SKI Report 02:33

The Swedish Nuclear Power Inspectorate's Review Statement and Evaluation of the Swedish Nuclear Fuel and Waste Management Co's RD&D Programme 2001

September 2002

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To the Government
Ministry of the Environment
103 33 Stockholm

Review Statement on the Swedish Nuclear Fuel and Waste Management Co's Programme for the Research, Development and Demonstration of Methods for the Management and Disposal of Nuclear Waste – RD&D Programme 2001

In the light of SKI's review and the statements of opinion submitted by the reviewing bodies, SKI proposes that the Government adopt the following position with regard to RD&D Programme 2001 which the Swedish Nuclear Fuel and Waste Management Co (SKB) has submitted for review in accordance with 12 § of the Act on Nuclear Activities (1984:3).

SKI's Proposal for a Position to be Adopted by the Government

Based on SKI's own review and the review statements received, SKI proposes that the Government should:

- establish that SKB, and thereby the reactor owners, have fulfilled their obligations in accordance with 12 § of the Act on Nuclear Activities, and

- establish as a requirement that SKB should immediately start work on preparing a strategy document for the implementation of the disposal programme. This document should be submitted no later than in connection with the submission of RD&D Programme 2004.

Furthermore, SKI would like to draw to the Government's attention the following observations and evaluations.

SKB's Timetable

- SKB's timetables for the implementation of the disposal programme leave very little scope for delays and contingencies, for example, a two-year period each for the regulatory review of applications for permission to construct the encapsulation plant and for permission to construct a repository is an underestimate.

- The time required for the development work on the canister probably means that 2005 is too early a date to submit a licence to construct the encapsulation plant. Furthermore, SKB

should ensure that sufficient time has been allocated to fully take advantage of the experience from the initial site investigations in connection with the planning of the full site investigations.

Decision-making Process

- One condition for granting SKB permission to construct an encapsulation facility is that the licence application should also include a safety assessment for disposal. It should also be required that a repository is approved for operation before SKB starts the encapsulation of spent nuclear fuel. This means that detailed characterisations must be conducted and that SKB must have been granted permission to start depositing waste in the repository.

- In future RD&D programmes, SKB should more clearly describe, specifying deadlines, how and where the long-lived low and intermediate-level nuclear waste is to be handled and stored prior to disposal. According to SKB's time-schedule, disposal is not expected to start until about 30 years' time.

Safety Assessment

- An international peer review should be conducted of the safety assessment that SKB plans to publish in 2004.

- The deadlines for reporting with respect to future safety assessments should be established within the framework of the consultation that SKB, in accordance with the Government's decisions of 1996 and 2001, is to conduct with SKI and SSI.

- SKB should specify the content of the preliminary safety reports and specify the nature of the feedback that they will provide to the full site investigation phase.

Long-term Experiments and Natural Analogues

- SKB should compile an overview of the long-term experiments that have been started at the Äspö Hard Rock Laboratory and should consider whether these need to be supplemented or expanded.

- SKB should give high priority to studies of natural analogues in its continued work.

Encapsulation

- SKB should, as soon as possible, compile into a single document, results and experience so far gained from the work on methods for non-destructive canister testing. There is a risk of SKB underestimating the time required to prepare and qualify methods for non-destructive testing.

Alternative Methods

- SKB should continue its programme concerning different alternatives for the management of waste with largely the same direction and scope as has been the case so far.

Regulatory Action

SKI has conducted the review of SKB's RD&D Programme 2001 in the same way as for previous RD&D programmes. The programme has been distributed to sixty reviewing bodies for comment (including government authorities, universities and NGOs). Review statements have been received from thirty-six of these.

Main Points of SKI's Review and Conclusions

Through SKB, the reactor owners have fulfilled their obligations in accordance with 12 § of the Act on Nuclear Activities

In SKI's opinion, SKB has presented a research and development programme that complies with the requirements of 12 § of the Act (1984:3) on Nuclear Activities.

Overall Evaluation of SKB's Programme

In terms of content, the programme is suitable for the continued development of a method for the disposal of spent nuclear fuel and nuclear waste in Swedish crystalline bedrock. The research is considered to be of good quality.

In SKI's opinion, disposal based on the KBS-3 method, in deep geological formations, is still the most suitable method for the disposal of the spent nuclear fuel from the Swedish nuclear power programme.

Strategy Document

The need for a planning instrument in the form of a strategy document, which describes how SKB will attain the goal of a safe disposal of spent nuclear fuel, has become increasingly urgent now that SKB's programme has entered a more intensive phase. It is not sufficient for SKB's plans to be reported solely in connection with the RD&D programmes, in the form of general descriptions of the content of various reports and connections between different activities. Already within a year or two, the competent authorities will need to know which regulatory reviews are anticipated over the next ten years and the extent to which these reviews depend on each other.

In SKI's opinion, it is especially important that SKB should, as soon as possible, start work on the preparation of a strategy document and should present this document no later than in connection with RD&D programme 2004 and, preferably, already in 2003.

Direction of Future RD&D Programmes

SKI understands SKB's wish to focus future RD&D programmes on the information that is required in order for an application to be submitted in 2005 for permission for the siting and construction of the encapsulation plant in 2007 and an application for permission in 2007 to site and start construction of the repository in 2009. However, this focus should not lead to the neglect of the legislative requirements on the comprehensiveness and completeness of the RD&D programmes.

In SKI's opinion, it is also desirable that SKB, in the next RD&D programme should describe its view on the future availability of expertise in the nuclear waste area.

SKB's Timetable

The two most important deadlines reported by SKB in RD&D programme 2001 are the submission of the application in 2005 for permission to start the construction of an encapsulation plant in 2007 as well as the submission of an application in 2007 for permission to start the construction of the repository in 2009. In SKI's opinion, these timetables leave very little scope for delays and other contingencies with respect to the following:

- The time required for the development work on the canister probably means that 2005 is too early a deadline for the submission of an application for permission to start construction of the encapsulation plant in 2007.
- More than one year will probably be required between the completion of the safety assessment based on generic data in 2004 and the safety assessment which is to be appended to the application in 2005 for permission to start the construction of the encapsulation plant in 2007.
- A period of two years each (2005-2007 and 2007-2009, respectively) for the review of applications for permission to construct the encapsulation plant and to construct the repository is an underestimate.
- SKB should ensure that full advantage is taken of the experience from the work on initial site investigations in connection with the planning of full site investigations.

Decision-making Process

SKI's view is that a condition for permission to construct an encapsulation plant is that a safety assessment for disposal should also be included in the licence application. Furthermore, in SKI's opinion, a repository should be approved by the authorities before SKB starts the encapsulation of spent nuclear fuel. This means that detailed characterisations must be conducted and that SKB must have been granted permission to start depositing waste in the repository.

SKB has stated that, after the application for permission to construct a repository for spent nuclear fuel has been submitted, it intends to submit a safety assessment for other long-lived waste in around 2009. Taking SKB's plan as a starting point, SKI considers that this is reasonable. SKI recommends that SKB should, already now, start the research that must be conducted.

Furthermore, in SKI's opinion, SKB should clarify, stating deadlines, how and when the long-lived low and intermediate-level waste shall be handled and stored before disposal is implemented, in accordance with SKB's proposal, in about thirty years' time.

Safety Assessment

In SKI's opinion, SKB should allow an international peer review to be conducted of the safety assessment that it intends to submit in 2004. SKI sees no need for SKB's planned safety reports to be connected to RD&D programme 2004. Instead, the reporting deadlines should be

established within the framework of the consultation that SKB, in accordance with the Government's decisions of 1996 and 2001, is to conduct with SKI and SSI.

In SKI's opinion, SKB should more clearly state objectives of and boundaries between the preliminary safety reports that SKB will be conducting after the initial phase of the site investigations. If these safety reports do not provide adequate information to evaluate the extent to which SKB has taken into account the feedback between safety assessment and the full site investigation phase, ways of reporting this should be included within the framework of the consultation on site investigations as well as system and safety assessments.

With respect to the safety assessment (in 2005) upon which an application for permission to construct the encapsulation plant is to be based, SKI considers that it is of decisive importance that SKB, in a convincing manner, can show that the assumptions of the safety assessment concerning canister defects have a very good potential to be met.

In SKI's opinion, a significant part of the remaining issues concerning safety assessment is related to the requirement on quality assurance. Because of this, SKB should plan and clarify its objectives in this area.

Long-term Experiments at the Äspö Hard Rock Laboratory and Natural Analogues

In SKI's opinion, the Hard Rock Laboratory is an important resource for SKB, both in terms of research on long-term safety performance and the development of disposal techniques under realistic conditions.

SKB should be aware of the possibility that experimental mishaps and deviations can entail the delay of expected results by several years. SKI recommends that SKB should conduct an overview of the long-term experiments started at the Laboratory and evaluate whether they need to be supplemented or expanded.

SKB should give high priority to studies of natural analogues in its further work. Furthermore, SKB should consider whether additional work is required to better utilise the information that already exists from completed projects.

Encapsulation

SKI would like to emphasise that a critical issue for the technical feasibility of constructing KBS-3 is that there should be suitable methods for the sealing and control of canisters in connection with series manufacturing. This means that an adequately large number of full-size canisters must be manufactured, sealed and controlled and these should be found to comply with the requirements of the long-term performance assessment.

Alternative Methods

Largely only two possible strategies exist for the disposal of spent nuclear fuel: disposal in the existing form (direct disposal) or reprocessing, possibly followed by separation and transmutation, and then disposal of the end-product.

