on the Financing of Future Expenses for Spent Nuclear Fuel, etc. (Financing Act) and the Financing Ordinance so that, since 1995, SKI may grant com-

pensation to municipalities in which feasibility studies are being, or have been, performed, for information expenses of up to SEK 2 million per calendar year. Compensation may also be granted until it is clear that a municipality is not a candidate for further investigations. In SKI's opinion, ample provision has been made for compensation to the municipalities involved in feasibility studies, even if the level of compensation may have to be adjusted in the future.

Environmental organisations have both previously and in connection with the review of RD&D Programme 98 requested funds for their own activities in connection with SKB's site selection process. In 1998, SKI objected to such a request from the Waste Network association, because the Financing Act and the Financing Ordinance only award compensation to municipalities. The Environmental Code, however, attaches considerably greater importance to environmental organisations than the previous legislation. For instance, the bill states that "among those organisations which may be concerned are environmental and nature conservation organisations". In its review statement, SSI proposes that the Government address the problem of how resources can be placed at the disposal of environmental organisations. In the light of the recent legislative changes, SKI agrees with SSI's proposal that the Government should investigate the possibility of providing support to environmental organisations which are particularly involved in the nuclear waste disposal issue.

SKB's proposed table of contents for an EIS comprises the compulsory issues stipulated in the Environmental Code which have been adequately adapted to the final disposal issue. SKI, along with several reviewing bodies, is of the opinion that SKB's proposal for a table of contents may constitute the basis for further discussions with the parties concerned.

4.3 General Siting Studies and Feasibility Studies

4.3.1 Introduction

In connection with the review of the supplement to SKB's RD&D Programme 92, many reviewing bodies requested a report compiling studies which had been undertaken on a national scale. In its decision of 18th May 1995, the Government requested such a report in connection with future RD&D programmes and in 1995 SKB presented General Siting Study 95 (SKB, 1995a). In its investigation of RD&D Programme 95, SKI explained that the General Siting Study had to be supplemented with an account of advantages and disadvantages of siting in northern or southern Sweden as well as in coastal or the interior of Sweden. In its decision of December 19, 1996, the Government stipulated that SKB must "complete General Siting Study 95 more thoroughly than the way in which it reported the factors which should govern the selection of a site suitable for a repository." In order to meet the Government's requirements and other viewpoints, SKB has now recorded in a separate report the general differences in criteria for the siting of a deep repository in different parts of Sweden (North-South/Coast-Interior; Leijon, 1998). In addition, SKB has commenced county-specific general siting studies for all counties except for Gotland.

Until now, SKB has completed two feasibility studies (Storuman and Malå; 1995b and 1996 respectively). Furthermore, there are preliminary final reports for Nyköping and Östhammar (SKB, 1997a and 1997b respectively), there is ongoing work in Oskarshamn and, recently, also in Tierp. In the evaluation of RD&D Programme 95, SKI agreed that there are many advantages to working on a municipal level but at the same time stressed that there are geoscientific factors which require studies in larger regions. SKB has undertaken such studies with the county-specific general siting studies which have been presented in stages.

In Table 6-2 of RD&D Programme 98, SKB presents an overview of the siting material. Compared with previous RD&D programmes, this one includes the north-south/coast-interior report, county-specific general siting studies and further feasibility studies. The discussion below refers to this material. The other siting material which includes site selection factors and site investigation programmes, is discussed in Section 4.4.

4.3.2 North-South/Coast-Interior

SKB s Report
SKB's report of general differences in the criteria for siting repositories in different areas of Sweden - the North-South/Coast-Interior report – identifies several important factors which play a part in evaluating the safety and technology of the repository, and for the land and environment. According to SKB, an important element of the investigation has been the evaluation of the importance of general variations on the above-mentioned factors for the deep repository, in relation to the variations which, for many factors, appear on a local level. The main conclusion of the investigation is that, from general comparisons and considerations on a general scale, it is not possible to prioritise either the north or the south, the coastal or interior region, with respect to siting. This is a result of the fact that many important siting factors present major local variations. SKB's opinion is that suitability should instead be based on studies of actual areas.

Comments by the Reviewing Bodies
"The Geological Survey of Sweden (SGU) agrees with SKB's opinion that, based on general comparisons and considerations on a general scale, it is not possible at present to recommend or exclude a coastal siting, an interior siting, a northern siting or a southern siting". However, SGU states that "areas with a higher frequency of earthquakes and rock movements since the last ice-age are concentrated in the four northern counties. This indicates certain disadvantages for a northern siting". SGU reiterates that which the authority has already stated in its review statement on RD&D Programme 95 that, from a hydrogeological point of view, there are several factors (e.g. a low hydraulic gradient, weakest future glaciation) which indicate that a repository should be sited by the coast in the southern part of Sweden.

SKI s Evaluation
SKB has chosen to base its report on a general, national scale. Selected levels (scales) of detail of input data and reports give rise to considerable uncertainty and difficulty in the interpretation of the results. SKI can thus state that with its chosen approach, involving qualitative reasoning, SKB has difficulties in drawing any lucid conclusions from the

advantages and disadvantages of different siting alternatives. One problem in this context is, according to SKI, that SKB did not make any clear attempt to establish measurable targets for which the report should attempt to provide an answer and guidance in connection with future siting.

SKI considers the factors handled by SKB to be fully relevant for discussion in this context. SKI, however, is lacking a more thorough analysis which would clarify the importance of the factors from a siting point of view. SKB is merely conducting a qualitative discussion of any positive or negative influences of the factors. SKI is lacking basic quantitative analyses on an appropriate scale which support the conclusions SKB draws in its report, regarding, for instance, the problems of recharge and discharge, climatic impact, etc. For example, a model based on parameters such as regional brittle tectonics, water conductivity in regional zones and regional topographical gradient will give an idea as to whether there is a large turnover of groundwater, as well as where the discharge areas are located and how fast transport takes place. A model such as this can also show that old groundwater need not be the same as stagnant groundwater.

SKI considers for example, that regional modelling of the groundwater flow with respect to the importance of recharge and discharge areas, combined with SKB's approach in the North-South/Coast-Interior study, should result in less ambiguous conclusions and, thereby, provide a more useful basis for decision-making prior to the selection of sites for site investigation. SKI would like to see a proper impact analysis and an account of how SKB intends to handle identified factors in its ongoing activities.

SKB itself does not believe that the report contributes to the screening material for the siting process but believes that it will hopefully contribute to the background material. According to SKB, the screening material for the siting process consists of studies carried out in regional general siting studies and feasibility studies. SKB also claims that the investigation has not aimed at identifying the areas which may be appropriate for further siting studies. SKI finds it difficult to understand that SKB could put forward this latter factor as a target for the investigation right from the start.

SKI thus proposes that SKB take a step further at the detailed level and use the material from the county-specific general siting studies which have been, and are currently being, carried out. In a coherent and consistent way, these studies cover large areas of Sweden which have the potential for the possible siting of a repository. According to SKI, these studies also constitute selection material, together with feasibility studies, in the siting process and also indicate areas of interest for further studies.

SKI therefore regards SKB's report as a good starting point for identifying and discussing important factors. However, SKB cannot explain the importance of the factors from a siting point of view, and to that end the background material and SKB's report are too general. Furthermore, the material does not allow for any comparisons of regions or sites.

SKI considers that, by utilising and combining the knowledge acquired in the county-specific general siting studies with the north-south/coast-interior analysis, there is

greater opportunity for SKB to obtain guidance and support in its statement so that sites selected for future site investigations, based on feasibility studies, are adequate. It is important for SKB to take into account the factors discussed in this report together with other factors which influence site selection. In connection with the identification of areas considered to be of interest for further siting studies (or feasibility studies), these regional-scale factors should, according to SKI, also be taken into account and considered in the analysis.

According to SKI, the refined analysis outlined above enables requested integrated analyses of siting factors to be conducted in the correct order and at the right time.

4.3.3 County-specific General Siting Studies

SKB s Report
In connection with RD&D Programme 95, SKB presented a general siting study of siting criteria for a deep repository on a national scale. SKI considered that the study needed to be supplemented by additional material in several areas before it could be of use in SKB's ongoing work with site selection factors and in the siting process.

In the government decision of December 19, 1996, the Government also considered that SKB should expand General Siting Study 95 by reporting more thoroughly the factors which should guide the selection of a site suitable for a repository for spent nuclear fuel and long-lived radioactive waste.

SKB has taken SKI's viewpoints and the government decision into consideration by supplementing its material with county-specific general siting studies, in connection with RD&D Programme 98. The aim of county-specific studies is, according to SKB, to produce material for setting investigated areas (completed feasibility studies) in their regional context, which SKI lacked in its evaluation of RD&D Programme 95.

There were county-specific general siting studies of ten coastal counties in April 1999. SKB intends to use county-specific general siting studies in order to find municipalities in which further feasibility studies can be performed.

Comments by the Reviewing Bodies
The Geological Survey of Sweden, SGU, which is conducting county-specific general siting studies in 20 counties on behalf of SKB, indicates that there is a good potential for finding areas appropriate for further siting studies in a total of 10 counties. According to SGU, the four counties in northern Sweden pose particular problems, with a concentration of post-glacial rock movements.

Geologist N.A. Mörner believes that evaluations/consideration of post-glacial geotectonics should also be included in the county-specific general siting studies, and presents Strängnäs Municipality as an example.

SKI s Evaluation

SKI considers SKB's intention of conducting county-specific general siting studies in 20 counties to be laudable. In SKI's view, these studies should provide adequate possibilities for identifying additional municipalities that are suitable for feasibility studies. The level of ambition for conducting the studies has been appropriate and the quality of the county-specific studies recorded so far, performed by the Geological Survey of Sweden (SGU), has been evaluated positively by SKI.

The county-specific general siting studies coherently and consistently cover large areas of Sweden which show potential for the possible siting of a repository. Moreover, according to SKB, they constitute a basis (one of several) for screening in the siting process and also indicate interesting areas for further studies. SKI also shares the conclusion drawn in RD&D Programme 98 that both county-specific studies and feasibility studies are required for a comprehensive picture of the geoscientific conditions.

SKI also considers that the reports fulfil the function of demonstrating, to a wider audience, SKB's evaluation of siting potential with respect to geoscientific factors. However, the reports are not sufficiently detailed for presentation in terms of resolution, data, choice of scales for diagrams and so on, for them to be used as a direct basis in connection with, for example, an analysis which sets a selected site in a regional perspective. The latter is mentioned in RD&D Programme 98 as one of the objectives of the county-specific general siting studies. SKI presumes, however, that SKB, which will need to use the presented material, has access to a database which makes this and other necessary kinds of analysis possible. SKI also sees a future need to gain access to this information in order to carry out its own independent analyses.

SKI can confirm that SGU has produced new compilations showing plastic deformation zones (older deformations). Although this is satisfactory, SKI would like to see a similar level of ambition with respect to brittle deformation zones (younger deformations) on a regional scale. Even though these often result from older "scarring " in the bedrock, the occurrence of younger structures which intersect or cross over older structures is not unusual and in certain instances the fracture zones are also very long (up to 25-30 km) even when they are very narrow. A presentation of coherent brittle-tectonic maps on a suitable scale could probably show structural patterns which have previously not been analysed with respect to their importance to the siting of a repository.

It is also desirable for the county-specific general siting studies to describe more clearly how these data which constitute the basis for the compilations were selected. SKI also states that the compilations for certain areas apparently show a homogeneous picture, but that this in reality is inhomogeneous with respect to the data (a mixture of old and new background material). SKI considers it important for the user of the general siting studies to be clear as to what compilations of this nature do and do not permit. In certain cases some of these deficiencies are highlighted in the text, but not, according to SKI, in a comprehensive way, as the consequences are not clearly explained.

4.3.4 Feasibility Studies

SKB s Report

Purpose of the feasibility studies

In a feasibility study, SKB investigates the possibilities for future siting of a deep repository within a municipality which has shown an interest in participating in a feasibility study. The objective of the study is, according to SKB, to develop a broad factual background for all parties concerned.

SKB intends to perform 5-10 feasibility studies, which it has deemed necessary in order to obtain sufficiently broad background material for later stages of the programme. This intention has also been supported by the Government which, in its decision concerning the RD&D Programme 92 Supplement, stated that SKB's forthcoming licence application must include the background material from 5-10 feasibility studies and from at least two site investigations.

Feasibility studies have been completed in Storuman and Malå, where referendums resulted in SKB terminating all siting activities in both municipalities. There are preliminary final reports from the completed feasibility studies in the municipalities of Nyköping and Östhammar. In Oskarshamn Municipality, the feasibility study was commenced in 1997 and in Tierp Municipality in 1998. Furthermore, SKB hopes to start at least one other feasibility study during 1999.

Below is a brief summary of feasibility studies in Nyköping and Östhammar, since SKB published preliminary final reports for these municipalities after the previous RD&D programme.

Feasibility studies in Nyköping and Östhammar

SKB's initial assessment is that the areas which can be reached by a tunnel from Studsvik are of most interest for a possible site investigation within Nyköping Municipality.

In Östhammar Municipality, SKB considers the area in Forsmark between the Repository for Radioactive Operational Waste (SFR) and Bolundsfjärden as the most interesting for further studies, due to geological factors, interest in land use, environmental impact and transportation potential. Resulting from experiences in the construction of the facilities in Forsmark and SFR, SKB believes that, with a possible site investigation within the area (Case 1a), particular attention should be paid to issues such as:

- the importance of shear zones for long-term safety,
- advantages and disadvantages of a deep repository in a tectonic lens,
- the possibility of bedrock with ore potential at considerable depth,
- the existence and importance of horizontal zones,
- the existence and importance of high rock stresses,
- the water permeability of the bedrock,
- hydrochemical conditions.

Comments by the Reviewing Bodies
Uppsala University (UU) does not believe that completed and planned feasibility studies provide sufficient material for selecting two sites for detailed site investigations, and recommends additional studies. It states that "another conclusion, which should be presented more clearly, is that the databases which SKB is using for site selection feasibility studies (e.g. SGU's groundwater archives) do not provide material for an assessment of the composition and movements of the groundwater at a depth of 500 metres" and that "it can be reiterated that the 'feasibility studies' are not sufficient as a basis for selecting sites for future detailed characterisations. There needs to be an intermediate stage". UU further points out "that regional shear zones are often characterised by very different grades of deformation – areas (lenses) with little affected bedrock often arise internally (e.g. in the area of Östhammar). These "low strain lenses" can be particularly suitable for nuclear waste disposal and should be investigated in greater detail".

The Geological Survey of Sweden (SGU) maintains that "the evaluation of the feasibility studies in the municipalities of Nyköping and Östhammar indicates that there are potentially favourable areas in both the municipalities as a whole and in connection with the reactor in Studsvik and the nuclear power plant in Forsmark. Based on the material currently available, it is not possible to rank the areas of interest when all of them possess potentially suitable rock."

The Swedish Anti-Nuclear Movement (FMKK) is sceptical about SKB's siting methodology due to the fact that SKB, in its feasibility study in Östhammar, highlights an area directly south-east of Forsmark in immediate contact with a wide shear zone which is "a primary area of interest for a deep repository". This is being done at the same time as SKB, in its background report to the RD&D programme, says that "there is no clear opinion at present as to how regional shear zones and tectonic lenses affect the safety of a deep repository…To be on the cautious side, the areas which are affected by plastic shear zones have therefore been dismissed in the feasibility studies".

SKI s Evaluation
As regards SKB's feasibility studies, SKI is today making the same comprehensive evaluations as it did with the investigation of RD&D Programme 95. These evaluations are, in summary:

- SKI shares the view that municipalities are suitable administrative units for feasibility studies,
- several important geoscientific conditions must be investigated on a regional scale (this work has been started in connection with SKB's county-specific general siting studies),
- SKI supports SKB's intention to identify actual potential sites for a repository in the municipalities concerned,
- SKB must conduct field surveys in the areas identified (and possible additional geophysical measurements), of important existing geoscientific data in order to reduce the risk of an early decision based on deficient data making a significant impact on the site selection process.

In its evaluations (ranking of potential repository sites in a municipality) SKB also takes into consideration other siting factors besides geoscientific factors. In SKI's view, it is important that SKB, as far as possible, should account for the emphasis placed on different factors when ranking sites in the different feasibility studies and account for how it has treated variations in the data for the different sites.

One example is that, within Östhammar Municipality, SKB recommends the area in Forsmark between SFR and Bolundsfjärden (Case 1a) in spite of a number of disadvantages reported in the preliminary final report. These include few outcropping areas and largely comprise water-catchment areas, relatively limited land mass, as well as sensitive species of flora and fauna. In addition, in the above-mentioned points, SKB specifies a number of important factors which must be taken into account in a site investigation within the Forsmark area. In addition, SKI considers it difficult to understand which siting factors led to SKB being able to draw such far-reaching conclusions that Case 1a can be recommended over Case 1b and Case 2.

The research group at Uppsala University (UU) which reviewed the feasibility studies on behalf of Östhammar Municipality, shares the same opinion. The group's conclusion is that "it is therefore recommended that Siting Case 2 is kept in the ongoing discussion until further geological background material is obtained" (Eriksson et al., 1998). It must be emphasised that SKB intends to supplement the feasibility study in several of the areas proposed by the research group. SKB's preliminary evaluations may thus have to be modified.

An issue about which SKI is frequently asked, especially by feasibility study municipalities, concerns the review of feasibility studies. SKI will evaluate the feasibility study material once all the feasibility studies have been completed. The evaluation will bear reference to the quality and scope of the reports. Prior to the evaluation both of feasibility study reports and of other material, which SKB will present before the site investigations, SKI will consult the feasibility study municipalities. SKI will thereby ensure that the review also meets the needs of the municipalities.

4.4 Selection of Sites for Site Investigation

In the review of SKB's RD&D Programme 95, SKI and several reviewing bodies requested a clear report regarding SKB's methods of selecting the areas for site investigations. In its decision (December 19, 1996), on this RD&D programme, the Government stated that municipalities concerned should have access to SKB's complete report of general siting studies, feasibility studies and other background material as well as comparative material before the site selection process can move on to site investigations in at least two locations. The Government also stated that SKB should consult SKI and SSI about the criteria which should apply to the investigative work for the site investigations.

SKB now specifies in RD&D Programme 98 the reports which are planned prior to the start of the site investigations. SKB refers to the system analysis reported in RD&D Programme 98 (SKB, 1998, Ekendahl and Papp, 1998) for the basis for the selection of

a method. As background material for the site investigation, SKB intends to present a broad body of material in the siting issue, with justification of the selected sites and a site selection programme with criteria for site evaluation. SKB maintains that it is necessary for the authorities to decide whether the planned reports of *method selection* and *site selection* are sufficient for continuing with site investigations.

4.4.1 Background prior to Site Selection

SKB s Report
Before SKB selects the areas for site investigations, it intends to present *background material*, *comparison material* and *screening material*. General surveys or special investigations, General Siting Study 95, county-specific general siting studies and the North-South/Coast-Interior study are referred to as the background material. Study site investigations, general siting studies in municipalities hosting nuclear facilities, feasibility studies in Malå and Storuman municipalities and Finnish site investigations are referred to as comparison material. Results from feasibility studies in the municipalities participating in the siting process constitute screening material.

In addition to the above-mentioned, SKB also plans to present, within the next three years, an assessment of long-term safety (SR 97), a site investigation programme and criteria for site evaluation. SKB states that the selection of areas for site investigations will be made in 2001 and that it will be based on a combined report of screening material with reasons for the selected areas.

Comments by the Reviewing Bodies
The municipalities, local safety committees and county administrative boards in which SKB is carrying out feasibility studies show in their review statements a strong commitment to issues concerning SKB's reports and decision-making process before the transition to site investigations. The reviewing bodies stress that the authorities must state their opinion of the (KBS-3) method and site selection before they can decide whether to participate in the site investigations. The reviewing bodies therefore consider that the authorities must evaluate and decide on all the reports which the Government requested from SKB in previous RD&D decisions prior to the start of the site investigations, such as the system analysis with the report on alternative methods, safety assessment for the KBS-3 method (SR 97), general siting studies and feasibility studies, site selection factors and site investigation programme.

The feasibility study municipalities further maintain that there must be a *defined procedure* with an evaluation of the collected material which will lead to statements from the authorities. With the support of the authorities' statements, the Government must then decide whether the siting programme should make the transition to site investigations. The feasibility study municipalities and SSI propose that a possible procedure could be for the Government, in connection with RD&D Programme 98, to decide that SKB should supplement the programme with the combined reporting which is required prior to selecting sites for site investigations.

SSI is of the opinion that this additional material should be submitted for review by a broad range of reviewing bodies in the same was as for RD&D Programme 98, and then become the subject of a government decision. According to SSI, the government decision should be made *before* the selection of areas for site investigations has been made. SSI further maintains that SKB, in connection with the supplementary reporting, should:

- develop its system analysis for the different strategies as for alternative methods in these strategies,
- report on how consultation at different stages of the siting process is intended to take place, based on the provisions of the Environmental Code,
- report on ecosystems affected in the areas which are included in the screening material, and
- provide a preliminary account of how SSI's regulations (SSI FS 1998:1) can be met for sites which are included in the screening material.

The Swedish Board of Housing, Building and Planning and the Swedish Environmental Protection Agency argue that a strategic environmental assessment of the method selection must be carried out before SKB undertakes the site investigations. The objective should be to make an overall evaluation of all available action alternatives and to establish a method for the continued site selection process. SSI's judgement is that a strategic environmental assessment as mentioned in the Espoo Convention is not appropriate in terms of civil law organisations such as SKB (see also Section 4.2).

The environmental organisations believe that the site selection process should cease and that the selection of areas for site investigations should not be made until the method for final disposal has been approved by authorities and the Government. The environmental organisations agree that it is necessary to carry out additional research into alternative methods for the management of nuclear waste before a method can be selected. Several of the environmental organisations also claim that SKB should report more clearly how it values the partly conflicting claims on freedom from supervision, inaccessibility and retrievability.

Several environmental organisations question SKB's role as a responsible organisation for siting activities. Friends of the Earth, Opinion Group against Nuclear Waste in Malå and Waste Network propose that an independent party should take over responsibility for the siting process. Greenpeace considers that SKB should concentrate on method development and that the decision regarding responsibility for the siting process can be made at a later stage, once the method has been developed and approved. Save Fjällveden considers that SKI and other authorities play far too passive a role in the siting process. The Swedish Anti-Nuclear Movement (FMKK) is of the opinion that site selection and a decision on site investigations should be postponed until after RD&D Programme 01.

SKI s Evaluation

The choice of area for site investigations and the implementation of the site investigations are not regulated in Swedish legislation. However, SKI understands that SKB and many reviewing bodies, including the municipalities in which feasibility studies are

to be carried out, are issuing a defined decision-making process which will result in the authorities and Government taking a position concerning site and method selection before the transition to site investigations.

Below, SKI reports on the authorities' requirements for the technical and safety reports which SKB should produce before undertaking site investigations. Issues concerning the decision-making process and proposals for the way in which the authorities can reach a decision on SKB's reports are discussed in more detail at the start of this chapter and in Chapter 2.

In SKI's opinion, SKB's planned reports before the transition to site investigations are of reasonable scope and can be expected to provide sufficient background material for a statement by the authorities concerning both the method of final disposal and selection of sites for site investigations. However, SKI wishes to state that RD&D Programme 98 does not provide an adequate basis for SKI to now reach a decision concerning site selection and site investigations (see Table 4.1). Therefore, SKI concludes, like the munici-palities involved in feasibility studies and SSI, that the authorities should conduct an evaluation of the entire body of material that SKB intends to present for the selection of sites for site investigation. The authorities' overall evaluation, therefore, should also include SKB's safety assessment SR 97, a complete report of the system analysis and SKB's proposal for a site investigation programme in addition to the screening material.

SKI supports the proposal of the reviewing bodies that the evaluation should be linked to a supplement to RD&D Programme 98, with a review by external bodies and a subsequent statement by the authorities and a government decision. In SKI's opinion, it is reasonable for SKB to also include proposed sites for site investigation along with a justification of the selection of these sites in the overall basis for decision-making. This will give authorities, municipalities involved in feasibility studies and other parties concerned the possibility of evaluating the practical application of siting factors and criteria. However, SKI considers that the final selection of sites for site investigations should not be made until the authorities and Government have reached a decision concerning SKB's supplementary reporting.

As stated in Table 4.1, there is a need for further reporting and harmonisation before SKB starts its site investigations. SKI does consider, however, that these should be managed in the current contacts between SKB and the authorities and through consultation with municipalities concerned.

In summary, SKI considers that SKB should not start site investigations before:

- a full system analysis has been made, which justifies method selection and investigates alternative courses of action for the disposal of nuclear waste[2,3] a thorough assessment (SR 97) of the long-term safety of the selected principle method has

[2] Requirements on reporting have been stipulated in the government decision of May 18, 995 concerning RD&D Programme Supplement.
[3] Requirements on reporting have been stipulated in the government decision of December 19, 1996 concerning RD&D Programme 95.

been made and subjected to international peer review. The analysis must show that the KBS-3 method can fulfil the requirements of SSI and SKI as specified in the authorities' regulations[3],
- additional material has been submitted, with justifications for the selection of sites for site investigations[3]
- from the safety assessment and with respect to the experiences of the Äspö Project, a relevant site investigation programme has been derived[3],
- the principles for the successive stages in the site selection have been clarified, such as selection criteria and site evaluation[3].

Reporting / Activity:	RD&D Programme 98	When selecting 2 sites for site investigations	Prior to the start of site investigations
System analysis	Preliminary report	Full report	Updates taking into account work on canister development etc.*
Safety assessment	Not included as a separate report (SR 97). Report planned for August 1999	Report submitted and subjected to inter-national review and evaluation by authorities	Evaluation by SKB and presentation of additio-nal material taking into account the findings of regulatory evaluations*
Site selection	Reports from general siting studies and feasi-bility studies as well as structure of siting factors	Complete body of material for selection of at least 2 sites for site investigation	Updates taking into account possible supplements to feasibility studies*
Site investigations	Preliminary plans	General programme	Site-specific programmes
EIA	Proposal for content of the EIS	Plans for implementa-tion based on the requirements of the Environmental Code	Site-specific program-mes for extended consultation on EIA in accordance with the Environmental Code

Table 4.1
*Summary of SKB s published and planned reports prior to the start of site investigations. Additional material proposed by SKI is marked with * .*

4.4.2 Selection Procedures and Criteria

The Government asked earlier for clarification of the current site selection process concerning, for example, the factors which should guide the choice of a site for a repository and the criteria which will be applied in order to evaluate the site investigations (government decision of December 19, 1996 concerning RD&D Programme 95). In RD&D Programme 98 (Sections 6.4 and 6.6), SKB provides a progress report of the current work in this area. The work involved in structuring and defining siting factors and criteria is recorded in a separate background report (Ström et al. 1998).

SKB s Report
SKB states that the areas for site investigations will be selected in close consultation with authorities, municipalities and other parties concerned. The selection procedure consists of three stages: the structuring of facts, evaluation of facts, and choice of sites. The results from all the feasibility studies will be structured under four different groups of siting factors: safety, technology, land use and environment as well as society, for which advantages and disadvantages will be evaluated. The choice of sites for site investigations will then be made from an *overall assessment* of all the siting factors (screening and comparison material, background material). According to SKB, it will become clear which facts, assessments and appraisals will form the basis for the selection of sites, as well as which obscurities and uncertainties there are in the characteristics and conditions of the selected sites.

In RD&D Programme 98, SKB provides examples of possible reasons for evaluation (criteria) for different types of siting factors. SKB stresses that there is only a limited opportunity for assessing long-term safety, as data from the bedrock at the depth of the repository is, to a great extent, lacking at this stage of the siting process. SKB intends, however, to use data and performed safety assessments from similar geological environments which are included in the comparison material.

In RD&D Programme 98 and the "Criteria Report" (Ström et al. 1998), SKB presents its work with the development of a uniform structure and nomenclature for the suitability of siting factors and criteria for site investigation. There are basic requirements concerning the performance, safety and radiation protection of a deep repository which must be fulfilled. These are defined by laws, ordinances and authorities' regulations concerning the management of nuclear waste. Over and above this, in the additional material for RD&D Programme 92, SKB has previously drawn up basic requirements and preferences for the performance of the deep repository as well as siting factors.

In the criteria report, SKB now reports on a concept structure and nomenclature for further specification of the basic requirements and preferences for the performance of the deep repository, divided into the subject areas of chemistry, hydrogeology, transport properties in the rock, thermal properties, rock mechanics and geology.

For every basic safety function, the *requirements* and *preferences* for functions and parameters are given. SKB states that there are relatively few direct requirements for the function, while it is necessary, however, to identify a large number of parameters and circumstances where there are requests for appropriate value ranges. SKB also states

that requirements and preferences must be checked against the ongoing safety assessment SR 97, in which parts of the performance analyses are being carried out.

For every safety function, *geoscientific evaluation factors* and *criteria* are further identified, and which are applied at various stages of the siting work, in order to prove that the requirements and preferences have been fulfilled. Evaluation factors are defined as being measurable or estimable parameters, such as groundwater flow. Criteria are measurements or indicators which are needed in order to assess whether a site meets particular requirements and are included in the values or value domains for measured or estimated parameters.

SKB mentions that criteria can vary at different stages of the siting (feasibility studies, site investigations and detailed characterisations), due to variance in the available information about sites. Requirements and requests for the basic safety functions, however, remain the same.

In the criteria report, SKB provides examples of how requirements, evaluation factors and criteria may be presented clearly in different types of tables. The tables show how different evaluation factors and criteria will be applied and how the knowledge base changes at different stages of the site selection process. SKB also states that an initial inventory has been carried out, of geoscientific parameters which must be decided upon with a site investigation (Andersson et al., 1998).

The structuring which has been carried out is, according to SKB, a basis for a consistently and comprehensively presented set of requirements from a functional perspective. However, SKB emphasises that only the complete picture of a range of interacting factors will determine whether or not a site is appropriate. Therefore, in SKB's view, the suitability of the site must ultimately be determined by a combined safety and construction assessment. However, the criteria are not expected to provide reliable guidelines as to what an assessment such as this will result in.

SKB's objective with the ongoing work is, among other things, to be able to present a comprehensive set of evaluation factors and criteria, according to the structure presented in the criteria report, before commencing site investigations. After this, work will be broadened to include other long-lived waste (SFL 3-5).

Comments by the Reviewing Bodies

The Royal Institute of Technology (KTH) and the Geological Survey of Sweden (SGU) are of the opinion that the site selection should be based on a strict scientific evaluation and that the opinions of the municipalities should not be deciding factors. SGU is discussing geoscientific siting factors, such as the effects of a future ice age and hydrological conditions, and points out the advantages of a coastal siting of a deep repository in southern Sweden. Göteborg University (GU) believes that more political support is needed for the siting process, thus enabling geoscientific criteria to have a decisive role in the site selection.

SSI and SGU are of the opinion that SKB should explain more clearly the importance of biospheric conditions and recharge and discharge areas as site selection criteria. SSI

further states that, prior to site selection, SKB should study and record the various relevant ecosystems in the feasibility study municipalities concerned in order to learn how radionuclides appear in the biosphere. The Royal Institute of Technology (KTH) and Tierp Municipality believe that the authorities should clarify their safety requirements so as to give a better idea of what will be acceptable.

Municipalities in which feasibility studies are to be carried out, the local safety committees and the county administrative boards share the opinion that, as previously stated, transparent criteria for site selection must be presented before the selection of sites for site investigations can be made. They also maintain that the site selection criteria are a part of the overall body of material which must be evaluated by the authorities before making the transition to site investigations. Oskarshamn Municipality and several reviewing bodies point out in particular that SKB should elucidate the way in which the various siting factors (safety, technology, land, environment and society) will be weighed together and indicate that the issue must be discussed in the EIA.

The environmental organisations are of the opinion that the siting process should be abandoned (see later Section 4.4.1).

SKI s Evaluation

In SKI's opinion, in RD&D Programme 98, SKB has presented an adequate structure for defining siting factors and general safety functions prior to the selection of sites for site investigation and site evaluation. SKI supports SKB's ambition of systematically reporting how different requirements and preferences for the function of the repository can be evaluated with the help of evaluation factors and criteria at different stages of a site selection programme. However, SKI is in full agreement with SKB that the suitability of a site for a repository must finally be evaluated from a combined safety and construction assessment which takes into consideration *uncertainties* and *interaction between different factors*. The criteria fulfil an important function in clarifying what characterises a suitable site for a repository. However, on their own, the criteria do not provide an adequate basis for judging whether the site complies with the basic safety criteria.

SKI agrees with SKB that there is only a limited opportunity for evaluating long-term safety, based on feasibility studies. In addition, direct comparisons of different areas are complicated by the fact that the level of information varies considerably between municipalities and within a municipality. Like Oskarshamn Municipality, SKI emphasises that it is important for SKB to account for how it balances the various siting factors (safety, technology, land, environment and society) in the selection of sites for site investigations. According to SKI, such an explanation is also required for the feasibility studies for which SKB has already proposed areas which may be of interest for further studies. On the basis of an up-to-date safety assessment (SR 97), SKB must also reconcile and clearly account for the minimum criteria and discriminating factors which determine whether a site can be judged to be suitable for a repository.

SKI concludes, as do SSI and the Geological Survey of Sweden, that SKB should improve the investigation and account of the importance of biosphere conditions and recharge and discharge areas as siting criteria, before selecting sites for site investigations.

SKI also agrees that SKB may need to ensure that the feasibility studies provide a sufficient basis for evaluating the importance of the biosphere in terms of safety.

SKI concludes that SKB's work on defining requirements and preferences relating to basic safety functions which can be made with respect to the function of the bedrock is closely connected to the development of a description of the repository process system. The aim of the system description in the safety assessment is to identify and describe all the processes and conditions which may affect the performance and safety of the repository (see Section 6.2.1). In SKI's opinion, SKB should improve the explanation of how these activities have been co-ordinated.

On account of comments from Tierp Municipality and the Royal Institute of Technology (KTH), SKI notes that the authorities are currently defining their requirements for final disposal. In autumn 1998, SSI established regulations concerning the protection of human health and the environment in connection with the final management of spent nuclear fuel and nuclear waste (SSI FS 1998:1). In a memorandum (Dverstorp, 1997), SKI has reported its premises for the development of SKI's corresponding regulations concerning long-term safety in connection with final disposal. Work with SKI's regulations is currently being carried out and a review by external bodies is being planned in 1999. SKI is also planning on supplementing its regulations on final disposal with guidelines for site investigations and site evaluation.

The authorities' regulations specify the basic safety and radiation protection requirements which will provide the basis for future evaluations and licence applications. The regulations also include requirements for the content and quality of the safety reports which SKB is obliged to produce. However, the authorities will not stipulate detailed requirements and criteria for the various functions of the final disposal system at this stage of the siting process. This is the task of SKB, since the nuclear power industry, according to the Act on Nuclear Activities, has full responsibility for providing an ultimate solution to the management of Swedish nuclear waste disposal.

4.5 Site Investigations and Site Evaluation

In this Section, SKB's reports on site characterisation, i.e. site investigations and site evaluation (Section 6.5 – 6.7. in RD&D Programme 98) are discussed. Site investigations concern the geoscientific measurements which SKB plans to conduct from the surface and in boreholes at a minimum of two candidate sites for a repository. SKB estimates a site investigation will take between four and eight years to conduct. SKB states that if the selection of areas for site investigations is made in 2001, the site investigations can start during 2002.

The site investigations are not regulated under Swedish legislation and thus do not require any formal permit from SKI. In its decision on RD&D Programme 95, however, the Government has said that SKB should consult SKI and SSI about the conditions which should apply to the investigation work.