In SKI's opinion, the direction of SKB's programme concerning separation and transmutation is suitable with respect to both basic research and method development. System and safety-related research as well as the work on co-ordinating different projects are particularly valuable since they, for a reasonable cost, provide an opportunity for good insight into international developments.

In SKI's opinion, it is too early to state, at this point, which alternatives should be dealt with in the Environmental Impact Statement to be prepared in accordance with the Environmental Code. Such alternatives should be prepared in the forthcoming consultation process that SKB is to conduct in accordance with the requirements of the Environmental Code.

The need for and scope of a safety assessment for the deep borehole alternative that SSI has proposed in its review statement to SKI should, in SKI's opinion, be discussed within the framework of the consultation decided by the Government in 1996 and 2001.

In summary, SKI's opinion is that SKB should continue its programme concerning different alternatives for the management of nuclear waste with largely the same direction and scope as before.

Other Comments Directed to SKB

In the attached Review Report, SKI presents, on the basis of its own review and the statements of opinion from the reviewing bodies, a number of comments that SKB should take into account.

Conduct of this Regulatory Action

A decision on this matter was made by SKI's Board. Apart from the undersigned chairperson, the following board members participated in the decision: Andersson Öhrn, Holm, Karlsson, Persson and Veiderpass, as well as SKI employees Westerlind and Toverud, the latter in the capacity of rapporteur.

SWEDISH NUCLEAR POWER INSPECTORATE

Judith Melin

Öivind Toverud

Appendices

Swedish Nuclear Fuel and Waste Management Co.

RD&D Programme 2001. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste. September 2001.

Swedish Nuclear Power Inspectorate

SKI's Evaluation of SKB's RD&D Programme 2001. Review Report. (Review Statement and Review Report also published as SKI Report 02:33).

Reviewing Bodies' Statements on SKB's RD&D Programme 2001. SKI-PM 02:02 *[Only in Swedish]*.

Reviewing Bodies

Statements from 36 reviewing bodies.

Distribution List for Copies of the Review Statement and Review Report

Swedish Work Environment Authority[1]
The National Board of Housing, Building and Planning[1]
National Chemicals Inspectorate
Swedish Environmental Protection Agency[2]
National Heritage Board
National Archives
National Rescue Services
SP Swedish National Testing and Research Institute
Swedish Energy Agency
Swedish Geotechnical Institute[2]
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Municipality of Älvkarleby[2]
Municipality of Östhammar[2]
Swedish Association of Local Authorities

County Council, Kalmar County[2]
County Council, Uppsala County[2]

KSO (Network for co-operation among nuclear municipalities)
Local Safety Committee, Municipality of Kävlinge
Local Safety Committee, Studsvik[1]

Local Safety Committee, Oskarshamn Nuclear Power Plant[2]
Local Safety Committee, Municipality of Varberg
Local Safety Committee, Municipality of Forsmark[2]

Waste Network[2]
Waste Network Association[2]
Swedish Anti-Nuclear Movement[2]
Swedish Anti-Nuclear Movement - Oskarshamn[2]
Greenpeace Sweden
Mehedeby-Orrskog Group[2]
Friends of the Earth[2]
Opinion Group for Safe Disposal, OSS - Östhammar
SOS – Tierp[2]
SOS – Älvkarleby[2]
Swedish Society for Nature Conservation/Society for Nature Conservation in Uppsala County[2]

Westinghouse Atom AB
Studsvik Holding AB

[1] Submitted a review statement but refrained from disclosing its position
[2] Submitted a review statement

For Information

Danish Emergency Management Agency
Forsmarks Kraftgrupp AB
Swedish National Council for Nuclear Waste (KASAM)
OKG AB
Swedish Parliament
Norwegian Radiation Protection Authority
Office of the Prime Minister
STUK, Finland
Swedish Nuclear Fuel and Waste Management Co., SKB
Swedish IAEA Delegation
Swedish OECD Delegation
Sydkraft AB
Vattenfall AB

The Swedish Nuclear Power Inspectorate's Evaluation of the Swedish Nuclear Fuel and Waste Management Co's RD&D Programme 2001

Review Report

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Summary

In SKI's opinion, SKB, and thereby the reactor owners, have fulfilled their obligations in accordance with 12 § of the Act on Nuclear Activities,

Overall Opinion on SKB's Programme

Direction of Future RD&D Programmes

SKB would like future RD&D programmes to focus on the information that is required in order for an application to be submitted in 2005 for permission for the siting and construction of the encapsulation plant in 2007 and an application for permission in 2007 to site and start construction of the repository in 2009. SKI understands SKB's focus but emphasises that this focus should not lead to the neglect of the legislative requirements on the comprehensiveness and completeness of the RD&D programmes.

Since a number of reviewing bodies have requested a social scientific (for example, psychosocial factors, the development of tourism and industry) perspective on the disposal programme, SKI considers that SKB in its continued programme should also include such issues. It is also desirable that SKB, in its next RD&D programme, should present its view on the future availability of expertise in the nuclear waste area.

In SKI's opinion, SKB's reporting deadlines for planned specific safety reports should be established within the framework of the consultation that SKB, in accordance with the government decisions of 1996 and 2001, must conduct with SKI and SSI. SKI supports SKB's plan to carry out an international peer review of the safety assessment that has been planned for 2004.

SKB's Timetable

The two most important deadlines reported by SKB in RD&D programme 2001 are the submission of the application in 2005 for permission to start the construction of an encapsulation plant in 2007 as well as the submission of an application in 2007 for permission to start the construction of the repository in 2009. In both cases, SKB anticipates a two-year period each for the regulatory review of applications for permission. In other contexts, SKB has presented a timetable for the publication of future safety assessments, where the first complete safety assessment after SR 97 is planned to be completed in 2004. Safety assessments will also be attached to the application for permission to construct the encapsulation plant and the application for permission to construct the repository.

The site investigations which are planned to be started in the current year will be divided into two phases with initial site investigations that will take about 2 years and the subsequent phase with supplementary site investigations which will take about 3 years. In accordance with the plans, the site investigations will be completed when the licence to construct the repository is submitted in 2007.

In SKI's opinion, SKB's timetables leave very little scope for delays and other contingencies with respect to the following:

- A period of two years each (2005-2007 and 2007-2009, respectively) for the review of applications for permission to construct the encapsulation plant and to construct the repository is an underestimate.
- More than one year will probably be required between the completion of the safety assessment based on generic data in 2004 and the safety assessment which is to be attached to the application for permission to start the construction of the encapsulation plant in 2005.
- The time required for the development work on the canister probably means that 2005 is too early a deadline for the submission of an application for permission to start construction of the encapsulation plant
- SKB should ensure that full advantage is taken of the experience from the work on initial site investigations in connection with the planning of full site investigations.

Decision-making Process and Site Investigations

According to the Government decisions from 1996 and 2001, SKB is to consult with the authorities on the site investigation programme before and during the site investigations.

In SKI's opinion, as is the opinion of Oskarshamn Municipality and the Local Safety Committee at Oskarshamn Nuclear Power Plant and SSI, SKB should describe the role of the RD&D programmes in relation to the consultation process in the Environmental Impact Assessment in order to achieve a consistent and structured decision-making process. Furthermore, SKB should document the consultation processes in a clear and traceable manner.

In SKI's opinion, as is the opinion of Oskarshamn Municipality, the Local Safety Committee and County Administration in Kalmar, the link between the encapsulation plant and the repository is important. In SKI's opinion, a condition for obtaining permission to construct an encapsulation plant is that a safety assessment for disposal should also be included in the licence application. Furthermore, SKI considers that a repository should be approved by the authorities before SKB starts the encapsulation of spent nuclear fuel. This means that detailed characterisations must be conducted and that SKB must have been granted permission to start depositing waste in the repository.

SKB has stated that, after the application for permission to construct a repository for spent nuclear fuel has been submitted, it intends to submit a safety assessment for other long-lived waste in around 2009. Taking SKB's plan as a starting point, SKI considers that this is reasonable. SKI recommends that SKB should, already now, start the research that must be conducted before 2009.

Furthermore, SKI considers that SKB, in future RD&D programmes should clearly describe how and where the long-lived waste is to be handled and stored before disposal which, according to SKB's time-schedule is not expected to start until about 30 years' time. At the same time, SKI finds that the regulatory authorities have adequate opportunities to make demands on the waste producers also with respect to the management of long-lived waste.

System Analysis

In SKI's opinion, the system analysis has two purposes: to justify in a logical and structured manner, selected solutions in the form of combinations of components in a system as well as to establish that all essential connections between the components in a selected system have been taken into account from various standpoints, such as safety, radiation protection, accessibility and societal aspects.

It is reasonable that a complete update of the system analysis should be conducted as a basis for licensing the construction of an encapsulation plant. In SKI's view, as was already stated in the review of RD&D Programme 98, the system analysis must be updated at all levels and, above all, prior to the final method and site selection that the application for permission to conduct detailed characterisations entails. Such a view is also completely in line with the views on the decision-making process presented by Oskarshamn Municipality and the Local Safety Committee at Oskarshamn Nuclear Power Plant.

SKI does not wish to commit itself, at this stage, to a definite opinion on the issues of the time, scope and direction of future system analyses apart from expressing the view that these issues must be included in the basis for decision-making for the planned facilities. These issues are to be taken up through the dialogue that, in SKI's opinion, it is necessary to have with SKB regarding the preparation of the strategy document.

Strategy Document

The need for a planning instrument in the form of a strategy document, partially similar to that advocated by the OECD/NEA, has become increasingly urgent now that SKB's programme has entered a more intensive phase. It is not sufficient for SKB's plans to be reported solely in connection with the RD&D programmes, which have so far been fairly vague with respect to the description of the content of different reports and links between different activities. Already within a year or two, the competent authorities will need to know which regulatory reviews are anticipated over the next ten years and the extent to which these reviews depend on each other. Above all, this is necessary for the authorities to be able to plan their work and to describe in other contexts how SKB is to achieve its goal of a safe disposal of nuclear waste.

In 2002, SKI plans to enter into a dialogue with SKB concerning the preparation of one or several strategy documents for SKB's programme and to prepare review plans that are based on these documents. This work, which it is assumed will be conducted in consultation with SSI, has been generally described in a letter from SKI to SKB, SSI, KASAM and the Ministry of the Environment.

In SKI's opinion, it is especially important that SKB should, as soon as possible, start work on the preparation of a strategy document and should present this document no later than in connection with RD&D programme 2004 and, preferably, already in 2003.

Safety Assessment

In SKI's opinion, it would be valuable to achieve a detailed international peer review of SKB's capacity within the area of safety assessment, before the application for permission to construct the repository is submitted as well as the application to construct the encapsulation plant. In SKI's opinion, SKB's planned safety assessment 2004, which will be based on generic data, should be the object of an international peer review.

In SKI's opinion, SKB should more clearly state objectives of and boundaries between the preliminary safety reports that SKB will be conducting after the initial phase of the site investigations. If these safety reports do not provide adequate information to evaluate the extent to which SKB has taken into account the feedback between safety assessment and the full site investigation phase, ways of reporting this should be included within the framework of the consultation between SKB and the authorities on site investigations as well as system and safety assessments.

With respect to the safety assessment (in 2005) upon which an application for permission to construct the encapsulation plant is to be based, SKI considers that it is of decisive importance that SKB, in a convincing manner, can show that the assumptions of the safety assessment concerning canister defects have a very good potential to be met. The review of this safety assessment can primarily be expected to focus on evaluating canister quality and design-related issues and on reconciling how viewpoints from the review of safety assessment 2004 have been dealt with.

In SKI's opinion, in RD&D Programme 2001, SKB has largely taken into account the most important viewpoints from SKI and SSI's joint review of SR 97. In SKI's opinion, a significant part of the remaining issues concerning safety assessment is related to the requirement on quality assurance. Because of this, SKB should plan and clarify its objectives in this area.

Research on Long-term Safety

In SKI's opinion, SKB has, with RD&D Programme 2001, prepared a considerably improved structure for reporting on research concerning the initial state of the repository and the repository's long-term properties. By linking to the basic structure of the "process report", the necessary conditions are established for integrating research and safety assessment in a clearer manner than before.

In SKI's opinion, SKB's overall prioritisation of research on the long-term safety of engineered barriers and the geosphere is largely suitable in relation to the needs of the safety assessment. This evaluation is partly based on the results of the review of SR 97. The subjects where SKI particularly looks forward to obtaining information in future research include materials strength issues for the canister, copper and iron corrosion, the resaturation process, fuel dissolution, models for damaged canisters, matrix diffusion in the rock and seismic issues.

Spent Fuel

In SKI's view, the results that SKB has so far reported provide a basis for developing a credible and realistic fuel model which will provide a significant barrier to radionuclides in the fuel matrix. However, in order to achieve this, a more comprehensive experimental basis as well as essentially improved process models that can explain the experimental results are needed.

In SKI's opinion, SKB should study how fuel dissolution is affected by various degrees of exposure (to groundwater) and canister and buffer damage. SKB should also itself question whether it is possible, for very long time periods, to include the hydrogen gas that is formed from the corrosion of the canister insert.

To conclude, in SKI's opinion, SKB's fuel programme has shown positive developments in recent years and has largely been conducted in a suitable direction in relation to the needs of the safety assessment.

Canister

In RD&D Programme 2001, SKB provides a plan for how acceptance criteria are to be developed and states that the experience from the trial welding will provide information on types and frequencies for defects that can occur in connection with welding. SKI would like to emphasise that there must be a strong link between the input data in the safety assessment, established acceptance criteria for the canister and the test statistics from the non-destructive testing.

In SKI's view, it is important for SKB to perform new calculations for the mechanical strength of the canister, where all components that are included are reviewed. Taking into account the scope of the work, SKB needs to ensure that the timetable for the work is reasonable.

SKI is positive to fact that SKB has compiled the knowledge base for copper corrosion. As SKI has previously stated, the next step must be to apply this knowledge in the safety assessment and in the work on the design basis since the reasoning from this work will result in the determination of the thickness of the copper. SKI agrees with SKB that further research is needed within microbial processes, properties of oxide film, the effect of concrete on copper and stress corrosion. However, SKB has not indicated how it intends to handle the spread of corrosion rates and canister lifetime in the safety assessment.

As previously stated, in SKI's opinion, SKB's model for the damaged canister shows that even a damaged canister has an important barrier function. However, SKI is sceptical to an approach where a too literal interpretation of the quantitative data obtained from individual modelling is directly integrated into a consequence analysis. SKI agrees with SKB's point that full-scale experiments will probably be needed to understand the scale dependency and relevance of small-scale experiments that have been conducted.

Buffer

SKI has observed that the role of the buffer in a spent fuel repository has not been given the same level of attention as the other two main components of the KBS-3 method, namely the rock and the canister. This could give the impression that the buffer is less important, which would be incorrect. The repository cannot perform as intended unless the buffer performs as intended. This particularly applies to the buffer's role in protecting the canister.

In SKI's opinion, it is difficult, from SKB's description, to assess each area separately since deficiencies in one area will often have an impact on or will be connected to several other areas. One example is that chemical changes that have occurred as a result of thermal effects (poor thermal conductivity) can impact on the mechanical properties.

In SKI's opinion, within the areas described by SKB, there is no evidence of anything that would seriously prevent the manufacturing of a buffer with acceptable properties. SKB's programme for the buffer appears to be comprehensive and shows that there is a good understanding of relationships between initial properties and long-term processes. However, SKI questions whether the work that SKB itself believes is remaining to be done can be accomplished in the allotted time until the repository licensing, according to SKB's plans. This primarily concerns the development of a validated model for combined thermohydraulic transport in the unsaturated buffer and for gas transport in the saturated buffer. In both cases, a need for experiments on different scales, including some long-term full-scale experiments, is anticipated. Of equal importance are studies of the buffer's mechanical/reological properties, particularly with respect to material selection, the buffer/canister/rock interaction and the interaction with the backfill in the deposition tunnel.

Among chemical properties and processes, SKI would particularly like to emphasise cementation under an early (unsaturated) phase and the development of knowledge regarding what this can mean for other properties (mechanical, hydraulic) of importance for long-term safety.

Backfill

To an even greater extent that the buffer, the backfill has not been afforded as much attention as the rock and canister. However, the backfill is necessary for the buffer to perform as intended and to ensure that the rock in the near field does not short-circuit as a barrier against the groundwater flow.

SKI's general viewpoints on properties and processes in the backfill and on SKB's report are the same as for the buffer.

An essential question that must be resolved before an application for the construction of the repository is submitted is the final choice of a suitable clay component in the backfill material.

The ongoing studies of the THM properties within the framework of the ongoing Backfill and Plug Test in the Äspö Hard Rock Laboratory are also of considerable importance. SKB should ascertain, in time, how useful results from these experiments are, bearing in mind the choice of material and the interaction with the buffer in the deposition holes.

Among chemical properties and processes, SKI particularly wishes to emphasise the impact of the infiltration of saline groundwater on the hydraulic properties of the backfill.

Geosphere

SKI considers that it is important for a study to be conducted on the issue of recharge and discharge areas since this is an important aspect for the geoscientific understanding of hydrological processes. In SKI's view, it would be most logical if SKB in its ongoing study primarily described the hydrological conditions in Småland and, secondly, in Uppland.

In SKI's opinion, it is important for SKB to describe overall existing experience that supports the assumption that possible new fracturing will not affect a tectonic lens during a future glaciation. In SKI's opinion it is also justifiable for SKB to investigate the long-term erosion of the geosphere since no investigation of the erosion effect over several glacial cycles has previously been reported. SKI considers that there are indications that the erosion can be relatively extensive, also in the coastal areas.

In SKI's view, on the whole, SKB has a suitable geochemical programme where the quality of the individual scientific projects is generally high. However, SKI can note certain deficiencies in how results from geochemical models, experiments and field measurements are integrated into the safety assessment work. In SKI's view, perhaps the most important geochemical issue with respect to the long-term safety is the stability of the groundwater chemistry over a glacial cycle, and particularly, the salinity of the groundwater. Therefore, SKB should report calculations of how the salinity may change for scenarios that involve extensive climate changes over long time periods.

In SKI's opinion, future safety assessments must provide an in-depth and clear treatment of the above issues. SKI also assumes that SKB, in the framework of site investigations, will study traces of previous occurrences of oxygen at different depths with the same methodology as previously described in the case of, for example, Äspö and Klipperås.

With respect to radionuclide transport, SKI considers that SKB should clearly describe how, in the site investigations, it intends to measure properties relevant to radionuclide transport. Furthermore, in SKI's view, SKB should study the matrix diffusion process further, and conduct sorption studies on site-specific material in order to be able to better determine the site-specific importance of the sorption process. In future safety assessments, SKB should also include the effect of the heterogeneity of the rock and the resulting variability in properties that determine radionuclide transport in the rock.