Previously, such as in the statements to RD&D Programmes 92 and 95, SKI has given its opinion on the structure of SKB's planned site investigations. SKI has also carried out a comprehensive safety assessment project, SITE-94, based on SKB's site investigation data from Äspö Hard Rock Laboratory (SKI, 1996). In connection with the evaluation of this project, SKI has combined its experiences of SKB's site investigation methodology and data management and has made suggestions as to how they can be improved (see e.g. Geier et al., 1996, Geier, 1997, Dverstorp and Geier, 1999). As mentioned earlier, SKI intends to supplement its regulations concerning final disposal with guidelines for site investigations.

Below, SKI gives its opinions of SKB's reporting in RD&D 98 with corresponding background reports.

4.5.1 Geoscientific Site Investigation Programme

SKB s Report
In RD&D Programme 98, SKB refers to the general description of site investigations which are reported in RD&D Programme 95. In brief, SKB's plan involves the site investigations being divided into an initial and a complete site investigation with an intermediate evaluation.

The initial stage covers measurements from the surface and two deep boreholes and aims to provide a general picture of the bedrock in the immediate area and to select a preferred site for the site investigation. If, after the initial stage, SKB deems the site suitable for further investigations, the complete investigation will be carried out with a more comprehensive drilling programme. The objective of the complete site investigation is to obtain the data necessary to perform site-specific safety assessments as background material to a potential application for SKB to perform detailed investigations and to build a repository.

In RD&D Programme 98, as in RD&D Programme 95, SKB states that there is currently access to the measurement methods and the evaluation methodology necessary for reliably describing the features and conditions of the rock which are important for a repository, from a surface-based site investigation. The conclusion is based partly on the evaluations made of the site investigation at Äspö.

SKB is continuously developing its instruments and measurement methods for site investigations. SKB also says that it can now review what resources are available in order to perform parallel site investigations. The development programme for the coming three-year period includes, for example:

- testing new geophysical methods for determining the depth to saline groundwater,
- improving positional accuracy of measurements in boreholes,
- stabilising unstable sections in the boreholes,
- testing new hydraulic measurement methods,
- taking groundwater samples during the drilling process,
- developing a complete documentation of different measurements in the boreholes,

- further developing the SICADA database and the three-dimensional code for the visualisation of the bedrock (RVS),
- improving instructions and technical documentation of investigation methods and instruments.

The tools and basic procedures for data collection and quality assurance produced at the Äspö Hard Rock Laboratory will, according to SKB, be used in future site investigations. SKB aims to attain complete traceability in all its investigations and data evaluations.

SKB has, in a separate report, (Andersson et al., 1998) produced a preliminary compilation of the geoscientific parameters which must be determined in connection with a site investigation. The authors base their report on the data requirements which were identified for various types of analysis in the site evaluation and the safety assessment. They state, however, that the compilation should be re-evaluated against an up-to-date safety assessment (SR 97). The authors further maintain that the extent to which the parameters proposed in this report can be determined with available measurement methods (i.e. which measurement methods should be applied, how many measurements are necessary – e.g. the number of boreholes, how the measurements should be evaluated and how different measurements influence each other) must still be evaluated. It is therefore proposed that the completed compilation of geoscientific parameters should be checked against the evaluations of measurement methods which were carried out in the Äspö Project.

Comments by the Reviewing Bodies

Chalmers University of Technology (CTH) maintains that it is of great importance that the site investigations are carried out in clearly-defined and similar ways at the various sites. It also points out that great demands will be placed on SKB's project management for the practical undertaking of the full site investigations and that SKB should therefore review its competence in terms of project management, procurement of consultancy services, geology/geotechnology, etc.

GU believes that SKB should carry out site investigations at a minimum of four sites, in accordance with the Finnish model, so as to obtain sufficient geological/safety assessment material before site selection for a repository. The municipalities in which feasibility studies are to be carried out maintain, as mentioned earlier, that SKB should present a site investigation programme which can be evaluated by the authorities before SKB selects its sites for site investigations.

The Swedish Council for Planning and Co-ordination of Research (FRN) and other reviewing bodies are of the opinion that SKB's databases should be made accessible to independent national and international researchers.

SKI s Evaluation

SKI is satisfied that SKB is planning to carry out site investigations in various stages with repeated performance assessments and safety assessments. This, together with clearly reported determining factors, will provide SKB with the opportunity to abandon

the site investigation if it became apparent that a site could not be deemed appropriate for further studies.

SKI does not agree with GU that it is necessary, from a safety point of view, to carry out comprehensive site investigations at more than two sites. The chances of finding a suitable site with a larger basis for selection would certainly be greater, but the final evaluation of long-term safety can still not be made until SKB has carried out the detailed investigations and the repository has been built. According to SKI, SKB's task is to find a site which may be considered *sufficiently safe*, i.e. a site which can be regarded as meeting the authorities' safety and radiation protection requirements based on an overall, integrated safety assessment.

SKI agrees with SKB that the Äspö Hard Rock Laboratory has given SKB access to established measurement methods and expertise for conducting site investigations and geoscientific site evaluation. SKI is also optimistic that SKB is further developing certain measurement methods and instruments for site investigations and can confirm that SKB has paid full attention to SKI's recommendations in its statement to RD&D Programme 95.

SKI declares at the same time that, now as in the statements to RD&D Programmes 92 and 95, considerable development work remains to be carried out, both concerning single measurement methods and mainly how different measurement methods will be combined into an appropriate site investigation programme. SKB itself has identified these requirements in the "Parameter Report" (Andersson et al., 1998) in which the need for balance between (1) the requirements of the safety assessment, (2) SKB's preliminary compilation of geoscientific parameters and (3) the evaluation of site investigations at Äspö is highlighted. SKI is therefore hesitant about SKB's categorical statement that it already has access to sufficient measurement methods to determine which parameters are important for a repository.

In SKI's opinion, SKB must show that it has relevant measurement methods in order to determine, on a site-specific basis, some of the more critical parameters in the safety assessment. Included in this are the measurement methods which are necessary for obtaining data for analyses of radionuclide transport, rock stability and the rock's capability of buffering future changes in groundwater chemistry.

SKI's own analyses of SKB's site investigation data from Äspö (SKI, 1996) showed that the use of measurement methods provides very limited information about the parameters which are necessary for assessing the rock's ability to retain and retard radionuclides, if a canister were to break. According to SKI, it should be possible to make better use of measurement methods which are already accessible in order to determine, more accurately than in the preliminary investigation at Äspö, the rock's transport properties. SKI therefore recommends that SKB review and, where necessary, further develop the measurement methods which can be used to determine these parameters already in a site investigation (e.g. increased use of different types of tracer tests in combination with a more systematic characterisation of fracture structures and filling material).

SKI further believes that SKB should analyse and report on whether the proposed site investigation programme provides sufficient data for testing the alternative geoscientific models which SKB developed for groundwater flow and transport. SKI's experiences from SITE-94 showed that the type of site investigation which was carried out at Äspö does not provide sufficient information for the calibration and discrimination of alternative statistic/stochastic models of groundwater flow and transport. SKI would therefore like to see an account of the measurement work, e.g. deep boreholes, which is being planned on a regional scale in connection with a site investigation. In SKI's opinion, it is important that SKB, at an early stage of a site investigation, should prepare the necessary data for determining the large-scale flow pattern and regional trends in geochemical conditions, e.g. deep to saline groundwater around the repository site.

In principle, SKI agrees with the reviewing bodies which consider that SKB's databases should be made available to independent Swedish and international researchers. SKI can, however, understand if SKB first wishes to make its own evaluation and quality control of produced data. According to SKI, it can be considered reasonable for SKB to make its data available in connection with the publication of the repeated evaluations and performance assessments which are planned for the various stages of a site investigation.

SKI discusses the need for quality assurance in Section 6.2.5. SKI states here that SKB is now working to correct the quality problems in the data and data processing which SKI presented in previous RD&D evaluations and in the SITE-94 Project. SKI also emphasises that SKB, prior to the start of site investigations, should present an overall programme for quality assurance of all of the components of a site investigation (measurement instructions and procedures, a description and verification of measurement instruments, the management of data, including databases, evaluation methods, documentation etc.).

4.5.2 Site Evaluation

SKB s Report

SKB points out that site investigations will gradually give rise to very extensive amounts of data which must be quality assured, analysed and assessed. SKB sees the geoscientific site evaluation as a "vehicle" for co-ordination and information exchange between various activities during the site investigations. In this way, the site evaluation will ensure that basic safety requirements and other essential technical pre-requisites are met, and that the deep repository is as well adapted to the conditions of the site as possible. The evaluation will also enable comparisons between sites with respect to long-term safety and other assessment factors. SKB states that this puts substantial demands on the flow of information between different activities and that well-prepared and clearly stated evaluations are required.

The results of the investigations will be combined in a geoscientific description of the site, which is being created in the form of subject-specific models which are closely linked to each other. As previously described, SKB has made an initial compilation of

the geoscientific parameters which are required for these models (Andersson et al., 1998).

Comments by the Reviewing Bodies
CTH believes that SKB needs to review its system of processing data and information before performing future site investigations.

SKI s Evaluation
In SKI's opinion, SKB's general premises for site evaluation are good. However, it is not possible to make a thorough evaluation based on RD&D Programme 98 and earlier reports of the site evaluation at Äspö. The latter has not had the direct connection with the safety assessment requirements which will be necessary for the evaluation of candidate sites for a repository. SKI is therefore considering submitting comments on SKB's programme for site investigation in connection with SKB's account of the safety assessment SR 97, and when SKB reports its complete programme of site investigations and site evaluation for the next three-year period.

SKI is of the opinion that SKB, prior to the planned site investigations, should clarify its strategy for the identification, evaluation and comparison of alternative conceptual models for, e.g. hydrogeology and radionuclide transport. SKI also emphasises that SKB should take into account alternative interpretations and models within other areas such as structural geology and geochemistry etc.

SKI regards repeated evaluations of collected data from a site investigation as an important part of quality control. SKI's experiences from SITE-94 show that many uncertainties and data deficiencies were first discovered when they were used in the analyses for which they were intended. SKI also encourages SKB in advance of every stage of the site investigations, to use its geoscientific models when planning the continued measurement programme. Thus, how the continued measurements should be designed so as to provide the basis for distinguishing between alternative interpretation models and reducing those uncertainties which are of greatest importance to the results of the safety assessment can be analysed.

Like Chalmers University of Technology, SKI recommends that SKB should review and account for how it intends to manage and document the comprehensive body of data and information which will have to be handled during the site investigations. This applies not least to data transfers from the detailed and partly supplementary geoscientific models to the various performance and safety assessments. These transfers often involve different kinds of simplification which must be justified and recorded.

4.6 SKI s Overall Evaluation

4.6.1 EIS and Consultation

The Environmental Code, which entered into force on January 1, 1999, has an impact on the final disposal programme in several ways. Licence applications submitted by SKB in the future are to be evaluated in accordance with the Environmental Code.

Consequently, it must be established how co-ordination with licensing under the Act on Nuclear Activities should be achieved. Furthermore, the Environmental Code contains new regulations for the content and structure of Environmental Impact Statements (EIS). SKI concludes, as do several reviewing bodies, that it is important for the Government, in its decision on RD&D Programme 98, to state its opinion on the application of the Environmental Code in connection with SKB's ongoing site selection process and prior to future licensing actions.

A question which is becoming more and more relevant, and which is being asked by many, concerns when the EIA will be considered to have started. It is important to identify suitable points for initiating and conducting the early and extended consultation processes required by Chapter 6 of the Environmental Code.

SKI considers that SKB's early consultations (Ch. 6, § 4 of the Environmental Code) with relevant County Administrative Boards should take place when the municipalities concerned decide to participate in site investigations. As this consultation will be followed by the decision of the County Administrative Board concerning extended consultations (Ch. 6, § 5 of the Environmental Code), a clear and formal start to the Environmental Code's requirements for extended consultation with EIA will be achieved. In SKI's opinion, it is advantageous that such a decision should be made in conjunction with the vital stage of site investigation within SKB's programme. A process for SKB's planned encapsulation plant can be conducted in a similar manner.

SKI supports SSI's proposal that SKB should be required to submit material which will comprise the basis for SKB's selection of sites for site investigation along with its plans for achieving consultation in the different stages of siting. SKI therefore proposes that the Government should stipulate such a condition for SKB's future work.

Several reviewing bodies have proposed that a process of strategic environmental assessment (SEA) of SKB's final disposal programme should be introduced. All of these bodies share the view that the selection of a method for final disposal can be based on such an assessment. SKI shares the opinion that the issue of nuclear waste covers many problems of a strategic nature, and primarily method selection. Strategic issues, and in particular the method selection, are often discussed today in the various consultations which take place in connection with SKB's feasibility studies. Strategic issues have also been the focus of attention in previous RD&D programmes, with corresponding evaluations, and particularly in government decisions. For instance, SKI is of the opinion that the Government's request for a system analysis of the entire final disposal system including a report of alternative solutions to the KBS-3 method must be regarded as constituting an important basis on which to make a decision as to whether or not SKB's programme has the right strategic direction.

A couple of reviewing bodies refer to the work which has been in progress for several years within the European Commission on preparing a directive on strategic environmental assessment. A revised directive proposal was presented by the Commission in 1999. However, it will be a long process before such a directive is adopted and can be implemented in Swedish legislation. In SKI's opinion, it is not reasonable, at present, to develop a Swedish process for nuclear waste disposal on the basis of the directive

proposal. However, SKI considers that the proposal may be a source of assistance and inspiration to SKB, authorities, municipalities and other parties involved in the work of developing the Environmental Impact Assessment.

The proposals for establishing a separate body for supervision of and/or responsibility for EIA, put forward by some reviewing bodies, is closely related to the issue of SEA. SKI does not support this proposal. In SKI's view, the most important factor is that the various actors in the nuclear waste disposal issue should have transparent and unambiguous roles and responsibilities. At present, these roles are sufficiently clear in both the Act on Nuclear Activities and the Environmental Code. It is clear that SKB is responsible for preparing the EIS and any other basis for decision-making before submitting a licence application. In SKI's opinion, the authorities which are responsible for supervision and review, under various laws and ordinances, of the planned activity are also responsible for monitoring the EIA to ensure that it is adequate. SKI therefore concludes that an EIA Commission for nuclear waste disposal is not necessary. On the contrary, such an organisation would lead to a lack of clarity in relation to the statutory and established division of responsibilities.

When SKB started conducting feasibility studies, the municipalities' need for resources to provide information to the general public came to the fore. This resulted in amendments to the Financing Act and Ordinance so that, since 1995, SKI can grant municipalities where feasibility studies are being or have been conducted, compensation for information-related costs. In SKI's opinion, ample provision has been made for compensation to the municipalities involved in feasibility studies, even if the level of compensation may have to be adjusted in the future.

On the basis of the current wording of the Financing Act and Financing Ordinance, environmental organisations cannot obtain funds from the Nuclear Waste Fund. However, the Environmental Code attaches considerably greater importance to environmental organisations than previous legislation. SSI proposes in its statement that the Government should investigate how resources could be placed at the disposal of the environmental organisations. In the light of the recent legislative changes, SKI agrees with SSI's proposal that the Government should investigate the possibility of providing support to environmental organisations which are particularly involved in the nuclear waste disposal issue.

SKB's proposed table of contents for an EIS comprises the compulsory issues stipulated in the Environmental Code which have been adequately adapted to the final disposal issue. SKI believes that SKB's proposed table of contents can form the basis for continued discussions with the actors concerned.

4.6.2 General Siting Studies and Feasibility Studies

North-South/Coast-Interior

In SKI's opinion, SKB's comparative study of siting in north or the south of Sweden and of siting along the coast or in the interior of Sweden is a good start in identifying and discussing important siting factors.

SKI concludes that, with the approach adopted by SKB, involving qualitative reasoning, it is difficult for SKB to draw any unambiguous conclusions about the advantages and disadvantages of siting a repository in different parts of Sweden. One problem in this respect, according to SKI, is that SKB has not made any clear attempt at establishing any measurable targets to which the report should attempt to provide the answer and guidance for future siting.

SKI considers for example, that regional modelling of the groundwater flow with respect to the importance of recharge and discharge areas, combined with SKB's approach in the North-South/Coast-Interior study, should result in less ambiguous conclusions and, thereby, provide a more useful basis for decision-making prior to the selection of sites for site investigation.

SKI therefore proposes that SKB should increase the level of detail of this study and use the data from the completed and ongoing county-specific general siting studies. These studies cover large areas of Sweden in a coherent and consistent way, which can be appropriate for the siting of a repository.

SKI considers that, by using and combining knowledge obtained in the county-specific general siting studies with the north-south/coast-interior analysis, there will be greater opportunities for SKB to receive guidance and support when sites for future site investigations are to be selected.

County-specific General Siting Studies

SKI considers SKB's intention of conducting county-specific general siting studies in 20 counties (of which 10 have been published) to be laudable. In SKI's view, these studies should provide adequate possibilities for identifying additional municipalities that are suitable for feasibility studies.

The level of ambition for the implementation of the general siting studies has been appropriate. SKI considers the county-specific studies so far reported to be of good quality. SKI shares SKB's conclusion in RD&D Programme 98 that both county-specific general siting studies and feasibility studies are necessary for a comprehensive view of the geoscientific conditions. SKI also considers that the reports fulfil the function of demonstrating, to a wider audience, SKB's evaluation of the siting potential with respect to geoscientific factors.

The Geological Survey of Sweden (SGU) has presented new data in the general siting studies which show plastic deformation zones (old deformations). Although this is satisfactory, SKI would like to see a similar level of ambition with respect to brittle deformation zones (younger deformations) on a regional scale. A presentation of coherent brittle-tectonic maps on a suitable scale could probably show structural patterns which have previously not been analysed with respect to their importance to the siting of a repository.

SKI also considers it preferable for the county-specific general siting studies to describe more clearly how the data were selected for the compilations. SKI believes it important

that the limitations of both the data and the actual general siting studies are presented clearly.

Feasibility Studies
As far as the SKB feasibility studies are concerned, SKI is currently making the same comprehensive evaluations as in connection with the evaluation of RD&D Programme 95. These evaluations are, in summary:

- SKI shares the view that municipalities are suitable administrative units for feasibility studies.
- Several important geoscientific conditions must be investigated on a regional scale (this work has been started in connection with SKB's county-specific general siting studies).
- SKI supports SKB's intention to identify actual potential sites for a repository in the municipalities concerned.
- SKB must conduct field surveys in the areas identified (and possible additional geophysical measurements) of important existing geoscientific data in order to reduce the risk of an early decision based on deficient data making a significant impact on the site selection process.

In its evaluations (ranking of potential repository sites in a municipality) SKB also takes into consideration other siting factors besides geoscientific factors. In SKI's view, it is important that SKB, as far as possible, should account for the emphasis placed on different factors when ranking sites in the different feasibility studies and account for how it has treated variations in the data for the different sites.

4.6.3 Selection of Sites for Site Investigations

Basis for Site Selection
SKI regards SKB's planned reports prior to the transition to site investigations as having a reasonable scope and can be expected to provide a sufficient basis for a statement by the authorities concerning both the method of final disposal and the selection of sites for site investigations.

SKI concludes, like the municipalities involved in feasibility studies and SSI, that the authorities should conduct an evaluation of the entire body of material that SKB intends to present for the selection of sites for site investigation. SKI also shares the opinion that such an evaluation should be followed by a government decision. The authorities' complete evaluations and the government decision should, over and above the basis for selection, also cover SKB's safety assessment SR 97, a full report of the system analysis and SKB's proposal for a site investigation programme. In SKI's opinion, it is reasonable for SKB to also include proposed sites for site investigation along with a justification of the selection of these sites in the basis for decision-making. However, the final selection of areas for site investigations should not be made by SKB until authorities and the Government have taken a position on SKB's additional material.

SKI therefore proposes that the Government stipulate conditions for SKB's future work which will include submitting additional material (see Table 4.1) prior to the selection of sites for site investigation and the review by the authorities and external bodies, followed by a government decision, as in the case of the RD&D programmes. This will give authorities, municipalities involved in feasibility studies and other parties concerned the possibility of evaluating the practical application of siting factors and criteria.

Selection Procedure and Criteria

In SKI's opinion, in RD&D Programme 98, SKB has presented an adequate structure for defining siting factors and general safety functions prior to the selection of sites for site investigation and site evaluation.

SKI shares SKB's opinion that the suitability of a site for a repository must ultimately be judged on the basis of an integrated safety and design analysis which takes into account uncertainties and the interaction between different factors. The criteria fulfil an important function in clarifying what characterises a suitable site for a repository. However, on their own, the criteria do not provide an adequate basis for judging whether the site complies with the basic safety criteria.

Like Oskarshamn Municipality, SKI emphasises that it is important for SKB to account for how it balances the various siting factors (safety, technology, land, environment and society) in the selection of sites for site investigations. On the basis of an up-to-date safety assessment (SR 97), SKB must also reconcile and clearly account for the minimum criteria and discriminating factors which determine whether a site can be judged to be suitable for a repository.

SKI concludes, like SSI and the Geological Survey of Sweden (SGU), that SKB should improve the investigation and account of the importance of biosphere conditions, recharge and discharge areas as siting criteria.

SKI concludes that SKB's work on defining requirements and preferences relating to basic safety functions which can be made with respect to the function of the bedrock is closely connected to the development of a description of the repository process system. The aim of the description in the safety assessment is to identify and describe all of the processes and conditions which can affect the performance and safety of the repository. In SKI's opinion, SKB should improve the explanation of how these activities have been co-ordinated.

4.6.4 Site Investigations and Site Evaluation

Geoscientific Site Investigation Programme

In SKI's opinion, it is positive that SKB is planning to conduct the site investigations in stages with periodic performance and safety assessments, since this will give SKB an opportunity to interrupt the investigation at a site if the site is not considered to be suitable for further study.

SKI agrees with SKB that the Äspö Hard Rock Laboratory has given SKB access to established measurement methods and expertise for conducting site investigations. SKI also views SKB's programme for the further development of certain measurement methods and instruments as a positive step and concludes that SKB has taken SKI's previous recommendations fully into account.

At the same time, SKI now concludes, as in previous RD&D statements, that considerable work remains to be done to develop individual measurement methods and, particularly, to determine how different measurements should be combined into a suitable site investigation programme prior to the safety assessment. In SKI's opinion, SKB must show that it has relevant measurement methods in order to determine, on a site-specific basis, some of the more critical parameters in the safety assessment. This applies, for example, to the measurement methods which are necessary to analyse the retention and retardation capabilities of the bedrock, rock stability and the capability of the bedrock to buffer any changes in the groundwater chemistry. SKI therefore urges SKB to review, and if necessary, develop the measurement methods which can be used to determine these parameters, already at the site investigation stage.

In SKI's opinion, it is important that SKB, at an early stage of a site investigation, should prepare the necessary data for determining the large-scale flow pattern and regional trends in geochemical conditions, e.g. deep to saline groundwater around the repository site. SKI would therefore like to see an account of the measurement work, e.g. deep boreholes, which is being planned on a regional scale in connection with a site investigation.

SKI also emphasises that SKB, prior to the start of site investigations, should present an overall programme for quality assurance of all of the components of a site investigation (measurement instructions and procedures, a description and verification of measurement instruments, the management of data, including databases, evaluation methods, documentation etc.).

Site Evaluation

In SKI's opinion, SKB's general premises for site evaluation are good. However, a safety assessment (SR 97) is required for an in-depth evaluation and this assessment has not yet been completed. Consequently, SKI intends to wait and present its views on SKB's site evaluation programme once SKB has presented SR 97 and when SKB has presented the entire body of material for site investigation and site evaluation.

SKI is of the opinion that SKB, prior to the planned site investigations, should clarify its strategy for the identification, evaluation and comparison of alternative conceptual models for, e.g. hydrogeology and radionuclide transport. SKI also emphasises that SKB should take into account alternative interpretations and models within other areas such as structural geology and geochemistry etc.

Like Chalmers University of Technology, SKI recommends that SKB should review and account for how it intends to manage and document the comprehensive body of data and information which will have to be handled during the site investigations.

5 Technical Development

5.1 Introduction

In Chapter 7 of RD&D Programme 98, SKB describes the status of the development of technology and its programme for future development work within different areas. For natural reasons, there is no sharp distinction between research and development. However, in SKI's opinion, where different activities are reported is not so important. The important factor is that the report should be complete and that nothing essential should be omitted.

SKB's programme for technical development should focus on meeting the performance requirements which can be made with respect to the different barriers on the basis of safety assessments for each facility. SKB must be able to show that the performance requirements can be fulfilled no later than when it submits a licence application.

In the introduction to Chapter 7 of RD&D Programme 98, SKB reviews and defines "fundamental technical requirements" which, in qualitative terms, correspond to the performance requirements above. SKI is of the opinion that SKB should review the structure of its account of these requirements and how the requirements can be developed, in stages, into increasingly detailed technical requirements and goals for the development work, as the decision-making process and the construction of facilities progress. This applies to engineered and natural barriers as well as barrier functions.

Another issue of importance to a technical development programme is the range of variation in the design of barriers which SKB will have to specify in its applications for permission to construct facilities. In SKI's opinion, it is not only quite acceptable but also necessary to include a certain range of variation, or freedom of choice, in the licence for a facility. In future reporting, SKB should also address these issues more clearly than it has done in RD&D Programme 98, even though the account of freedom of choice in the system analysis report (SKB, 1998) is a good start.

5.2 Canister

In this section, SKI discusses Sections 7.1.1, 7.2, 7.6.1 and 7.6.2 of RD&D Programme 98, and the background reports entitled Design Premises for Canister for Spent Nuclear Fuel (Werme, 1998) and Trial Fabrication of Copper Canisters with Cast Inserts (Andersson, 1998).

5.2.1 Design Basis

SKB s Report
SKB describes the basic requirements on the canister divided into initial integrity, chemical resistance and mechanical strength. The general integrity requirement is that no more than 0.1 % of the canisters may contain defects which exceed the acceptance

criteria permitted for non-destructive testing (NDT). Another requirement on the canister is that the material should not obviously impair the performance of the buffer. This means that requirements must be determined for maximum surface temperature, radiation levels, impact of the corrosion products and for ensuring that the canister does not reach criticality. In addition, it must be possible to handle the canister at the various necessary stages, and for it to be serial fabricated with a sufficient level of quality.

Based on a number of possible scenarios concerning the load conditions, SKB has performed strength analyses on the copper/cast iron canister. The usual safety factors for the anticipated load cases in a repository are applied in the design of the canister. For extreme load cases, such as an ice load, no safety factors are applied but the load is used as a design basis load case.

SKI s Evaluation

The derivation of the design basis from the basic requirements on the canister has an adequate structure, but the requirements need to be justified to a greater extent through consequence analyses in the safety assessment of the repository. The requirements should also be updated according to changes in the design of the canister. SKI therefore requires an updated version of the criticality analyses. Section 5.2.5 provides a more detailed discussion of the general integrity requirement that no more than 0.1 % of the canisters may contain unacceptable defects.

The criteria for the materials strength analyses require further clarification. These criteria depend, to a certain degree, on the properties of the bentonite and uncertainties arising from them, for which an integrated canister and buffer programme is important (see also Section 7.4.3). Furthermore, the materials strength analyses need to be updated with the results from investigations of the actual material properties of the canisters produced (defects, grain size, dimensions, etc.).

In the design basis, permitted values of stresses/strains and other loads should be clearly specified and justified. In addition, safety factors for the individual load scenarios should be justified based on the consequences each separate load case may have on the integrity of the canister. These will later be specified in the design basis. The load scenarios which are regarded as being less likely, and to which safety factors cannot be applied, such as for the impact of an anticipated ice load, are to be analysed and justified separately.

It is clear from the completed materials strength analyses that the handling loads can give rise to local plastic deformation, such as in the lid. The effects of this on the initiation/increase of fractures and other defects, particularly against the background of possible fabrication and design defects and possible radiation-induced embrittlement, should be analysed.

SKI’s rough estimates performed on the lid of the canister indicate that the lid will undergo plastic deformation due to the postulated repository loads. As a result of this deformation, certain parts of the canister and lid will be exposed to tensile stresses. SKI considers, therefore, that there is a risk of stress corrosion on these surfaces, and that

SKB needs to show that this risk of stress corrosion is negligible in the environment around the canister.

5.2.2 Selection of Material

SKB s Report
SKB has selected copper as a barrier against corrosion to fulfil the chemical requirements in the repository environment. In order for a canister to fulfil the requirements for mechanical strength, SKB has chosen a pressure-bearing cast-iron insert.

A material specification for the copper proposed by SKB has been reported in (Werme, 1998). According to the specification, the material will have a 40-60 ppm phosphorus content. This is justified by the positive effect of the phosphorus on the creep properties of the copper. SKB specifies 350 μm as an appropriate upper limit for the grain size of the copper, with the justification that, with grain sizes smaller than this, sufficient resolution is attained during ultrasonic testing.

SKB has proposed nodular iron SS 14 0717 for the insert. The use of cast iron, instead of the cast steel tested previously, is justified by the fact that cast iron is easier to mould.

SKI s Evaluation
SKI considers SKB's description of its choice of copper as canister material to be both well-structured and well-reasoned, in view of both the chemical resistance and the mechanical strength criteria, and from a review of how and whether other design criteria affect the selection of material.

The mechanism by which phosphorus affects the creep properties of the material has not been explained, and SKI is of the opinion that this issue should be investigated, and that SKB should find out whether an improvement to the creep properties will also include the creep strain to fracture.

SKI considers the grain size to be an important property of the material. The mechanical properties and creep properties are both affected by the grain size of the copper. SKB must justify the grain size criteria based on the anticipated properties of the copper canister and the consequences of an incorrect grain size, and not merely allow the resolution in connection with ultrasonic testing to be the determining factor for the grain size criteria.

In connection with investigations of material properties, SKB should observe that the results obtained from fine-grain material are not necessarily representative of course-grained material. For example, material with a lower grain size was used for investigations of creep properties which have been conducted. SKI considers, therefore, that SKB should ensure that the positive impact which it claims that the phosphorus has on the creep ductility also applies to the material which is to be used to fabricate the copper canisters.

In its evaluation of SKB's RD&D Programme 95, SKI enquired about whether hot shortness could pose a problem if copper is used for fabricating the canisters. The problem lies in the production of the wire, but can be avoided by maintaining an oxygen content of 200 to 300 ppm in the copper, which will oxidise the low-melting substances in the grain boundaries. If oxygen-free (OF) copper is used, this will not be possible. According to SKI, SKB should investigate the issue in connection with its selection of copper material.

SKI agrees with SKB that nodular iron is a better alternative to cast steel for the insert, in terms of casting. Furthermore, the present design provides better support and mechanical strength. However, SKI emphasises that the mechanical properties of the nodular iron are very dependent on the shape and size of the cast insert. SKI is of the opinion that SKB should investigate the actual mechanical properties of the cast insert, and then use these properties to estimate its strength. Similarly, the defects which arise (in the copper canister and iron insert as well as in the weld) need to be identified and catalogued so that they can be used when the safety factors are determined for the materials strength estimations.

5.2.3 Design of the Reference Canister

SKB s Report
SKB is of the opinion that, when corrosion resistance and mechanical strength criteria as well as criteria for fabricating and handling are balanced, 30 mm appears to be a suitable wall thickness for the copper. However, until now, trial fabrication has taken place based on the reference canister which has a 50 mm copper thickness.

In order to fulfil the requirements of a surface dose rate which does not exceed 1 Gy/h, the total wall thickness must be a minimum of 100 mm. When switching to copper with a 30 mm wall thickness, the thickness of the insert must be increased accordingly.

Comments by the Reviewing Bodies
Oskarshamn Municipality and the Local Safety Committee, Oskarshamn Nuclear Power Plant (LSNO) question whether a reduction in the copper thickness to 30 mm is scientifically supported and also say that a reduction in the level of ambition for the various barriers is not to be determined by financial factors.

SKI s Evaluation
Safety factors and descriptions such as "the canister must withstand all known corrosion processes" are applied in SKB's derivation of criteria for wall thickness in terms of corrosion. SKI's consultants, Bowyer and Hermansson (1999), indicate that the corrosion processes in question are to be described as quantitatively as possible, and further maintain that the use of safety factors can be misleading. They give the well-informed reader the impression that there is considerable uncertainty, whilst the unfamiliar reader may gain a false sense of security. SKI emphasises the importance of the assumptions and analyses which form the basis for the corrosion rates used in designing the thickness of the copper.

In view of the work which has been in progress in recent years, and SKB's current work in the field of corrosion (for a detailed discussion concerning corrosion research, see Section 7.3.1), SKI is of the opinion that SKB should compile a new account of how various kinds of corrosion affect the design of the copper canister.

SKI agrees with SKB's reasoning that there are both advantages and disadvantages to the copper canister having a smaller thickness, in terms of fabrication, sealing and control methods. The fabrication of copper plates (for rolling), sealing and control methods will probably be simplified with thinner walls. However, fabrication by extrusion or pierce and draw processing, however, can be more difficult when the material thickness is reduced, as it makes the canister more sensitive in terms of handling and transportation. The thicker insert which, due to radiation factors, is necessary for a thin-walled canister, will probably have a positive effect on the load-bearing capacity of the canister. At a later stage, SKB intends to investigate and report on how these factors are balanced in connection with the design of the canister. SKI presumes that the reporting will take place in the same structured way as for the derivation of other design basis factors.

Presuming that SKB can prove, with results obtained through fabrication and with consequence analyses in the safety assessment, that the canister fulfils the design requirements, SKI is not opposed to a change in design to a thinner wall thickness for the copper canister.

5.2.4 Sealing

SKB s Report

For many years, SKB has concentrated on using electron beam welding (EBW) for joining copper tubes and lids. Successful tests have been performed, but defect-free welding has not yet been achieved. The design of the weld joints is being developed to achieve a better weld.

SKB has commenced initial studies on an alternative sealing method: friction stir welding (FSW). The test welds, which have been made in 40 mm thick copper, are currently under evaluation, and SKB is planning to continue this project.

SKI s Evaluation

SKI observes that electron beam welding with a reduced vacuum has not been fully developed, and that a comprehensive development programme is required for understanding and solving the problems associated with the EBW method. In addition, SKI is of the opinion that SKB should show that the problems with the welding process (flash-overs) can be monitored so that neither the canister nor its contents are damaged in the encapsulation plant.

In view of the time which has so far been dedicated to developing the EBW method, SKI considers that more work concentrating on alternative methods will be required if the method testing in the Canister Laboratory does not give the desired results within a

reasonable period of time. SKI would therefore like to see a more detailed programme for the development of other methods, such as the FSW method.

Methods and criteria for weld repair should also be developed. Similarly, methods for cutting up welds which have completely failed need to be developed and reported.

5.2.5 Non-destructive Testing

SKB s Report
SKB specifies that no more than 0.1% of the canisters are permitted to contain non-detected defects which are greater than the acceptance criteria tolerance level. SKB considers that this level can be attained using methods available for testing, in this case ultrasonic and X-ray testing.

Over the next three years, SKB intends to test the equipment for non-destructive testing. The chosen method of testing must fulfil the criteria for detecting defects. Only in the period subsequent to this does SKB intend to qualify the equipment.

Comments by the Reviewing Bodies
Oskarshamn Municipality and LSNO understand that the critical parts which still need to be developed and affirmed through investigations and research include:

- fabrication of the copper for the canister,
- sealing the copper canister,
- testing the copper canister.

SKI s Evaluation
SKI does not consider that SKB has proven in RD&D Programme 98 that, the claim that, with available methods for testing, the criteria of a maximum of 0.1% defective canisters can be met. SKI further considers that SKB must derive acceptance criteria for permitted defects. This should be based on the safety assessment; the consequences, if more/greater defects than the acceptance criteria level are found in both the canister material and the weld, must be described.

SKI emphasises that it is important for the development programme for ultrasonic testing to continue, and for a similar programme for the development of X-ray testing to be reported, and for these testing methods to be qualified. For detailed comments concerning further research and development work on non-destructive testing, see Section 7.3.3.