Äspö Hard Rock Laboratory

In SKI's opinion, the Hard Rock Laboratory is an important resource for SKB, both in terms of research on long-term safety performance and the development of disposal techniques under realistic conditions. SKB should ensure that adequate resources are set aside for research and development at the Äspö Hard Rock Laboratory throughout the site investigation phase.

SKB's long-term experiments are of particular importance for the long-term planning of the activity at the Äspö Hard Rock Laboratory. SKB should be aware of the possibility that experimental mishaps and deviations can entail the delay of expected results by several years. SKI recommends that SKB should conduct an overview of the long-term experiments started at the Laboratory and evaluate whether they need to be supplemented or expanded.

Biosphere

In RD&D Programme 98, SKB stated that its goal for the biosphere research was to analyse and evaluate alternative safety indicators, namely indicators that would complement dose and risk. Examples of such safety indicators can be radionuclide concentrations and flows. In the opinion of both SKI and SSI, it is essential that these plans should be completed. SKI finds that RD&D Programme 2001 does not mention alternative safety indicators at all. In its statement of opinion, SSI also stated that the issue was not treated by SKB. In SKI's view, it is important for SKB to implement the plans reported in RD&D Programme 98.

SKI notes with satisfaction that SKB has started various inventories, control programmes etc.

SKI's overall evaluation, which SSI also shares, is that SKB's biosphere programme is both methodical and ambitiously structured. However, considerable work remains before the overall goal of conducting credible consequence estimates in the safety assessment can be achieved.

Climate Development

For repositories in coastal areas, the future position and impact of the shoreline on groundwater conditions and the biosphere is an important safety and radiation protection issue. SKB's choice of two coastal sites in its programme will therefore place considerable requirements on future reports of climate effects for the repository, the rock and the biosphere.

In RD&D Programme 2001, SKI does not have a clear plan of how SKB intends to conduct research in this area. SKI would therefore like SKB to present concrete goals and timetables.

Natural Analogues

In SKI's opinion, SKB should give high priority to studies of natural analogues in its further work. Furthermore, SKB should consider whether additional work is required to better utilise the information that already exists from completed projects or consider the value of supplementary field experiments on these sites.

Methods for Site Investigations

In SKI's opinion, some of the reporting in RD&D Programme 2001 is already out-of-date and replaced by more detailed activity plans which are now being discussed in the ongoing consultation between SKI, SSI and SKB.

In these consultations, SKI has expressed the view that the characterisation of geochemical conditions should be accorded high priority in the initial site investigation phase since undisturbed conditions still exist at the site. SKI has also emphasised the importance of traceability and quality assurance concerning data management in the field and in SKB's databases.

SKI has set up an advisory group (INSITE) comprising international experts in important areas relating to site investigations that are within SKI's area of responsibility. The group will continuously follow the progress of SKB's site investigation programme and advise SKI.

Repository

In SKI's opinion, the permissible water flow to deposition holes is one of the most important acceptance criteria that SKB must report no later than in connection with an application to conduct detailed characterisations. Furthermore, SKI questions whether it is adequate for SKB, on the basis of expected test results, to draw any far-reaching conclusions on the natural resaturation of the bentonite, which is dependent on the flow to deposition holes, on the basis of only two short-term tests (5 years) in the Äspö Hard Rock Laboratory.

In SKI's opinion, it is important for SKB to detail its plans for the evaluation of the importance of the repository depth, access tunnel alternatives down to repository depth and alternative variations on repository design. SK would like to emphasise that, when the repository depth is ultimately determined, how the depth affects the long-term safety must be the dominant and decisive factor.

SKB is developing methodology for the sealing of boreholes in order to avoid having to take into account borehole location in the site investigations. In SKI's opinion, it is unnecessary to risk long-term safety by drilling far too many holes from the surface, particularly in the deposition areas. The possibility that a seal may be deficient or that future events may cause flowpaths to open up in old borehole locations cannot be completely excluded.

Transport, Safeguards and Physical Protection

Transport

In SKI's opinion, it would have been valuable if transports had been described in greater detail in the main report, since the issue is of considerable public interest. In SKI's view, conducting heavy transports with a 75-tonne cask, including canisters and trucks on a country road or railroad is much more sensitive than sea transport to disruptions, such as demonstrations. Such transports will also make heavy demands on the load-bearing capabilities of roads and railroads.

Furthermore, SKI considers that it is not possible, in the way that SKB has, to assume that the present-day surveillance, communication and incident response systems will be of use for future transports to a repository. This issue will be particularly important with an inland siting, that is, if longer transports by land are necessary. Therefore, SKI recommends SKB to conduct studies of the experience of other countries in this area.

SKI's overall evaluation is that the transport problem, bearing in mind uncertainties concerning the ultimate location of the repository, is adequately described in the RD&D programme.

Safeguards and Physical Protection

In SKI's opinion, the areas of safeguards and physical protection are described in very general terms in the main report. In principle, the future repository will host the irradiated nuclear fuel from the entire Swedish nuclear programme. Therefore, SKI would like to emphasise that stringent demands must be made both with respect to safeguards and the physical protection of such material.

In SKI's view, it is very important that these aspects should be taken into account at an early stage of the process, since experience has shown that it is very expensive to redesign facilities once they have been built.

SKI's conclusion is that SKB must describe how it intends to organise any research and investigations on how safeguards and physical protection are to be arranged at these new types of facilities. In the case of the encapsulation plant, the results must be presented in connection with the submission of a licence for construction permission.

Encapsulation

In SKI's view, SKB's work on encapsulation is largely being conducted in a suitable manner. However, in SKI's view, SKB should, to a greater extent than before, identify the critical issues in order to obtain adequate data for the application to construct the encapsulation plant.

SKI views the ongoing work with the design basis for the repository, and the acceptance criteria for the canister, as very important. In SKI's opinion, any delays arising in this work can delay other parts of the canister work because this work should determine many activities and because it may have to be revised after the consequence analyses that must be conducted in order to show that the design basis and acceptance criteria are adequate.

SKI agrees that there are both advantages and disadvantages of using a thinner-walled (30 mm) copper tube than the reference alternative (50 mm). SKI is positive to SKB's overall approach to the work on manufacturing methods and materials strength calculations for the cast iron insert. However, in SKI's view, SKB must ensure that adequate time has been set aside for this.

SKI recommends that SKB should, as soon as possible, compile into a single document, results and experience obtained from the work on non-destructive testing. Furthermore, in

SKI's view, there is a risk that SKB will underestimate the time needed to develop and qualify methods for non-destructive testing.

In summary, SKI would like to emphasise that a critical issue for the technical feasibility of constructing KBS-3 is that there should be methods for the sealing and control of canisters that are suitable in connection with series manufacturing. This means that an adequately large number of full-size canisters must be manufactured, sealed and controlled and these should be found to comply with the requirements of the long-term performance assessment.

Alternative Methods

The review of RD&D Programme 2001 primarily concerns whether the proposed programme is adequate to be able to meet the requirements on alternative reporting in connection with the licensing of the encapsulation plant and repository for spent nuclear fuel.

In SKI's view, the work currently being conducted on separation and transmutation is enough to follow and contribute, in a meaningful manner, to international development. However, in view of the current level of work in this area, this work should not be reduced. The work is also important for the maintenance and further development of national expertise which is required for the safe disposal of nuclear waste.

In its statement of opinion, SSI stated that SKB should prepare a safety assessment for the deep borehole alternative and that this could be conducted using existing data. In SKI's view, such a safety assessment would not be a comprehensive safety assessment in the sense that the term is used for repositories based on the KBS-3 method. Under such circumstances, SKI can support the idea of a safety assessment as a step in a broader discussion of different alternatives. In SKI's view, the need for and scope of a safety assessment for deep boreholes, should be discussed within the framework of the consultation process between SKB and the authorities that the Government decided on in 1996 and 2001.

Decommissioning

In SKI's opinion, SKB is handling the issue of the decommissioning and dismantling of nuclear power plants in an ambitious manner. This is also reflected in SKB's RD&D Programme 2001.

SKB's view that nuclear power reactors in Sweden (apart from Barsebäck 1) should be operated for 40 years before they are decommissioned and dismantled as quickly as possible, is acceptable from a purely technical standpoint. However, since there are significant uncertainties associated with the financial and political variables, it is reasonable to request that it should be possible for all types of decommissioning waste to be placed in interim storage or should be disposed of already from 2015.

Furthermore, SKI shares SSI's view that, the RD&D reports should more clearly state that it is the nuclear facilities, in their capacity of licensees (under the Act on Nuclear Activities) and waste producers, which have the overall responsibility for the dismantling of the facilities as

well as for the management of the decommissioning waste. The licensees can only transfer this responsibility to a limited extent to SKB.

Other Long-lived Waste

In SKI's opinion, RD&D Programme 2001 lacks an overall account of issues concerning the design basis requirements that must be made with respect to the repository from the perspective of long-term safety. Furthermore, SKB should describe the requirements that must be made on a possible candidate site in order for it to comply with the requirements that are being made on the proposed design of SFL 3-5.

In SKI's opinion, it is positive that SKB will follow up the uncertainties that can exist in the radionuclide concentration of the waste and quantity. SKI agrees with SSI that SKB should prepare guidelines for the characterisation and treatment of the waste.

In order to evaluate the long-term stability of the concrete in its preliminary safety assessment, SKB has used data from old (90-year old) concrete in water and models of concrete leaching. In SKI's view, SKB should state whether the processes that determine this leaching, in the short term, can also apply thousands of years in the future. The impact of saline groundwater on the long-term properties of the concrete should be investigated.

SKB assumes that the concrete structure may have a number of cracks from the start and does not consider that this has a negative effect on long-term safety. In SKI's opinion, SKB should conduct an analysis that shows the size and the number of cracks that can be allowed in different time-perspectives without a substantial deterioration in the capability of the concrete to protect against radionuclide leaching.

1 Introduction

1.1 Background to the Programme

According to the Act on Nuclear Activities, the holder of a licence to operate a nuclear reactor must adopt all necessary measures to manage and dispose of spent nuclear fuel and nuclear waste. The Act stipulates requirements on a research programme which is to be submitted to the competent regulatory authority once every three years. The Swedish Nuclear Power Inspectorate (SKI) is the competent authority that evaluates and reviews the programme. SKI distributes the programme to a wide circle of reviewing bodies for comment, including authorities, municipalities, universities and NGOs.

The Swedish programme for final disposal of spent nuclear fuel started about 25 years ago. According to the Swedish Nuclear Waste Management Co. (SKB), the planned repository will not be closed until sometime in the 2050's. A series of decisions must be made before this goal is attained. The decision process can therefore be described as a multi-stage process. During each stages, safety will be evaluated and there is a possibility of taking additional time for development work or of selecting improved solutions. SKI's task is to ensure safety compliance throughout all of these stages.

In its decision in January 2000, the Government explained that the Programme for Research, Development and Demonstration for the Treatment and Final Disposal of Nuclear Waste (RD&D Programme 98) complied with legislative requirements but that certain supplementary reporting should be conducted by SKB and submitted no later than when the next programme, in accordance with 12 § of the Act on Nuclear Activities, was prepared (September 2001).

The supplementary reporting requested by the Government, and which was submitted by SKB to SKI in December 2000, dealt with issues relating to method selection, site selection and the site investigation programme. SKI submitted its review of the supplement to the Government in June 2001 and the Government made a decision on the matter on November 1, 2001. The decision meant that SKB received support to start site investigations in the municipalities of Oskarshamn, Tierp and Östhammar. The Government emphasized, with reference to a previous government decision, that SKB must consult with SKI and SSI before starting site investigations as well as while site investigations are in progress.

1.2 Conduct of this Regulatory Action

RD&D Programme 2001, which is the sixth complete programme presented since 1986, has a clear focus and concentration on issues relating to scientific research and technology development. SKB plans to report on issues concerning the siting of an encapsulation plant and repository in connection with licence applications and associated environmental impact statements.

SKI has conducted the review of SKB's RD&D Programme 2001 in the same way as with SKI's previous reviews of RD& D programmes. SKI has distributed the programme to sixty reviewing bodies for comment (authorities, municipalities, universities, NGOs etc.). Review statements were received from thirty-six of these, of which five refrained from stating their

opinion on the programme. Some of the statements focused on issues relating to the breadth of the programme and the lack of non-technical and non-scientific research reporting. A significant number of reviewing bodies expressed views on the canister and encapsulation, the geosphere and biosphere, climate evolution, methods for site investigation, transportation, alternative methods and other long-lived waste. A small number of reviewing bodies presented opinions on the direction of future RD&D programmes, on the decision-making process, system analysis and safety assessment, the buffer, the Äspö Hard Rock Laboratory, natural analogues and the decommissioning of nuclear facilities.

In February, SKI's Board was informed of the content of the review statements received and of SKI's preliminary views on SKB's programme. SKI's review statement to the Government and accompanying review report has been submitted to and evaluated by SKI's Board in March.

At the beginning of each chapter in its review report, SKI indicates which parts of SKB's programme are being evaluated. Several chapters contain the following headings: "SKB's Report", Comments by the Reviewing Bodies" and "SKI's Evaluation". Some chapters are also entitled, "SKI's Overall Evaluation".

The following documents: a) "SKI's Review Statement on SKB's RD&D Programme 2001 – the Swedish Nuclear Fuel and Waste Management Co's Programme for the Research, Development and Demonstration of Methods for the Management and Disposal of Nuclear Waste" and b) the accompanying Review Report, "The Swedish Nuclear Power Inspectorate´s Evaluation of the Swedish Nuclear Fuel and Waste Management Co´s RD&D Programme 2001" (SKI Report 02:33) have been compiled into a single volume. In addition, the complete set of review statements has been submitted to the Government as well as a summary (SKI-PM 02:02, in Swedish) containing the review statements referred to in the Review Report.

2 Overall Opinion of SKB's Programme

2.1 Introduction

In this chapter, SKI presents its opinion on the layout and content of the present and planned RD&D programmes. SKI also states its opinion on certain issues that SKI has previously observed and that SKB has chosen not to include in this programme, such as issues relating to the decision-making process, system analysis and the need for a strategy document.

In RD&D Programme 2001 (SKB, 2001a), SKB has focused on research and technology development, referring to the fact that the latest report – RD&D Programme 98 Supplement – focused on method, site selection and on the site investigation programme. The entire report is, unlike previous RD&D programmes, presented in a single volume, without any reference to background reports. On the other hand, each chapter in the report includes a substantial list of references.

RD&D Programme 2001 has been structured differently, compared to previous programmes. SKB's starting point is the regulatory requirements on long-term safety and links these to the development of the safety assessment methodology, research on the long-term processes in the repository and the repository environment.

With the aim of making the text more accessible to readers and reviewers, SKB starts each chapter with background information on each research area. Each chapter presents the regulatory opinion that was stated in connection with the review of the SR 97 safety report and RD&D Programme 98. Finally, new knowledge that has been acquired since the latest reviews were conducted as well as planned research are presented.

In RD&D Programme 2001, SKB did not have time to act upon the review comments in SKI's review report and review statement on the RD&D Programme 98 Supplement (SKI, 2001a), which was submitted to the Government in June 2001. However, SKB has stated that it aims to act upon the comments in its continued work on the site investigation programmes.

SKB proposes that forthcoming RD&D programmes should focus on different parts of the activities that SKB, in accordance with the proposed timetable, intends to conduct. This means that SKB intends to *focus* the next five RD&D programmes: 2004, 2007, 2010, 2013 and 2016 on encapsulation technology – the choice of sealing method, deep repository technology, the ultimate choice of deposition method, operation of the KBS-3 system and planning and evaluation.

2.2 Report Structure and Content

Comments by the Reviewing Bodies

Several of the reviewing bodies, with the exception of a few NGOs and opinion groups, particularly the Waste Network and the Waste Network Association, consider that the report is easy to read, well-written, pedagogically and methodologically structured with a suitable layout. Nevertheless, several reviewing bodies point out that the report is solely focused on scientific research and technology development.

In the Waste Network's view, many parts of SKB's report are unreadable and incomprehensible for anyone apart from very highly educated specialists and this makes it difficult to review.

The Waste Network Association considers that the structure of the report is particularly deficient in pedagogical terms and difficult to read, that it requires a high level of expertise and that the reader, at the same time, has access to a number of other reports.

The feasibility study municipalities do not consider the report to be complete since, in their opinion, social science research and social and ethical aspects are missing.

The Royal Institute of Technology (KTH) maintains that the social aspects of risk management have not been dealt with and that transmutation has been given a cursory treatment. Uppsala University and Chalmers Institute of Technology (CTH) also share this view.

The Swedish University of Agricultural Sciences (SLU) believes that there is an obvious risk for experimental radioecology in Sweden declining due to a lack of resources, or disappearing altogether. In order to rectify this situation, SLU suggests that SKB should support a few research groups within the area of experimental radioecology. SSI has also expressed reservations concerning the future of radioecological research.

Uppsala University considers that a holistic perspective is missing from SKB's programme proposal and would like to see a long-term focus in the planning concerning the future availability of expertise and information needs. Furthermore, the University considers that the programme lacks an international outlook that provides a global perspective on technical as well as society-related developments.

The Science Council considers that, bearing in mind that RD&D Programme 2001 is one of a series of research programmes where each programme is based on previous experience, it is reasonable for RD&D Programme 2001 to be designed in the way that it is. Furthermore, the Council considers that SKB has largely taken into consideration the comments that have emerged from the review of RD&D Programme 98 and SR 97. Where SKB has not done so, it has clearly stated why.

The Swedish Agency for Civil Emergency Planning (ÖCB) maintains that, in order to maintain all acquired knowledge and to provide new knowledge, a sustainable supply of competent personnel is required.

SKI's Evaluation

In SKI's opinion, RD&D Programme 2001 is well-structured and considerably facilitates the work of the reviewer. In particular, the reviewer does not have to refer extensively to previous review documents in order to ensure that SKB has dealt with the comments that have been presented. However, in SKI's view, in future RD&D programmes, SKB should provide an even better description of how SKB has dealt with the regulatory authorities' comments. SKB should more clearly describe which issues are still outstanding and which issues have been sufficiently investigated and therefore can, at least temporarily, be excluded from the review process.

SKI understands that SKB in RD&D Programme 2001 has chosen to focus on research and technological development, with reference to the scope of RD&D Programme 98 and RD&D Programme 98 Supplement which focused on method, site selection and the site investigation programme. At the same time, SKI can partly understand the reviewing bodies which, referring to the requirements on a comprehensive research programme stipulated in the Act on Nuclear Activities, have expressed criticism of the limited breadth of the programme.

2.3 Direction of Future RD&D Programmes

Comments by the Reviewing Bodies

The Swedish Radiation Protection Institute (SSI) proposes that the Government should stipulate that, as a condition for SKB's further research and development programme, SKB should, no later than in connection with the submission of RD&D Programme 2004, describe the programme results that must be attained prior to the forthcoming stages of the disposal of spent nuclear fuel and other long-lived waste. This report should describe the knowledge that is necessary for the decisive issues for long-term safety and radiation protection, when this knowledge must be acquired and how it is to be acquired.