Like Oskarshamn Municipality and LSNO, SKI considers that a crucial issue for the technical feasibility (with the KBS-3 method) is for SKB to show that methods both for sealing and for inspection (non-destructive testing; including qualification of the methods) really are available and suitable for serial fabrication. This means that a sufficiently large number of full-size canisters will have to be produced, sealed and inspected, and shown to fulfil the long-term safety criteria stipulated in the safety assessment.

5.2.6 Trial Fabrication of Full-Scale Canisters

SKB s Report

SKB has fabricated full-scale copper tubes using three different methods: roll-forming into tube halves which are welded longitudinally, extrusion of tubes, and pierce and draw processing of tubes. The lid and base of the copper canister are made of forged copper, whereas the insert and its lid are made of cast iron.

During 1996-1998, ten copper tubes were fabricated by roll-forming. Coarse-grained structure and considerable variations in grain size have been obtained. Moreover, a large number of problems have been reported concerning the longitudinal welding of these tubes.

Two seamless tubes had been fabricated previously. In recent years, three tubes have been fabricated by extrusion. The results are very promising. Low tolerances and a fine-grained material have both been achieved.

Three ingots have been fabricated for pierce and draw processing. During 1998, an ingot was processed into a seamless copper tube. The results from the first tube fabrication test have not been sufficient, but the methods will be investigated further, with more fabrication tests.

Three further alternative fabrication methods (hot isostatic pressing, electrodeposition and spray forming) for the copper tube have been investigated by SKB, but full-scale fabrication tests have not yet been performed using these methods. Laboratory-scale tests are being performed for hot isostatic pressing and electrodeposition. Results from these tests will determine whether it is appropriate to continue work with these methods.

During 1996-1998, eight inserts were fabricated out of nodular iron and one insert of cast steel. In an earlier test, half a length was also fabricated out of cast steel. One of the nodular iron inserts is intended for PWR fuel. Both tests using cast steel inserts showed substantial porosity and transverse cracks between the channels. The cast steel profiles were highly deformed in parts. The insert consisted of two halves, which were attached to each other, and had a welded base. Due to the fabrication problems and defects which arose, SKB chose to change the material to nodular iron.

Seven inserts designed for BWR fuel and one for PWR fuel have been cast in three different foundries. When nodular iron is used, the inserts can be cast directly with integrated bases. Better results have been obtained with nodular iron. However, the ductility of the fabricated nodular iron insert is much lower than that of cast steel inserts.

SKI s Evaluation

According to SKI, the grain size of the copper has a substantial effect on the mechanical and creep properties of the material. With further trial fabrication, SKB needs to show that an improved and more even material can be obtained using the roll-forming method, if this is to be used for fabricating copper canisters.

The results from the longitudinal welding of the roll-formed copper tubes are difficult to assess as there are still no criteria for weld evaluation. As soon as possible, SKB must produce such criteria, based on the effects that defects can have on the integrity of the canister. SKI questions the validity of SKB's claim that the method is probably fully developed and that the roll-forming and longitudinal welding methods are appropriate for fabricating copper tubes. According to SKI, quality improvements are necessary both for the material and for the weld, before the roll-forming method for copper halves and longitudinal welding can be shown to be a functioning method. SKI's consultants, Bowyer and Hermansson (1999) do not consider that the method is sufficiently reliable to be used for serial fabrication. SKI agrees that it may be difficult to attain a sufficiently consistent quality.

SKI notes that annealing is specified for the rolled tubes. In consideration of the low and variable stresses which occur, SKB should investigate whether this could result in critical grain growth.

SKI agrees that the extrusion method is a very interesting alternative for fabricating copper tubes. SKI also agrees with SKB that the pierce and draw processing method is an interesting alternative which should be investigated further.

SKI considers that SKB still has a lot of work to do before it can fabricate a copper canister which fulfils the criteria stipulated by the safety assessment on the performance of the canister. SKI is also of the opinion that SKB should still be prepared, in the future, to change over to alternative methods of fabrication.

As the mechanical properties of nodular iron are very dependent on the dimensions of the cast insert, SKI is of the opinion that materials testing must be performed on the completed inserts in order to establish their actual mechanical properties. The results from the described tests can form the basis for any adjustments to the casting process. The final results will also be able to provide input data in connection with the final materials/strength calculations which SKI considers necessary. In addition, SKB must demonstrate that the mechanical properties of the cast component are satisfactory for the integrity of the canister. An inspection programme for detecting defects in the insert material which arise due to shrinking or other reasons must also be produced. In addition, a thermal load model showing where creep stresses occur in the cast insert should be developed, as well as the reporting of acceptance limits for such defects.

5.2.7 Quality Assurance

SKB s Report

According to SKB, in accordance with the requirements of ISO 9001 and IAEA 50-C-QA, the development of a quality system for the canister fabrication has commenced and is in developed progress in connection with trial fabrication. The Quality Manual – Canister Fabrication covers the quality system for canister fabrication.

SKI s Evaluation
SKI is of the opinion that the Quality Manual should be a living document and adjusted or supplemented with regard to the facts which arise during the development process.

Only a few canisters have been fabricated to date. SKI considers that SKB needs to show that it is possible to fabricate a large number of canisters which have been approved in accordance with the stipulated quality criteria, in existing or new industrial facilities

The canisters and cast inserts which have been fabricated to date have not been fully analysed with respect to structure, mechanical properties, etc. Differences in grain size in canisters fabricated using different methods, or the same method but using different parameters, have nevertheless been reported. The roll-formed tubes have been longitudinally welded and the base and lid have been welded to the tube. The weld joints have contained different kinds of defects, and SKB considers that the welding process must be developed further. The measured prolonged values for the cast inserts in nodular iron have been shown to be significantly lower than anticipated. SKI is of the opinion that the identification of defects which have arisen and of the properties of the fabricated canister are very important for future work with quality assurance and especially for producing reliable quality control methods.

5.2.8 Full-Scale Testing of Technology

SKB s Report
In RD&D Programme 95, SKB gave details of plans to establish a pilot facility for canister sealing. This facility has now been constructed in the Canister Laboratory in Oskarshamn, with the main objective of being a centre for developing encapsulation techniques and for training personnel.

A central part of SKB's future work is to develop, test and demonstrate the various parts of the final disposal system, on a full scale and under realistic conditions. The testing will include the most important factors associated with fabricating and sealing canisters, and with building, operating and closing the repository. Tests using trial fabrication of canisters have been in progress over several years. Activities will increase over the next few years.

Comments by the Reviewing Bodies
The Swedish Natural Science Research Council (NFR) points out that SKB's forthcoming programme puts emphasis on full-scale tests. NFR is of the opinion that the tests may provide valuable experience in terms of processes which are of important for "pollution", but also that interdisciplinary work is required for designing and for interpreting the experiments.

SKI s Evaluation
In its review of RD&D Programme 95, SKI was very positive towards SKB's plans to establish a pilot facility for canister sealing, and now considers it very valuable that SKB has a facility to develop sealing and testing for full-size canisters, and to secure a

basis for its work with designing the processes, and also for the actual encapsulation plant.

As SKI is of the opinion that SKB may need to develop other methods of sealing in parallel with its development of electron beam welding, SKI also regards it necessary for SKB to consider the requirements of these alternative methods in connection with the design of the encapsulation plant.

SKI's comments about canister deposition and retrieval demonstrations at the Äspö Hard Rock Laboratory are discussed in Section 7.12.

5.2.9 SKI s Evaluation of the Canister

SKI states that canister development has begun in earnest within several areas. Examples of this include the fabrication techniques for both the copper canister and insert, as well as the sealing and inspection of the canister, which SKI considers to be positive. However, many issues remain, concerning both technical problems which need to be solved as well as concerning how long-term safety criteria and requirements will be derived from the safety assessment. SKI does, however, consider it very valuable that SKB has set up the Canister Laboratory in Oskarshamn, where full-scale sealing and testing can be developed.

SKI considers that the design basis which is derived from the basic canister criteria has a good fundamental structure, but that the requirements need to be justified, to a greater extent, through consequence analyses in the safety assessment for the repository. The requirements also need to be updated due to changes made in canister design and due to the results form investigations of the actual materials properties of canisters (defects, grain size, dimensions, etc.). In addition, SKB should show that the risk of stress corrosion is negligible on the surfaces which are exposed to tensile stresses due to plastic deformation in connection with repository loads.

SKI considers SKB's description of its choice of copper as canister material to be both structured and justified, based both on chemical and mechanical strength requirements, and on a survey of how and whether other design criteria affect the choice of material. However, the mechanism whereby phosphorus affects the material's creep properties is unclear, and SKI considers that this issue needs to be investigated. Furthermore, SKI is of the opinion that grain size is an important material property which affects both mechanical and creep properties and testability. SKB is to justify the requirements stipulated for grain size, based on the properties expected in the copper canister and the consequences which incorrect grain size can give rise to.

SKI agrees with SKB that nodular iron is a better choice of material than cast steel for the insert. However, SKI emphasises that the mechanical properties of the nodular iron are heavily dependent on the form and size of the cast insert. SKI considers that SKB should investigate the actual mechanical properties of the cast insert, and identify and catalogue occurring defects. The latter applies, in general, to all the components of the canister, including the weld.

SKI emphasises that the central factors when deriving the requirements for the wall thickness of the canister are the assumptions and analyses on which the corrosion rates for determining the copper thickness are based, and not the actual application of the safety factors. Bearing in mind the work carried out in recent years, and SKB's current work within the area of corrosion, SKI is of the opinion that SKB should produce new documentation describing how different types of corrosion form the basis for the design of the copper canister.

SKI agrees with SKB's line of reasoning that there are both advantages and disadvantages to thinner walls for the copper canister in terms of fabrication, sealing and inspection methods. SKI assumes that further reporting on how other factors are also balanced in connection with the design of the canister will take place in the same structured way as in connection with the derivation of the design basis factors which have been used so far.

SKI observes that electron beam welding with a reduced vacuum has not been completely developed, and that a comprehensive development programme is required, in order to understand and solve the remaining problems. In SKI's opinion, if the testing of the method in the Canister Laboratory does not show satisfactory results within a reasonable period of time, intensified efforts to develop alternative methods may be necessary.

SKI does not consider SKB's claim that, using available testing methods, it can fulfil the criterion of no more than 0.1% of the canisters being defective, to have been proven in RD&D Programme 98. Further, SKI considers that SKB must produce acceptance criteria for permitted defects in all the canister's components and the weld. SKI also underlines the importance of continuing the development programme for ultrasonic testing, and for a corresponding programme for the development of X-ray testing to be reported as well as for these testing methods to be qualified.

SKI questions SKB's claim that roll-forming and longitudinal welding is an adequate manufacturing method for copper tubes. In SKI's opinion, quality improvements are necessary both for the material and the weld, before the method can be proven to be one which performs well. SKI agrees that the extrusion and pierce and draw processing methods are very interesting alternatives for the fabrication of copper tubes, and that they should be investigated further.

As with Oskarshamn Municipality and LSNO, SKI considers that a critical issue for the technical feasibility (for the KBS-3 method) is for SKB to show that sealing and inspection methods (non-destructive testing, including qualification of the methods) really are available and suitable for serial fabrication, which means that a sufficiently large number of full-size canisters need to be fabricated, sealed, inspected and proven to fulfil the requirements stipulated by the performance assessment for long-term safety.

5.3 Encapsulation

SKB s Report

Facilities in the Encapsulation System

SKB describes a system for the encapsulation of spent fuel, consisting of a canister factory, an encapsulation plant and a buffer storage facility for filled canisters. In the encapsulation plant, spent fuel is placed in the canisters which are then sealed. The interim store for filled canisters is intended to function as a buffer, with the purpose of reducing the effects of disturbances during deliveries to the repository.

Canister Factory

SKB states that the canisters for the encapsulation of fuel will be fabricated in a special canister factory and, in an initial investigation, accounts for how such a factory could be designed (Andersson, 1997). The investigation is based on a fabrication method whereby rolled copper plates are roll-formed into tube halves which are then joined by longitudinal electron beam welding.

The site for the factory has not been determined, and issues which need to be considered before making a decision on siting concern transportation to and from the factory, as well as access to labour and the industrial environment. An alternative which will be studied is a siting in the same region as the encapsulation plant or the repository, but other sites may also be of interest.

Over the coming years, SKB will perform more detailed analyses of the design of the plant and investment expenses.

Encapsulation Plant

The encapsulation plant consists of an encapsulation building for sealing canisters. Initially, only spent fuel will be encapsulated, but the plant will be prepared for subsequent expansion with equipment for handling core components. The plant will be designed for operations comprising a capacity of approximately 200 fuel canisters per annum and approximately 100 moulds per annum for core components. It is presumed that the encapsulation of spent fuel and the production of moulds with core components will take place at separate points in time.

SKB describes four essentially different siting options for an encapsulation plant; at CLAB (central interim storage facility for spent nuclear fuel), at the repository, at existing nuclear facilities or at another site. The various alternative options have, in the present situation, only been generally investigated, and SKB maintains that they will be analysed in greater detail before a final decision is reached in connection with its application for a licence to build the plant.

SKB recommends and describes a plant located next to CLAB, which will provide several advantages compared with other alternatives, such as co-ordination with existing operations, access to competence in terms of fuel handling, and experience with radiological activities. Moreover, off-site transportation is avoided in connection with the transfer of fuel from CLAB to the canister (Gillin, 1998).

The encapsulation plant, like the other stages in the planned process, including the treatment of core components, is described in detail, based on the existing concept for the canister and sealing. The intention is to co-ordinate service functions, to a great extent, with existing activities on the Simpevarp Peninsula.

During the next few years, SKB intends to use its experiences from activities at the Canister Laboratory in Oskarshamn for developing the encapsulation process. It also intends to conduct in-depth studies on the treatment of core components in the encapsulation plant and to produce background material before applying for a licence for building an encapsulation plant.

Comments by the Reviewing Bodies
Oskarshamn Municipality and LSNO indicate that both the encapsulation plant and the canister factory constitute parts of a system for final disposal of nuclear waste, and that siting decisions for these facilities cannot be made until siting decisions for the repository have been made. Nyköping Municipality, Oskarshamn Municipality and LSNO also discuss the fact that the basis for the initial reasoning was that the encapsulation plant would be sited next to CLAB. In view of this, it is important that alternative sites should be further investigated prior to a siting decision, and especially in terms of siting next to the repository.

SKI s Evaluation
In SKI's opinion, the work completed on the design of the canister factory and encapsulation plant seems reasonable. However, SKI would like to emphasise that the detailed design will be determined by the canister fabrication and sealing methods which are ultimately selected.

SKB describes an encapsulation plant located next to CLAB and, to a certain degree, integrated with CLAB's existing handling and service systems. A substantial part of the reporting is made up of references to established activities and to existing documentation concerning criteria and safety reporting for CLAB.

SKI agrees that co-siting the encapsulation plant with CLAB has many advantages. However, SKI highlights the importance of performing a systematic analysis of siting aspects which affect the operation of the plant, for the essentially different siting options which SKB has reported.

SKI also emphasises the importance of a clear and separate safety report presented prior to SKB's application for a licence to build the plant.

5.4 Transport

SKB s Report
In RD&D Programme 98 and in the background report concerning transportation (Ekendahl and Petterson, 1998), it is stated that the encapsulation plant is planned to be located near CLAB.

The entire transportation chain from the encapsulation plant to the repository is described. To a large extent, the reporting builds on SKB's current transportation concept for fuel shipments from NPPs to CLAB with special tonnage. The parts which have been added are handling in connection with a possible reloading terminal for rail transportation and also the possibility of using road transportation. The report discusses important points such as organisation, protection, incidents and extreme events.

Comments by the Reviewing Bodies

The Swedish Board of Housing, Building and Planning states that the transportation issue has not been sufficiently investigated, as infrastructure investments are dealt with in a separate planning process with a ten-year time scale. Necessary investments as result of a siting must therefore be made at an early stage. The Swedish Board of Housing, Building and Planning also considers that alternatives to heavy road transportation and hence the resulting need for road reinforcements, the construction of a new railway, etc. have not been explained sufficiently. The Swedish Board of Housing, Building and Planning's conclusion is that the transportation systems need to be studied more thoroughly.

The county administrative board in Västerbotten states that the environmental impact statements must also include transportation to the deep repository.

The Royal Institute of Technology (KTH) states that the transportation issue has been given cursory treatment despite the fact that its risks are not negligible.

SKI s Evaluation

SKI concludes that the transportation system presented is based on the assumption that the encapsulation plant will be located next to CLAB. This will simplify the transportation chain considerably, and will result in less handling of non-encapsulated fuel. A concept in which the encapsulation plant is not located next to CLAB must, however, be reported. A hypothetical description of how a canister that is damaged during handling would be transported from the repository back to the encapsulation plant is also needed.

The concept for the transportation of canisters between the encapsulation plant and the repository is largely based on SKB's current transportation system for spent fuel and nuclear waste. Operating experience from the current system has been good. Safety during transportation is mainly based on the use of B packaging, according to IAEA's definition. This certified packaging is designed to withstand considerable stresses, without its barrier performance against the dispersion of radioactive substances being affected.

SKB mentions transportation by road as an alternative method of transportation. SKI emphasises the difficulties associated with long-distance road transportation of canisters containing spent fuel, as the weight of the whole load and equipment can be expected to exceed 100 tonnes and this may require a special licence. Apart from upgrading roads and bridges, such transportation will lead to an increased environmental impact. SKI concludes, as does the Swedish Board of Housing, Building and Planning, that SKB should investigate and consider the alternative of building a new railway instead of

using road transportation, in the event of siting the repository in the interior of Sweden, in a region without a railway.

5.5 Final Disposal Technology

Sections 7.4 and 7.6 of RD&D Programme 98 and Chapter 14 of the Detailed Programme for Research and Development 1999-2004 are discussed here. The points listed below are discussed and commented upon in particular:

- Design co-ordinated with R&D, safety assessment and siting work.
- Size and design of the deposition tunnels (method).
- Vertical vs. horizontal deposition (or other alternative deposition angles).
- Acceptable damage zone in deposition tunnels and deposition holes.
- Criteria for acceptance and rejection of deposition holes (need for grouting).
- Performance of the bentonite in the deposition holes (resaturation).
- Backfill with bentonite and crushed rock.
- Use of concrete in the repository.
- Full-scale testing of technology.

5.5.1 General Comments

SKB considers that the design must be continuously co-ordinated with research, safety assessment and siting work. SKI particularly emphasises that it is important that the requirements of the research and safety assessment are fulfilled in this context.

In its evaluation of RD&D Programme 95, SKI requested that a repository on two levels should be investigated. This has not yet been done.

5.5.2 Design of the Repository

SKB s Report

Deposition tunnels

In its initial layout descriptions, SKB outlined a number of different sizes for the tunnel area, depending on tunnel type. For financial reasons, SKB is trying to obtain as small a cross-section as possible for the deposition tunnels, in this case a tunnel height of approximately 5 m (Lönnerberg and Pettersson, 1998). The width of the deposition tunnels depends on the space needed for the operation and design of the deposition machine (with radiation shield).

Alternative deposition technology

SKB’s completed system studies have not altered SKB’s opinion that the KBS-3 method should still be the main alternative, but SKB still intends to continue investigating horizontal deposition in medium-long holes (the MLH method), for both technical and economic reasons.

Damage zone in tunnels and deposition holes
Comprehensive tests on the extent of a damage zone in both blasted and drilled (by TBM) tunnels have been conducted by SKB at the Äspö Hard Rock Laboratory (ZEDEX). In Olkiluoto, Posiva Oy has conducted similar tests on full-face bored deposition holes. SKB's and Posiva's assessments of the results indicate that boring with TBM equipment results in a significantly reduced damage zone in the rock, in comparison with the conventional drill and blast technique.

Performance of bentonite in deposition holes
One requirement for the buffer in the deposition holes is that the swelling pressure must be sufficiently high to provide good contact with the surrounding rock and the canister, but not so high that the canister and surrounding rock cannot withstand it. Another requirement is that the plasticity must not be so great that the canister can be dislodged, but not too small to prevent rock movements from being absorbed without damaging the canister.

Technology demonstrations for the performance of important parts of the final disposal system are planned at the Äspö Hard Rock Laboratory. The "Prototype Repository" experiment will be included in this. The experiment will focus on testing and demonstrating the performance of the final disposal system in terms of certain processes or quantities, such as:

- water uptake in the buffer and backfill,
- distribution of temperature in the canister, buffer, backfill and rock,
- swelling pressure and movements in the buffer and backfill.

Backfill
In a study for SKB, Karnland (1997) has described how saline groundwater affects the swelling properties of the bentonite in the backfill. Impaired swelling properties can cause, or contribute toward, the formation of channels which can create fast flowpaths in the backfill.

Concrete in the repository
SKB discusses permanent concrete plugs for tunnels and fracture zones (even disturbed zones). SKB has also indicated in Lönnerberg and Pettersson (1998) that concrete is needed in the floor of the deposition tunnels in order to stabilise the rails for the deposition machine. SKB plans to use large quantities of concrete in the SFL 3-5 repository.

Comments by the Reviewing Bodies
The Swedish Anti-Nuclear Movement (FMKK) considers it reprehensible to use concrete plugs to seal the deposition tunnels, as it is a well-known fact that concrete and bentonite are probably an unsuitable combination because of the mutually destructive effect that both materials have on each other.

SKI s Evaluation
SKB proposes a more detailed method investigation for blasting or boring (TBM technique) deposition tunnels with the desired cross-sections. SKI agrees with SKB that

TBM requires further development for the boring of short tunnels, which SKI considers necessary in order to use TBM equipment for boring deposition tunnels.

SKB's proposed deposition tunnel height of 5 m seems far too narrow if the size of the canister (height 4.8 m) is taken into consideration. If SKB's proposed technique with the sequential deposition of bentonite blocks and canister in vertical holes does not perform as planned, a simultaneous deposition of the bentonite and canister in a "package" will place a considerably larger (and more expensive) demand on the tunnel area.

In SKI's opinion, it is important for SKB to keep the way open for alternative deposition techniques, even though SKI agrees with SKB that the KBS-3 method is, for the time being, the main alternative.

In its review of RD&D Programme 95, SKI proposed testing horizontal canister deposition in medium long holes (MLH) at Äspö. SKB, which is taking part in a full-scale experiment on horizontal deposition in a bored tunnel (FEBEX) at the Rock Laboratory in Grimsel, Switzerland, will monitor the results from this experiment and from planned vertical deposition at the Äspö Hard Rock Laboratory, before deciding whether to perform a full-scale test of the MLH method at the Äspö Hard Rock Laboratory. SKI considers it appropriate that SKB is monitoring the results from the FEBEX experiment in order to use relevant knowledge before any decision is reached concerning testing at the Äspö Hard Rock Laboratory.

In SKI's opinion, it is important to develop and use reliable methods to identify the scope of the damage zone in tunnels and deposition holes in a repository, as the zone may constitute a direct transportation path for released radionuclides from any damaged canisters in the repository. A further discussion about the interpretation of SKB's results from the ZEDEX experiment is presented in Section 7.12.

As far as the acceptance or rejection of deposition holes is concerned, SKI concludes that SKB has not yet discussed which criteria should apply for the acceptance of a deposition hole. The most important criterion concerns the size of the water flow that can be accepted in order to obtain an even resaturation of the bentonite. A decisive factor in this context is whether cement grouting around the deposition holes should be permitted in order to stop or limit the water flow. In SKI's opinion, too extensive grouting may have an adverse affect on the chemical environment around the deposition holes.

The size of open or closed mineralised fractures in the walls of the deposition holes are other factors which, from a safety point of view, may be important in the long term (in connection with future rock movements which can affect the canister). SKI considers that these are criteria and issues which require further investigation and analysis. An uneven resaturation of the buffer can lead to a heterogeneous stress distribution over the canister and can also result in heterogeneous transport and sorption properties in the buffer.

SKI emphasises that SKB should carefully take into account the experience gained in connection with completed or ongoing large-scale experiments (prototype repository) such as STRIPA, Kamaishi or FEBEX. Experience has proven that it is difficult to con-

vert small-scale laboratory experiments to a large scale, with respect to the possibility of analysing what the experiments really show. It is important to keep good control over boundary conditions, effects of scale, measurable sizes, etc. and related uncertainties, in order to be able to evaluate the experiments. It is also essential to perform calculations and make predictions prior to the experiments, so that it is possible to compare prediction with outcome.

As regards backfilling, SKI considers that a mixture of bentonite and crushed rock requires the homogenisation of the material to be guaranteed in order to obtain an acceptable barrier performance. Considerable geological variations (mineral composition) can cause problems in terms of the homogenisation criterion. Furthermore, a small percentage of potassium in the crystalline rock can affect the bentonite (illitisation). The compression criterion in the material must also be guaranteed in order to prevent the bentonite from swelling out of the deposition holes.

Pure crushed rock as backfill material has been studied by SKB in combination with permanent tunnel sealing. For this to work, a narrow grain size will probably be needed for the crushed rock. The same criterion applies in terms of compressibility for pure crushed rock as for the mixture of bentonite and crushed rock.

As crystalline rock is deposited above the ground for lengthy periods of time, it is likely that mineral alteration will take place, and that a new microbial environment will form (biofilm formation) which, when returned to the level of the repository, can have an adverse impact on the backfill.

SKI's consultant (Savage et al., 1998) believes that the use of concrete in SFL 3-5 may pose a problem, as this repository part may affect the SFL 2 repository. SKI is also of the opinion that SKB has still not made much progress in its assessment of the impact of concrete and other materials on the long-term safety of a repository. SKI considers that SKB should, as far as possible, avoid unnecessarily introducing foreign material into the environment of the repository and, if an undesirable impact is discovered, should show this impact can be analysed and dealt with. Before closure, it may also be necessary to remove any inappropriate material.

5.5.3 Full-Scale Testing of Technology

SKB s Report

SKB considers that the Äspö Hard Rock Laboratory has provided valuable experience in terms of the further development and testing of technology for building a repository and the investigation of the rock in connection with construction. As tunnel construction was performed with both conventional blasting and drilling, and with a tunnel-boring machine (TBM), valuable material was obtained for the choice of excavation methodology in the future repository.

SKI s Evaluation

SKB's programme for boring deposition holes, testing a deposition machine, testing backfill techniques and testing retrieval at the Äspö Hard Rock Laboratory are activities

which SKI considers essential in order for SKB to gain credibility and acceptance for the concept of final disposal.

As regards the boring of deposition holes, SKI approves of SKB's plans for supplementary laboratory experiments and field experiments in order to study, in particular, the hydraulic properties of the bentonite - bedrock - damage zone interface (see SKI's discussion of ZEDEX in Section 7.12).

SKI regards the deposition of radiation-shielded canisters at the Äspö Hard Rock Laboratory with a prototype of a deposition machine as a relatively large technical challenge, especially as SKB considers that it should be possible to perform the deposition of full-size canisters in a TBM tunnel with a limited (5 m) diameter. However, planned retrieval tests will be performed in a blasted tunnel with a considerably larger tunnel area.

5.5.4 SKI s Evaluation of Final Disposal Technology

The tunnel height proposed by SKB of 5 m in the deposition tunnels seems to be far too narrow if the size of the canister (height 4.8 m) is taken into consideration. If SKB's proposed technique with the sequential deposition of bentonite blocks and canisters in vertical holes does not perform as planned, a simultaneous deposition of bentonite and canister in a "packet" will place considerably higher (and more expensive) demands on the tunnel area.

SKI considers it important for reliable methods to be developed and used in order to identify the extent of the damage zone in the tunnels and deposition holes in a repository, as the zone may constitute a direct transport path for released radionuclides from any damaged canisters in the repository. A detailed discussion about the interpretation of SKB's results from the ZEDEX experiment is presented in Section 7.12.

As far as the acceptance or rejection of deposition holes is concerned, SKI concludes that SKB has not yet discussed which criteria should apply for the acceptance of a deposition hole. The most important criterion concerns the size of the water flow which can be accepted in order to obtain an even resaturation of bentonite. A decisive factor in this context is whether cement grouting around the deposition holes should be permitted in order to stop or limit the water flow. In SKI's opinion, too extensive grouting may have an adverse affect the chemical environment around the deposition holes.

Further investigations and analyses are needed in order to explain how an uneven resaturation of the buffer can cause heterogeneous stress distribution over the canister and can also result in heterogeneous transport and sorption properties in the buffer.

In SKI's opinion, SKB should, as far as possible, avoid unnecessarily introducing foreign material, such as cement and concrete, into the environment around the repository.

5.6 Retrieval of Deposited Canisters, Monitoring

SKI discusses below Section 7.5 of RD&D Programme 98, Section 14.4.5 of the Detailed Programme for Research and Development 1999-2004 and the Safety during Operation of the Deep Repository report (Lönnberg and Pettersson, 1998).

5.6.1 General Comments

SKB considers that the repository should be designed so that the retrieval of deposited canisters is possible, but this requirement is not to impair the long-term performance of the repository. Individual canisters may need to be retrieved if it is proven that precisely these canisters do not meet the requirements or if, during monitoring , it becomes apparent that other components of the repository do not meet the safety criteria. Retrieval should also be feasible for all canisters, if there was preference for another method for disposing of or using nuclear fuel in the future.

The now accepted step-by-step construction of a repository for spent nuclear fuel and the issue of safeguards for a repository over an indefinite period of time have helped to bring the issue of retrieval and monitoring to the fore.

Another contributing factor for the discussion on retrieval in Sweden has been the application of KASAM's ethical principle. SKI supports this principle, which means that this generation, which has reaped the benefits of nuclear energy, must also take care of the waste and not transfer the responsibility to future generations; monitoring and retrieval must therefore not be made necessary. Moreover, future generations, probably with better knowledge and other values, must still have the freedom to make their own decisions; we should therefore not make retrieval and monitoring unnecessarily difficult.

5.6.2 Retrieval Methods

SKB s Report
Four different techniques for releasing the canister have been studied by SKB (Svemar, 1997). According to SKB, it appears that two methods - a hydrodynamic (with salt water) and a thermal (cooling) method – could be developed further. In Lönneberg and Pettersson (1998), SKB has illustrated the deposition process for canisters, which is believed to be reversible.

In Section 7.5.4 of RD&D Programme 98, SKB states that it intends to further develop methods for retrieving deposited canisters through:

- equipment and method development,
- full-scale demonstration (at the Äspö Hard Rock Laboratory),
- development of techniques which can be used in the repository,
- design of an interim storage facility for retrieved canisters.

SKB's objective for retrieval tests (after 3-5 years, in two deposition holes) at the Äspö Hard Rock Laboratory is to develop and test methodology and equipment for releasing the canister from the water-saturated bentonite, and to show how a released canister can be retrieved under realistic conditions.

Comments by the Reviewing Bodies

Greenpeace would prefer a more detailed discussion about reasons for retrieval as well as methods, time frames and financial frames in order to show that reversibility is viable. For instance, Greenpeace considers that, in addition to knowledge gained about the site and design of the repository, a method of continuously monitoring the performance of the repository is also necessary.

The Swedish Anti-Nuclear Movement (FMKK) considers that SKB is clearly doubtful about whether the proposed repository is intended to be a temporary interim storage facility or a repository. FMKK's opinion is that the only reason for retrieval should be if deep disposal does not appear to be fulfilling the criteria with respect to health and living environment in both short and long term perspectives. FMKK seeks a detailed and thorough scenario analysis for retrieval at different points in the final disposal process, up to 100,000 years, by which time SKB considers the waste to be "harmless". FMKK states, "basically, we would like to once again emphasise that, as long as the Act on Nuclear Activities stipulates final disposal, the direction of the project should also be final disposal and nothing else!" FMKK also states that, if there are valid reasons for changing the focus, amendments to the Act should be confirmed in the customary way, through a decision by the Riksdag (Swedish parliament).

The Waste Network believes that SKB's double message - the inaccessibility criterion and retrievability criterion - destroys the credibility of SKB's choice of method (the KBS-3 repository).

SKI s Evaluation

Retrievability is not yet a formal requirement in Sweden, but SKI intends to stipulate a requirement such as this in its future regulations on final disposal. SKI agrees with SKB that retrieval can be achieved at a number of different stages; from CLAB, during encapsulation, at the deposition stage, and after backfilling and sealing of deposition tunnels, as well as after repository closure, as expenses gradually increase at every new stage.

Even if there can be no question of planning for retrieval when it ultimately comes to final disposal, i.e. of viewing the repository as an interim storage facility, SKI is of the opinion that SKB must develop methods for retrieval. It is the opinion of SKI, and important for credibility, that methods of retrieval should be developed, tested and demonstrated on a full scale, no later than before a decision is made concerning the beginning of a detailed characterisation. Therefore, it is a positive step that SKB has started to study retrieval techniques and SKI is looking forward, with interest, to the results of the planned retrieval experiment at the Äspö Hard Rock Laboratory.

Like the Swedish Anti-Nuclear Movement (FMKK), SKI is of the opinion that the repository which SKB is planning to build must be regarded as a final repository and

nothing else. SKI also considers that requirements for difficult accessibility (rather than inaccessibility) may seem hard to combine with requirements for retrievability. It is therefore a question of balance and whether a chosen method, such as KBS-3, should simultaneously meet both these requirements as far as possible.

Based on the long life of the canister, SKI's opinion is that retrieval is probably possible without substantial difficulties at least several thousand years into the future, but that there is no sense in speculating over longer non-foreseeable periods of time. However, it should be borne in mind that retrieval after a very long period of time should be placed on equal footing with mining rather than with retrieval, in the sense which is now being discussed.

Some form of monitoring (e.g. of temperature and rock stress measurements) will take place during the deposition phase. Such monitoring may also be required for a certain period of time after the closure of the repository, for political or other reasons. However, the repository must be designed so that monitoring is not at all necessary after closure. If monitoring is carried out, this must be done in such a way that it does not jeopardise the safe performance of the repository.

5.7 Safeguards and Physical Protection

5.7.1 Safeguards

SKB s Report
SKB refers to Chapter 7 of its System Report (SKB, 1998), in which the international criteria and principles for safeguards are reported, including EURATOM's roll. IAEA's current verification criteria are described, as is the expected strategy for the safeguarding of a repository in accordance with IAEA's SAGOR study. With this as its basis, SKB describes a principal design for the control of nuclear materials in a final disposal system.

Comments by the Reviewing Bodies
Greenpeace states that the monitoring of the repository will place a burden on future generations as it will last for an indefinite period of time, and will require considerable resources.

SKI s Evaluation
An efficient international safeguards system exists for the transport and handling of radioactive substances. However, SKI would like to emphasise the need for developing new technology for safeguards from the time that the spent fuel is encapsulated.

Safeguards such as the monitoring of a closed repository are expected to be carried out for as long as the Non-proliferation Treaty is in force. Monitoring as it is described in the SAGOR report, however, is expected to be conducted using relatively simple methods, such as irregular international inspections of the closed repository and the near field, as well as with stationary seismic detection equipment. IAEA can also use information from commercial satellite photographs, which at present have an adequate

resolution for the surface monitoring of activities which may be an issue in this context. However, SKI highlights the need for technical development in this area and considers that this should also be included in SKB's programme.

5.7.2 Physical Protection

SKB s Report
RD&D Programme 98 states only that all handling of fuel is safeguarded by physical protection, with no further references. In the transport report (Ekendahl and Pettersson, 1998) there is a discussion of the general objectives and performance of physical protection measures involved in the transport of nuclear fuel.

Comments by the Reviewing Bodies
Greenpeace is of the opinion that a repository needs to be monitored. This will mean a need to preserve knowledge and set aside resources for an indefinite future, which would place responsibility on future generations.

SKI s Evaluation
Sweden has an adequate system for the physical protection of nuclear substances in nuclear facilities and in transit. According to RD&D Programme 98, the concept of final disposal does not require any change in the basic concept, even if the system needs to be adapted to an expanded transportation system and new types of facilities, in the form of an encapsulation plant and repository. A closed repository will not need any physical protection. The monitoring of a site is included under the international obligations of the Non-proliferation Treaty (IAEA control).

5.8 SKI s Overall Evaluation

5.8.1 General Comments

In Chapter 7 of RD&D Programme 98, SKB describes the status of the development of technology and its programme for future development work within different areas. For natural reasons, there is no sharp distinction between research and development. However, in SKI's opinion, where different activities are reported is not so important. The important factor is that the reporting should be complete and that nothing essential should be omitted.

SKB's programme for technical development should focus on meeting the performance requirements which can be made with respect to the different barriers, on the basis of safety assessments for each facility. SKB must be able to show that the performance requirements can be fulfilled no later than when it submits a licence application.

In the introduction to Chapter 7 of RD&D Programme 98, SKB reviews and defines "fundamental technical requirements" which, in qualitative terms, correspond to the performance requirements above. SKI is of the opinion that SKB should review the structure of its account of these requirements, and ways in which the requirements can be

developed, in stages, into increasingly detailed technical requirements and goals for the development work, as the decision-making process and construction of facilities progress. This applies to engineered and natural barriers as well as to barrier functions.

Another issue of importance to a technical development programme is the range of variation in the design of barriers which SKB will have to specify in its applications for permission to construct facilities. In SKI's opinion, it is not only quite acceptable but also necessary to include a certain range of variation, or freedom of choice, in the licence for a facility. In future reporting, SKB should also address these issues more clearly than it has done in RD&D Programme 98, even though the account of freedom of choice in the system analysis report (SKB, 1998) is a good start.

5.8.2 Canister

SKI concludes that the development of the canister is seriously underway within several areas, such as fabrication technology for the copper canister and the cast iron insert as well as sealing and control. SKI views this progress as positive. Furthermore, it is particularly valuable that SKB has now established a canister laboratory, where sealing and testing can be developed on a full scale.

In SKI's opinion, the design basis for the canister has been adequately derived from the fundamental canister requirements. However, the justification of these requirements on the basis of the safety assessment of the repository must be improved.

As far as the selection of canister material is concerned, SKI is of the opinion that the mechanism whereby phosphorus affects the creep properties of the canister must be investigated. Furthermore, SKI considers that SKB must improve its justification of the requirement for the grain size of the copper.

SKI emphasises that the central factors when deriving the requirements on the wall thickness of the canister are the assumptions and analyses on which the corrosion rates for determining the copper thickness are based, and not the fact that safety factors are used. In SKI's opinion, SKB should conduct a new analysis of canister corrosion. However, the wall thickness which is selected is determined by several factors, primarily the potential for achieving satisfactory results during fabrication, sealing and control. An important task for SKB will be to balance these factors against each other.

SKI questions SKB's claim that roll-forming and longitudinal welding is a functioning manufacturing method for copper tubes. However, SKI agrees that extrusion and pierce and draw processing are interesting alternatives which should be further investigated.

SKI concludes that electron beam welding has not been fully developed on the scale required for canister sealing and that a comprehensive development programme may be required in order to understand and solve the remaining problems. In SKI's opinion, if the testing of the method in the Canister Laboratory does not show satisfactory results within a reasonable period of time, intensified efforts to develop alternative methods may be necessary.

SKI agrees with SKB that nodular iron is a better choice of material for the insert than cast steel. SKI recalls that the properties of nodular iron are highly dependent on the shape and size of the object that is cast. Consequently, SKB should investigate the actual mechanical properties of the cast insert, and identify and determine any defects.

In SKI's opinion, SKB has not yet shown, through testing, how it can comply with the criterion of a maximum of 0.1% defective canisters. SKB must improve the way in which it derives the acceptance criteria for permissible defects in the weld. SKI also emphasises the importance of continuing the development programme for ultrasonic testing and the importance of presenting an account of a similar programme for the development of X-ray testing.

SKI concludes, like Oskarshamn Municipality and the Local Safety Committee, Oskarshamn Nuclear Power Plant, that a critical issue for the technical feasibility of the KBS-3 method is that SKB can show that sealing and control methods actually exist and are suitable for serial fabrication. This means that, no later than at the stage when SKB submits an application for permission to conduct detailed characterisations, a number of full-scale canisters must be fabricated, sealed and quality-controlled. Moreover, the canisters must show that they comply with the criteria specified in the assessment of long-term safety.

5.8.3 Encapsulation

In SKI's opinion, the work completed on the design of the canister fabrication and encapsulation plants appears to be reasonable. However, SKI would like to emphasise that the detailed design will be determined by the canister fabrication and sealing methods which are ultimately selected.

SKI agrees that co-siting the encapsulation plant with CLAB has many advantages. However, in SKI's opinion, a systematic analysis of how siting aspects affect the operation of the plant needs to be carried out, for the essentially different siting options.

5.8.4 Transport

SKI concludes that the transportation system presented is based on the assumption that the encapsulation plant will be located next to CLAB. This will simplify the transportation chain considerably and will result in less handling of non-encapsulated fuel. However, no account is given of alternatives which do not involve co-siting. Furthermore, no account is given of how canisters damaged during handling are to be returned from the repository to the encapsulation plant.

The transportation of canisters between the encapsulation plant and repository is largely based on SKB's current transportation system for spent fuel and nuclear waste, from which the operating experience has been good. Safety during transportation is mainly based on the use of internationally certified packaging which is designed to withstand considerable stresses.

In SKI's opinion, long-distance transportation by road of canisters containing spent fuel is a less realistic alternative. SKI concludes, like the Swedish Board of Housing, Building and Planning, that SKB should investigate and consider the alternative of building a new railway, in the event of siting the repository in the interior of Sweden, in a region without a railway.

5.8.5 Final Disposal Technology

SKB's proposed tunnel height of 5 m in the deposition tunnels seems far too narrow if the size of the canister (height 4.8 m) is taken into consideration. If SKB's proposed technique with the sequential deposition of bentonite blocks and canister in vertical holes does not perform as planned, a simultaneous deposition of bentonite and canister in a "package" will place a considerably larger (and more expensive) requirement on the tunnel area.

In SKI's opinion, it is important to develop and use reliable methods to describe the extent of the damage zone in tunnels and deposition holes in a repository. An in-depth discussion concerning the interpretation of SKB's results from the disturbed zone experiment (ZEDEX) is presented in Section 7.12.

As far as the acceptance or rejection of deposition holes is concerned, SKI concludes that SKB has not yet discussed which criteria should apply for the acceptance of a deposition hole. In SKI's opinion, the most important issue is how an even resaturation of the bentonite can be achieved and which acceptance criteria for water flow to the deposition holes should therefore be made. A decisive factor in this context is whether cement grouting around the deposition holes should be permitted in order to limit the water flow. In SKI's view, such grouting should be avoided. In SKI's view, SKB should avoid introducing foreign material, such as concrete, into the repository environment as far as possible.

Further investigation and analysis is required to determine whether an uneven re-saturation of the buffer can result in heterogeneous stress distribution on the canister and also degradation of the barrier properties of the buffer.

5.8.6 Retrieval and Monitoring

In Sweden, the retrievability of deposited spent nuclear fuel is not yet formally required. However, SKI intends to stipulate such requirements in future regulations on final disposal. SKI agrees with SKB that retrieval can be achieved in a number of stages: from CLAB, during encapsulation, during deposition, after backfilling and sealing of deposition tunnels as well as after repository closure.

Even if there can be no question of planning for retrieval when it ultimately comes to final disposal, i.e. of viewing the repository as an interim storage facility, SKI is of the opinion that SKB must develop methods for retrieval. In SKI's opinion, and important for credibility, retrieval methods should be developed, tested and demonstrated on a full

scale no later than when a decision is made to start a detailed characterisation. Therefore, it is positive that SKB has started to study retrieval technology and SKI is looking forward, with interest, to the results of the planned retrieval experiment at the Äspö Hard Rock Laboratory.

In SKI's opinion, the repository must be designed to ensure that monitoring is not necessary after closure. If, however, monitoring is carried out, for political or other reasons, this must be done in such a way that repository barriers are not damaged.

5.8.7 Safeguards and Physical Protection

An efficient international safeguards system exists for the transport and handling of radioactive substances. However, SKI would like to emphasise the need for new technology for safeguards from the time that the spent nuclear fuel is encapsulated. Based on studies carried out within the IAEA, SKI considers that safeguards with respect to a closed repository can be achieved with relatively simple methods such as inspections, seismic measurements and satellite monitoring. This type of control will be conducted as long as treaties on the non-proliferation of nuclear weapons exist (such as the existing Non-proliferation Treaty).

Sweden has an adequate system for the physical protection of nuclear facilities and shipments. A closed repository will not need any physical protection.

6 SAFETY ASSESSMENTS

6.1 Introduction

SKI's views on SKB's safety assessment work and on the post-closure safety report programme for the geological repository (long-term safety) are presented in this chapter. Safety reports concerning the operation of facilities and other safety reports to be included in the system analysis report for the entire final disposal system are dealt with in Chapter 3 of this Review Report. SKI's evaluation is based on Chapter 8 of RD&D Programme 98 as well as on the detailed description of safety assessment methods and models in the Background Report to RD&D Programme 98 (Chapter 2 and 3 of the Detailed Programme for Research and Development 1999-2004).

Safety assessment is the method used to systematically analyse and assess the performance and safety of a repository. Consequently, safety assessment reports are an important part of the basis for decision-making that SKB must present, and SKI evaluate, in connection with future licence applications for a repository and encapsulation plant. Safety reports are also an important basis for the Environmental Impact Statements (EIS) that are submitted along with licence applications.

In connection with the evaluation (SKI, 1996a) of RD&D Programme 95 (SKB, 1995a), SKI's opinion was that SKB had prepared an adequate framework for future safety reports, SR 95 (SKB, 1995b). SKB also recommended that SKB should apply and evaluate the methodology by conducting a complete safety assessment, based on site-specific data prior to planned site investigations and licence applications for a repository and encapsulation plant. This requirement was subsequently established in a government decision on RD&D Programme 95 (December 19, 1996).

SKB's work on the new safety assessment (SR 97) is not yet complete. Consequently, this evaluation is limited to work and plans presented in RD&D Programme 98. SKI will conduct a separate evaluation once SR 97 has been published. According to SKB, SR 97 will be published in 1999.

6.2 Safety Assessment Methodology

6.2.1 System Description

The basis of each safety assessment is a well-documented description of the process system, i.e. all of the Features, Events and Processes (FEPs) which, directly or indirectly, can affect the performance of different barriers and lead to radionuclide release and migration. The description of the process system (which SKB refers to as the *system description*) also includes an account of the deficiencies and uncertainties in the knowledge base.

The FEP databases included in the description of the process system have to be continuously updated as new knowledge is gained and the repository design becomes more

detailed. Since much of the description can be applied to different types of geological repositories, e.g. processes which affect radionuclide migration in the geosphere, the international FEP databases which are being developed within OECD/Nuclear Energy Agency (NEA) can also be used.

SKI is developing its own description of the process system for different types of repository in order to conduct an independent review of SKB's safety reporting in connection with licensing. SKB's presentation of its new safety assessment, SR 97, during 1999, will be the next, major safety reporting stage.

SKB s Report

SKB has previously used *interaction matrices* and *influence diagrams* to structure process system data (RD&D Programme 95 and SR 95). SKB has now started developing a new method within the ongoing SR 97 safety assessment. Briefly, the new method of structuring information involves dividing the repository into four different parts (fuel, canister, buffer/backfill and geosphere). For each part, a list is compiled of different categories of processes and state variables which have to be taken into account in the safety assessment (THMC = thermal, hydraulic, mechanical and chemical processes). The processes and their inherent interactions can then be presented using THMC diagrams. For each process, documentation is prepared comprising a general description, experimental data, a discussion of uncertainties and deficiencies and a description of how the process is handled in the safety assessment.

The purpose of SKB's further work is to develop a database of process descriptions which can be used in future safety assessments, including the evaluation of the THMC method which is being developed within SR 97. SKB states that another new method will be evaluated in the planned safety assessment for deep boreholes.

Comments by the Reviewing Bodies

Stockholm University (SU) considers SKB's description of system analytical methods to be inadequate. Taking into account the fact that considerable progress has already, at this stage, been made with SR 97, SKB should be able to present a clearer line of argument concerning scenario selection, analysis and the evaluation of results.

SKI s Evaluation

In its evaluation of RD&D Programme 95, SKI found that SKB's work on system description and scenario methodology work was of a high quality but that parts of the methodology had to be further developed and applied. SKI can establish that this is now being done within SR 97. SKI's initial impression is that SKB's work and the further programme for system descriptions appears to be promising, especially the high level of ambition for the development of different process descriptions. SKI also supports SKB in its ambition to develop alternative approaches to system description, even if SKI predicts that SKB will have some difficulty in presenting the THMC method so that it can be easily understood by a layman.

However, the report in RD&D Programme 98 is not sufficient for SKI to make a qualified judgement of methodology issues or of the completeness of the databases which have been developed. SKI shares Stockholm University's (SU) view that SKB

must explain how the newly developed system description will be used for scenario analysis, selection of calculation models and formulation of calculation cases. Furthermore, the relationship between THMC diagrams and previously developed methods must be explained, e.g. with respect to terminology and field of application. In SKI's opinion, it is necessary for authorities and SKB to agree on definitions of terms, otherwise it will be impossible for external experts and laymen to understand the premises of SKB's safety assessments.

6.2.2 Scenarios

A safety assessment analyses how repository performance changes over time. Since it is not possible to predict, in detail, what may occur in the future, possible event sequences or scenarios must be assessed. Systematic scenario selection and classification ensures that the safety assessment will provide a complete description of what a repository must be able to withstand and what the consequences would be if radioactive substances should leak out of the repository.

It is the task of the safety authorities (SKI and SSI) to stipulate general criteria for scenarios which must be included in SKB's repository safety reports. These criteria are stipulated through regulations and other documents.

SKB s Report
In RD&D Programme 98, SKB presents the general principles for the selection and analysis of scenarios which are applied within the safety assessment that is currently in progress, SR 97. SKB describes four categories of phenomena that can affect deep repository performance, namely, external impact through tectonics, climatic changes and human intrusion as well as internal events such as defects in the engineered barriers. For each category, a preliminary assessment is made of the phenomena that must be analysed. Scenarios are then formulated on the basis of these phenomena using the system description (THMC diagram). SKB states that the following main groups of scenarios will be studied in the safety assessment:

- repository development under undisturbed conditions
- consequences of manufacturing defects in copper canisters
- influence of ice ages
- influence of earthquakes
- consequences of human action.

SKB's objective in its further work on scenarios is to develop and describe a method for the evaluation of scenarios based on the system description. The programme comprises the description, documentation and evaluation of the scenario methodology which has been used in SR 97. Further research work will identify and describe the external features, events and processes which can affect the future development of the repository, with respect to climate changes, tectonics and human action.

Comments by the Reviewing Bodies
Stockholm University (SU) would like to see a clearer description of scenario analysis methodology and probability assessment, e.g. with respect to the use of deterministic and probabilistic calculation methods. SU maintains that the safety assessment will always contain calculation cases whose consequences cannot be accepted if it cannot be shown that the probability is sufficiently low. SU believes that such probabilities can only be quantified using complementary probabilistic calculation and evaluation methods.

In SSI's view, SKB should state how the selected method for the final disposal of spent nuclear fuel and nuclear waste can be expected to comply with SSI's regulations (SSI FS 1998:1).

The Royal Institute of Technology (KTH) would like an explanation of how different scenarios have been selected or excluded and proposes that SKB should use a more statistical approach in the scenario analysis. KTH also emphasises the importance of taking into account human error in the scenario analysis. For example, human error could result in the fabrication of canisters of a lower quality than intended.

N-A Mörner, Geologist, questions SKB's competence with respect to analyses of how an ice-age scenario could affect repository safety. N-A Mörner is of the opinion that the safety of a deep repository can be called into question after the first ice-age due to earth-quakes and changes in groundwater chemistry in connection with deglaciation.

SKI s Evaluation
SKI supports SKB's work on developing a systematic method for scenario selection and description based on a well-documented description of the process system. However, the details of the methodology and its practical application are not presented in RD&D Programme 98. SKI intends to return to these issues in connection with the evaluation of SR 97. SKI will place considerable emphasis on critical issues such as postulated canister defects and the internal and external features which must be analysed.

In SKI's opinion, SKB's proposal for scenario classification is a good starting point for further analysis work in the safety assessment. However, SKI would like to see a clearer description of how the assessment of various uncertainties is linked to different scenarios. For practical reasons, it may be suitable to handle different types of un-certainties in different scenarios. However, repository performance and safety assess-ment must be based on a single scenario which includes both reasonable assumptions concerning defects in the engineered barriers and possible climatic changes.

In its evaluation of RD&D Programme, SKI stated that a clearer strategy was desirable for the selection of conceptual models and the formulation of calculation cases for different scenarios. This viewpoint also applies to RD&D Programme 98.

The risk concept which SSI has introduced into its regulations concerning the final management of spent nuclear fuel and nuclear waste (SSI FS 1998:1) means that SKB must, to a greater extent, describe and quantify probabilities for scenarios and estimated consequences. SKI agrees with Stockholm University (SU) that a review, by SKB, of

the possibility of making greater use of probabilistic calculation and evaluation methods is warranted. However, in SKI's opinion, several complementary approaches and models (deterministic and probabilistic, qualitative and quantitative) should be used to provide as comprehensive a view as possible of the risks associated with the repository.

SKI approves of the fact that SKB is now planning to develop a strategy for the handling of scenarios based on human action. Already in its evaluation of RD&D Programme 95, SKI stated that such work was desirable.

6.2.3 Safety Assessment Models

The safety assessment includes a description of the consequences of damage to one or more canisters and subsequent leakage of radioactivity. The consequence calculations are performed with different types of computer models that describe radionuclide dissolution and release from the spent nuclear fuel, leakage through the canister and the bentonite buffer, groundwater flow and radionuclide transport in the bedrock and then migration in the biosphere. The calculation models are often classified into two categories: near field and far field. The near-field models describe the release and transport of radioactive substances from the engineered barriers, while the far-field models describe the groundwater flow and transport processes in the geosphere, i.e. the bedrock, between the repository and the biosphere. SKB describes these computer models in Chapter 3 of the Detailed Programme for Research and Development 1999-2004.

SKB s Report

SKB's safety assessment code package includes models for radionuclide inventory, fuel dissolution, leakage from a damaged canister, chemical processes and radionuclide transport in the near field as well as groundwater flow and radionuclide transport in the far field. The PROPER code package and the menu-based MONITOR 2000 system are used for the handling of coupled models. SKB plans to evaluate and review these programs after the SR 97 safety assessment.

In RD&D Programme 98, SKB describes three different types of fuel dissolution models: a conservative model with immediate dissolution, a model where the release is limited by the matrix solubility in the case of insignificant oxidant formation and a model with radiolytic oxidation of spent fuel. The first two relatively simple models are probably extreme cases of rapid and slow dissolution, respectively. The latter is a considerably more detailed model with radiolytic oxidation which has been developed prior to the SR 97 safety assessment. Further development of the model can be expected since SKB states that a realistic fuel dissolution model will be prepared by the year 2001.

The model for radiolytic oxidation, introduced in RD&D Programme 98, includes a recombination of hydrogen and oxygen, which is a new feature, compared with fuel models used in connection with previous safety assessments, e.g. SKB-91. This means that the estimated radionuclide release will be slower over a long time since the recombination reduces the net oxidant production which can increase the dissolution of the fuel matrix.

In SKB's view, a damaged canister also has considerable potential to retain radionuclides, partly because gas formation prevents the canister becoming water filled. This has been studied using a model for water ingress, iron corrosion, corrosion product build-up as well as corrosion product impact on the structural integrity of the canister (Bond et al, 1997). In the programme, SKB will continue to study how and to what extent a damaged canister is a barrier to radionuclide transport.

It must be possible to predict the chemical environment in the repository near field since it affects engineered barrier stability, radionuclide solubility and sorption. The most important factors are probably the redox conditions, pH, ion strength, salinity, carbonate concentration and the presence of other complexing agents. The site-specific groundwater chemistry is of decisive importance, although the chemistry will also be considerably affected by the proximity to the bentonite clay and any cement. When the repository is open, oxygen will be introduced and this will affect conditions for some time after closure. If a penetrating hole occurs in a canister, corrosion of the iron insert and the spent nuclear fuel will affect local groundwater conditions. In the very long term, the impact of the engineered barriers on the chemistry will decrease while the importance of the natural groundwater and its evolution will increase. For a long time, SKB has worked with different models to predict the chemical environment in different parts of the repository system. RD&D Programme 98 states that the most important aim is to integrate these models so that the chemical evolution can be assessed in the case where all of the processes are allowed to influence the system. Furthermore, the impact of different external and internal FEPs will be studied.

SKB uses the NUCTRAN/COMP23 model to calculate radionuclide transport in the near field. In future, work will focus on developing and maintaining the tool by combining the different variants that exist as well as through further verification studies of complex geometries, in particular. Furthermore, SKB intends to introduce shared element solubilities into the model (between different isotopes of the same element).

SKB has access to several alternative models of varying complexities for the calculation of radionuclide transport in the far field. SKB's main model, FARF31, is a one-dimensional (streamtube model), but includes the most important processes which affect radionuclide mobility in the groundwater. In order to obtain relevant input data for FARF31, more detailed flow models are used which can better describe the complex rock fracture system and the spatial variability of the rock properties e.g. stochastic continuum-model, fracture network model and channel network model.

SKB's objective for further work is to have access to relevant calculation tools prior to forthcoming safety assessments and site evaluations. SKB specifically states that, after the coming 3-year period, it should have full access to alternative models for flow as well as transport in the rock. SKB also states that it will investigate the possibility of conducting complete radionuclide transport calculations with one of the more detailed flow models (the discrete fracture network model).

SKB uses BIOPATH to model radionuclide migration in the biosphere. Site-specific conditions are modelled in the SR 97 safety assessment, by adapting the structure of BIOPATH to local conditions.

The benefits of introducing various improvements to measurement methods for site-specific data and calculations must be weighed against the uncertainties in the models, prior to the forthcoming site investigations. SKB has identified deficiencies in the description of transport from the far-field to the biosphere and the lack of a forest model.

SKB's specific goals within the area of radionuclide migration in the biosphere are:

- to evaluate which parameters can be described with generic data versus site-specific data
- maintain and modernise modelling tools for the biosphere (BIOPATH and PRISM), including the testing of model sensitivity to variations in site-specific data,
- integrate the biosphere models in the calculation chain, including a re-evaluation of the transport rates between the geosphere and biosphere, as well as develop a forest model
- investigate alternative safety indicators.

Comments by the Reviewing Bodies

The Royal Institute of Technology (KTH) considers that further work must be done to clarify how various sub-models for the release and transport of radioactive substances are interconnected in the safety assessment, i.e. the couplings between fuel dissolution, processes in the near field, processes in the far field and the biosphere. In terms of the coupling between the geosphere and biosphere, KTH emphasises the importance of achieving a good understanding of how precipitation, surface water and land/vegetation conditions affect the groundwater flow at different depths. Furthermore, KTH proposes that SKB, in parallel with the more complex geosphere migration models, develop simpler analytical models which are easier to reproduce and to evaluate by various parties involved in Environmental Impact Assessment. KTH also believes that it would be worthwhile to develop measures for how much different parts of the repository system, e.g. the near field and the geosphere, contribute to radionuclide retention.

SSI considers that SKB should supplement dose and risk assessments with analyses based on safety indicators, bearing in mind the considerable uncertainties associated with the evolution of the biosphere in a long-term perspective. SSI proposes that repository performance assessment can, instead, be based on outflow calculations and subsequent concentration changes in the biosphere.

Stockholm University (SU) is of the opinion that SKB has a powerful set of analysis tools for application in the safety assessments. However, SU believes that SKB should more closely study higher order effects and parameter correlations in sensitivity analyses of models of radionuclide transport in the near and far field. In SU's opinion, probabilistic methods should be used in modelling the evolution of a damaged canister.

The Local Safety Committee, Forsmark Nuclear Power Plant considers that, since the radiation dose is a measure of the hazard it is important for the general public to be informed of how the dose consequences are calculated.

SKI s Evaluation

In SKI's view, it is of great importance that SKB should continue to develop and update the various models used for safety assessment. The conceptual models used to describe different sub-systems must be evaluated at regular intervals on the basis of results from SKB's own research programme as well as from other research. Databases used must also be maintained and supplemented. SKI considers that SKB should explore the possibility of developing alternative models and of finding out about similar models from other nuclear waste programmes with the aim of evaluating the selected models through direct comparisons.

SKI approves of the fact that SKB is describing parallel fuel models, since this can give good insight into the interaction between the radionuclide retention mechanisms in the near field. It can also illustrate which of the uncertainties coupled to these mechanisms are most important on the whole. However, assessments of the total, integrated system should be based on a conceptual fuel model which can be shown to be conservative, together with a conservative choice of parameters. In order to evaluate and compare parallel models, results must be reported for different types of chemical phenomena that are considered to be reasonable as well as different radionuclides with different chemical properties.

SKI considers that SKB should describe all of the conditions which must be fulfilled for the radiolytic oxidation model to be valid. Furthermore, SKB must justify why these conditions can be expected to correspond to those in the repository environment. The descriptions of the radiolytic oxidation model indicates a relatively high degree of complexity which is reminiscent of a research model to study the interaction of different elemental reactions. Therefore the model may not be as robust as required, since mechanical models with many reactions may be sensitive to relatively minor uncertainties in the input data. Therefore, in its sensitivity analyses, SKB should show that the proposed model is sufficiently robust and, if possible, attempt to simplify it.

SKI is of the opinion that SKB should make a clear distinction between more realistic fuel dissolution models, e.g. those used to improve the understanding of how different sub-processes interact and safety assessment models which can be shown to give a conservative estimate of radionuclide release.

In SKI's view, the results presented in RD&D Programme 98 indicate a high level of ambition with respect to the development of new fuel models. However, the tight deadlines given for model development may prevent an adequate integration with the ongoing experimental studies. Conditions and assumptions used in new models which are discussed can probably not be justified in a manner that is adequately convincing without establishing a clear coupling to experiments. It is important that experiments that have been initiated should be allocated the time that is necessary for longer measurement series, review and evaluation to be conducted.

SKI considers that it is important for SKB to continue to study the processes which determine the evolution of a damaged canister. SKI shares SKB's view that a damaged canister can also be an essential barrier to radionuclide migration over a long period of time. SKB's model for how hydrogen gas pressure can be maintained in a damaged

canister is important. However, SKI can anticipate difficulties in using this model for consequence calculations in a safety assessment. The system is dependent on several coupled processes whose interactions may be difficult to predict with adequate reliability. SKI therefore emphasises the importance of integrating canister-related work with the work on buffer programmes and radionuclide transport models in the near field.

SKI approves of SKB's intention to achieve integrated modelling of chemical processes in the near field. However, the description in RD&D Programme 98 is not detailed enough to determine the intended level of ambition. It is probable that a rigorous evaluation of the impact on each other of the chemistry of sub-systems could be a new area of research for SKB.

SKB's model for calculating radionuclide transport in the near field, NUCTRAN/ COMP23 describes the different parts of the near field as separate but coupled compartments. Like the Royal Institute of Technology, SKI considers that SKB should investigate how different assumptions and simplifications in the coupling between the different compartments, e.g. between the fuel, canister and bentonite, affects the results of the entire calculation chain. The same applies to the coupling between the models for near-field transport, far-field transport and radionuclide migration in the biosphere.

SKI considers that SKB's development work on models for calculating the groundwater flow and radionuclide transport in the geosphere is suited to the purpose and of a high quality. The aim of developing a "toolbox" of simple as well as more detailed models is laudable. In SKI's opinion, alternative conceptual models should be used, as far as possible, in the safety assessment to illustrate the impact of uncertainties on the calculation results and, thereby, increase the credibility of the safety assessment. However, SKI would like to reiterate its recommendation from the evaluation of RD&D Programme 95 that SKB must develop a strategy for how the different transport models are to be applied in safety assessments and site investigations. This particularly applies to the evaluation of results from alternative models.

SKI points out that the modelling of radionuclide migration with the groundwater in the rock is associated with significant uncertainties. This is primarily due to the difficulty of conducting field measurements of the properties which affect host rock retardation of radionuclide transport through sorption and matrix diffusion. SKI assumes that SKB will evaluate and update its transport models, taking into account the knowledge gained from ongoing experiments at, e.g. Äspö, and taking into account relevant improvements in knowledge internationally. Furthermore, SKI considers that, in connection with forthcoming reports of site investigation programmes, SKB should describe the experimental methods which will be used at different stages of a site investigation to determine the transport properties of the rock. The parameters which can be determined in a surface-based site investigation and detailed characterisation from tunnels and shafts should be specified.

SKI approves of SKB's attention to deficiencies in the description of the transport from far field to biosphere. SKI also supports SKB's plans to use site-specific biosphere data in the evaluation of future site investigations. The need for data should be specified before the site investigations are initiated to improve the possibility of obtaining data

under more undisturbed conditions before other work starts. SKI shares SSI's opinion that it is positive that SKB's goal is now to investigate alternative safety indicators – a measure which SKI has recommended in its evaluation of RD&D Programme 92 as well as RD&D Programme 95.

6.2.4 Treatment of Uncertainties

This section deals with the treatment of uncertainties in the safety assessment. The term "uncertainties" refers to deficiencies in the knowledge and data base which is necessary for the safety assessment. Uncertainties can be divided into four groups, namely:

1. *Uncertainties in the description of the process system*: have all important processes been identified and is the knowledge of the identified processes adequate?
2. *Scenario uncertainty*: have the most important events been taken into account, e.g. climatic changes, earthquakes and human intrusion, which can affect repository performance?
3. *Model uncertainty*: are the models in the safety assessment relevant and sufficiently reliable?
4. *Data and parameter uncertainty*: are the site investigation data and other input data for the models adequate and correct?

A safety assessment will always be associated with uncertainties. To achieve a credible safety assessment and an adequate basis for decision-making it is therefore necessary to identify all types of uncertainties and to evaluate how they affect the results of the safety assessment. SKB describes work on the treatment of uncertainties in Chapter 8 of the Detailed Programme for Research and Development 1999-2004.

SKB s Report
In RD&D Programme 98, SKB announces a new method for the treatment of uncertainties in the safety assessment. The method is based on SKB's newly developed method for the description of the process system (THMC diagram) which is developed in SR 97. The aim is to develop a systematic description of all important processes in the safety assessment and to be able to consistently handle deficiencies in numerical data for all processes.

One new feature in relation to previous RD&D Programmes is that SKB now discusses the safety assessment as a "prioritising instrument" for the planning of the continued research programme. In a separate table in the Detailed Programme (Table 2-1), SKB lists the processes which were identified in SR 97 for the fuel, canister, buffer/ backfilling and geosphere. For each process, SKB states whether there is adequate knowledge to meet the needs of the safety assessment or whether additional research is necessary to reduce the uncertainties. The term "adequate knowledge" also means that it is not expected that additional knowledge will decisively lead to a refined, less conservative treatment of the process in the safety assessment.

Comments by the Reviewing Bodies
Stockholm University (SU) considers that SKB should have presented a more detailed line of argument concerning safety assessment methodology, especially with respect to the analysis of selected scenarios and the evaluation of results, bearing in mind how far SKB has come in its work on SR 97. Göteborg University (GU) would like an account of how SKB treats uncertainties concerning the fracture geometry of the rock and the reaction to future loads. Chalmers University of Technology (CTH) points out that the results from SR 97 should be used to give less priority to future studies within areas which are of minor importance for the safety assessment in order to concentrate on key issues.

Greenpeace considers that uncertainties and remaining R&D needs should be more clearly described in the RD&D Programme and that SKB should not claim that present research is sufficient before the first steps towards a deep repository are to be taken. The Swedish Society for Nature Conservation questions the lengthy extrapolations of important safety functions in the safety assessment on the basis of short experimental measurement series, e.g. concerning the mechanical properties of the bentonite. The Society also draws attention to the problem of unforeseen risks and mentions, as an example, that new data from an atomic bomb test site in the USA show that plutonium could have been transported by colloids in the bedrock much more rapidly than previously anticipated.

SKI s Evaluation
In connection with the evaluation of RD&D Programme 95 and SR 95, SKI found that SKB had made a laudable review of different aspects of uncertainties and uncertainty treatment in safety assessments. However, the account of work provided in RD&D Programme 98 is not of the same calibre. The presentation is limited to a new classification of uncertainties and does not give an adequate description of how SKB intends to treat uncertainties in different parts of the safety assessment. SKI is aware that much of the methodology is under development and that it will be presented in SR 97. Nevertheless, SKI agrees with Stockholm University (SU) that SKB should have been able to present a clearer overview of ongoing development work. The fact that the treatment of uncertainties is an integrated part of the entire safety assessment means that SKB's strategy should include everything from data analysis, selection of conceptual models, formulation of calculation cases to interpretation of results (see also SKI's evaluation of RD&D Programme 95).

SKI approves of the fact that SKB is further pursuing the intention to evaluate alternative models for the calculation of groundwater flow and radionuclide transport. In SKI's view, alternative, complementary approaches are necessary for a credible description of the uncertainties in the safety assessment results. However, SKI reminds SKB that it is also important to develop a strategy for the application of these alternative models. SKI also reiterates its recommendation from the evaluation of RD&D Programme 95 that SKB should develop a strategy/methodology for how it plans to handle and, above all, *report*, validation-related issues in the safety assessment, e.g. evaluation of model validity and relevance on the basis of laboratory and field experiments, natural analogues, paleohydrological information and other knowledge.

SKI shares Chalmers University of Technology's (CTH) view that SKB should use safety assessments that have been carried out to focus the further R&D work on issues which are most important for the results and credibility of the safety assessment. However, SKI emphasises that SKB must clearly specify the basis supporting its assessment that the current knowledge of different processes is sufficient.

In SKI's view, SKB's assessment that the current knowledge is sufficient for different processes identified in SR 97 (Table 2-1 of the Detailed Programme for Research and Development 1999-2004) is reasonable. However, the table is not an adequate basis for setting priorities since no justification, references to safety assessments or other references are provided to support SKB's assessment. SKI also points out that the basis for setting priorities must be regularly re-evaluated as new research results are obtained. This means that SKB must continue to monitor, to a certain extent, research areas where it assesses the knowledge base to be adequate. New findings concerning colloidal transport of plutonium mentioned by the Swedish Society for Nature Conservation is a good example of research results which must be studied by SKB. SKI is prepared to participate in a continued dialogue with SKB concerning the basis for setting priorities for further R&D work.

SKI is in complete agreement with the Swedish Society for Nature Conservation that many of the extrapolations of various safety functions in a safety assessment are associated with uncertainties. It is for this very reason that the safety assessment must clearly describe the scientific basis for different extrapolations (see SKI's comment on validation above). It is also important to analyse, using sensitivity analyses and alternative models and approaches, how such sources of error can affect the results of the consequence analysis (dose calculations etc.).

6.2.5 Quality Assurance

SKB s Report

In RD&D Programme 98, SKB states that the quality assurance of the safety assessment is not a separate activity but an integral part of safety assessment work. The Detailed Programme for Research and Development 1999 – 2004 presents various tools used for traceability and quality in the calculations performed in the safety assessment. A newly developed menu-based user interface (MONITOR 2000) which is used to control probabilistic radionuclide transport calculations in the PROPER code package is one such tool. The computer models and input data used for all of the calculations are documented in MONITOR 2000. Furthermore, a graphics program (HYDRAVIS) has been developed for the illustration and checking of calculation results.

With respect to the quality assurance of site investigation data to be used in safety assessments, SKB refers to tools and routines for data management and quality assurance developed at Äspö Hard Rock Laboratory, including the SICADA database.

The objective of further work is to refine the above-mentioned tools and routines including systems for the handling of different versions of computer models to achieve complete traceability concerning investigations, data and the calculations to be per-

formed in future safety assessments. SKB also refers to quality and management manuals developed in the encapsulation plant and deep repository projects.