Furthermore, in SSI's opinion, the method report planned by SKB for safety assessment should be provided in the form of a background report to RD&D Programme 2004 and SKB should allow an international peer review to be conducted of the method report (see Section 3.1).

Other reviewing bodies, and in particular the County Administrative Board, Uppsala, state that further research and development work should be conducted taking into account the requirements of the Environmental Code with respect to alternative reporting for the evaluation of alternative sites and alternative facility designs in connection with subsequent licensing.

The County Administrative Board also considers that future RD&D programmes should aim at providing a complete view of the current state of knowledge, nationally and internationally, both with respect to technical/scientific issues and social issues that are of importance prior to and during the establishment of facilities for the final disposal of spent nuclear waste.

Umeå University states that SKB's report does not, in any respect deal with the cost-related aspects of the activity.

SKI's Evaluation

SKI understands that SKB wishes to focus future RD&D programmes on the information needed so that a licence application can be submitted in 2005 for permission for the siting and construction of the encapsulation plant in 2007 and an application for a licence in 2007 for permission to site and start the construction of the repository in 2009 (start detailed characterization). SKI shares SSI's view that it is important that SKB, in RD&D Programme 2004, should describe the level of knowledge for both natural and engineered barriers, since knowledge is the basis of the licence applications and, thereby, also the basis of the regulatory review of long-term safety and radiation protection.

However, SKI emphasizes that an in-depth account of knowledge should not lead to the neglect of the legislative requirements on the comprehensiveness and completeness of the RD&D programmes. SKI proposes that SKB should keep the basic structure established in and with RD&D Programme 2001, but that topical issues should be reported in greater depth.

One issue which is raised in different contexts in SKI's contact with the public and NGOs concerns the extent to which special research work is needed, bearing in mind a repository's inventory of chemitoxic substances, particularly heavy metals (SKI dnr 5.8-001293). An evaluation of this issue is outside the scope of SKI's authority. SKI assumes that SKB is taking the necessary contact with the competent authorities in that area to decide whether initiating any specific research within the area of the chemitoxicity of nuclear waste is warranted.

Since a number of reviewing bodies request a social scientific (ethical, moral, social) perspective on the repository programme, SKI considers that SKB in its future programmes should also include these issues.

SKI shares the opinion of Uppsala University, the Swedish University of Agricultural Sciences, SSI and the Swedish Agency for Civil Emergency Planning that the maintenance of available expertise and the future supply of expertise is a very important issue for the industry as well as the authorities and research community. In order to maintain and achieve a high level of safety in existing and planned nuclear facilities, it is necessary that competent personnel should be available over the next fifty years until the time that the nuclear waste repository is closed. Therefore, it is desirable that SKB, in its next RD&D programme, should present its view on the future supply of expertise in the nuclear waste management area.

In its decision on SKB's supplement to RD&D Programme 98 from November 2001, the Government has stated that SKB, in consultation with SKI and SSI, should reach a decision regarding how and when future safety assessments and system analyses should be reported. In the light of this, SKI does not share SSI's view that specific safety reports, already at this stage, must be linked to RD&D Programme 2004. Instead, the time of reporting should be established when the consultation has been conducted. On the other hand, SKI shares SSI's opinion that SKB should allow an international peer review to be conducted of the safety assessment that is planned for 2004.

2.4 SKB's Time-table

SKI's Evaluation

The two most important deadlines that SKB specifies in RD&D Programme 2001 (Figure 1-3 in RD&D Programme 2001) are the submission of an application in 2005 for permission to start the construction of an encapsulation plant in 2007 as well as in 2007, to submit an application for permission to start the construction of the repository in 2009. In both cases, SKB assumes that the review and licensing will take about two years. In other contexts (SKB 2001b), SKB has presented a time-schedule for the publication of future safety assessments, where the first complete safety assessment after SR 97 is planned to be completed during 2004 (see also Section 3.1). The purpose of this safety assessment, which will be based on generic data, is to demonstrate the development of safety assessment methodology.

Safety assessments will also be attached to the application for permission to construct the encapsulation plant and the application for permission to construct the repository.

The site investigations which are planned to be started in the current year will be divided into two phases with initial site investigations that will take about 2 years and the subsequent phase of full site investigations, which will take about 3 years. According to the plans, the site investigations will be completed when the licence to construct the repository is submitted (2007).

In SKI's opinion, SKB's timetables leave very little scope for delays and other contingencies. The quality requirements on individual activities must not be affected by a tight and inflexible timetable. A significant degree of flexibility must be incorporated into the scheduling. SKI particularly emphasizes the following aspects of SKB's timetable:

- The time required to make adequate progress in the development work on the canister probably means that 2005 is too early a deadline for the submission of an application for permission to start construction of the encapsulation plant in 2007. In particular, SKI has noticed the scope of the remaining work on insert manufacturing (specification, trial manufacturing, consequence calculations etc.), and the development of methods for non-destructive testing, including qualification procedures for these (see also Section 4.3 and Chapter 11).
- More than one year will most probably be required between the completion of the safety assessment based on generic data in 2004 and the safety assessment which is to be attached in 2005 to the application for permission to start the construction of the encapsulation plant (2007) in order to allow for adequate time for the review and for SKB to deal with the review comments in the safety assessment.
- A period of two years each for the review of applications for permission to construct the encapsulation plant and to construct the repository is an underestimate. This is due to the fact that the Government must make a decision on allowability under Chapter 17 of the Environmental Code and on licensing under the Act on Nuclear Activities. Furthermore, after allowability is evaluated, the Environmental Court must make a decision on licensing under the Environmental Code.
- SKB should ensure that full advantage is taken of the experience from the work on initial site investigations in connection with the planning of full site investigations, which means that adequate time must be planned for the evaluation between the initial and the full phases.

2.5 Decision-making Process and Site Investigations

Comments by the Reviewing Bodies

The Municipality of Oskarshamn and the local safety committee at Oskarshamn nuclear power plant reiterate in similar statements that the disposal programme must have come so far that a licence for detailed characterization has been handled by the authorities and the Government before the municipality makes its decision (in accordance with Chapter 17 of the Environmental Code) regarding an encapsulation plant. The Municipality also states that the links between encapsulation, the transportation system and the repository must be investigated in detail and must be very clear with respect to when the decision should be made for the different parts and what information is required. The municipality also wishes to have an

explanation of the role of the RD&D programmes versus the consultation process in connection with Environmental Impact Assessment (EIA) which aims at achieving a consistent and transparent decision-making process.

The County Administrative Board, Kalmar also reiterates in its statement that SKB must clarify the temporal links between the different components, namely the repository and encapsulation plant, in a repository system and that SKB should, clearly and as soon as possible, specify when decisions are to be made regarding the different components and the relationships between these.

In its review statement to SKI, SSI proposes that SKB should present an annual report of all ongoing EIA consultations, with the aim of reconciling the EIA work between SKB, the authorities and other parties.

In SSI's view, it is also important for the Government to provide a timetable and to set conditions for SKB's programme for the management of other long-lived waste.

SKI's Evaluation

During the site investigation phase that includes initial and full site investigations for a time-period of at least 5-6 years, several consultation and decision processes will occur. In addition to the regular three-year RD&D programmes, an extensive EIA consultation will be conducted between the parties involved. Furthermore, according to government decisions from 1996 and 2001, SKB must consult with the authorities prior to and during the site investigations and, in addition to this, consultations must be conducted concerning the reporting of future system and safety assessments.

SKI notes that SKB intends to deal with all issues connected to the siting process during the EIA and does not intend to report on these issues in future RD&D programmes. SKI assumes that SKB will clarify what it means by *all issues relating to the siting process* in the EIA process planning that SKB intends to present during the year. SKI also shares the view of Oskarshamn Municipality and SSI that SKB must clarify the role of the RD&D programmes versus the EIA consultation in order to achieve a consistent and structured decision-making process.

In SKI's view, it is necessary for the EIA consultations to be documented by SKB in a transparent and traceable manner. SSI's proposal involving annual reports is one way of contributing to this. However, the consultations affect several parties, not only SSI and SKI. Therefore, in SKI's opinion, the question of documentation and reporting should be dealt with within the framework of the consultations and should not be determined already at this stage.

SKI shares the opinion of the Municipality of Oskarshamn, the local safety committee at Oskarshamn Nuclear Power Plant and the County Administrative Board, Kalmar that the link between the encapsulation plant and disposal is important. In SKI's opinion (SKI, 1996 and SKI, 2001a), a prerequisite for permission to construct an encapsulation plant is that a safety assessment for disposal should also be included in the licence application. Furthermore, in SKI's view, a repository should be approved by the authorities before SKB starts the encapsulation of spent nuclear fuel. This means that detailed characterizations must be conducted and that SKB must have received permission to start disposal in the repository. In SKI's opinion, during the consultations that are to result in Environmental Impact Statements

(EIS) for the repository and the encapsulation plant, SKB should clarify the co-ordination between the applications for both facilities.

In the RD&D programme, SKB states that, after the application for permission to construct the repository for spent nuclear fuel has been submitted, it intends to submit a safety assessment for other long-lived waste in the year 2009. Based on SKB's plan, SKI's view is that this is reasonable. However, SKB is recommended to initiate the research that must be conducted before 2009.

However, in SKI's view, in future RD&D programmes, SKB should clarify how and where the long-lived waste will be managed and placed in interim storage pending disposal which, according to SKB's plan, will be conducted in about 30 years. At the same time, SKI asserts that the authorities have ample opportunity to make demands on the waste producers also with respect to the management of long-lived waste.