Comments by the Reviewing Bodies

In the opinion of Chalmers University of Technology (CTH), RD&D Programme 98 does not describe how SKB conducts quality assurance of its own work and points out that a documented and efficient quality control system will gain in importance when projects become more comprehensive. CTH also considers that SKB must review its systems for data and information management so that technical reports and other sources of information can be stored in a structured manner. The Swedish Natural Science Research Council, the Royal Institute of Technology, the Swedish Council for Planning and Co-ordination of Research and other reviewing bodies are of the opinion that SKB's databases should be made available to independent national and international researchers. Göteborg University (GU) would like a clearer description of how the RD&D Programme is produced (organization and authors etc.).

SKI s Evaluation

In SKI's view, the reported work on databases and the quality assurance of computer models and calculations is suited to the intended purpose and of a high quality. In the same way as a strategy for the treatment of uncertainties, quality assurance is an integrated part of each safety assessment. Furthermore, the need for quality assurance will become increasingly important as SKB's repository siting and encapsulation plant programme becomes more detailed. However, SKI agrees with Chalmers University of Technology that SKB's reporting of the quality assurance of safety assessments in RD&D programme 98 is incomplete and fragmented. SKI considers that SKB should develop/describe an integrated programme for the quality assurance of safety assessments and related areas, e.g. within the framework of the continued development of SKB's template for safety reports (SR 95), which can be evaluated by the safety authorities and other parties concerned before site investigations start. This view has previously been presented in SKI's evaluation of SKB's latest RD&D Programme 95. SKI assumes that SKB will base further work on a thorough evaluation of the quality assessment work on the SR 97 safety assessment.

In addition to the more administrative aspects, e.g. data management, documentation and code version management, a quality programme for safety assessments should also describe the procedures and instruments of control necessary to guarantee a high scientific quality and suitability of the work on the safety assessment. This includes a systematic treatment of uncertainties, the selection and justification of conceptual models and assumptions, information transfer between different analyses and models as well as the possible need for national and international peer review of data and analyses.

The programme should also highlight necessary couplings and the need for co-ordinating different sub-projects, e.g. siting, site investigations, design and construction planning, encapsulation plant and safety assessments. For example, in order to develop a site investigation that is suitable for the intended purpose, there must be a close co-operation between site characterisation and safety assessment. The final disposal method and barrier engineering must be reconciled with the safety assessment in order

to ensure that all parts of the repository actually have the properties postulated in the safety assessment.

6.3 Safety Report Programme

SKB's plans for safety reporting are evaluated in this section. SKI gave a relatively detailed account of the regulatory authorities' expectations of SKB's planned safety reports in its review statement on RD&D programme 95 (SKI, 1996a). SKI's comments on RD&D Programme 98 is therefore focusing on the safety reporting which the Government has requested of SKB prior to the start of the site investigations.

The purpose of a safety assessment may vary and safety assessments must be conducted at several points during the development of a repository. At an early stage of the siting work, safety assessments are used to derive the parameters which have to be determined in site investigations and the performance requirements which can be made with respect to the engineered barriers. The results of safety assessments are also used to focus the continued R&D work on those issues which are of greatest importance to repository performance and safety.

The safety assessment in connection with method selection decisions and licence applications for the construction and operation of a repository, is an important part of the basis for decision-making which is needed in order to judge the compliance of the repository with regulatory safety and radiation protection criteria. During the operation of the repository, safety assessments must be repeatedly conducted to evaluate how new knowledge and data affect previous conclusions concerning long-term safety. Finally, extensive safety reporting will be necessary prior to decision-making concerning repository closure.

SKB s Report

SKB's report on the safety assessment programme in RD&D Programme 98 (Section 8.7 – 8.8) contains an overview of ongoing work on the SR 97 safety assessment of a deep repository for spent nuclear fuel and plans for follow-up work. SKB also lists future licence applications where safety assessments will be reported.

According to SKB, the structure and methodology of SR 97 must be considered to be a development of the template presented in SR 95. SKB states that the new features in SR 97 are: a description of the repository system, the treatment of deficiencies in numerical data, studies of the event sequence inside defect canisters, alternative models for water flow and radionuclide transport in the rock as well as analyses of earthquakes. SKB states that its intention with SR 97 is to "describe where science and the assessment methodology stand today when it comes to evaluating the long-term safety of a deep repository."

SR 97 will be evaluated by regulatory authorities and subjected to international peer review. During the forthcoming three-year period, SKB plans to evaluate the experience gained from SR 97 and refine different parts of its assessment methodology.

In Chapter 3 of RD&D Programme 98, SKB states that safety assessments previously conducted (SKBF/KBS, 1983, SKB, 1992 and SKI, 1996b) have shown that it is possible to construct a deep repository which complies with the long-term safety criteria.

Comments by the Reviewing Bodies

A large number of reviewing bodies, including the Local Safety Committees and feasibility study municipalities, consider that SKB's new safety assessment is an important part of the basis for decision-making which must be developed and evaluated by the authorities prior to the start of site investigations.

Greenpeace and other environmental organisations do not consider that SKB has presented sufficient material in RD&D Programme 98 to allow SKB's request to be fulfilled for government and regulatory approval of the KBS-3 method. The Swedish Anti-Nuclear Movement (FMKK) questions SKB's claim that safety assessments previously conducted provide support that a repository can be constructed which complies with long-term safety criteria. Chalmers University of Technology points out that SKB's safety assessment for the repository for other long-lived waste is not as detailed as that for the spent nuclear fuel repository.

SKI s Evaluation

As was mentioned above, SKI cannot provide a qualified evaluation of SKB's ongoing work on the new SR 97 safety assessment on the basis of the information provided in RD&D Programme 98. However, SKI would like to emphasise that SKB's level of ambition in SR 97 should not be limited to a development of safety assessment methodology. SKI shares the view of many of the reviewing bodies that SR 97 is an important part of the material that must be available before the step is taken to initiate site investigations and before resulting commitments are made to the KBS-3 method and geological final disposal. SR 97 will also be an important part of the system reporting which, according to the government decisions (May 18, 1995 and December 19, 1996) must be presented before SKB submits a licence application for repository construction (see also Chapter 3 of this Review Report). SKI would therefore like to remind SKB that, in addition to demonstrating safety assessment methodology, SR 97 must also provide a basis for:

- demonstrating the possibility of identifying a site in the Swedish bedrock which fulfils the long-term safety and radiation protection criteria stipulated in SSI and SKI's regulations.
- specifying the factors on which the selection of sites for site investigation will be based
- deriving the parameters which must be determined and the other criteria which should be made with respect to a site investigation.
- deriving preliminary performance criteria with respect to the canister and the other engineered barriers.

SKI intends to evaluate SR 97 in the light of the above when SKB presents SR 97 later this year.

On this point, SKI shares the Swedish Anti-Nuclear Movement's view that safety assessments so far conducted in Sweden do not provide an adequate basis for SKB's claim that a repository can be constructed which will comply with long-term safety criteria. The safety assessments that SKB has so far conducted must be considered to be preliminary and lack the focus and scope which will be required in connection with a licence application for siting and construction of a repository. For the sake of clarity, SKI also emphasises that the purpose of SKI's own safety assessments has been to develop safety assessment methodology prior to future evaluation work – not to provide a basis for a judgement of compliance.

SKI agrees with Chalmers University of Technology that SKB's safety report regarding the final disposal of long-lived low and intermediate level waste is too brief. The repository for other long-lived waste (SFL 3-5) is included in the concept for nuclear waste management which SKI must evaluate, as is the case for the repository for spent nuclear fuel (SFL 2).

In SKI's opinion, SKB, in its further safety assessment work, should describe the performance and safety of SFL 3-5 on the same level of detail as for the repository for spent nuclear fuel. In addition to the fact that the performance of the cement-based SFL 3-5 repositories require the investigation of new issues, it is also necessary to describe how co-siting SFL 2 and SFL 3-5 would affect the performance and safety of each repository. SKB must also describe how it has taken into account safety assessments for SFL 3-5 in the work on developing a measurement programme for the planned investigations at two sites.

6.4 SKI s Overall Evaluation

In RD&D Programme 98, SKB presents a short description of its ongoing development work within the new SR 97 safety assessment project which, in accordance with a Government decision from December 19, 1996, must be reported no later than prior to the start of site investigations. SKI's preliminary assessment is that SKB's safety assessment work is suited to the intended purpose. However, SKI will present a more detailed evaluation in connection with the review of SR 97. SKI summarises below the most important observations and viewpoints relating to the account presented in RD&D Programme 98 and relevant parts of the Detailed Programme for Research and Development 1999 – 2004.

6.4.1 Safety Assessment Methodology

System Description and Scenarios

For some time, SKB has had access to influence diagrams and interaction matrices for the description of a coupled model of the system comprising all of the processes and characteristics of the repository as well as the various barriers (*the process system*) which must be taken into account in the safety assessment. SKB has stated that it is now developing, within SR 97, a new method to describe the process system which is based on a classification into thermal, hydrological, mechanical and chemical (THMC)

processes. In SKI's opinion, SKB's programme for the documentation of the basic assumptions used in safety assessment is ambitious. However, SKI considers that the presentation of the new methodology is unclear with many unresolved questions concerning the practical application of the safety assessment and the possibility of making comprehensible presentations.

In SKI's view, SKB's proposal for the classification of scenarios is a sound basis for the safety assessment calculations. However, SKI would like to emphasise that the assessment of repository performance and safety must be based on a scenario which includes reasonable assumptions concerning defects in the engineered barriers *as well as* probable external impacts such as climate changes.

SSI's regulations concerning the final management of spent nuclear fuel and nuclear waste (SSI FS 1998:1) mean that SKB, to a greater extent than before, must take into account and quantify scenario and calculated consequence probabilities. In SKI's opinion, several complementary approaches and models (deterministic and probabilistic, qualitative and quantitative) should be used to provide as comprehensive a view as possible of the risks associated with the repository.

Safety Assessment Models

In SKI's view, it is positive that SKB is now developing more detailed/realistic models for fuel dissolution and damaged canister processes. The detailed models fulfil a vital function in improving the understanding of different transport processes and their interaction in the near field. However, SKI would like to emphasise that there is considerable work left to be done to show that these models are sufficiently reliable to be directly applicable to consequence calculations in the safety assessment.

SKB intends to develop alternative models for calculations of radionuclide transport in the geosphere. SKI considers that this development work is necessary and that, in combination with the migration experiments which are being conducted at Äspö, it should provide SKB with an adequate basis to develop suitable calculation tools for future detailed characterisations and safety assessments. SKI also views as positive the fact that SKB is extensively updating the models necessary for the calculation of radionuclide migration in the biosphere.

Treatment of Uncertainties

In RD&D Programme 98, SKB presents a strategy for the treatment of uncertainties which is based on the newly developed THMC method for the description of the process system. SKI considers, like Stockholm University, that the description is deficient and that it does not present an adequate view of how SKB intends to treat uncertainties in the safety assessment. However, SKI is aware that the methodology is currently being developed within SR 97. Consequently, SKI intends to once again raise these issues in connection with its evaluation of the SR 97 safety report.

SKI also reiterates the recommendation from its evaluation of RD&D Programme 95 that SKB should develop a strategy for describing validation issues in the safety assessment, e.g. the assessment of model validity and relevance on the basis of laboratory and field experiments, natural analogues, paleohydrological data and other knowledge.

SKI approves of the fact that SKB, in this context, is discussing the possibility of using safety assessments to prioritise future work in the R&D programme. However, SKI emphasises that the prioritisation of work must be clearly justified and documented. The priorities proposed in the Detailed Programme for Research and Development 1999 – 2004 are not supported in this manner. SKI is prepared to continue to participate in a dialogue with SKB on this important issue.

Quality Assurance
It is positive that SKB is pursuing its work on the quality assurance of data, models and the traceability of calculations in the safety assessment. However, an overall description of SKB's work on the quality assurance of safety assessments is still lacking. In SKI's opinion, during the coming three-year period, SKB should present an overall description of the quality systems and control instruments which are necessary to attain a high level of quality and suitability of the future safety assessment work.

6.4.2 Safety Report Programme

In RD&D Programme 98, SKB presents a description of planned safety reporting in the form of a list of times when comprehensive safety reports will be required for decision-making. SKI considers that SKB, in the coming three-year period, should prepare more detailed descriptions with respect to the purpose and scope of the planned safety reports. It is important for SKB to clarify the role of the safety assessments in the subsequent stages of the nuclear waste programme.

SKI concludes, as do the municipalities where SKB is conducting feasibility studies, that SR 97, SKB's forthcoming safety report, is an important document in view of the imminent transition to site investigations and the resulting commitments to the KBS-3 method and geological disposal. Consequently, SKI would like to remind SKB that SR 97, in addition to demonstrating safety assessment methodology, should also provide a basis for:

- demonstrating the possibility of identifying a site in the Swedish bedrock which fulfils the long-term safety and radiation protection criteria stipulated in SSI and SKI's regulations.
- specifying the factors on which the selection of sites for site investigation will be based
- deriving the parameters which must be determined and the other criteria which should be made with respect to a site investigation.
- deriving preliminary performance criteria with respect to the canister and the other engineered barriers.

SKI intends to evaluate SR 97 in the light of the above when SR 97 is presented by SKB in 1999.

SKI also reminds SKB that future safety reports must include the repository for other long-lived waste (SFL 3-5). SFL 3-5 is a part of the final disposal method which the Government, regulatory authorities and municipalities concerned must decide upon.

SKB must describe how different parts of the repository can affect the performance of other parts. Finally, SKB must ensure that the planned site investigations can provide adequate data to analyse all of the repository parts.

7 Research

In this chapter, SKI will discuss Chapter 9 of SKB's RD&D Programme 98 and Chapters 4 to 18 of the Background Report, Detailed Programme of Research and Development 1999-2004.

7.1 Introduction

SKI provides a general discussion of SKB's report of its research in RD&D Programme 98. SKB's prioritisation and motivation of different research work will also be briefly discussed.

SKB has put considerable effort into preparing an RD&D programme report which is easy to understand. The report covers the areas of research, safety assessment, method selection, safety, siting, technology and decommissioning. Since research-related aspects of the programme are only briefly dealt with in the Main Report, SKB has also compiled a Background Report with a more detailed account of its research and development work (Detailed Programme for Research and Development 1999-2004). SKI believes that this distribution may be warranted since the accessibility for a non-specialist has probably improved compared with previous RD&D programmes. In SKI's opinion, this structure, which emphasises issues other than research, should not be allowed to lead to a loss of the status of SKB's research programme. SKB should therefore strive to ensure that the quality of the actual reporting of research is maintained. In SKI's opinion, with the current structure, it may be difficult, even for someone with the necessary background, to understand which problems are the most critical in each area of research and how much progress SKB has made within each area. There may be reason for SKB to consider how the problems and the research results should be reported and presented from now on.

SKI is of the opinion that SKB's descriptions in RD&D Programme 98 of attained results have, in most cases, a requisite level of detail. However, in certain chapters SKB has very generally and briefly described planned work (e.g. Chapters 6, 10 and 12). SKI needs to be provided with more detailed information so as to make a more accurate evaluation of SKB's prioritisation of work before 1999-2004. Timetables also need to be more specific, with the aim of properly showing what SKB intends to carry out during the current RD&D period.

SKI considers it important that a follow-up to the research report would be simplified if SKB selects a more consistent method of collecting references. There are a number of references to unpublished manuscripts which have not been reviewed in RD&D Programme 98. There are reasons for refraining from reporting such results, from the points of view of both quality assurance and availability. In other cases there are important conclusions which lack both justification and references, thus making evaluation work difficult.

SKI emphasised, at the time of its evaluation of RD&D Programme 95, that references cited in SKB's material do not reflect the full range of knowledge of the scientific community.

SKI still believes that SKB should, at an early stage, look for support for its research results in the general research community. In this way, discussions at a late stage (of licensing) of issues which could have been resolved at an earlier stage, can be avoided as far as possible.

Certain parts of RD&D Programme lack clear descriptions concerning how different results can contribute towards the overall description and safety assessment. SKI has previously emphasised the importance of continuous integration between the results from different areas and the needs of the safety assessment. It is also important to use the results from completed safety assessments as a basis for decisions concerning future research work. Clearer objectives with links to safety assessment should make it easier to determine whether the knowledge base is adequate to be able to justify a definite standpoint. SKI presumes that this will be dealt with in SR 97. SKI intends to follow up and discuss this in connection with SKI's separate evaluation of SR 97 during autumn 1999.

7.2. Spent Fuel

7.2.1 Introduction

In this section, SKI discusses Spent Fuel, as presented in Section 9.3 of SKB's RD&D Programme 98 and Chapter 4 of Detailed Programme for Research and Development 1999-2004.

The aim of SKB's research in the field of spent fuel is to quantify the release of radionuclides from spent fuel under different conditions, and to create an understanding of the complex mechanisms involved. The objective of the programme is, according to SKB, to validate fuel models which will be used for safety assessments (see also Section 6.2.3). As spent fuel consists mainly of components of relatively low solubility, the release of radionuclides will probably be limited even if groundwater were to leak into a damaged canister of spent fuel. The fuel itself can therefore be seen as a barrier to radionuclide dispersion, in addition to the canister, bentonite and rock barriers.

7.2.2 Experimental and Theoretical Studies of Fuel Dissolution

SKB s Report

In RD&D Programme 98, SKB describes how, at the end of the 1970s, it studied the characterisation of spent fuel and leaching tests on spent fuel. SKB's results, together with experience from countries such as Canada, the USA and Germany, have formed a basis for justifying the development of fuel dissolution in safety assessments. SKB's experimental material, which mainly comprises sequential leaching tests, has been put into a database.

The release of radionuclides from the fuel is a very slow process, in which there are often very low concentrations in the leachate. SKB has therefore considered it necessary to invest in substantial resources in order to produce sufficiently accurate analysis methods (ICP-MS and ion chromatography). The further development of analysis methods which has taken place is a requirement for obtaining improved data from leaching tests on spent fuel. Separate work has involved designing equipment for making precise measurements of pH and Eh values in ongoing experiments, and developing a method for analysing nuclides of the same mass number (isobar separation).

Two important types of test reported in RD&D Programme 98 are leaching experiments on spent fuel specimens and combined leaching and nuclide diffusion experiments on spent fuel and bentonite. In evaluating the former type of experiment, the effects of the degree of burn-up and linear power density have been studied in particular, while in other cases the diffusivities of different actinides have been assessed.

SKB has also carried out radiolysis experiments on fuel, with the purpose of studying the mass balance of refined hydrogen and oxygen. The kinetic data which appeared in these experiments are useful for the development of a kinetic model of fuel dissolution.

SKB has recently developed a realistic model of fuel dissolution under oxidising conditions (RDC). This was in good agreement with results from experiments on both unirradiated uranium dioxide and spent fuel.

In RD&D Programme 98, there is further discussion about a number of planned or initiated measurement series, which aim at studying chemical conditions on the dissolution of fuel, the effects of the specific area of the fuel, basic studies of radiolysis reactions with the purpose of determining rate constants, the effects of alpha radiolysis alone (without beta and gamma radiolysis) etc. In these experiments, the objective is to attain greater control of specific conditions (pH, Eh, specific surfaces, radiation field etc.) than in previous experiments, and this can provide a better foundation for developing and testing different types of models.

Comments by the Reviewing Bodies

Stockholm University (SU) lacks information in RD&D Programme 98 concerning the way in which spent fuel may be affected by gamma radiolysis. The opinion of Chalmers University of Technology (CTH) is that there is a lack of information about the inventory and characteristion of spent fuel.

SKI s Evaluation

SKI believes that SKB's fuel programme is suitably directed towards the issues which are important for safety assessments and the development of models. SKI has previously questioned whether the chemical environment which is used for SKB's leaching tests is relevant to the repository (SKI, 1996a). No essentially new material has appeared prior to this evaluation, but SKB's planned experiments in flow reactors with continuous measurements of redox and pH conditions during the experiments look promising. SKI is also looking forward to studying the results of SKB's planned fuel experiments in the CHEMLAB probe, during which the redox status of the groundwater

is expected to be significantly less affected than in previous experiments. In order to progress further with the research within this area, experimental data of a very high quality will probably be required, which will make it possible to make significant distinctions between different types of fuel conversions and release mechanisms for radionuclides. It should be possible to make meaningful comparisons with process models based on fundamental chemical and physical mechanisms.

However, it is not sufficient to only study fuel dissolution under the chemical conditions seen in deep groundwater today, where changes in groundwater chemistry (salinity, redox etc.) can be anticipated in different time perspectives. The chemical composition and redox situation can also be altered by processes in the actual repository, such as the radiolysis of the fuel, corrosion of the fuel canister's cast iron insert, reactions between the groundwater and different types of minerals in the bentonite clay, etc. It is therefore important for the fuel programme to be co-ordinated with the chemistry programme, so that it covers all chemical conditions considered relevant.

As with previous evaluations, SKI considers a continued development of realistic fuel models to be important for efficiently interpreting existing experimental data and planning new experiments. It will perhaps not be possible to verify and justify these models to the extent that they can be included in the safety assessments, but they should provide a basis for assessing the simplified assumptions which are used for developing the models which are intended for the safety assessment (see Section 6.2.3).

SKB reports the results from experiments with unirradiated uranium and magnetite (expected corrosion products from the iron insert). SKI considers these experiments extremely relevant as SKB's own analyses indicate that the iron system will have a significant impact on the chemistry inside a failed canister. However, unirradiated uranium is not a satisfactory replacement material, and therefore SKB should consider continuing and also experimenting with magnetite and spent fuel.

Other issues which SKI is interested in following up include the distribution of radionuclides of relatively high solubility in the spent fuel, which can have a considerable effect on the way in which the release will be distributed as a function of time. Physical changes in the structure of the fuel should also be taken into consideration, as they can influence the proportion of radionuclides which can be rapidly released. Mechanisms which control the release from metallic inclusions (e.g. Tc, Mo, Ru, Rh, Pd) are not described further in RD&D Programme 98 but may need to be characterised more clearly. Radiolysis effects of actinides which have precipitated as secondary minerals or sorbed inside the canister may, in time, need to be considered in the analysis of the development of the system over time.

In SKI's opinion, SKB's work is generally of adequate scientific quality and makes a significant contribution towards international research. However, SKI has found that SKB's reporting is, in places, fragmented and difficult to grasp. SKB should be able to explain more clearly how the individual experimental studies are expected to contribute towards the research as a whole and especially towards model development.

7.2.3 SKI s Overall Evaluation of Spent Fuel

In SKI's opinion, there are still a number of issues within the area of spent fuel which require further explanation, and this makes it difficult to assess the reliability of the fuel models which claim to be realistic. However, this does not necessarily mean that present knowledge is inadequate for assessing the reliability of fuel models which are based only on conservative yet simplified assumptions. Examples of these intractable issues are the relevant importance of various release mechanisms, the effects of radiolysis and the formation of secondary minerals. These uncertainties mean that it is difficult to fully demonstrate the barrier function of the fuel and, consequently, this is why it has only been included in previous safety assessments to a limited extent.

In SKI's view, SKB's experimental work is adequately focused on issues which are important to resolve. In spite of this, it is presumably not realistic to expect rapid progress within the area, depending on the general difficulty of studying very slow processes and the major practical problems of managing the highly radioactive material. The resources which SKB must invest in this area will depend on the extent to which the potential barrier function of the fuel will be used in future safety assessments.

7.3 Canister Material

Comments on Section 7.2.3 of RD&D Programme 98 and Chapter 5 of the Detailed Programme for Research and Development 1999-2004 will be provided in this section.

7.3.1 Corrosion

SKB s Report
SKB has several ongoing corrosion projects, which cover both basic theoretical work (updating thermodynamic data for copper, literature studies of corrosion on canisters prior to deposition and models for corrosion), and experimental work with pitting, bacterial corrosion, stress corrosion cracking and corrosion tests in realistic environments. Results from these projects will determine the extent to which further studies and experiments are to be performed.

At the same time, SKB writes (in RD&D Programme 98) that, after providing additional material by these studies, the knowledge base for the corrosion of copper is sufficient for evaluating corrosion attack on the canister over a period of 100 000 years, in the environment which is presumed to prevail in the repository. Research into corrosion will therefore concentrate on the initial period, before reducing conditions prevail.

SKB also discusses the importance of studying the course of corrosion in the gap between the iron and copper, and if possible, obtaining a measure of the forces which may result from the increased volume of the corrosion products, as iron corrodes during hydrogen gas formation when it comes into contact with water. Apparatus for testing corrosion is currently being designed.

Comments by the Reviewing Bodies
Uppsala University (UU) highlights the importance of studying the movement of the groundwater and its effect on the groundwater composition, which in turn influences copper corrosion. UU believes that similar studies can advantageously be carried out at the Äspö Hard Rock Laboratory. UU further considers that sulphide production by microbial processes must be investigated in greater detail, and that more research is required on the microbial flora in the bedrock. The Geological Survey of Sweden (SGU) considers further research into the significance of microorganisms for the long-term safety of the repository to be well-reasoned.

The Swedish Testing and Research Institute is of the opinion that the investigations carried out to update the thermodynamic database for copper, risk assessment and possible impact of pitting, stress corrosion and microbial corrosion of copper, are justified, and agrees with SKB that the compiled knowledge base on copper corrosion should therefore be sufficient.

SKI s Evaluation
According to SKI, the central issue within the field of corrosion is the way in which knowledge about corrosion processes is used in the assumptions and analyses which form the basis for the corrosion rates that are used to design the thickness of the copper. In light of the work performed in recent years and the work which is being carried out by SKB in the field of corrosion, SKI considers that SKB should compile a new presentation of how different types of corrosion are factors in the development of the design of the copper canister.

SKI further considers that SKB should gather results from these ongoing corrosion studies, before changing direction to research with an emphasis on corrosion in the initial period, i.e. before reducing conditions prevail.

SKB writes that sulphate-reducing bacteria and their survival in the repository are one of the most important issues with respect to microbes, but that results from ongoing tests will determine whether further work will be done, and if so, what will be done. SKI encourages SKB to continue its studies of the impact of microbes on the integrity of the canister (see also Section 7.8.4).

SKI considers it laudable that SKB is planning a programme for testing corrosion in a realistic environment at the Äspö Hard Rock Laboratory, but lacks a more detailed description of the experiments.

In SKI’s opinion, it is also important that SKB should study the corrosion process in the gap between the iron insert and the copper canister. In this context, issues concerning galvanic corrosion should be clarified, in case metallic contact occurs in the gap. Work within this area should also be closely related to work with safety assessment models for the process in a damaged canister.

7.3.2 Materials Testing

SKB s Report
SKB is carrying out studies of copper material in relation to the creep testing of weld metal, analysis of phosphorous alloys of sulphurous copper (in theory, planned additional experiments), and the distribution of phosphorus and sulphur in oxygen-free copper.

Full-scale experiments are planned for the validation of completed materials strength and temperature calculations. Further calculations may also be needed in order to investigate the slow build up of stresses when the swell pressure of the bentonite increases.

Comments by the Reviewing Bodies
Chalmers University of Technology (CTH) would like clarification of the issue of whether the radiation environment in the repository can affect the durability of the canisters.

SKI s Evaluation
SKI wishes to stress the importance of studies of both the mechanical properties and the creep properties of the copper material, and the importance of using material samples which are collected from canisters that have actually been fabricated. SKI also considers that the mechanisms for the impact of phosphorus on the creep properties of copper require further investigation (see also Section 5.4.2).

SKI agrees with Chalmers University of Technology (CTH) that the issue of the impact of radiation on durability should be clarified.

7.3.3 Non-destructive Testing

SKB s Report
SKB states that all copper tubes and the base and lid will be tested using ultrasound. All welds in the copper canister are to be tested by ultrasonic and X-ray methods. In addition, SKB states that a procedure for the qualification of non-destructive testing is being formulated. SKB has a programme for the development of equipment and software for ultrasonic testing of the copper welds, the main objective being the development of systems for “phased array” testing and software for noise reduction. Until now, results have only been obtained for known artificial defects. SKB also mentions that methods for X-ray testing are also being developed.

SKI s Evaluation
SKI emphasises the importance of continuing with the development programme for ultrasonic testing. It is essential that the programme also includes a link to grain size in the copper and the welding zone, as well as actual defects, and this is why SKB must supply information about anticipated types of defect. In particular, the development of noise reducing algorithms can have crucial importance on the testability of the welding

zone, depending on the material structure which is obtained through the sealing method that is ultimately selected.

SKI is lacking information about current research on X-ray testing. SKI assumes that there is also a research and development programme for X-ray testing, similar to the one being carried out for ultrasonic testing.

7.3.4 SKI s Overall Evaluation of the Canister Material

SKI is of the opinion that SKB should compile a new report of how different types of corrosion form a basis for the design of the copper canister, and show how knowledge about corrosion processes are to be used in the assumptions and analyses which form the basis for the corrosion rates used in the safety assessment. SKI further believes that SKB should collect and interpret results from ongoing corrosion studies, before changing direction to research with an emphasis on corrosion in the initial period (before reducing conditions prevail). The studies of the impact of microbes on the integrity of the canisters should continue.

SKI considers it laudable that SKB is planning a programme for corrosion testing in a realistic environment at the Äspö Hard Rock Laboratory, and that SKB is studying the corrosion process in the gap between the iron insert and the copper canister. Work within the latter area should be closely related to the work with safety assessment models for the process in a damaged canister.

SKI wishes to highlight the importance of studies of both the mechanical and creep properties of the copper material, and the importance of using material samples which are taken from actual fabricated canisters for studies of material properties and corrosion. SKI also considers that the mechanisms for the effects of phosphorus on the creep properties of the copper need to be investigated in greater detail.

SKI underlines the importance of SKB continuing with the development programme for ultrasonic testing. It is essential that the programme also includes a link to the grain size in the copper and welding zone, and real defects. SKI would like to see information about current research on X-ray testing.

7.4 Buffer and Backfill

7.4.1 Introduction

SKI comments below on Sections 7.1.2, 7.1.4 and 9.3 of SKB's RD&D Programme 98 and Chapter 6 of Detailed Programme for Research and Development 1999-2004.

In connection with SKI's evaluation of RD&D Programme 95, SKI provided a detailed evaluation of SKB's bentonite programme with the help of external experts (Roaldset et al. 1996). The evaluation below shows that certain comments made on this occasion are still relevant. SKB has, however, dealt with a whole range of viewpoints, and has started

RD&D work which is being carried out at present. SKI recently performed an investigation of SKB's bentonite programme, which is reported in Savage et al. (1999).

7.4.2 Performance Requirements on the Buffer Material and Backfill

SKB s Report
The main function of the buffer in the repository is to protect the canister from chemical and mechanical impact, and to keep the canister in place in the deposition hole. In order to achieve this, certain performance requirements must be made on the buffer material, of which SKB specifies the following:

- Hydraulic conductivity should be so low that any transport of corrosives and radionuclides will only occur through diffusion.
- Gas permeability must be sufficient should large amounts of gas form in the canister, and the gas must not cause permeable channels or cavities to remain in the buffer.
- Swelling pressure must be high enough to provide good contact with the surrounding bedrock and with the canister, but not so high that the canister and surrounding bedrock cannot withstand the pressure.
- Deformability must not be so great as to dislodge the canister, but at the same time, not so low that rock movements cannot be taken up without the canister being damaged.
- Colloid particles are to be filtered by the buffer.
- The thermal properties (heat conductivity) must not cause unacceptable physical and chemical changes to the buffer.

SKB's most commonly used reference material is MX-80 Volclay which, after water saturation, will have a density of 1900-2100 kg/m^3. Other materials with a smaller amount of expanding clay mineral has also been studied. As these minerals are more homogeneous and appear to provide sufficiently high swelling pressure, SKB specifies the option of replacing MX-80 with some of these materials. According to SKB, different kinds of commercially available smectite clay have been fully tested and compiled in a database.

SKB also describes demands on the material which is to be used as backfill and also on the rock in the proximity of deposition holes and tunnels, for which SKB does not mention equally specific requirements at present. However, an important property is that the backfill must provide sufficient support for the roof and walls of the tunnels. Certain issues have not yet been tackled, such as whether the nearby rock will be sealed by grouting.

Work with identifying and describing the buffer and backfill material has been compiled in SKB's Technical Report Series under the title "Bentonite and Backfill Handbook", which is gradually updated. According to SKB, its purpose is to attain consistent definitions and method descriptions, i.e. SKB intends in this way to keep a combined knowledge base.

SKI s Evaluation
According to SKI, a number of issues still need to be dealt with by SKB in order to show that the engineered barriers (bentonite clay) selected in the KBS-3 concept fulfil the performance requirements set for the relevant time periods for the repository, based on the requirements of the safety assessment.

SKI notes that SKB intends to detail requirement specifications for the buffer and backfill over the next three-year period. SKI plans to follow up this work during the subsequent RD&D period, concerning, for example, how a balance will be reached between requirements/preferences regarding the canister, rock and buffer, and how they will affect each other. In SKI's opinion, it is essential for SKB to present, to a greater extent, an overall view of the requirement specifications and to co-ordinate this work so that all aspects can be covered simultaneously.

SKI approves of SKB investigating the possibility of replacing MX-80 with other materials. However, SKI assumes that a relatively large amount of work may have to be carried out in order to show that another type of material could be an adequate substitute. This is due to the fact that MX-80 has been SKB's reference material for a long time and that a range of other material properties besides swelling properties must be investigated and proven to be equally adequate.

SKI approves of SKB compiling the existing large amounts of data and method descriptions into a "Bentonite and Backfill Handbook". However, SKI points out that much of the knowledge acquired is not available at present. Experimental, theoretical and empirical data production and data models will need to be compiled in a more complete database, to be made accessible.

7.4.3 Results from Studies of the Buffer and Backfill Material

SKB s Report
During the last period, SKB improved its understanding of the structure of the bentonite clay and how this influences transport properties. The ways in which thermal, hydraulic and mechanical processes can interact in the buffer have been studied within the framework of international projects. Chemical processes have also been included, where illitisation and reactions between bentonite and pore water from the concrete have been important issues.

In parallel with the basic studies, SKB has also worked with technique development, and, as an experiment, has produced full-scale highly compacted bentonite blocks. The materials strength of these blocks is currently being tested. The location and backfilling of the deposition tunnels have also been the aim of practical experiments at the Äspö Hard Rock Laboratory. Laboratory-scale investigations have been performed to show the ways in which the buffer can be disintegrated, which is necessary for the possible retrieval of deposited canisters.

An important issue which is being investigated is how saline groundwater can affect the swelling pressure of the buffer. SKB has produced a model which shows that the

swelling pressure is only marginally affected by saline groundwater rich in both sodium and calcium. The bentonite in the backfill, however, is expected to be affected to a greater extent as its density is substantially lower.

SKB believes that the increase in temperature of the buffer, caused by the residual heat of the fuel, is a particularly important issue. The clay in the buffer can be affected by salt enrichment and steam formation. In order to minimise this risk, SKB suggests the use of buffer blocks with a high degree of water saturation.

Modelling studies have been performed in connection with participation in two different EU projects, one of which has the purpose of producing a basis for quantitative calculations of water saturation courses and ion transport, and the other has the purpose of studying linked thermo-hydro-mechanical functions. In the latter case, practical studies have started, namely buffer experiments in Japan (Kamaishi) and Switzerland (FEBEX).

SKB intends to model the water saturation process in greater detail, using microstructural models. As regards ion diffusion, SKB states that there is at present a greater understanding of the fundamental mechanisms, but that separate migration of cations cannot be fully modelled because chemical processes such as complex formation, are not currently included in existing models.

SKB has shown, through experiments, how a gas flow can initiate through the buffer as the pressure reaches a critical level. Within the framework of the international "GAMBIT Club" co-operation, in which SKB participates, the aim is to produce a model for calculating gas flow through bentonite. The initial phase has concentrated on gaining an understanding of the mechanisms and testing a calculation model. Gas transport will probably initiate through microcracks formed in the clay, and after propagation of the gas transport paths, a continuous gas flow can be maintained.

In RD&D Programme 98, SKB summarises the issues which it considers most critical to pursue:

- the chemical long-term stability,
- possible cementing and permanent contraction of smectite particles ,
- extrapolation of results from gas transport tests to the conditions which apply to a repository,
- demonstrate practically that requisite block density can be attained so that the matured buffer in the deposition hole will have a sufficient density,
- investigation of microstructural changes in connection with the buffer saturation phase, which can result in considerable anisotrope water permeability,
- evaluate the content of accumulated shear deformations (0.01-10 cm) in a long-term perspective and the link between shear movements in the earth's crust, stress conditions and the structural composition of bentonite.

SKI s Evaluation

SKI agrees with SKB that the long-term chemical stability of the bentonite is one of the most important issues. Chemical changes in the bentonite could degrade the buffer's function of protecting the canister and retarding the transport of radionuclides, in

relation to the criteria on which the safety assessment is based. It is therefore very important for SKB to gain an adequate understanding of all processes which may affect buffer performance. Both theoretical and experimental studies, as well as investigations into how natural bentonites change under different conditions, can be expected to contribute towards improving knowledge.

SKI considers that the previously used illitisation model can still be regarded as an applicable tool. The choice of parameter values must, however, be adequately justified. According to SKB, experiments have been performed to derive e.g. activation energy from natural analogues. SKI wishes to reiterate the statement, from the evaluation of RD&D Programme 95, that this model has its limitations and that there are also alternative models based on other conversion processes. In SKI's view, this places demands on SKB to make further assessments of the suitability of the selected model.

SKI shares SKB's opinion that the cementing and permanent contraction of smectite particles can be a more significant problem than the illitisation of the bentonite. More work should, therefore, be concentrated on investigating the above-mentioned effects during the next RD&D period. SKI is of the opinion that resources must be invested so as to be able to show any unfavourable impact of the process and how this will be handled in SKB's ongoing work with the repository concept.

In SKI's opinion, the block density in the buffer requires further work on both the laboratory and the field scale, and considers SKB's planned work reasonable at this stage.

SKI noted in its statement on RD&D Programme 95 that the knowledge on water saturated buffer material is adequate, and that SKB has made considerable progress in this area. In comparison, SKB has not made as much progress with respect to un-saturated conditions, which should give rise to measures during the next RD&D period. The initial resaturation phase can be important for the long-term properties of the buffer, as heat from the canister, under unsaturated conditions, might cause dryout, cracking, chemical changes, and so on. SKI considers that SKB needs to carry out analyses which will clarify the influence of the factors that affect the wetting rate of the buffer and backfill. SKB should also show how it intends to deal with the results.

SKI is of the opinion that the temperature increase inside the canister at the start of the deposition period and the problems which it can cause for the buffer should be investigated in greater detail. The T-H-M model to which SKB refers is a complex model with many detailed parameters, and has aided SKB in certain analyses. It is positive that SKB is continuing this development work, but if it is to be possible to evaluate the results with some certainty, the results from simpler models should also be reported in parallel. It will then be possible to gradually make more in-depth analyses in an iterative process which will take into account the results provided before the next analysis cycle. It should be possible to make a rough investigation to determine which processes and parameters are of greatest importance. It seems cumbersome to use a three-dimensional model with all of the influencing mechanisms, and may produce results which are difficult to interpret.

As regards the modelling of the water-saturated buffer's mechanical, thermal and hydraulic properties, SKI has observed that, in connection with the evaluation of RD&D Programme 95, further work is necessary mainly within two areas, namely verification through experiments and statistical analysis. Verification is rather limited, even though the results attained seem reasonable. Further comparisons should be made with laboratory experiments, where direct comparisons can be made with e.g. pressure, temperature and flows. The planned full-scale experiment at Äspö presumably cannot be used in this respect, as it will initially deal with buffer material in unsaturated states.

With respect to the understanding of the transport of gas through bentonite, SKI agrees with SKB that certain progress has been made although a number of important questions still remain to be answered. SKI agrees with SKB that work is needed so as to assess how the boundary conditions influence gas transport. It is important to understand how gas transport can affect the bentonite and how this in turn affects the boundary conditions in the field situation. A sound understanding of how the situation in the field can differ from the laboratory experiments will be required, in order to produce a suitable model for gas transport. In this context, SKB wishes to highlight the risk that gas formation can cause overpressure which can further damage a canister or the surrounding bedrock. Another risk is that preferential transport paths form in the parts of the bentonite where gas has already passed.

In connection with the statement on RD&D Programme 95, SKI put forward a few questions which needed to be answered, e.g. regarding whether any gas can leave without the pressure increasing to such levels that the bentonite buffer around the canister cracks causing more permanent damage in the surrounding bedrock. SKI considers that this has still not been sufficiently investigated, and that it should be included in SKB's continued work with bentonite, e.g. in the "GAMBIT Club" collaboration project.

SKI is doubtful about SKB's reported critical load cases, that rock movements and buffer deformation which cause damage to the canister can be dismissed as unharmful with the help of a semi-empirical rheological model. SKI is performing its own sensitivity analysis regarding these issues. Preliminary results show that continued work within this area can be justified.

7.4.4 SKI s Overall Evaluation of the Buffer and Backfill

According to SKI, it is essential that SKB should present an integrated account of its requirement specification for the buffer and co-ordinate this work so that all aspects are covered at the same time.

In SKI's opinion, SKB must be able to show, more clearly than before, that the buffer fulfils the performance requirements on maintaining favourable chemical and physical properties in a long-term perspective. Further work on developing a knowledge base will be required to identify possible chemical and structural changes in the bentonite which can occur in the long term and in order to be able to predict the effects of the changes.

SKI is of the opinion that SKB needs to improve understanding of the saturation phase of the bentonite, as heat from the canister can weaken the bentonite's properties over a lengthy period of wetting. SKB has made considerable progress in understanding the properties of bentonite under saturated conditions. SKI considers that SKB needs to carry out analyses which elucidate the factors that influence the saturation rate in both the buffer and the backfill.

7.5 Structural Geology and Mechanical Stability of the Rock

In SKB's RD&D Programme 95, SKB presented comprehensive background material and a presentation of this subject. RD&D Programme 98 contains a shortened version of the presentation, and additional material to this subject can be found in Section 9.3 of the main report and in Chapter 7 of Detailed Programme for Research and Development 1999-2004. These sections are discussed here by SKI.

The rock is the natural barrier which will mechanically protect the canister. The rock will also have a retaining and retarding function with respect to radionuclide transport. In addition to these functions, the rock must have such properties that the repository can be constructed and operated with a high demand placed on safety and known techniques. This means that operation must be able to take place with adequate control over the stability and inward leakage of water.

Knowledge of structural geology and rock mechanical conditions is required so that the repository can be located and adapted with respect to larger fracture zones. The mapping of seismic activity is also important, as these can cause displacement along fractures in the rock.

SKB s Report
SKB's prioritised objectives during the period 1999-2004 are to:

- gather available knowledge about the potential tectonic and seismic consequences of a repository in the Swedish crystalline bedrock,
- compose a method of identifying and interpreting structural geological elements, lineaments, zones and fractures which will be used for characterising the geological criteria for building and operating a repository.

Discontinuity patterns in rock appear on a scale ranging from mm to km, and are characterised by brittle shear ruptures and/or tension ruptures. According to SKB, it is improbable that extensive fracturing or propagation will occur within the next hundred thousand years, and the reactivation of existing discontinuities is more likely.

Comments by the Reviewing Bodies
The Geological Survey of Sweden (SGU) believes that the work and priorities within this area are correct. SGU also considers that the effects of glaciation, land evaluation, seismicity and neotectonic and post-glacial movement on a repository need to be studied. SGU also considers it important to identify the importance of regional plastic shear zones and to study the advantages and disadvantages of siting the repository in a

relatively unaffected tectonic lens in a regional plastic shear zone, and mentions the area next to the Forsmark nuclear power plant as such an example.

The Department of Mathematics and Science at Göteborg University (GU) considers that SKB has a professional attitude and scientific approach to its work, but regards the links between scientific and technical issues as insufficient. GU specifies a lack of a fracture analysis model and a thorough discussion of the importance of the fractures to the repository as examples of gaps in knowledge.

The Swedish Anti-Nuclear Movement (FMKK) believes that many questions remain unanswered with reference to pages 62-64, 67 and 68 of Detailed Programme for Research and Development 1999-2000 where there is discussion of issues such as the safety importance of regional shear zones and tectonic lenses on a repository, little known mechanisms which control seismic events in the continental drifts, the impact of the repository on the regional strength of the rock, and conceptual uncertainties about creep processes in fractured rock.

Geologist N.A. Mörner believes that SKB has been ignoring new findings concerning post-glacial tectonics, geodynamic and bedrock movements which may affect a repository.

SKI s Evaluation

SKI, like the Geological Survey of Sweden (SGU), considers that SKB's current and planned R&D work should be performed as SKB reports this work with reference to structural geology and the mechanical stability of the rock. SKI also wishes to underline how important it is that activities are undertaken in the form of an easily identifiable and coherent project with a clear division of responsibility for what SKI considers to be an important area of research.

SKB's RD&D Programme 98 now discusses the areas in which further/additional research is required. The couplings between the work within existing geological and rock mechanical programmes, and the needs and requirements of the safety assessment and site characterisation are, according to SKI, better than in RD&D Programme 95, but need to be clarified in greater detail. For the present and long-term work, SKI would like to see both clear and specific objectives and links (strategies) to the users of the geological and rock mechanical work which SKB intends to carry out.

SKB's programme work is presented very briefly, and frequently using vague terms, such as "touch on issues", "further develop methods/criteria", "improve understanding", "compile available knowledge", "attention must be paid to", "discernable R&D problems", "analysis of issues", etc. This makes it difficult for SKI to evaluate the level of ambition for SKB's planned activities. However, SKI points out that it is important to undertake and complete the activities discussed in the status report, and starting out from this, to observe results attained in the continued work with, for example, site characterisation.

SKI wishes to emphasise how important it is that SKB's proposed work actually discusses the risks of a repository and its components, such as the impact on bentonite, the canister and groundwater flow. There are strong links here to the scenario analysis which must be carried out within the framework of a safety assessment.

During current work on the DECOVALEX international project (in which SKI and SKB participate), a number of shortcomings have been identified in the knowledge required to perform analyses of related thermo-hydro-mechanical-chemical (THMC) processes. There is uncertainty in the theoretical assumptions, difficulties in making predictions for long periods of time and in scaling up experimental results from the laboratory to large-scale field experiments. There is also a lack of data about the mechanical properties of the fracture zones. SKI also regards it as preferable for SKB to report knowledge on about the THMC processes and their links to the safety assessment.

SKI considers that uncertainties about the mechanical stability of the rock need to be analysed, by setting them in relation to other uncertainties, for instance, and by investigating how they should be handled in future analyses. A significant factor is the understanding of the mechanical properties of the rock over lengthy periods of time and how changes in these properties affect groundwater flow. In RD&D Programme 98, SKB has identified a need for development within this area. In SKI's view, the development work mentioned by SKB should be undertaken, and discusses some of these activities below.

SKB intends to study plastic shear zones and their significance for a repository. SKI considers these studies to be important, especially if SKB really intends to site a repository in or near a regional plastic shear zone (tectonic lens) which, until now, SKB had generally consistently tried to avoid. It is important for SKB to report the advantages and disadvantages of such a siting with respect to opportunities for site characterisation, predictability, recharge and discharge zones. In this context, SKI is lacking information about SKB's research activities on the deformability and strength of the large zones of weakness, and the development of methods for characterising their properties.

In SKI's opinion, R&D work on the representativity of the rock stresses needs to continue, with a concerted effort made in understanding stresses in connection with discontinuities and the reorientation which these can bring about in the regional stress field. The results from stress measurements performed within the Äspö area show the need for more work within this field of research.

In terms of mechanical issues in the repository, attention must be devoted to the zones disturbed by blasting or full-face boring and to what size of the deformation of deposition holes can be permitted (see also comments in Section 7.12). These results and mechanical analyses can serve as material for presenting acceptance criteria for the location and orientation of deposition tunnels and drifts.

SKB discusses the occurrence of discontinuities (fractures and fracture zones) their displacement and the way in which important properties can vary and change with time, with respect to future ice ages, for example. According to SKI, it is important to have

control over movement directions and movement times so as to statistically gather and study data on displacement regarding discontinuities.

SKI also wishes to highlight the importance of SKB continuing to further develop quantitative criteria for classifying discontinuities in the bedrock. SKB needs to explain how these criteria will be applied for evaluating the "respect distance" to different repository parts and canister positions and how this relates to the actual stress characteristics. According to SKI, this should be done stringently and based on scientifically approved methodology, which will permit independent evaluation.

Rock mechanical modelling is represented by a good schematic, illustrative diagram in the Detailed Programme for Research and Development 1999-2004. However, SKI lacks proposals for specific work which aims to investigate the issues illustrated by the figure. RD&D Programme 98 does not present any specific information concerning SKB's intentions within this important area during the next period of research.

SKI does not think that present knowledge permits definite forecasts of young movements arising, for example, in connection with glaciation, and this places demands on SKB to carry out further analyses of underlying mechanisms and to analyse the importance of the movements to long-term safety.

SKI agrees that it is important to further develop methods for identifying sub-horizontal structures (low-dipping fracture zones) in the bedrock and refers to opinions which were expressed in SKI's evaluation of previous RD&D programmes. The issue of whether the excavated and backfilled repository itself constitutes a horizontal plane of weakness has been touched upon by SKI and other reviewing bodies on various occasions. SKI observes that SKB has not yet looked into this issue.

SKI s Overall Evaluation of Structural Geology and Mechanical Properties of the Rock

In SKI's opinion, in the account of this subject presented in RD&D Programme 98*, a clear discussion* is lacking of the areas where knowledge, according to SKB, is adequate and of the areas where SKB considers that further work must be done. SKI notes that SKB intends to study plastic shear zones and the importance of these zones to a repository. It is important to do this, especially if SKB actually intends to locate a repository in or near to a regional plastic shear zone (tectonic lens). SKI also wishes to emphasise the importance of completing the work that has been described and started, and of SKB assimilating acquired knowledge in its ongoing work with site characterisations. SKI intends specifically to follow SKB's work within the area of structural geology and rock mechanics, in order to provide viewpoints on areas where additional work must be done in the coming years.

SKI also wishes to underline the importance of completing the work started in RD&D Programme 98 and of SKB assimilating acquired knowledge in its continued work with site characterisation. According to SKI, it is important that the activities are performed and further developed within the framework of a clear and coherent programme.

7.6 Water Flow in Rock

Below, SKI discusses SKB's report on its research into water flow in the rock, etc. in Chapter 8 of the Detailed Programme for Research and Development 1999-2004.

Water flow in the rock is an important parameter to consider when evaluating the suitability of a site for a repository and in the safety assessments. Groundwater can carry soluble substances which may affect the performance and degrade the engineered barriers. The flow of groundwater and the flow paths are determining factors for the transport of radionuclides in the rock.

SKB s Report
In this chapter, SKB has highlighted parts of the R&D project which are presently being performed or are planned for studying important issues concerning water flow and its relevance to the transport of radionuclides in the rock. SKB refers here to current tracer tests (TRUE) and the project for classifying and describing fractures at Äspö, which have the purpose of obtaining data for calculations of how both non-reactive and reactive (sorbing) elements are transported with the groundwater in the rock.

SKB is also designing a special TV camera which it plans to use for characterising fractures in boreholes. SKB hopes that the pictures will provide information about the hydraulic and perhaps also retarding properties of the more highly water-bearing fractures.

SKB states that it has developed an analytical method of analysing recharge and discharge conditions. This method has been applied to three sites in SKB's SR 97 safety assessment project, and has resulted in very long transport times from the repository to the biosphere, compared to previous calculations. SKB draws the conclusion that the regional flow conditions do not seem to affect the flow of groundwater at repository depth. Instead the topographical conditions are the decisive factor. Consequently, SKB is planning to conduct further studies to improve the understanding how local topographical and hydrological factors affect the groundwater flow around a repository. According to SKB, these studies are also justified by the need to describe the relationship between the geosphere and the biosphere in greater detail.

SKB has performed a study of the applicability of well data (from SGU's well archive) so as to determine, on a regional scale, the hydraulic properties of the bedrock. According to SKB, the results show that well data is applicable, although extrapolation at greater depths is made difficult by the preference for drilling to greater depths in low-permeability rock.

SKB also mentions that one of the most important specific aims of the coming three-year period is to investigate the problem of the scaling up of flow and transport parameters. Both modelling and field tests are planned at the Äspö Hard Rock Laboratory.

Comments by the Reviewing Bodies
The Royal Institute of Technology (KTH) seeks more thorough analyses of the connection between the geosphere and the biosphere and of the surface factors which affect the groundwater flow at different depths. In this context, KTH proposes that new methods be used for determining the age of the groundwater, such as measurements of freon content as an indicator of the age of post glacial groundwater.

Uppsala University (UU) maintains that the Geological Survey of Sweden's (SGU) well archive cannot be used for drawing conclusions about the composition and movements of the water at a depth of 500 metres. The university therefore considers that the feasibility studies should be supplemented in order for SKB to have sufficient material prior to the selection of sites for site investigation.

SKI s Evaluation
On the basis of the overall account presented by SKB in RD&D Programme 98, SKI is of the opinion that SKB's research programme on water flow and transport in the bedrock is appropriate. However, Chapter 8 of Detailed Programme for Research and Development 1999-2004 does not present any clear overview of SKB's complete research programme in this area. Therefore, SKI urges SKB to review the co-ordination of research on these important issues within the different projects for site characterisation, safety assessment and supporting R&D at Äspö and elsewhere.

SKI considers SKB's work on determining the transport properties of the rock at the Äspö Hard Rock Laboratory to be relevant and of a high quality. However, SKI would like to reiterate its recommendation of the last RD&D programme that SKB should also develop measurement methods (e.g. combinations of different types of tracer tests) which can be used for determining the transport properties of the rock in connection with (surface-based) site investigations. According to SKI's own experience with analyses of data from the pre-investigations at Äspö (SKI, 1996b) the measurement methods used until now have been inadequate for determining the rock's capability to retain and retard sorbing radionuclides.

SKI supports SKB's ambitions of producing measurement methods (TV logs) which will facilitate a more systematic description of the properties of the fractures from boreholes. SKI believes this type of data, together with systematically performed laboratory investigations of fracture minerals and pore structure, can provide valuable data for modelling the retention properties of the rock in connection with site investigations.

SKI has previously required more thorough studies of regional groundwater flow systems, and in particular of the significance of recharge and discharge areas for the siting of a repository. SKI is therefore optimistic about the work reported in RD&D Programme 98. However, SKI has doubts about the far-reaching conclusions SKB draws about the significance of the local topographic conditions on the groundwater at repository depth, based on the recently-developed analytical model, and in particular because SKB draws the opposite conclusion in another report (Andersson et al., 1998, p. 73). SKI therefore considers that SKB, prior to the selection of sites for site investigation, should explain the role of the regional groundwater flow as a siting factor.

SKI agrees with SKB that further studies of the local hydrological conditions, and their importance for the groundwater flow conditions in the interface between the geosphere and the biosphere, are justified.

SKI agrees with Uppsala University (UU) that extrapolation of hydraulic and groundwater chemical conditions to repository depth, based on SGU's well archive, is a somewhat uncertain method and that SKB should be more cautious when making such extrapolations in the feasibility studies. In SKI's opinion, however, it is not reasonable to ask SKB to produce a detailed description, in a feasibility study, of the hydrogeological and geochemical conditions at repository depth. This should be done in connection with the planned site investigations.

SKI approves of the fact that SKB has now formulated an overall research programme with both field experiments and modelling to deal with the difficult problem of scaling up hydraulic parameters and transport parameters. The evaluation of a site and the preparation of data for the safety assessment necessarily involve several stages of model simplification and scaling up of data and model parameters. It is therefore important to clarify how these will influence the ultimate results of the safety assessment.

SKI s Overall Evaluation of Water Flow in the Bedrock

On the basis of the overall account presented by SKB in RD&D Programme 98, SKI is of the opinion that SKB's research programme on water flow and transport in the bedrock is appropriate. However, SKI considers that SKB should review its research methods concerning these important issues within the various projects for site characterisation, safety assessment and supporting R&D at Äspö. SKI wishes to reiterate the recommendation made in the evaluation of RD&D Programme 95 that SKB should also describe how it plans to determine the bedrock transport properties in connection with surface-based site investigations.

Prior to the selection of sites for site investigations, SKB should explain more clearly the role of the regional flow conditions as a siting factor. SKB's own account contains contradictory conclusions concerning the factors which determine groundwater flow at repository depth. A site evaluation and estimate of parameters for consequence calculations in the safety assessment will require several stages of model simplification and the scaling up of measurement data and model parameters. SKI is therefore positive to the fact that SKB is now planning to conduct field experiments and modelling to study the problem of the scaling up of hydraulic parameters and transport parameters.

7.7 Groundwater Chemistry

7.7.1 Introduction

Below, SKI discusses the report on groundwater chemistry found in Section 9.3 of RD&D Programme 98 and Chapter 9 of Detailed Programme for Research and Development 1999-2004.

SKB's most important aims in the programme on groundwater chemistry are: 1) to explain chemical conditions and processes which influence the barrier function of the repository, and 2) to support the geohydrological groundwater flow models.

SKI considers that, in addition to the above-mentioned aims, the modelling and description of groundwater chemistry must also contribute ensuring that the understanding of the geochemical and hydrological development and the historical account of the proposed repository site build confidence in site selection and the compilation of scenarios within the safety assessment. Site characterisation must provide a significantly more detailed understanding of the specific hydrochemical conditions than the understanding on which a safety assessment is based, otherwise it will be impossible to assess whether or not the simplifications and abstractions used are reasonable. However, SKI agrees with SKB that its top priority should be to investigate and create an understanding of the conditions which directly affect the function of the engineered barrier, such as current redox conditions, bentonite stability, copper canister integrity, radionuclide solubility, sorption properties, etc.

7.7.2 Analysis of Types of Groundwater

SKB s Report

Over the years, SKB has produced extensive background material for groundwater chemical conditions at various depths and at different sites around Sweden. In RD&D Programme 98, SKB summarises its work by reporting concentration ranges for the main components of the groundwater and for other components of particular importance. Groundwater from different depths is characterised principally by its highly variant salinity.

In RD&D Programme 98, SKB describes in detail its work on interpreting water chemistry data from the Äspö Hard Rock Laboratory. After the introductory investigations at the sites, SKB produced a model for classifying groundwater (Model 90). Once the tunnel was built, SKB was able to produce a more detailed model (Model 96). The comparison of the two models shows how the interpretation models have been developed, as well as how the groundwater chemistry changes due to the flow into the tunnel. The most important process for explaining the composition of the groundwater is the mixture of water from different sources. The "M3 method", which is based on principal component analysis, has been developed so that the mixing conditions can be analysed, mainly with the help of conservative tracer elements (e.g. Cl and O-18).

In RD&D Programme 98, SKB emphasises the need to combine analyses of many components in order to gain a clear picture of the characteristics of the groundwater. The opportunities for doing this are considerably better today than previously, as methods for isotope measurements, for example, have improved. However, it is still necessary to be certain about the reliability and accuracy of the various measurement techniques, e.g. by comparing different methods, if possible. In RD&D Programme 98, SKB presents a table of different analysis classes for groundwater tests which it intends to use in future site investigations.

An important issue in the groundwater chemistry programme is the assessment of the extent to which the groundwater samples are affected by sampling or other activities in connection with the site investigations. Experience gained at Äspö shows that groundwater chemistry at a specific site can change considerably with the drilling of boreholes and when using different types of measurements in the boreholes. SKB describes how the short circuiting of waterways in connection with drilling can give rise to the groundwater remixing at different depths. Remixing also takes place when the fall in pressure builds up during sample collection.

SKB has invested resources into visualising water chemistry data, which should facilitate integration with other parts of the site characterisation, such as hydrological modelling.

Comments by the Reviewing Bodies

The Royal Institute of Technology (KTH) is of the opinion that SKB should investigate the possibilities of applying new methods for identifying the age of the groundwater at different depths, e.g. with the help of low-degradable freons (anthropogenous substances). The Geological Survey of Sweden (SGU) considers that the M3 method may be very important in future site investigations. Uppsala University (UU) stresses that measurements must be carried out under as realistic conditions as possible, and considers it important for the characterisation of groundwater and microbes at the Äspö Hard Rock Laboratory to continue.

SKI s Evaluation

SKI considers SKB to have made significant progress within the groundwater chemistry programme, with the help of experience gained at the Äspö Hard Rock Laboratory. SKI welcomes continued work to refine the M3 method and believes that SKB possesses a highly usable tool for future site investigations. However, SKI wishes to point out that the method only partially covers the processes which are expected to be significant in the context of the repository, and that all interpretation models are dependent on the quality of the data on which they are based.

SKI does, however, question SKB's conclusion that the knowledge about the source and development of different types of water acquired through the research carried out at Äspö is directly applicable to all other conceivable site evaluations. SKI considers that the possibility of some site-specific feature differing essentially from previous characterisations at a new site cannot be rejected.

In SKI's view, SKB has an adequate basis for producing a suitable programme for describing groundwater chemistry in connection with site investigations. An important factor is to produce an analysis programme for the groundwater and another for planning the measures which are required in order to obtain samples that are as undisturbed as possible. SKB's proposed analysis classes can be used to ensure that the data are adequate, and also to ensure that the amount of analysis work does not become unreasonable. However, a continuous development of the analysis classes, starting from the interpretation models, should be considered. Furthermore, SKI does not exclude the possibility that additional analyses may be required, to allow alternative interpretations,

for example. Analysis programmes should also be established for colloids, micro-organisms and isotope analyses of solid phases, such as fracture filling minerals.

SKI will attach great importance to SKB taking measures to ensure that its groundwater samples are as representative as possible. Undesired effects in connection with sampling should be minimised by prioritising the groundwater sampling for the relatively undisturbed conditions which prevail, before starting the comprehensive pump tests and similar tests. SKI considers that, prior to a site investigation, SKB should especially report the measures it is planning for ensuring that the groundwater sampling and analyses are as representative and of as high a quality as possible. SKB should also ensure that the sampling is not restricted too locally around the proposed repository.

SKB writes that the presence of "brines" (groundwater with a high salt content) is a clear indicator that stagnant conditions prevail, which is a claim that SKI has previously called into question (SKI 1996a; SKI 1993). The probability of this conclusion depends on whether groundwater flow at repository depth is controlled by regional gradients or the local topography, which modelling studies have attempted to explain (e.g. Voss and Andersson, 1993). In addition, there is some uncertainty about the way in which land uplift can affect the situation for a coastal repository (work in progress TILA 99). SKI believes that SKB should justify its conclusions more clearly in this issue, especially if it may be important to the repository from a safety point of view.

7.7.3 Chemical and Biological Processes in the Groundwater

SKB s report
In RD&D Programme 98, SKB describes the most important chemical processes in the deep groundwater:

- dissolution of minerals in the rock matrix and dissolution and precipitation of fracture minerals,
- surface reactions such as sorption and ion exchange,
- reactions with organic material or geogas catalysed by microbes.

Important variables which are affected by these processes include pH and Eh (redox) values. SKB points out that pH values are mainly controlled by the carbonate system with calcite and dissolved carbon dioxide. High pH values can also be the result of feldspar weathering which, together with calcite, is the predominant capacity for pH buffering.

SKB points out that the redox conditions and their development over time are of considerable importance to the repository. This is due to the fact that both the canister's resistance against corrosion and the retention of radionuclides deteriorate considerably in the presence of oxygen and oxidising conditions (deep groundwater is usually oxygen-free and reducing). SKB has studied the kinetics and capacity of iron(II)-rich minerals in the bedrock which can consume oxygen. With the help of the REX experiment at the Äspö Hard Rock Laboratory (see Section 7.12), SKB has also studied the way in which oxygen is consumed when organic material which has infiltrated from the

surface decomposes due to microbial activity. The risk of oxidising conditions having an affect on the repository is mainly relevant in two cases: in connection with an ice age and with the closure of the repository. These cases are therefore being studied by SKB.

Comments by the Reviewing Bodies
According to Uppsala University (UU), sulphide production should be studied in greater detail, bearing in mind the time-scale which must be considered.

SKI s Evaluation
SKI considers it important for SKB to continue investing resources into models and experiments for studying chemical processes in deep groundwater. These models and experiments should be able to show integrated effects of processes which are controlled by kinetics, microbial catalysis and chemical equilibrium. As regards models, SKB mainly highlights the M3 concept in RD&D Programme 98, which only indirectly refers to specific geochemical processes as addition or loss in the mixture and mass balance calculations. For non-conservative components in the groundwater which may be affected by many processes, the M3 calculations may therefore need to be supplemented by other types of calculations. SKI believes that SKB should simultaneously use both experimental studies and other models in order to clarify, as far as possible, the concentrations and distribution of the non-conservative components in the bedrock. It is important to produce material to be able to assess how the chemical conditions can be influenced by the changes and disturbances which may occur (e.g. climatic change, change in groundwater flow, influence of the repository on the groundwater chemistry, etc.)

SKB mentions a number of geochemical equilibrium codes each of which feature a separate thermodynamic database. SKI believes that it is only possible to attain a higher degree of consistency if SKB evaluates, selects and uses one database which can be adapted to all codes.

SKB has investigated several processes which can consume oxygen, e.g. the weathering of sulphide and silicate minerals in the bedrock, oxidation of organic material from the surface layer, and microbial turnover of reductants in the form of dissolved gas such as hydrogen and methane. The relative significance of these processes will certainly vary between different possible siting options and external conditions such as climate, and this should be explained in greater detail than it is in SKB's report. SKB points out in RD&D Programme 98 that the possibility of dissolved oxygen being transported down to the repository level in the event of an ice age cannot be rejected. As with previous evaluations of SKB's RD&D programme, SKI considers that this is an important issue requiring further investigation. It should also be relevant to test developed models with the help of criteria from the sites where dissolved oxygen has actually been detected in deep groundwater (however, these sites are not located in Sweden, see Winograd and Robertson, 1982).

SKI attaches considerable importance to the integration of different scientific disciplines and is therefore positive about the fact that SKB is giving priority to the integration of hydro and chemical modelling using data from Äspö.

7.7.4 SKI s Overall Evaluation of Groundwater Chemistry

SKI is of the opinion that, from the experience gained at Äspö, SKB has made considerable progress with the groundwater chemistry programme. Both the purely practical experience gained at Äspö and the development of interpretation and analysis models have been valuable. This work must continue, focusing on the further improvement of interpretation models, analysis methods and, in particular, the possibility of taking samples that are as undisturbed as possible. SKI believes that, prior to a site investigation, SKB should report the measures it plans to take in order to ensure that the groundwater sampling and analyses are as representative and of as high a quality as possible. SKB will need to carry out more work in order to optimise the analysis classes so that the site-specific information is adapted to the interpretation models and provides maximum results in the classification of groundwater types.

Besides the development of methodology for characterising groundwater, SKB should allocate research funds to the long term and more basic scientific investigation of chemical processes in deep groundwater. There are still knowledge gaps in terms of the interaction between groundwater, minerals and geogas, and the mechanisms for these processes which can be controlled by microbial catalysis, kinetics for slow mineral reactions, etc. This knowledge is necessary to assess how the chemical phenomena can be affected by different types of disturbances and changes (climatic changes, changes in the groundwater flow, repository-related effects etc.).

7.8 Radionuclide Chemistry, Sorption and Diffusion

7.8.1 Introduction

Below, SKI discusses radionuclide chemistry, as presented in Section 9.3 of RD&D Programme 98 and Chapter 10 of Detailed Programme for Research and Development 1999-2004.

Research into radionuclide reactions and retention properties, colloids, organic substances, microbes, concrete and environmentally hazardous substances besides radionuclides is included in SKB's chemistry programme. The work is focused on producing material for safety assessments, but also on developing knowledge and expertise which can be employed in other programmes of which chemical issues are a part, such as the fuel, buffer and bedrock programmes.

7.8.2 Radionuclide Chemistry

SKB s Report

SKB is planning to continue to focus on basic chemistry research on actinides and fission products. In RD&D Programme 98, radionuclide redox processes and the influence of kinetics are mentioned in particular. Earlier studies focused on the chemistry of plutonium and solvent extraction. Solvent extraction has proved to be useful for deter-

mining complex constants, and satisfactory results have been obtained from comparisons with other methods.

SKI s Evaluation
SKI agrees with SKB that studies of the kinetics and redox processes of radionuclides should be an area of priority. Insufficient knowledge about the importance of the kinetics may result in an uncritical use of thermodynamic data and equilibrium modelling. This in turn may lead to an overestimation of the importance of the solubility restrictions in the safety assessment.

Knowledge gaps and considerable uncertainty also remain within thermodynamics, and this should lead SKB to conduct further work in this area. For reasons of efficiency, major efforts should be co-ordinated on an international scale (e.g. within OECD/NEA), although it should be possible to perform additional studies within Sweden. Attention should be paid to the risk of a depletion of Swedish expertise, especially in narrow fields such as radionuclide chemistry, where the opportunities for support from other sources of research funding may be more limited.

SKB does not make any mention of co-precipitation studies, even though this is an area in which it is possible to make considerable progress. In SKI's view, the aim should be to produce realistic solubility models for solid phase solutions containing radionuclides. It is uncertain as to whether these models can be used in a safety assessment, but the credibility of the analysis should increase, in any case, if there is an improvement in the understanding of the actual solubility behaviour of the radionuclides.

7.8.3 Sorption and Diffusion

SKB s Report
SKB has studied sorption mechanisms for various metal ions on mineral surfaces. SKB reports on how the sorption of ions which form inner-sphere complexes such as cobalt, thorium and neptunium, differ from the sorption of ions such as caesium and strontium, which form outer-sphere complexes. In the former instance, the sorption of the hydrolysis and complexing of metal ions is affected, whereas the ion strength is of substantial importance in the latter instance. SKB believes that detailed process models can be used for increasing the understanding of sorption, but cannot yet replace the use of the empirical K_d method in safety assessments. Prior to the SR 97 safety assessment, SKB has produced databases for the sorption of radionuclides on bentonite and rock, which summarises much of the experiment results in order to produce and evaluate K_d values.

SKB considers the most important properties for evaluating the importance of the matrix diffusion to be those properties in the rock near the water-bearing fractures, which are characterised by the flow-wetted surface, the penetration depth and the actual diffusivity of the rock. SKB has compiled available data in a literature report in order to describe matrix diffusion. The diffusion of caesium, strontium and iodine in bentonite has been studied in particular detail, and SKB underlines the importance of anion exclusion and surface diffusion. SKB plans to improve the data over the next three years.

Comments by the Reviewing Bodies
Stockholm University (SU) considers that batch experiments for determining K_d values can give misleading results. It proposes that sorption in combination with matrix diffusion should be studied using methods from nuclear physics and image analysis. The Geological Survey of Sweden (SGU) believes that further work on researching sorption and diffusion is well-justified.

SKI s Evaluation
In SKI's opinion, meaningful extrapolations in time and space can only be performed where there is a fundamental understanding of the sorbing processes. It is therefore equally essential to develop an understanding of sorption as it is to produce high-quality databases. It is important to bear in mind that sorption data are often produced under a short period of time in small batch experiments, although they are used for field-scale predictions over periods of thousands of years. SKI sees the need for SKB to continue its work with investigating the possibility of surface complexing models illustrating the influence of the groundwater chemistry on the sorption of different radionuclides (e.g. the effects of different pH values and redox conditions, as well as the effects of competing ions in the groundwater). In order to overcome uncertainty when scaling up in space, the migration experiments at the Äspö Hard Rock Laboratory (TRUE experiments on the detail and block scale) could be of decisive importance.