Some reviewing bodies consider that the issue of responsibility for a repository after closure is unclear and must be clarified. This viewpoint has also been expressed to SKI in several other contexts, for example in the public meetings that SKI and SSI jointly conducted as a stage in the review of SKB's RD&D Programme 98 Supplement.

SKI provides a description of the basic principles for the management of spent nuclear fuel and nuclear waste that the Riksdag (Swedish parliament) has supported on various occasions.

The Riksdag has supported four basic principles for the management of spent nuclear fuel and nuclear waste (bill 1980/81:90, Appendix 1, p. 319, bill 1983/84:60, p. 38, bill 1997/98:145, p. 381, bill 1992/93:98, p. 29 as well as the final reports of the Standing Committee on Industry and Trade, 1988/89:NU31 and 1989/90:NU24):

1. The expenses for the disposal of spent nuclear fuel and nuclear waste are to be covered by fees on the production of energy that has resulted in these expenses.

2. The reactor owners are to safely dispose of spent nuclear fuel and nuclear waste.

3. The state has the ultimate responsibility for spent nuclear fuel and nuclear waste. The long-term responsibility for the handling and disposal of spent nuclear fuel and nuclear waste should rest with the state. After a repository has been closed, a requirement should be established to ensure that some kind of responsibility for and supervision of the repository can be made and maintained for a considerable time. A government authority could assume responsibility for a closed repository.

4. Each country is to be responsible for the spent nuclear fuel and nuclear waste generated in that country. The disposal of spent nuclear fuel and nuclear waste from nuclear activities in another country may not occur in Sweden other than in an exceptional case.

These are the basic principles for the structure of the Act (1984:3) on Nuclear Activities. They are also contained in the Act (1992:1537) on the Financing of Future Expenses for Spent Nuclear Fuel etc. (Financing Act). The first principle has been wholly incorporated into the Financing Act. The second principle has been regulated in 10-12 §§ of the Act on Nuclear Activities. The fourth principle is embodied in 5 a § second paragraph of the Act on Nuclear Activities.

With respect to the third principle, that the state should bear the long-term responsibility, the Government has stated that it is quite natural for the state to bear the ultimate responsibility for ensuring that the activity, as it is regulated in the Act on Nuclear Activities, is conducted in a long-term perspective. Therefore, according to the Government, regulating this issue in the Act on Nuclear Activities would not fulfill any real purpose (bill 1997/98:145, p. 381 fourth paragraph).

2.6 System Analysis

Comments by the Reviewing Bodies

In its statement to SKI, the Royal Institute of Technology (KTH) states that an overall system analysis is lacking in RD&D Programme 2001.

In its statement, SSI recalls SKB's reporting on system analyses in connection with RD&D Programme 98 and RD&D Programme 98 Supplement as well as the regulatory authorities' review of these analyses. In Section 1.3.2 in the RD&D programme, SKB presents its plans for future system analyses of the encapsulation plant and repository. SKB states that these analyses, together with the safety assessments, will be the basis for the applications for permission to construct these facilities.

In its statement, SSI states that SKB's forthcoming system analysis for the encapsulation plant is not adequate and that it must cover all parts of the waste management system. According to SSI, the justification for this is that only such a complete system analysis will make it possible to describe links between the design of the different facilities and siting. Only with such an analysis can it be ascertained that the commitments that are made, as a direct consequence of constructing the encapsulation plant are acceptable.

The Municipality of Oskarshamn also expresses in its statement that the system analysis should encompass the whole system rather than describe individual parts of the system.

SKI's Evaluation

SKI's position on system analysis as a tool for reporting plans prior to the disposal of nuclear waste is founded on the development work that SKI and SSI conducted together prior to the review of RD&D Programme 98 (SKI dnr 5.8-971083, SSI dnr 6220/1994/97, from March 5, 1998). The result of this work then formed the basis of the consultation with regulatory authorities on system analysis that SKB was required to conduct in accordance with the government decision of 1996.

In SKI's opinion, system analyses have two functions: to justify, in a logical and structured manner, solutions chosen in the form of combinations of components in a system and to ensure that all essential links between the parts of a chosen system have been examined from various standpoints such as safety, radiation protection, accessibility and society. Furthermore, system analysis methodology can be applied at different levels in the development of a system. At the highest, overall level, the system analysis is used for method selection. On the next level, the system analysis should be used to optimize and justify sub-

solutions within a given system comprising different facilities. At an even lower level, the system analysis can be used to select and justify sub-solutions within a given system.

Furthermore, in SKI's view, in the case of a waste management programme that does not extend over a number of years, like a normal industrial project, but over decades, it is necessary to update system analyses for different purposes and for different levels, as described above. The main reason for this is that updates are needed to manage any new knowledge and experience that have been acquired during the long period of time in which the development work occurs. SKI and SSI submitted this opinion on the need for new system analyses in their joint report from 1999 (SKI, 1999).

Consequently, SKB's future system reports are a complex issue. The regulatory authorities and SKB must agree on when such reports should be conducted, which level they aim at and what they should contain.

In its review on RD&D Programme 2001, SSI focused on the need for a system analysis in connection with the application for permission to construct the encapsulation plant and which, according to SSI, should focus on links in the handling system. SKI agrees with SSI that SKB's first planned system analysis must encompass the entire system and not only the encapsulationplant, which is the impression gained from SKB's plans as presented in Section 1.3.2 of RD&D Programme 2001. In SKI's opinion, this, together with safety assessments and the obligatory EIS, will provide an adequate basis for decision-making when licensing this facility.

It is reasonable that a complete update of the system analysis should be conducted as a basis for the licensing of the construction of an encapsulation plant. In SKI's opinion, which was expressed in connection with the review of RD&D Programme 98, the system analysis must be updated at all levels and, above all, prior to the final method and site selection which the evaluation of the application for permission to conduct detailed characterizations involves. Such an approach is also entirely in line with the views on the decision-making process put forward by the Municipality of Oskarshamn and the local safety committees at Oskarshamn nuclear power plant.

SKI does not want to commit itself, at this stage, to a definite opinion with respect to issues relating to deadlines, scope and focus of future system analyses except to state that these analyses must be included in the basis for decision-making for the planned facilities. These issues will be dealt with in the dialogue that SKI considers is necessary to conduct with SKB regarding the design of a strategy document, see next section (2.7).

2.7 Strategy Documents

Comments by the Reviewing Bodies

SSI expresses the need for various strategy documents for SKB's programme in its statement. According to SSI, in such a document, SKB should clarify the results that should be achieved prior to the successive stages of the disposal programme. This would clarify the links between the different parts of the disposal programme and make it easier to judge whether the RD&D activities are suitable and adequate. According to SSI, examples of issues that should be treated in a strategy document are:

- requirements on the engineered barriers in the successive stages of the programme
- purpose and objective of future system and safety reports, including the data and modeling tools necessary
- objectives of ongoing and planned long-term research
- report on when critical research results and models must be prepared.

In SSI's opinion, SKB should prepare and submit a strategy document for the management of spent nuclear fuel no later than by 2004. SSI also considers that SKB should prepare a strategy document for the disposal of other long-lived waste.

In SSI's view, it is important for the Government to specify a timetable and conditions for SKB's programme for the management of other long-lived waste.

Some of the other reviewing bodies indirectly broach the issue of a strategy document. Above all, plans for the content of future reports and analyses within the framework of the EIA are requested. The County Administrative Board, Kalmar states, for example, the importance of clarifying the temporal links between the different components in a disposal system and of ensuring that SKB clearly states when decisions must be made for the different parts.

SKI's Evaluation

In 2002, SKI is planning to conduct a dialogue with SKB regarding the preparation of one or several strategy documents for SKB's programme and is planning to prepare review plans that are based on these documents. This work, which is expected to be conducted in dialogue with SSI, has been described in general terms in SKI's letter to SKB, SSI, KASAM and the Ministry of the Environment, dated February 13, 2002 (dnr. 5.8-020195).

The idea of a "strategy document" was originally raised by the OECD/NEA International Peer Review Team for SR 97 (SKI, 2000) and in connection with SKI and SSI's joint review of SR 97 (SKI, 2001b). The Review Team focused on the need to identify critical safety factors for the repository, the safety philosophy and, above all, how this has developed over time. The Team also considered that such a document could be used to describe the relationship between different parts of the disposal system. SKB's view on the different purposes to be served by the safety assessment should also be presented.

However, several of these ideas concerning the content of a strategy document were already dealt with, especially in the authorities' development of the system analysis and system report approach (SKI dnr 5.8-971083, SSI dnr 6220/1994/97, from March 5, 1998, SKI, 1999). This also applies, in a way, to the historical retrospective that, in a broader perspective, was reported by SKB (for example, Kjellman, 2000).

The need for a planning instrument or strategy document, partially similar to that advocated by the OECD/NEA, has become more salient now that SKB's programme has entered a more intensive phase. It is not sufficient for SKB's plans to only be reported in connection with the RD&D programmes, which have so far been fairly vague with respect to the description of the content of different reports and links between different activities. Within a year or two, the authorities will need a clear idea of which regulatory reviews are expected to be conducted over the next 10 years and of inherent dependencies between these reviews. Above all, this is

necessary for the authorities to be able to plan their work and to, in other contexts, describe how SKB is to attain the goal of a safe disposal of nuclear waste.

Examples of issues that, in SKI's opinion, should be treated as a living document, are presented below. SKI intends to discuss these with SKB and SSI as well as also solicit the viewpoints of other stakeholders.