The extent to which matrix diffusion affects the retardation of radionuclides is of considerable importance for the sorption capacity of the rock, but it also affects the available pore space and is thus also important for weakly-sorbing radionuclides. SKI also believes that the transfer of data gathered from experiments on a laboratory scale to full-scale application is a point of uncertainty to which attention should be paid. The flow-wetted surface, effective diffusivity and penetration depth parameters mentioned in RD&D Programme 98, which are of considerable importance for calculating the transport of radionuclides, cannot be clearly quantified either in the field or in laboratory experiments. SKI is of the opinion that, in order for matrix diffusion to be modelled realistically in a safety assessment, there needs to be a coupling to the results from laboratory experiments, field experiments and site-specific data. Results from SKB's planned studies of matrix diffusion at the Äspö Hard Rock Laboratory may be very important in this context. Studies of matrix diffusion of natural analogues and large-scale laboratory experiments are also likely to make a contribution - in the latter case, where experiments can be better defined than field tests.

It is probably less difficult to obtain representative data on diffusion in bentonite. However, there are still issues to work with in this matter, such as the extent to which surface diffusion is of any significance in practice, which is debated in the scientific literature (Conca et al., 1993). It is also necessary to show how diffusion and sorption may be affected by the long-term chemical changes in the bentonite buffer.

7.8.4 The Influence of Colliods, Microbes and Concrete

SKB s Report
The influence of colloids is another area in which SKB is planning further work. SKB points out that there are very low colloid contents in the areas being investigated, and according to SKB, they are low enough not to be of significance. However, SKB does not believe that it has sufficient knowledge about colloids which may be formed in connection with the building of the repository.

SKB's results from its research on microbes suggest that they mainly have a positive effect on the stability of a repository, due to the fact that they can help to maintain a reducing environment at repository depth by catalysing the degradation of organic material and/or using e.g. dissolved hydrogen or methane as a reductant. A potentially ad-verse effect is microbially catalysed sulphate reduction, which can increase the risk of significant copper corrosion. SKB also mentions that microbes can also produce complexing agents (which can have an effect on the transport of radionuclides).

Comments by the Reviewing Bodies
The Geological Survey of Sweden (SGU) and Uppsala University (UU) are of the opinion that further microbiology studies must be considered well-justified. UU finds it difficult to accept, without objection, the fact that bentonite constitutes a completely bacterially hostile environment. The Swedish Society for the Conservation of Nature believes, based on new data from the USA (Kersting et al., 1999), that SKB has not correctly assessed the importance of colloidal transport of radionuclides, and that the gaps in knowledge may be substantial.

SKI s Evaluation
SKI agrees with SKB that there is much reason to believe that natural colloids in deep groundwater probably have little impact on the transport of radionuclides. The very low concentrations measured so far in the Swedish bedrock have a small potential to affect transport. This should, however, be monitored with a programme for colloid sample collection in connection with future site investigations. In the groundwater near the ground surface, colloids can have a considerable impact on radionuclide transport and may therefore need to be included in, for instance, biospheric models. SKB may need to pay close attention to the impact of cement and bentonite on colloids which can be formed through the introduction of foreign material and any changed chemical conditions in the repository. SKI is of the opinion that SKB should continue to develop basic knowledge about conditions and mechanisms for colloidal transport, especially under more extreme conditions (such as large flows, oxidising conditions, etc.).

In SKI's view, SKB, through its microbiology work, has contributed towards a decided improvement to the basic scientific understanding of micro-organisms in deep groundwater, which also provides a firm basis for being able to predict the effects on the long-term safety of a repository. As work continues, a clearer integration of microbial studies, principally with geochemistry but also with safety assessment and site characterisation, is anticipated. The issue of microbial sulphate reduction in the buffer and its effect on the integrity of the canister may require further investigation, in case

the buffer's properties deteriorate in any way, for instance if the swelling pressure is lower than intended.

SKI approves of the fact that SKB agrees and is financing studies into the way in which concrete can affect groundwater chemistry. SKI is particularly interested in following up the risk of colloid formation, where cement pore water with a high pH value reacts with the surrounding rock.

7.8.5 SKI s Overall Evaluation of Radionuclide Chemistry, Sorption and Diffusion

In SKI's view, it is essential that SKB should provide a reasonable level of long-term support for the more basic research on radionuclides, sorption and matrix diffusion. The development of the basic understanding of the processes which have so far mainly been covered by empirical data (such as K_d values) will provide the basis for gradually developing and improving the input data for the safety assessment. Alongside this work, databases used for safety assessment must be maintained and updated. SKI reminds SKB that it needs to determine the importance of colloidal transport and complexing even in more extreme conditions bearing in mind the presence of materials, such as cement, organic substances and bentonite, in the repository. Furthermore, unresolved questions remain regarding how microbes can affect the chemical conditions in the near field as well as the radionuclide transport. A clearer integration with geochemistry, safety assessment and site investigation is recommended in the future.

7.9 The Biosphere

SKB s Report
Descriptions and calculations of the dispersion of radioactive substances in the biosphere are necessary for assessing the consequences of final disposal. SKB states here that the overall aim of the studies is so that credible consequence calculations can be performed. According to SKB, these studies will produce methods of

- describing the biosphere in a realistic manner, with supported justifications for simplifications carried out,
- providing a yardstick for comparing different facilities, technical solutions or siting options,
- showing that the requirements of the authorities have been met.

SKB's justification for the direction of work in this area is, briefly, that the modelling of the biosphere cannot always be simplified, so the calculations result in highly overestimated consequences. In turn, this can result in an incorrect setting of priorities in the design of the repository. SKB should therefore strive towards greater realism. SKB states that the overall aims of the biosphere programme are to be able to reduce uncertainties and, using the current knowledge base, to be able to describe the most important processes in the biosphere, from a radiological point of view.

In terms of the basis of the biospheric modelling, SKB underlines the importance of moving from the earlier focus on the uptake of radionuclides by man to a more system-ecological approach. This will provide better opportunities for describing the accumulation of substances in nature and the impact on the environment.

SKB presents the following as some of the objectives of its continued work:

- The development of methodology for assessing the effects on biota (incl. animals and plants).
- The description of processes in the geosphere-biosphere interface.
- The analysis of the effects of land uplift and climatic changes.
- The analysis and evaluation of alternative safety indicators.

Comments by the Reviewing Bodies
In the opinion of the Geological Survey of Sweden (SGU), the opportunity to consider the importance of topography on different scales may be worthwhile.

SU points out that most physical models of complex ecosystems and in particular, the models of radionuclide transport, contain correlated parameters. According to SU, it is therefore important to expand on the existing global sensitivity methods to correlated parameters for non-linear models.

The Royal Institute of Technology (KTH) believes that that the relationship between the geosphere and biosphere/atmosphere should be investigated in greater detail than had been proposed in RD&D Programme 98. For instance, it is important to improve the understanding of how precipitation, surface water and land/vegetation conditions affect the groundwater flow at different depths.

SSI presents the view that SKB's biospheric studies follow relatively far behind studies in other areas which are considered important for the safety assessment. SSI goes on to state that, during recent years, SKB has broadened the scope of its biosphere research. According to SSI, this has meant that SKB now has satisfactory ambitions for its biosphere studies and that the system-ecological work being carried out is of value.

In terms of the role of the biosphere in the safety assessments, SSI raises the issue of using "alternative safety indicators". SSI considers that SKB should supplement its dose and risk analyses with, for instance, calculations of radionuclide releases and changes of the concentration in the biosphere. (Other comments by SSI concerning the biosphere are presented in Chapters 4 and 6.)

SKI s Evaluation
SKI shares SSI's view that the fact that SKB, in recent years, has expanded the scope of its biosphere research – largely by applying a system-ecological approach - is a positive step. SKI approves in particular of SKB's awareness of the importance of a systems approach and of the fact that the dynamic modelling of processes in sediment and other effects in the transfer from biosphere to geosphere are discussed in the programme. At the same time, SKI and SSI consider that considerable work remains to be done before SKB reaches its overall goal of performing credible consequence calculations in the

safety assessments. Furthermore, taking into account the long time ranges involved, it is the opinion of the authorities that it is essential to complete plans to study other safety indicators besides dose and risk, e.g. concentration changes in the biosphere.

SKI concludes, as does SSI, that SKB has now established a satisfactory level of ambition for its biosphere studies. However, considerable work remains to be done, in quantitative terms, before material is available for an application for permission to construct a repository.

7.10 Other Waste

7.10.1 Introduction

Below, SKI discusses Deep Disposal of Long-lived Low and Intermediate-level Waste, and the Final Disposal of Low and Intermediate-level Operational Waste, as presented in Section 9.3 of RD&D Programme 98 as well as Chapter 12 of Detailed Programme for Research and Development 1999-2004.

The management of other long-lived (SFL 3-5) waste is an important part of the Swedish concept for the deep disposal of nuclear waste. Apart from spent fuel, the various types of nuclear waste which must be managed are operational waste from nuclear power plants, decommissioning waste, certain core components and alpha-contaminated (long-lived) waste. Radioactive waste from industry, research activities and hospitals are also to be treated and deposited in SKB's facilities. The system of managing this other waste includes the following types of repositories:

- Repository for radioactive operational waste *SFR 1* (taken into operation in 1988).
- Repository for decommissioning waste and long-lived low and intermediate-level waste *SFL 3*.
- Repository for decommissioning waste from CLAB and encapsulation plant, *SFL 4*.
- Repository for core components, *SFL 5.*

7.10.2 SFR Waste

SKB s Report
In RD&D Programme 98, SKB briefly accounts for present work in the SAFE project which involves the development of an updated safety assessment for SFR 1 up to the year 2000. The work consists of assessing the composition of the waste, reviewing processes which can influence the integrity of the repository, scenario analyses, consequence calculations, etc. The preparation of a new safety assessment every ten years is a requirement stipulated in the operating licence for SFR 1.

SKI s Evaluation
SKI wishes to remind SKB once more that the studies of biodegradable products from cellulose provide conditions for the continued operation of SFR 1. This requirement is, in turn, a consequence of SKI's follow-up evaluation of the long-term safety of SFR 1,

which was emphasised in the evaluation of RD&D Programmes 92 and 95. SKI therefore seeks a clearer report of results which have been obtained.

In connection with the issue of cellulose degradation products, SKI wishes to remind SKB of the possibility that other organic substances besides isosaccharinic acid can act as complexing agents for radionuclides, such as lignin degradation products and other organic material which is deposited in the repositories.

SKI approves of the fact that the SAFE project has been started, but lacks a more exhaustive account of the actual planning of the project, which would provide the reader with an idea of the project's level of ambition and how much progress SKB has made.

7.10.3 Other Long-lived Waste, SFL 3-5

SKB s Report
SKB accounts for the types of waste that the SFL 3-5 repositories will contain. These are described based on origin, total amounts, predominant material, predominant nuclides, etc. SKB also accounts for how it plans to package and condition the waste.

SKB reports a new layout of the repository whereby SFL 3 and SFL 5 are largely identical. The space between the concrete construction, waste containers and the rock is to be backfilled with crushed rock. The purpose of the crushed rock is to act as a hydraulic cage, in which water is led past the concrete constructions through the crushed rock with high permeability.

SKB has published a revised inventory and characterisation of the waste to be deposited in SFL 3-5 (Lindgren et al., 1998) compared with the report which was published within the framework of the feasibility study (Wiborgh, 1995).

SKB points out that knowledge about the radionuclide content of industrial packages of waste is limited, as it has to be based on "correlation factors" between the radionuclides which can and cannot be measured. As stated in the preliminary postulated values, SFL 5 is the predominant repository in terms of radioactive inventory.

SKB plans to perform a comprehensive safety assessment of SFL 3-5 (the Other Waste project) and to report on this mid-1999. The above mentioned presentation of radionuclide content and a chemical database will be included in this assessment.

Comments by the Reviewing Bodies
SSI would like the interviews carried out with senior personnel concerning historic waste to be documented, and not merely have references to "personal communication". Such references were supplied in connection with the inventory of waste for final disposal in SFL 3-5 (Lindgren et al., 1998). SSI further considers that the waste which will be transported to SFL 5 in the future and which mainly consists of active reactor internals should, in connection with production, be described and recorded in greater detail.

In the opinion of Chalmers University of Technology (CTH), the discussion of other long-lived waste in Chapter 12 does not have the same level of detail as other parts. Information is lacking about the technical reliability of the barriers and relevant time spans.

SKI s Evaluation

According to SKI, SFL 3-5 repositories are an important part of the Swedish concept for the deep disposal of nuclear waste, which should be analysed and predicted with a level of ambition as high as that of SFL 2 (the repository for spent fuel). Certain aspects of the methodology for safety analysis which have been employed for SFL 2 are probably also directly applicable to SFL 3-5, whereas other aspects will differ with respect to decisive factors (e.g. the parts which concern the barrier function of the cement). Comprehensive scientific material will be needed in order to cover these parts. Consequently, SKI wishes to highlight the importance of a continued development of knowledge within that area. SKI observes that SKB's report of its work to produce material for the comprehensive safety assessment of SFL 3-5 is very short in RD&D Programme 98 and is therefore difficult to evaluate.

SKI would like SKB to justify more clearly its proposed changes to the layout of SFL 3-5. SKI clearly sees that SKB is reporting a comparison of the advantages and disadvantages of the new layout using crushed rock and the earlier layout using bentonite and sand/bentonite (SFL 3) or sand (SFL 4-5). SKI states that, compared to previously proposed material, there is increased opportunity for diffusive transport from the cement constructions, with the larger available pore space and greater permeability of the crushed rock.

SKI believes that SKB's work with assessing the long-term barrier properties of the cement are not fully reported in RD&D Programme 98. The current timescales are far longer than those for SFR (due to the considerably larger amounts of long-lived nuclides), which means that even very slow processes in the cement can be of significance to the safety of the repository. For instance, the specified cement quality (Degerhamn Standard Portland cement) cannot simply be considered to be sulphur-resistant during the time span which must be considered. With the removal of the bentonite layer, the importance of the cement as a chemical and physical barrier in SFL 3 increases. SKI does not believe that SKB's "optimism" concerning the long-term properties of the cement is unfounded, but it wishes to see reports of relevant processes and the effects of changes in order to evaluate whether the criteria of the safety assessment can be considered fulfilled.

SKI considers it important for SKB to allocate sufficient resources to describe the uncertainties concerning the nuclide inventory and waste composition. The effects of the inevitably remaining uncertainties need to then be clarified within the framework of the planned safety assessments.

7.10.4 SKI s Overall Evaluation of Other Waste

In summary, SKI considers that several important aspects of the long-term safety of the SFR 1 and SFL 3-5 repositories are only very briefly touched upon in RD&D Programme 98. A more comprehensive report will probably be presented in the safety assessments of SFR 1 and SFL 3-5, but SKI would have preferred SKB to have made better use of RD&D Programme 98 as an opportunity to report on status prior to the forthcoming safety assessments.

SKI devotes much attention to the SFL 3-5 repositories in the overall evaluation of the Swedish concept for the deep disposal of nuclear waste, partly because the waste cannot be encapsulated in the same way as for spent nuclear fuel, and partly because it is very heterogeneous in places and therefore difficult to describe (in terms of nuclide content, other composition and chemical properties).

SKI emphasises the importance of continuous knowledge improvement with respect to issues relating to the barrier function of the cement and the transfer of knowledge between SFR and SFL 3-5 in terms of biodegradable products from cellulose and other organic substances which can form complexes together with radionuclides.

7.11 Alternative Methods

In this section, SKI discusses Chapter 13 of Detailed Programme for Research and Development 1999-2004.

SKB discusses “partitioning and transmutation” (P&T) and “disposal in deep boreholes” (VDH) as two of its alternative methods in the Detailed Programme. No specific reasons have been given as to why these methods have been included in SKB’s programme, but reasons should have been discussed in connection with strategy and method selection. Some development work on such alternatives, which can be considered as variants of the KBS-3 method, are reported under other headings, primarily the Äspö Project, in which the section on “disposal in medium-long tunnels” (VLH) is included. SKI does not have any major objections towards the methods which SKB reports in its programme.

7.11.1 Partitioning and Transmutation (P&T)

SKB s Report

“Transmutation” means the conversion of one element into another or several other elements. This process takes place on a large scale in regular nuclear reactors in which neutron irradiation of uranium causes nuclear fission and the formation of nuclei with atomic numbers greater than that of uranium, such as neptunium 237, plutonium 239 and americium 241. Since the 1960s, it has been clear that continued irradiation of long-lived radionuclides which are present in spent nuclear fuel and high-level waste should constitute a way of making the waste less hazardous. Radiation can take place in both thermal and fast-breeder reactors. Such a method presupposes the reprocessing of the

spent fuel, i.e. that uranium and plutonium are separated from the fission products, and that these products are included in the high-level waste. The long-lived radionuclides which are to be transmutated must be separated from the waste as completely as possible (at least 99 %) and in such a way that they can be transformed into a form suitable for transmutation.

Research into P&T was carried out both internationally and in Sweden during the 1970s, and in Sweden there was much emphasis on methods of partitioning. During the 1980s, interest in P&T declined and re-awakened in the early 1990s with respect to the idea of using accelerators to produce the high neutron flux which is necessary for an efficient depletion of long-lived radionuclides.

Since the start of the 1990s, SKB has supported P&T research mainly at the Institute of Nuclear Chemistry at Chalmers University of Technology (CTH) and at the Institute of Neutron and Reactor Physics at the Royal Institute of Technology (KTH). At CTH, research is being carried out into water-based partitioning processes with new extraction reagents which contain only carbon, hydrogen, oxygen and nitrogen, in order to facilitate the complete combustion of the waste (the CHON principle). The use of such reagents can be a way of reducing the amount of waste at the reprocessing and partitioning stage. At KTH, the simulation of transmutation in accelerator-driven systems is being studied. In addition, the reaction cross-sections of high-energy neutrons is being measured at the Svedberg Laboratory in Uppsala.

Most of the research is being carried out through international co-operation, for example in the form of EU projects. The KTH group is also participating in the certification of a project being carried out in Russia on the development of a spallation target for accelerators, which consists of a mixture of liquid lead and bismuth. In addition, the KTH group is co-ordinating a project about studies of accelerator-driven systems.

In the government decision on RD&D Programme 95, the Government requested SKB to report on “the ongoing international work with transmutation”. This should be interpreted as a way of satisfying the interest created by transmutation among the general public and the scientific community as a potential method of making spent fuel or high-level waste from reprocessing less hazardous. (There is no question of using the method for other types of nuclear waste.)

In its reasons for carrying out research in this area, which will take decades before it can be established whether the method is practically and economically viable, SKB states that the evaluation of alternative methods will also be relevant far into the future, after the first stage of the disposal of spent fuel is completed.

In RD&D Programme 98, SKB states that the objective of the work concerning P&T is to (be able to) evaluate the development of techniques and to assess whether, how and when such a system could be developed.

SKB maintains that the development of this type of facility is very costly and that international co-operation is necessary. With this in mind and in terms of Swedish energy

policy, SKB does not consider it feasible to initiate large development projects on its own.

SKB intends to continue its research in this area to the present extent. In SKB's opinion, its research should be directed towards issues concerning safety, material, process development and the composition of the waste streams.

Comments by the Reviewing Bodies

The Swedish Anti-Nuclear Movement, Oskarshamn (FMKK) is of the opinion that SKB should not only carry out research on a deep repository based on the KBS-3 method. FMKK further believes that the storage time of 100 years or longer in CLAB should provide sufficient time to invest in broader research and to collaborate on the waste problem with other countries in which nuclear power is used.

Uppsala University (UU) is surprised that SKB does not pay greater attention to alternative methods, and especially to P&T. UU regards the support provided by SKB to Swedish research in this area, at Chalmers University of Technology (CTH) and the Royal Institute of Technology (KTH), as valuable, especially as it maintains and develops the national competence in areas which are crucial for nuclear power activities in general. However, UU considers these measures insufficient and that it would be unfortunate if Swedish R&D were to lag behind in this area, since this may become a central issue for future energy supply and an attractive alternative for the management of nuclear waste. In its summary, UU also states that if SKB's involvement in this research is impeded by the Swedish energy policy, this is difficult to accept.

The University of Lund (LU) considers it gratifying to confirm the new interest in alternative techniques such as transmutation. According to LU, the proposed deep disposal also means that, when the necessary technical conditions for such a reprocessing/ conversion, which will probably be several decades into the future, the waste can be retrieved for processing relatively easily. LU considers it important for further work to be performed in this area, bearing in mind the complexity of such processes.

The Swedish Council for Planning and Coordination of Research (FRN) states that the importance of following developments concerning alternative methods and ensuring that the necessary expertise is available in Sweden was already mentioned in its comments on RD&D Programme 95. FRN further states that transmutation, which is still an interesting alternative to follow, was mentioned, at that time. FRN looks favourably on SKB's research in these areas.

The Royal Institute of Technology (KTH) considers that SKB's continued support of transmutation research enables Sweden to participate in this research which is increasingly the focus of international interest. Young researchers are becoming involved, which KTH believes contributes towards satisfying the future need for expertise in the field of nuclear technology. KTH also maintains that, in the long-term, transmutation can lead to safer nuclear power with fewer waste problems.

SKI s Evaluation
As stated in Chapter 3, SKI believes that P&T should be discarded as a realistic method of managing spent fuel within a foreseeable future. In spite of this, it is appropriate to follow up and participate in the work in this area which is being carried out on an international scale. This also increases the opportunities of being able to reach well-founded conclusions in the future, concerning method applicability for Swedish conditions.

The areas which SKB has so far selected for its work on P&T primarily concern basic technical research which is of central importance for the development of the new systems and according to SKI, the work has been successful. For future work, SKI considers it logical to continue building on existing expertise in Sweden. However, it would be worthwhile if SKB's work was directed towards system issues and studies of waste quantities from transmutation, something which SKB also states in its programme. Both of these issues are, of course, fundamental for an evaluation of the potential of the method(s). SKI also agrees with SKB that the focus on P&T should be kept at about the same level as before.

The system report which may be needed prior to selection of sites for site investigations (Chapter 3) includes a system analysis which involves one or several P&T concepts. If there is a need for separate R&D work for such purposes, this must be given high priority in SKB's planning.

7.11.2 Disposal in Deep Boreholes

In its account of Alternative Methods (Ekendahl and Papp, 1998), SKB mentions a number of disposal methods which were subjects of earlier studies, such, as "disposal in very long holes" (VLH), "disposal in medium-long holes" (MLH), "WP Cave" and "disposal in very deep holes" (VDH). Of these alternatives, MLH and VDH remain in SKB's programme, and continued R&D into VDH is reported in Detailed Programme for Research and Development 1999-2004.

SKB s Report
Disposal in very deep holes means, briefly, that encapsulated fuel is deposited in holes with a diameter of approx. 1 m (800 mm according to SKB) which are bored to a depth of 4-5 km. The canisters are emplaced, one on top of the other to a depth of up to approx. 2 km. The canisters are surrounded by bentonite and, from 2 km and upwards, the hole is plugged with bentonite, asphalt and concrete. Depending on the amount of fuel per canister, 20 to 40 such holes will be required. VDHs were investigated by SKB for the first time in the late 1980s, and were included in PASS, the comparative study of disposal methods, which was presented in connection with RD&D Programme 92. The concept was then abandoned, due to difficulties with the disposal technique, difficulties in demonstrating that it was safe, and the high costs in comparison with the main alternative.

SKB has recently published an analysis of the geoscientific level of knowledge within the area of disposal in deep boreholes (Juhlin et al., 1998). The level of knowledge has been compiled in a "geoscientific model" which means that:

- the fracture frequency is considerably lower at depths of more than 1 km,
- water-bearing fracture zones can still be present at very great depths,
- salinity is generally high at depths of more than 1 km,
- groundwater movements in the areas of flat topography are mainly restricted to the uppermost kilometre.

For the coming period 1999-2004, SKB intends to perform a system analysis, a safety assessment and a performance assessment of the VDH method. The system analysis will build on a follow-up of the earlier PASS study.

Comments by the Reviewing Bodies
Uppsala University (UU) puts forward the view that deep boreholes should be particularly attractive if the quantity of high-level waste could be reduced significantly (implying through P&T). For this reason, SKB should observe the "International Continental Drilling Programme" and possibly play an active part in this programme.

SKI s Evaluation
A reason provided by SKB as to why VDH should be brought to the fore is the development in the field of drilling techniques. As a reason for discussing VDH, SKI mentions the more general interest which has been shown towards this concept, which is also apparent from the comments by the reviewing bodies. The opportunity for better isolation from the biosphere and the difficulty of human intrusion are given as reasons for this interest. SKI agrees with these viewpoints, but thinks that the advantages the method may offer must still be considered along with the disadvantages, principally the difficulties here with the safety assessment and of making retrieval credible (see also Chapter 3 for a discussion of method selection).

SKB intends to present a system analysis for the VDH concept, which SKI considers to be not only a good idea but also a necessary one, if VDHs are to be compared with other disposal methods as discussed in Chapter 3. SKB mentions that once the system analysis has been carried out, a relatively broad performance and safety assessment will be carried out. In SKI's opinion, this is also a good initiative, but SKI wonders whether the safety assessment should not be carried out before the system analysis. (This is the case if SKB means the same thing here by "system analysis" as in other parts of RD&D Programme 98).

Finally, SKI wishes to remind SKB that the time schedule for work on the VDH concept may need to be accelerated, bearing in mind the reporting requirements recommended by SKI in connection with the siting process (see Chapter 2).

7.11.3 SKI s Overall Evaluation of P&T and Deep Boreholes

SKI concludes that only two alternative methods, P&T as well as deposition in Very Deep Holes (VDH) are dealt with in SKB's detailed programme. SKB does not provide any reason for this choice. However, SKI does not have any major objections to this selection of alternatives for more detailed and continued studies.

In SKI's opinion, SKB's work on P&T has been successful so far. SKI agrees with SKB's view that the work in this area should be kept to approximately the same level as before. However, at the same time, SKI emphasises the importance of including system studies and studies of the quantity and composition of the waste.

SKB's plans for the VDH method are more general in nature. In SKI's opinion, the focus of the plans on safety assessment and system analysis is suitable. However, SKI reiterates that, in this context, the safety assessment should be considered to be a part of the system analysis.

SKB may have to review its plans for both methods – P&T as well as VDH – to take into account the reporting requirements which may be made prior to the selection of sites for site investigation.

7.12 The Äspö Hard Rock Laboratory

7.12.1 Introduction

In this section, SKI discusses Sections 7.4 - 7.6 and 9.3 of SKB's RD&D Programme 98, and Chapter 14 of Detailed Programme for Research and Development 1999-2004.

SKB s Report
One of the main reasons behind SKB's decision to build the Äspö Hard Rock Laboratory was so that it could carry out research, development and demonstration activities in a realistic and undisturbed rock environment at the depth at which it intends to build future repositories. In SKB's programme, the laboratory is also intended to provide the opportunity for a "dress rehearsal" before a repository is put into operation. Based on this, SKB has defined four stage goals which are discussed in detail in Sections 7.12.2-5.

Construction work commenced in autumn 1990 and was completed in 1995. Between 1995 and 1998, several comprehensive experiments were carried out at the laboratory, the most important of which included ZEDEX, REX and TRUE.

SKI s Evaluation
As with the evaluation of previous RD&D programmes, SKI believes that the knowledge requirements in SKB's earlier project (now Siting) generally justify activities at Äspö. However, SKI now has certain comments to make regarding the scope, feasibility and time-schedule of the goals. SKI also wishes to state that the Siting project (site investigations) can not exclusively be based on, but is in fact completely dependent on, the knowledge acquired in the Deep Disposal Technology/Äspö Hard Rock Laboratory project. Certain methods of investigation can be more or less suitable depending on site-specific geological conditions.

SKI states that several of the recommendations given in the evaluation of RD&D Programme 95 still apply, as SKB has not yet completely carried out the measures/

evaluations which were recommended there (method development, clarification of safety-related factors, etc.)

SKI also observes that, of the reviewing bodies which expressed their opinions of SKB's RD&D Programme 98, only Royal Institute of Technology (KTH) has commented on the Äspö Hard Rock Laboratory. KTH approves of the current work at Äspö, in particular the investigations concerning hydrology and geochemistry, and tracer tests concerning radionuclide transport.

7.12.2 Verification of Pre-investigation Methods - Stage Goal 1

SKB s Report
SKB's aim is to show that investigations of the ground surface and boreholes provide sufficient data on essential safety characteristics of the rock at repository level. Pre-investigation methods and modelling have been verified successively during the construction period.

SKB believes that more than a decade of work at Äspö has proven that tools exist for collecting data from the ground surface and boreholes, as well as for modelling a site in such a way that its suitability as a site for a repository, and its ability to meet safety requirements, can be assessed.

SKI s Evaluation of Stage Goal 1
The implementation of the Äspö Project has resulted in an extensive development of measurement methods and scientific expertise. However, according to SKI considerable work remains to be done in the form of validation of methods for application in the Siting Project. It is not sufficient to use a ranking system for applicability on different geographic scales or to describe the advantages and disadvantages of different methods (Almén et al., 1994). Instead, SKB should have aimed to assess the application of the methods (quantification of parameters required for future safety assessments) based on the performance and any limitations of an instrument. In SKI's opinion, there is still a lack of reliable methods for detecting horizontal fracture zones, even though seismic reflection methodology could be an applicable method for shallow depths. (<500m)

SKB's report of the Äspö Project during 1997 does not clearly explain the limitations of the measurement methods, i.e. what is meant to be measured, the level of precision required for measurements, and sources of error which can occur in the instruments and when taking measurements. It is important to investigate the reasons for deviations between prediction and outcome (occurrence and 3D extension of fracture zones).

SKI disagrees with SKB that surface-based investigations alone, carried out at the stage of a site investigation, can enable the safety characteristics of the rock to be determined at repository level (see further discussion in Chapter 4). An overall evaluation of investigation methods (and instruments), in relation to a need for information for the safety assessment and construction is still lacking. SKI would like to once again remind SKB that many of the methods tested at Äspö are not necessarily applicable to other sites which have different geological conditions.

7.12.3 Finalise Detailed Characterisation Methodology - Stage Goal 2

SKB s Report

With rock engineering, a disturbed zone occurs around constructed tunnels and other hole spaces, the extent of which needs to be clarified. The characteristics and extension of the zone must be taken into account in the interpretation of measurement data from tunnel excavation as well as in the design of the repository and in the analysis of its long-term safety performance. The disturbed zone causes a change in the mechanical and hydraulic properties of the rock, which can affect the stability of drifts and tunnels and will thus affect the layout of a repository. The reasons for the disturbances can be interpreted as a combination of blasting damage and the redistribution of rock stresses.

Disturbed zone experiment (ZEDEX)

SKB's conclusion from the experiment at the Äspö Hard Rock Laboratory (Emsley et al., 1997) shows that a systematic increase in permeability around a tunnel is limited to the damaged zone. According to SKB, this implies that any transport of radionuclides in the rock along a tunnel can be limited by applying appropriate excavation methods and blocked by using appropriately designed plugs. SKB claims that it has been successful in determining the mechanical aspects of the system and that it also obtained applicable hydrological data. In further work concerning the disturbed zone, however, SKB intends to answer questions pertaining to :

- connectivity in generated fractures, and whether hydrogeological flow paths can be created,
- the impact of plugs and the system's seals.

SKI has engaged a consultant, Berggeologiska Undersökningar AB (Palmqvist, 1997) to evaluate the experimental results reported so far (Olsson et al., 1996). The consultant has identified a number of shortcomings and uncertainties in the aims of the project and therefore recommends further studies, concerning:

- supervised hydraulic characterisation of the disturbed zone,
- systematic reporting of the changes to various properties of the rock volume in the disturbed zone which are measured, and an account of the potential of different measurement methods for detecting such changes.

SKI s Evaluation of Stage Goal 2

Revised conclusions to the ZEDEX experiment, principally for the D&B (Drill and Blast) tunnel, are based on very limited data because four out of nine D&B tests did not run according to plan. Moreover, the objective was primarily to increase understanding of the mechanical properties of the disturbed zone, whereas the understanding of the hydraulic properties of the zone was not given equal priority. SKI believes that SKB should give equal priority to improving the understanding of the hydrological properties of the zone, as any radionuclide transport is expected to take place via groundwater in the disturbed zone.

Nevertheless, SKI considers it worthwhile that, through the ZEDEX experiment, SKB attempted to increase its knowledge of the extension of the disturbed zone, as the results

from the evaluation can also provide SKB with guidance when selecting excavation methods for different parts of the planned repository.

In SKI's opinion, it is important for SKB to map any flow paths and hydraulic couplings for radionuclide transport in affected/disturbed rock in connection with both the deposition holes and deposition tunnels. SKB should also further investigate whether it is possible to intercept transport paths through strategically positioned plugs. SKI therefore fully endorses SKB's recommendation for continued research in this area.

SKI reiterates that, as mentioned in the evaluation of RD&D Programmes 92 and 95, a full description of a rock volume cannot be carried out in either a site investigation or a detailed characterisation. The measurements made in the tunnel cannot be considered to provide the answer. The results of the detailed characterisations must also be interpreted and are also associated with uncertainties. SKI would like to see an account of the method limitations with respect to detailed characterisations (measurement precision, instrumentation errors, etc.).

7.12.4 Testing of Models for the Description of the Barrier Function of the Rock Stage Goal 3

SKB s Report

Within the framework of this stage goal, SKB conducts projects with the aim of evaluating the usefulness and reliability of different models for the description of the barrier function of the rock as well as to evaluate and test methods for the determination of parameters included in the models. SKB believes that a good agreement has generally been obtained so far between the models and reality (completed and ongoing experiments at the Äspö Hard Rock Laboratory). Below is a list of some current and planned activities at the laboratory:

- Classification and characterisation of fractures.
- Redox experiments on a detailed scale – REX.
- Degassing of groundwater and two-phase flow.
- Flow and transport of dissolved substances – TRUE.
- Radionuclide retention.

SKI s Evaluation of Stage Goal 3

SKI considers that it would be worthwhile if, during future site investigations and detailed characterisations, based on the developed fracture classification concept, SKB could give its opinion on the expected properties and features of fractures at repository depth (structural model), particularly with respect to hydrology and radionuclide transport. This is important particularly for predictive modelling and for selecting deposition holes in the repository.

According to SKI, it is important for SKB to continue both its laboratory and in situ experiments concerning reaction mechanisms and kinetics for remaining oxygen after the repository has been closed. SKI would like SKB to answer the question of whether,

from a safety point of view, it is important whether the oxygen is consumed 10,100 or 1,000 years after the repository has been closed (discussed further in Section 7.7).

SKI emphasises the importance of knowledge about changes in hydraulic properties, in connection with pressure reduction around the tunnels and degassing of groundwater (two-phase flow), in order to understand the function of the buffer and backfill material in connection with the backfilling and sealing of the repository's tunnel system.

SKI still considers the work undertaken in Task Force, using different models for predicting the barrier function of the rock, to be of a high international standard. SKI therefore gives full approval to SKB's current (TRUE-1) and planned (TRUE-2, TRUE Block Scale) experiments within this area.

SKI is of the opinion that it is important and worthwhile for SKB, at the Äspö Hard Rock Laboratory, to investigate and improve the understanding of the properties of different types of radionuclide in situ, as such knowledge is necessary for validating models and comparing predictions of radionuclide transport, and retention properties of the rock. SKI believes that an overall report of research into retention mechanisms linked with the methods to be applied to site investigations and detailed characterisations, is still necessary.

SKI approves of SKB's current R&D activities on microbes (and colloids) in the relatively undisturbed environment of the Äspö Hard Rock Laboratory. As SKB points out, apart from redox conditions, the transport of radionuclides can also be affected, to a certain extent, by a low percentage of colloids and microbes.

7.12.5 Demonstrate Technology for and the Function of Important Parts of the Repository System - Stage Goal 4

SKB s Report

SKB considers that the construction of the Äspö Hard Rock Laboratory has provided valuable experience in terms of the further development and testing of techniques for building a repository and investigating the rock in connection with the building of the repository. By carrying out tunnel excavation using conventional blasting and drilling and with a tunnel-boring machine (TBM), material has been obtained for the choice of excavation methodology for the future repository.

According to SKB, the Äspö Hard Rock Laboratory provides an opportunity to test, investigate and demonstrate, on a full-scale, the various components of the repository system which are important for long-term safety. SKB will build a prototype of the repository in order to simulate the deposition sequence, including the testing of different kinds of backfill material and techniques for backfilling tunnels.

SKB has classified the activities in the Äspö Project into a number of experiments with the headings listed below:

- Prototype repository.
- Testing of different backfill materials.
- Demonstration of deposition techniques and canister retrieval.
- Testing of alternative deposition techniques.
- Long-term tests of the buffer material function.
- Grouting technology.

SKI s Evaluation of Stage Goal 4

SKI supports SKB's plans to continue using the Äspö Hard Rock Laboratory to develop techniques and to demonstrate the performance and interaction of the various components of the repository system. SKB states that, despite the relatively long project period (up to 20 years), the prototype repository cannot be used to demonstrate the long-term safety of a repository. SKI considers it justified that SKB performs proposed tests on a full scale, as this will confirm whether a deposition technique functions from an engineering point of view, before it is used in the real repository. SKI is particularly keen to follow up hydraulic resaturation monitoring for the prototype repository.

SKI believes that some doubts remain about the use of crushed rock in the building of a future repository. An issue which has not yet been investigated concerns whether a possible biofilm (microbes) formed on the surface during storage of the crushed rock could affect the environment of the repository when the treated rock masses are brought back to the repository (Brown and Sheriff, 1998).

In the backfill test, SKI thinks it would be worthwhile if SKB were to investigate the axial water transport in the tunnel direction in the damaged zone and compare it with the water transport in the backfill material, in order to see whether the damaged zone can be considered to be an important channel for the transport of radionuclides from any leaking canisters.

With respect to the experiment on the demonstration of deposition technology and retrievability, SKI considers it justified for SKB to demonstrate the different stages of deposition and retrieval of canisters in the Äspö Hard Rock Laboratory for the benefit of members of the public and experts. SKI regards it as important that measures taken in the implementation phase of depositing canisters including the planned possibility of retrieval do not interfere with the long-term safety of the repository. When SKB applies for permission to begin deposition, SKB must be able to show that retrieval methods are available.

When SKI evaluated SKB's RD&D Programme 95, it expressed the view that SKB should consider the alternative of horizontally depositing a full-scale canister at the Äspö Hard Rock Laboratory. SKI still believes that this would be preferable, but considers it reasonable for SKB to await results of the FEBEX experiment in Grimsel, before it decides whether or not to test the alternative at Äspö.

SKI considers it important that SKB, through its experiments at Äspö, should broaden its knowledge of the performance of the bentonite buffer in the repository environment (see also comments in Sections 5.7 and 7.4). In connection with overcoring, SKI notes that, once the first stage of the project had been performed, a problem arose with core

loss when the buffer cores were to be brought up. There is therefore reason for SKB, in planned tests, to ensure that sufficient time is given for the bentonite to reach full water saturation, and for the method of overcoring to be reviewed after test completion.

As far as grouting methods are concerned, SKI stated in its evaluation of RD&D Programme 95, the opinion that tests conducted so far in the Äspö Hard Rock Laboratory with different grouting methods were generally too limited. SKI highlighted the importance of SKB increasing its knowledge of the durability and long-term properties of the grout. Any impact on the chemistry of the repository, which could have an adverse effect on its long-term safety, should be investigated.

SKI is therefore supportive of the work SKB is currently undertaking with the formation of a project organisation in which university experts and other Swedish grouting experts are involved. The work carried out by the project group so far (Stage 1) and its planned activities were presented at a Nordic symposium on rock grouting in Finland in November 1998. It became apparent at this symposium that SKI's previous observation about a need for research will probably be satisfied.

7.12.6 SKI s Overall Evaluation of Activities at the Äspö Hard Rock Laboratory

SKI believes that the need for SKB to produce a site investigation and detailed characterisation programme justifies activities at the Äspö Hard Rock Laboratory to the planned extent. SKI is of the opinion that the comprehensive experiment and demonstration programme which is currently being planned in the laboratory for the period 1999 – 2004 (with an estimated period of operation of approx. 15 – 20 years) can be expected to provide a good opportunity for increasing the understanding of important parameters and processes in crystalline rock and for further developing methodology for site investigations and detailed characterisations.

With regard to Stage Goal 1, SKI observes that an extensive method development and an important development of scientific competence have been achieved in the Äspö Project. However, a great deal of work remains to be carried out on the validation of individual methods and their implementation in continued work. Different methods still need to be combined to form a complete investigation programme which will provide the information necessary for evaluating the potential of a site for safe, long-term final disposal. SKI points out that this requires an overall evaluation of available methods and measurement strategies, based on the overall claims on the measurement data from the safety assessment and the requirements of SKB's Siting Project.

SKI also emphasises that there is still a need to develop individual methods, for the detection of horizontal fracture zones and programmes for groundwater chemistry sampling.

According to SKI, it is important when evaluating Stage Goal 2, to identify any flow paths and hydraulic couplings for radionuclide transport in affected/disturbed rock both in deposition holes and in deposition tunnels, and also to investigate further the

possibility of intercepting transport paths by using strategically-placed plugs. SKI therefore supports SKB's recommendation concerning continued research in this area.

SKI also wishes to emphasise that methods from both surface-based investigations as well as tunnel investigations at Äspö must be further developed on the basis of the experience gained in order to be of subsequent use in the planned site and detailed characterisations. SKI is of the opinion that SKB must establish, more clearly, which safety-related factors can be determined in connection with a surface-based site investigation as well as a detailed characterisation from tunnels and shafts.

As regards Stage Goal 3, SKB should explain the effects of various processes for the consumption of oxygen remaining after the repository has been closed. SKI would like SKB to answer whether, from the standpoint of safety, it is important whether it takes 10, 100 or 1,000 years for all the oxygen to be consumed after the repository has been closed.

SKI considers knowledge about the changes in hydraulic properties, in connection with pressure reduction around the tunnels and degassing of the groundwater (two-phase flow), to be important for understanding the function of the buffer and backfill material with regard to the backfilling and sealing of the repository tunnel system.

SKI regards the work with using different models for predicting the barrier function of the rock, which is being carried out in Task Force, as being of a high international standard. SKI therefore fully supports SKB's current (TRUE-1) and planned (TRUE-2, TRUE Block Scale) experiments within this area.

SKI considers that there is still a need for an overall report of the research into the retention mechanisms of different radionuclides, coupled to the methods which will be used for site investigations and detailed characterisations.

Within the scope of SKB's Stage Goal 4, SKI fully supports SKB's plans to use the Äspö Hard Rock Laboratory in order to develop technology and to demonstrate the performance and interaction of the various components of the final disposal system. SKI considers it justified for SKB to perform the proposed tests on a full scale, since this will confirm whether the disposal technique functions from an engineering point of view, before applying it to the actual repository. In the case of the prototype repository, SKI is particularly interested in following up the monitoring of the hydraulic resaturation.

With respect to the experiment on the demonstration of disposal technology and retrievability, SKI considers that there are good grounds for SKB to demonstrate the different stages of disposal and retrieval of canisters in the Äspö Hard Rock Laboratory for the public and specialists. SKI considers it important that measures taken at the implementation stage of canister deposition when there is the possibility of retrieval, do not interfere with the long-term safety of the repository. When SKB applies for permission to commence deposition, it has to show that retrieval methods are available.

At the time of the evaluation of RD&D Programme 95, SKI emphasised the importance of SKB improving its knowledge of the durability and long-term properties of the grout in the repository. The possible impact of the grout on the chemistry of the repository must be further investigated. SKI therefore lends full support to the work SKB is currently carrying out in the field of grouting, through the formation of a project organisation involving university experts and other Swedish grouting experts.

In SKI's view, SKB's planned activities at the Äspö Hard Rock Laboratory need to be clarified in terms of deadlines by which certain strategic issues must be resolved, in order to continue with the next phase of the development work. This does not necessarily mean that all research undertaken at the Äspö Hard Rock Laboratory must be completed before starting detailed characterisation at the repository site. SKI particularly wishes to emphasise the importance of prioritising the future activities according to the needs which emerge from an integrated safety assessment.

7.13 Natural Analogues

7.13.1 Introduction

For a number of years, SKB has been involved in international projects on the subject of natural analogues. In RD&D Programme 98, three ongoing projects (Maqarin, Oklo and Palmottu) and two completed studies (Poços de Caldas and Cigar Lake) are described, in which some supplementary interpretations were made about already existing material. In all the projects apart from Maqarin, studies were made of different types of uranium deposits, with the purpose of understanding how they were formed and how they have since been altered.

SKB believes that the aim of the studies is to test the assumptions and models to be used for assessing the long-term safety of a repository. SKI has previously proposed the more general aim that natural analogues should be oriented towards the problems relevant to the safety assessment. Experience shows that it is difficult to model the natural analogues, as it is often impossible to eliminate uncertainties concerning original states and boundary conditions. Moreover, the environment does not always correspond very well to the environment anticipated in the repository. It is therefore perhaps too ambitious to expect models for safety assessments to really be validated in this way. There are thus better prospects for assessing the comprehensiveness of the process descriptions, with the help of analogue studies - that is, assessing that important parts are not missing from the conceptualisations which are to be used. Studies of natural analogues can also be useful aids for understanding the development of geological systems over lengthy periods of time, and they can contribute towards the knowledge of individual processes.

7.13.2 Maqarin, Jordan

The hyperalkaline sources in Maqarin are used as a natural analogue of how cement affects the surrounding rock and groundwater. According to observations, new minerals

such as zeolites and hydrated calcium silicates are formed as the groundwater, which has a high pH value (approx. pH 12-13), reacts with the surrounding rock. SKB notes that these secondary minerals refill the fractures, reducing water flow in the rock. SKB also reaches the conclusion that matrix diffusion does not appear to be restricted by the secondary phases. In SKI's opinion, the studies in Maqarin were directed towards relevant issues, but the question remains as to how explicitly the results can be integrated in a safety assessment, such as the one for SFL 3-5. Differences in geology, hydrology and geochemical conditions, compared with those expected under repository conditions, must be observed.

7.13.3 Oklo, Gabon

Uranium in the mines in Oklo have an isotope ratio of ^{235}U /^{238}U, which is different to that of other uranium ores. This can only be explained by the occurrence of a spontaneous fission occurred almost 2 billion years ago. These uranium deposits are therefore known as natural reactors. In RD&D Programme 98, SKB describes the special criteria which made the fission possible, and the background to the Oklo Project. It should be possible to obtain the most applicable results if there was a description of the development of the reactor zones during the long period of time after the criticality phase. In RD&D Programme 98, there is mention of the possibility of analysing the transport and retardation of the fission products which were once formed in the reactor zones. No such results have been reported as yet, although a special group has been formed which has the purpose of co-ordinating the work needed for producing results applicable to the safety assessments (PAIG, Performance Assessment Interface Group). SKI devotes much attention to the Oklo study, and considers it important to make full use of the unique features of the natural reactors as material for the safety assessment work.

7.13.4 Palmottu, Finland

This project comprises studies of a uranium ore which was previously prospected but which is now being used only as an analogue for a final repository in granite rock. SKB's participation in the project has provided it with the opportunity to gain practical experience which can be used for its site characterisations. According to SKI, there are valuable similarities with the expected final repository environment.

7.13.5 SKI's Overall Evaluation of Natural Analogues

SKI is of the opinion that the projects with which SKB is currently involved complement each other well. However, these projects are all about to end. If the current projects are not extended, there is a risk that SKB's involvement in the field of natural analogues will decrease substantially. SKI considers that this would be unfortunate, since there are hardly any other methods of evaluating and confirming long-term hydraulic and geochemical changes which could be relevant to a repository. SKB

should strive towards the continuous improvement of knowledge and, therefore, ensure that work within the field of natural analogues continues.

Projects on natural analogues have mainly been performed as major international projects. For this arrangement to be possible in the future, the long-term support of a number of key organisations, with which SKB is involved, will be needed in the future.

SKI considers that:
- Maximum use should be made of information from natural analogues, by allocating resources for additional interpretations of field data as well as modelling.
- The usefulness of new or additional measurement series at existing sites should be assessed.
- SKB should at least ensure that it is prepared to conduct analogue studies at completely different sites in cases where the possibility of obtaining new knowledge is considered to be reasonable.

7.14 Paleohydrological Programme

SKI discusses here Section 9.3 of SKB's RD&D Programme 98 and Chapter 16 of Detailed Programme for Research and Development 1999-2004.

SKB s Report
SKB's paleohydrological programme has been in progress since 1994, and has the aim of:

- identifying and creating understanding of the processes caused by future climatic changes which can affect the performance of a deep repository,
- creating material for performance analyses and safety assessments of the repository from a long-term future perspective.

In RD&D Programme 98, SKB lists the work and results obtained for the:

- modelling of glaciations and their impact on the geosphere,
- hydrological and hydrochemical aspects,
- mechanical aspects,
- coupled effects of glaciations.

Through its work with coupled effects, SKB has identified considerable uncertainties but sees positive development opportunities for reducing these uncertainties, thereby obtaining reliable results. Important issues requiring further elucidation concern permafrost, the effects of groundwater chemistry, transport and THM effects.

SKB is involved in two EU projects: PAGEPA, which deals with how paleohydrological information can be used in a safety assessment, and EQUIP, which aims to investigate and test methods of predicting early hydrochemical and hydrological conditions, through the investigation of fracture minerals.

SKI s Evaluation
SKI states that the development of time-dependent glaciation models has now made so much progress that SKB maintains that the models will be of use in future performance analyses and safety assessments. In SKI's opinion, all of the issues dealt with by SKB in the paleohydrological programme are relevant and should be included in SKB's work in the future. However, SKI would like to see a coherent presentation (including time-schedules) of how SKB intends to deal with the issues, especially with respect to meeting the requirements of the safety assessment. SKI assumes that SKB's planned report will constitute an important basis for decision-making concerning which parts are to be prioritised.

During the current RD&D period, SKB must clearly show how it intends to integrate the issues in this area. SKI also highlights how important it is for SKB to properly specify and discuss input data, the suitability of applied theories, shortcomings and uncertainties. This knowledge must be placed in the appropriate context when assessing the usefulness of models and when evaluating the results obtained.

RD&D Programme 98 does not include any information pertaining to how much progress has been made in SKB's EU projects, or to conclusions which can be drawn so far. SKI is awaiting a more detailed report. Even though the development of knowledge is taking place on an international scale, of which SKI approves, it is important that the conditions relevant to Sweden should be dealt with in a focused way within the framework of SKB's own projects.

SKI considers the area, as a whole, to be important, and also aims to continue to follow up SKB's work in this area in the future.

7.15 Deep Drilling in Laxemar

SKI discusses here Section 9.3 of SKB's RD&D Programme 98 and Chapter 17 of Detailed Programme for Research and Development 1999-2004.

SKB s Report
In Laxemar, SKB has ordered the drilling of a vertical hole in the rock down to a depth of approximately 1700 m. The purpose of this was to test possibilities of different drilling techniques for investigative drilling to greater depths, and to demonstrate methods of investigating boreholes at depth intervals of 1000 – 1500 m. The aim was to broaden the knowledge of the composition and properties of the rock at greater depths and to obtain new information concerning the flow patterns and chemical composition of the groundwater in a regional perspective (for the Äspö Hard Rock Laboratory). SKB points out that, as the drilling and field investigations were performed involving a number of practical difficulties, they provided valuable experience prior to future site investigations. Moreover, the borehole has, according to SKB, provided essential input data for SKB's "Paleohydrological Programme" and for the programme which deals with the alternative repository concept, "Deep Boreholes".

Field investigations carried out to date have been summarised by SKB in a technical report (Ekman and Ludvigsson, 1998) which is yet to be published. Examples of the results reported in RD&D Programme 98 clearly show that important bedrock and groundwater chemical properties vary with depth.

SKI s Evaluation
SKI is of the opinion that SKB's work to date shows the importance of conducting drilling (at sites relevant for a repository) at greater depths than as are usual at present. SKI considers that it is high time that SKB plan and develop practical methods for obtaining necessary data in connection with site investigations and detailed characterisations down to a depth of approximately 1,500 m (see also Chapter 4).

SKI can establish that, after the report of the PASS study in RD&D Programme 92, SKB has focused on general research to develop knowledge concerning the concept of deep disposal. SKB's objective, since the completion of the PASS studies, has been to compile and assess available data concerning significant geoscientific parameters, using literature studies, and to follow the development of techniques for deep drilling.

SKI also wishes to emphasise the importance of generally making use of information at depths of 500 – 1,000 m. SKI concludes that the existing knowledge of the bedrock at depths exceeding 500 m is still deficient in spite of the investigations SKI has carried out at different sites (e.g. the study sites and Äspö). This is a deficiency, even if the repository were to be located at a depth of 500 m. Therefore, SKI is of the opinion that SKB should compile data relating to the full range of depths, 500 m – 1,500 m.

7.16 Scientific Information

SKB is working within the area of scientific information to produce fact sheets and easily understandable descriptions of particularly important obtained results. Planned efforts for improving the provision of information including focusing on the Internet and the development of a newsletter. Within SKB's risk project, a number of popular scientific reports have been produced in order to clarify various kinds of risks associated with nuclear waste (e.g. plutonium, spent fuel and transport).

In SKI's opinion, it is important to make the results of SKB's programme available to the public, in varying degrees of detail. Simple, general descriptions should refer to more detailed studies in order to make it easier for the public to conduct further reading on the subject and to satisfy the need for ensuring traceability. SKI's view is that publications which are referred to in published reports should be accessible. This applies principally to RD&D reports, background reports and corresponding references. All references are to be made available to SKI, as the supervisory authority. This principle will be applied to the international peer review of Safety Assessment SR 97. SKI is responsible for ensuring that this review, which will be performed by independent experts, is arranged in such a way that the demands on quality and suitability are satisfied.

In general, SKI considers that SKB has maintained a good level of quality in its research and has, on the whole, satisfied the need for accessibility to information and openness. To promote this trend, SKI considers it important for SKB to strive, as far as possible, to publish its work in scientific journals and, in this way, ensure that peer review is continuously achieved. This is very important for gaining the support of the rest of the research community.

7.17 SKI s Overall Evaluation of SKB s Research Programme

In SKI's opinion, in general, SKB has a research programme which is good in terms of quality and suitability. This opinion is not only based on RD&D Programme 98 since, in SKI's view, the account in this report does not do full justice to SKB's research. As SKI has emphasised in previous evaluations of SKB's RD&D programmes, it is important that the specific goals and focus of the research as well as the allocation of resources between different areas of research should reflect the needs which have emerged in connection with preliminary safety assessments. Once SKB has published SR 97, there may be reason for SKB to review the focus of its research programme. On the basis of the information presented in SKB's budget and in RD&D Programme 98, SKI has no objections to SKB's allocation of research funds over different areas of research. Within all of the areas, there are areas where it is important to continue research. However, this does not necessarily mean that, in all areas, there are issues which it is absolutely necessary to resolve. It all depends on which parts of the system (fuel, canister, buffer, geosphere, biosphere) are considered to be more or less important in the safety assessment. The requirements which can be made on demonstrating a certain redundancy between the parts of the system should also be considered.

SKI emphasises that it is important for SKB to evaluate the more basic research-related issues from a perspective that is adequately long-range in nature. As the details of the selected final disposal concept are worked out, greater demands will be made on the quality and scope of the data used in the safety assessments which must be prepared and this requires long-term planning. It is essential that SKB should take into account the need to develop and maintain competence when allocating research funds. Moreover, SKB should gain support for its research results in other research communities as far as possible, by publishing its work in scientific journals.

Spent Fuel

In SKI's view, SKB's experimental work is adequately focused on issues which it is important to resolve. In SKI's opinion, with the present level of knowledge, it is difficult to develop models for the corrosion of spent fuel which can claim to be realistic. Examples of issues which must be clarified include the relative importance of various release mechanisms, the effect of radiolysis and the formation of secondary minerals. In spite of these deficiencies, present-day knowledge may very well prove to be sufficient to assess the reliability of a fuel model which is exclusively based on simplified and conservative assumptions. The resources which SKB must invest in this area will depend on the extent to which the barrier function of the fuel will be used in future safety assessments.

Canister
As regards research into canister material, in SKI's opinion, SKB should compile a new report on how the knowledge of various types of corrosion processes is used in the assumptions and analysis on which corrosion rates in the safety assessment are based. SKB should obtain and interpret results from ongoing corrosion studies before it decides whether to conclude its studies of corrosion in reducing environments. It is expected that research into corrosion in the initial oxidising phase will be less important, as this phase can be expected to be a relatively short-term one. However, this research does need to be carried out and can be done in parallel. SKB deals with the following issues which are of particular importance: the corrosion process in the gap between the iron insert and the copper canister, microbial activity and corrosion studies in a realistic environment. In SKI's opinion, these are vital studies. SKI also emphasises the importance of conducting studies of the properties of the copper on samples collected from actual fabricated canisters. In addition, there needs to be further investigation into the effects of phosphorus on the creep properties of the copper. It is essential that the development programme for non-destructive testing continues.

Buffer and Backfill
Within the area of buffer and backfill, it is important for SKB, to a greater extent, to present an integrated account of its requirement specification for the selected materials and to co-ordinate this work so that all aspects are covered simultaneously. In SKI's opinion, SKB must be able to show, more clearly than before, that the buffer fulfils the performance requirements on maintaining favourable chemical and physical properties in a long-term perspective. Further work on developing a knowledge base will be required to identify possible chemical and structural changes in the bentonite which can occur in the long and short term in order to be able to predict the effects of the changes.

In SKI's opinion, SKB needs to improve understanding of the saturation phase of the bentonite as heat from the canister can degrade the properties of the bentonite over a lengthy phase of unsaturation. Analyses which clarify the factors influencing the saturation rate of the buffer and backfill must be investigated.

Structural Geology and the Mechanical Stability of the Rock
SKI considers SKB's report in RD&D Programme to be sufficient. However, a *clear discussion* is lacking of the areas where knowledge, according to SKB, is adequate, and of the areas where SKB considers that further work must be done in order to obtain sufficient knowledge for assessing the safety of a repository. SKI observes that SKB intends to study plastic shear zones and the importance of these zones to a deep repository. It is important to do this, especially if SKB actually intends to locate a repository in or near to a regional plastic shear zone (tectonic lens). SKI also wishes to emphasise how important it is for the work started in RD&D Programme 98 to be completed, and that SKB should take advantage of knowledge gained in the future work on site characterisation.

Water Flow in the Rock
On the basis of the overall account presented by SKB in RD&D Programme 98, SKI is of the opinion that SKB's research programme on water flow and transport in the bed-rock is appropriate. However, SKI considers that SKB should review its co-ordination

of research into these important issues within the different projects for site characterisation, safety assessment and supporting R&D at Äspö and elsewhere. SKI reiterates the recommendation from its evaluation of RD&D Programme 95 that SKB should also report how it intends to determine the bedrock transport properties in connection with surface-based site investigation.

Prior to the selection of sites for site investigations, SKB should explain more clearly the role of the regional groundwater flow conditions as a siting factor. SKB's own account contains contradictory conclusions concerning the factors which determine groundwater flow at repository depth. A site evaluation and estimate of parameters for consequence calculations in the safety assessment will require several stages of model simplification and the scaling up of measurement data and model parameters. SKI is therefore positive to the fact that SKB is now planning to conduct field experiments and modelling to study the problem of the scaling up of hydraulic parameters and transport parameters.

Groundwater Chemistry

Within the groundwater chemistry programme, SKB has made considerable progress in developing sampling, interpretation and analysis methods. This work must continue, focusing on the further improvement of interpretation models, analysis methods and, particularly, on collecting samples that are as undisturbed as possible. Furthermore, SKB will have to put more work into optimising the analysis classes on the basis of data needs and the interpretation models. In addition, SKB should set aside research funds for the long-term basic research on chemical processes in deep groundwater. Many gaps still exist in the knowledge of the interaction between the groundwater, minerals and geogas, as well as the mechanisms for these processes, which can be controlled by microbial catalysis, kinetics for slow mineral reactions, etc. This knowledge is necessary to assess how the chemical conditions can be affected by different types of changes and events in the bedrock (climatic changes, changes in groundwater flow, repository-related effects, etc.).

Radionuclide Chemistry, Sorption and Diffusion

In SKI's view, it is essential that SKB should provide a reasonable level of long-term support for the more basic research on radionuclides, sorption and matrix diffusion. The development of the basic understanding of the processes which have so far mainly been covered by empirical data (such as sorption data) will provide the basis for gradually developing and improving the data for the safety assessment. Alongside this work, databases used for safety assessment must be maintained and updated. As far as colloids are concerned, SKB needs to continue studying basic mechanisms, more extreme conditions, and the effects of cement and bentonite. Furthermore, unresolved questions remain regarding how microbes can affect the chemical properties in the near field as well as the radionuclide transport. A clearer integration with geochemistry, safety assessment and site investigation is recommended in the future.

The Biosphere

SKI shares SSI's view that the fact that SKB, in recent years, has expanded the scope of its biosphere research – largely by applying a system-ecological approach - is a positive step. SKI approves in particular of SKB's awareness of the importance of a systems

approach and of the fact that the dynamic modelling of processes in sediment and other effects in the transfer from biosphere to geosphere are discussed in the programme. At the same time, SKI and SSI consider that considerable work remains to be done before SKB reaches its overall goal of performing credible consequence calculations in the safety assessments. Furthermore, taking into account the long time ranges involved, it is the opinion of the authorities that it is essential to complete plans to study other safety indicators besides dose and risk, e.g. concentration changes in the biosphere.

SKI concludes, as does SSI, that SKB has now established a satisfactory level of ambition for its biosphere studies. However, considerable work remains to be done, in quantitative terms, before material is available for an application for permission to construct a repository.

Other Waste

With regard to the programme on other long-lived waste, SKI emphasises the importance of continuous knowledge improvement with respect to issues relating to the barrier function of the cement and the transfer of knowledge between SFR and SFL 3-5 in terms of biodegradable products from cellulose and other organic substances which can form complexes together with radionuclides. SKI is expecting a detailed description of long-term barrier properties in the cement in connection with future safety assessments. SKI would like SKB to clearly justify its alterations to the layout of SFL 3-5 as proposed in RD&D Programme 98.

Alternative Methods

SKI concludes that two alternative methods, partitioning and transmutation as well as deposition in Very Deep Holes (VDH) are dealt with in SKB's detailed programme. SKI has no objection to this choice of alternatives for future, more detailed study.

In SKI's opinion, SKB's work on partitioning and transmutation has been successful so far. SKI agrees with SKB's view that the work in this area should be kept to approximately the same level as before. However, at the same time, SKI emphasises the importance of including system studies and studies of the quantity and composition of the waste.

SKB's plans for the VDH method are more general in nature. In SKI's opinion, the focus of the plans on safety assessment and system analysis is suitable. However, SKI reiterates that, in this context, the safety assessment should be considered to be a part of the system analysis.

SKB may have to review its plans for both methods – partitioning and transmutation as well as Very Deep Holes – to take into account the reporting requirements which may be made prior to the selection of sites for site investigation.

Äspö Hard Rock Laboratory

In SKI's view, the extensive experimental and demonstration programme which is now being planned for the Äspö Hard Rock Laboratory for the period 1999-2004 can be expected to provide adequate opportunity to improve the understanding of important

parameters and processes in crystalline bedrock and to further develop methodology for site investigations and detailed characterisations. However, SKI is of the opinion that considerable work remains to be done on combining different methods into an integrated site investigation programme. SKI also emphasises the need to develop individual methods, e.g. detection of horizontal fracture zones and programmes for groundwater chemistry sampling.

According to SKI, it is very important to identify any flowpaths and hydraulic relationships for radionuclide transport in affected and disturbed rock in deposition holes and deposition tunnels as well as further investigate whether it is possible to block transport paths through strategically placed plugs. SKI is of the opinion that SKB must establish, more clearly, which safety-related factors can be determined in connection with a surface-based site investigation as well as a detailed characterisation from tunnels and shafts.

SKI emphasises that SKB should determine the impact of different processes on the consumption of oxygen remaining in the repository after closure. Furthermore, in SKI's opinion, knowledge of changes in hydraulic properties in connection with a pressure drop around tunnels and the degassing of groundwater (two-phase flow) must be improved. SKI fully supports SKB's present (TRUE-1) and planned (TRUE-2, TRUE Block Scale) tests on the barrier function of the rock, and, in its view, the application of different models in parallel is very valuable.

SKI also supports SKB's plans to use the Äspö Hard Rock Laboratory to develop technology for and to demonstrate the function and interaction between the different components of the deep disposal system. In SKI's opinion, SKB's plans to conduct full-scale testing are very important, since these tests may confirm whether or not the final disposal technology is suitable from an engineering perspective before it is applied on the actual repository. With respect to the experiment on the demonstration of disposal technology and retrievability, SKI considers that there are good grounds for SKB to demon-strate the different stages of disposal and retrieval of canisters in the Äspö Hard Rock Laboratory for the public and specialists. At the time of the evaluation of RD&D Programme 95, SKI emphasised the importance of SKB improving its knowledge of the durability and long-term properties of the grout in the repository. The possible impact of the grout on the chemistry of the repository must also be further investigated.

Natural Analogues

In SKI's opinion, SKB should ensure that knowledge is continuously improved within the area of natural analogues and should, therefore, ensure that work is continued in this area once the current projects are completed.

Paleohydrological Programme

SKI concludes that the development of time-dependent modelling of glaciation has now advanced to such a stage that SKB can claim that the modelling will be useful in future performance and safety assessments. In SKI's opinion, all of the issues dealt with by SKB in the paleohydrological programme are relevant and should be included in SKB's work in the future. However, SKI would like to see a coherent presentation (including time-schedules) of how SKB intends to deal with the issues, especially with respect to

meeting the needs of the safety assessment. SKI assumes that SKB's planned SR 97 report will be an important document prior to decision-making regarding which activities it will prioritise.

During the current RD&D period, SKB must clearly show how it intends to integrate the issues in this area. SKI also underlines the importance of SKB properly specifying and discussing input data, the applicability of theories used, as well as shortcomings and uncertainties. This knowledge must be placed in the appropriate context when assessing the usefulness of models and when evaluating the results obtained.

Deep Drilling in Laxemar

SKI finds that SKB's work to date shows the importance of conducting drilling (at possible repository sites) to a greater depth than has been the case so far (500-700 m deep). SKI considers it high time for SKB to plan for and develop practical methods to obtain the necessary data in connection with site investigations and detailed characterisations down to a depth of approximately 1,500 m.

SKI emphasises the importance of also making use of relevant information at depths of 500-1,000 m. SKI concludes that existing knowledge about the bedrock at depths exceeding 500 m is still deficient, in spite of the investigations which SKB has carried out at different sites (e.g. study sites and Äspö). This is a deficiency even if the repository were to be located at a depth of 500 m. Therefore, SKI is of the opinion that SKB should compile data relating to the full range of depths: 500 m – 1,500 m.

Scientific Information

In SKI's opinion, it is important to make the results of SKB's programme available to the public, in varying degrees of detail. Simple, general descriptions should refer to more detailed studies in order to make it easier for the public to conduct further reading on the subject and to satisfy the need for ensuring traceability. SKI's view is that publications which are referred to in published reports should be accessible.

In general, SKI considers that SKB has maintained a good level of quality in its research and has, on the whole, satisfied the need for accessibility to information and openness. SKI considers that it is important for SKB to continue to strive, as far as possible, to publish its work in scientific journals and, in this way, ensure that peer review is continuously achieved.

8 Decommissioning of Nuclear Facilities

8.1 General

SKB s Report
SKB states that on an international scale there is good practical experience of the decommissioning of nuclear facilities. In Sweden, there is limited experience from the decommissioning of the R1 research reactor and other smaller nuclear facilities. In addition, greater maintenance work, such as the replacement of steam generators, reactor internals etc. and the necessary decontamination has provided an adequate knowledge base in Sweden for the decommissioning of power-producing reactors.

Furthermore, SKB concludes that the power companies are responsible for planning and implementing the decommissioning work as well as for determining exactly when this will be done. The power companies are responsible for waste treatment while SKB is responsible for the final disposal of the radioactive decommissioning waste. SKB and the power companies consult with each other.

On the topic of the decommissioning of facilities, SKB refers mainly to its study from 1994, which it also refers to in RD&D Programme 95. SKB is participating in, and following international development work within the area, particularly within OECD/NEA and within the EU and IAEA.

According to SKB, its goal is to ensure that knowledge, technology and a final solution to the nuclear waste disposal problem is available before Swedish nuclear power plants are dismantled.

Comments by the Reviewing Bodies
In its review statement, SSI emphasises that SKB should give a clearer account of the different waste streams which are generated by the decommissioning of nuclear power plants and of the level of flexibility of its plans, including the waste facilities which will be necessary.

8.2 SKI s Overall Evaluation

The decommissioning of nuclear power plants in the world is accelerating as the technical and/or economic lifetimes of the plants expire. The dismantling of the radioactive components of a nuclear power plant is very similar to the major maintenance projects which are periodically conducted at the nuclear power plants.

In the case of the handling of very large components, such as reactor pressure vessels, international experience also exists of how safe handling can be achieved. The conclusion is that the actual decommissioning and dismantling of nuclear facilities is based on established, conventional technology.

However, finding a solution to the problem of nuclear waste disposal is an important step in the decommissioning and dismantling work, as described above. For this to be achieved, repositories for short and long-lived decommissioning waste must be constructed and licensed, SFR must be expanded or re-licensed and SFL 3-5 constructed.

In SKI's opinion, SKB is following international developments within the area of decommissioning and dismantling as well as the work on finding a solution to Sweden's nuclear waste disposal problems in a satisfactory manner. However, in view of a possible early shutdown of Swedish nuclear power plants, SKB must give greater priority to the issue of the disposal of the decommissioning waste.

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Reviewing Bodies

Chalmers University of Technology (CTH)
County Administrative Board, Kalmar County
County Administrative Board, Skåne County
County Administrative Board, Uppsala County
County Administrative Board, Västerbotten County
Greenpeace
Göteborg University (GU)
Local Safety Committee for the Nuclear Installations at Studsvik (LSNS)
Local Safety Committee, Forsmark Nuclear Power Plant (LSNF)
Local Safety Committee, Oskarshamn Nuclear Power Plant (LSNO)
Malå Municipality
National Heritage Board (RAÄ)
Nyköping Municipality
Opinion Group against Nuclear Waste in Malå
Oskarshamn Municipality
Royal Institute of Technology (KTH)
Save Fjällveden
Stockholm University (SU)
Storuman Municipality
Swedac
Swedish Anti-Nuclear Movement - Oskarshamn
Swedish Anti-Nuclear Movement (FMKK)
Swedish Association of Municipalities with Nuclear Reactors (KSO)
Swedish Board of Housing, Building and Planning
Swedish Environmental Protection Agency (SNV)
Swedish Geotechnical Institute (SGI)
Swedish National Energy Administration
Swedish National Testing and Research Institute (SP)
Swedish Natural Science Research Council (NFR)
Swedish Radiation Protection Institute (SSI)
The Environmental Federation Friends of the Earth
The Geological Survey of Sweden (SGU)
The Green Party, Tierp
The National Board of Psychological Defence
The Swedish Agency for Civil Emergency Planning (ÖCB)
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The Swedish Society for Nature Conservation
The Waste Network
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Statements have also been submitted by Hans Forsgren and Nils-Axel Mörner