Safety Philosophy
SKB should define the fundamental arguments for the safety of the disposal system, the barriers and barrier functions that the repository will depend on and should describe how and with what arguments safety will be shown to comply with the regulatory requirements. This has partly been achieved in connection with the SR 97 safety report and in SKB's various RD&D programmes. However, a coherent report of the principles that apply to the future work prior to the licensing of planned facilities is still lacking. A particularly important issue is how different safety/barrier functions are valued and how they, together, contribute to long-term safety.

Timetable for Future Reports
SKB needs to continually update a realistic timetable for its future reports (method reports, performance assessments, preliminary safety assessments) and safety assessment prior to the licensing of the encapsulation plant and repository etc. SKB also needs to state in which context different system analyses will be reported.

Content of Future Reports
SKB needs to specify the content, such as scope and limitations, of the intended safety assessments, safety reports and system analyses, including the reporting of alternatives.

Plan for Following Up Safety Requirements
SKB needs to describe how safety assessments and knowledge of different components in the systems are used to derive design basis criteria, technical requirements on barriers and how control methods and quality assurance are applied to show that the requirements are met. The occasions on which compliance with the various requirements must be shown should be specified. Such a plan partly agrees with the requirements on strategy documents presented in SSI's statement on RD&D Programme 2001. However, in SKI's opinion, the detailed follow-up and planning of concrete research, development and demonstration projects should preferably be conducted within the framework of the already established procedure of RD&D programmes every three years.

Terminology
A further purpose of the strategy document is that SKB and the authorities should prepare a co-ordinated terminology. The need for such a consistent terminology has been expressed in several different contexts in recent years. Examples of terms that need to be defined in this way are: performance requirements, technical criteria, barrier function/performance, safety requirements and safety function/performance.

Design of a Repository and Engineered Barriers
SKB needs to present a timetable for necessary strategic choices related to the design of engineered barriers and the realization of the repository concept. If this type of strategic choice is not conducted in accordance with a plan prepared in advance there will be an

evident risk that the research on long-term safety and the safety assessment development will not be consistent and optimally adapted to the method that will ultimately be adopted.

In SKI's opinion, the strategy document for conducting the disposal programme should be considered to be a living document which is to be constantly updated as progress is made and when necessary without being linked to specific reporting deadlines such as RD&D programmes.

3 Safety Assessment

In this chapter, SKI evaluates SKB's account of safety assessment which corresponds to Chapter 2 of RD&D Programme 2001.

3.1 SKB's Development Programme for Safety Assessment

SKB's Report

One of the main aims of SKB's activities is to ensure that the long-term safety in connection with the disposal of spent nuclear fuel and other nuclear waste can be shown to comply with regulatory requirements. The safety assessment is the tool for achieving this. The two most important planned deadlines for the assessment of the conditions for long-term safety are in connection with the submission of an application for permission to construct the encapsulation plant as well as the application to construct the repository for spent nuclear fuel (SFL 2). Furthermore, safety assessments are necessary for the evaluation of the following disposal facilities: the existing SFR (operational waste), the planned SFL 3-5 (long-lived low and medium-level waste) and an expansion of the SFR for decommissioning waste (SFR 3). The following approximate timetable for SKB's safety work is anticipated as reported by SKB in different contexts (SKB 2001a, SKB 2001b):

- Method report, safety assessment (2002)
- Safety assessment based on generic data (2004)
- Preliminary safety evaluations from site investigations (2004)
- Safety assessment focusing on canister function (appended to the application for permission to construct the encapsulation plant; 2005)
- Safety assessment based on site-specific data (appended to the application for permission to construct the repository; 2007)
- Safety assessment for SFL 3-5 based on data for site investigations for SFL 2 (2009).

An updated process report, describing the scientific basis of the assessment, is to be appended to each new safety assessment.

SKB intends to use the method report (2002) as a starting point to document and to obtain a response to a safety assessment methodology developed on the basis of SR 97 (SKB, 1999a). The results from the method report will then be the basis for the safety assessment based on generic data (2004).According to SKB, on this occasion, data from the ongoing site investigations cannot provide a basis for a safety assessment and, therefore, generic data will be used instead. However, the results that are available will be evaluated within the framework of preliminary safety evaluations (2004), which will provide a basis for judging whether each of the sites for initial site investigations qualifies for a full site investigation. The safety assessment that is appended to the application for permission to construct the encapsulation plant (2005) will also use generic data but is different in so far as it focuses specifically on the performance of the canister in the disposal system.

SKB is considering subjecting the method report to an international peer review.

Comments by the Reviewing Bodies

SOS-Tierp considers that SKB must present a new risk assessment, in the light of the deficient handling of certain factors of importance to safety in SR 97 (the depth of the permafrost, underestimated seismic frequencies, lack of scenario combinations, colloid transport, intrusion etc.).

In SSI's view, SKB should reinforce the role of the safety assessment for the integration of different parts of the programme, but notes that the description in RD&D Programme 2001 is too meagre for a judgement to made as to whether or not this will be fulfilled. Therefore, SSI proposes that this issue should be treated in a separate strategy document (see Section 2.7).

Furthermore, SSI considers that SKB's method report should be subjected to a formal regulatory review and an international expert review. The formal regulatory review should be linked to RD&D Programme 2004. According to SSI, SKB should, at an early stage, specify the scope of the preliminary safety assessments.

SSI indicates the importance of ensuring that the safety assessment, upon which the application for permission to construct the encapsulation plant will be based, takes into account new findings and data which have emerged in connection with the fabrication of copper canisters, buffer and backfill.

SKI's Evaluation

SKI agrees with SSI and SKB that it would be valuable to arrange a detailed international peer review of SKB's capacity within the safety assessment area before the application for permission to construct the repository is submitted and before the application for permission to construct the encapsulation plant is submitted. In SKI's opinion, the safety assessment based on generic data (2004) should be the object of an international peer review. This review could be conducted with the same level of ambition as the international peer review of SR 97 (OECD/NEA, 2000). SKI assumes that SKB's timetable will allow viewpoints from an international peer review and from SKI and SSI to be dealt with before SKB goes on to submit an application for permission to construct the encapsulation plant (see also 2.4). However, in order to ensure a certain flexibility in the scheduling, SKI considers that the publication and review of safety assessment 2004 can be independent of RD&D Programme 2004.

SKI sees a need to ensure that the feedback between safety assessment and the site investigation programme is utilized to the fullest, especially since neither of the two safety assessments that SKB is planning to publish in the next few years (2004 and 2005) will be based on data from the site investigations. In this context, SKI shares SSI's view that SKB should specify the objectives and limitations of the preliminary safety assessments that SKB will conduct after the initial phase of the site investigations. SKB should, in advance, specify the information that is necessary to adopt a position on whether or not a particular site qualifies for a full site investigation. In order to reinforce in the integration between the safety assessment and the full site investigation, a more liberal interpretation of site data is required in order to test and analyze implications of, for example, structural models, hydrological models and geochemical models. SKB should specify what is of direct relevance for the preliminary safety assessments. SKI will follow this up within the framework of SKB's and the authorities' consultation on site investigations, system analysis and safety assessment.

SKI proposes that, at some point before an application for permission to construct the repository is submitted, an updated version of the Process Report (SKB, 1999b) should be reviewed by international experts with a good understanding of the critical scientific disciplines and other nuclear waste programmes. The purpose is for the report to be as broadly established as possible within the research domains of all of the relevant scientific areas. SKI notes that SKB's account in RD&D Programme 2001 and SR 97, with certain exceptions, is to a relatively minor degree based on other work than that financed by SKB itself. SKI is developing an independent programme to evaluate the scientific foundation of SKB's process models within safety assessment. Nevertheless, SKI considers that SKB itself must arrange for an independent review to be conducted.

With respect to the safety assessment upon which the application for permission to construct the encapsulation plant (2005) will be based, SKI shares the view of SSI that SKB should include, compared with SR 97, a considerably improved basis for evaluating the expected quality of copper canisters manufactured on an industrial scale. It is of decisive importance that SKB, at that time, and in a convincing manner, can show that the safety assessment's assumptions regarding canister damage have very good possibility of being realized. The regulatory review of this safety assessment can primarily be expected to focus on the evaluation of quality and design issues for the canister as well as on evaluating how viewpoints from the review of safety assessment 2004 have been dealt with. In order to achieve the former, significant review work by independent experts is required with respect to design, manufacturing, sealing, testing and other canister handling issues as well as modeling and calculations for the purpose of verification.

3.2 Design of the Safety Assessment

SKB's Report

The basic stages in the safety assessment can be summarized as:

- System description, including a description of the initial state of the repository.
- Scenario selection.
- Analysis of selected scenarios.
- Consequence description, including risk assessment.

The system description is provided in a process report which describes the scientific background of all relevant processes, such as THMC diagrams that describe how they affect the disposal system (SKB, 1999a). Within the forthcoming period, SKB intends to investigate whether the THMC diagrams can be developed so that time dependency and scenario development can be described. The documentation of processes will be improved with procedures for expert judgement, internal evaluation and uncertainty description.

With respect to scenarios, SKB is planning an evaluation of different methods to achieve a systematic selection. Certain improvements, compared with SR 97, can be expected, for example, with respect to the integration of seismic calculations with other aspects of long-term safety, site-specific conditions and uncertainties in the initial state.

With respect to the analysis of selected scenarios, in the future, SKB plans to more clearly describe in the process report how all processes are incorporated into different models in the safety assessment. Specific validity documents will be developed for the most important consequence analysis models. SKB's specific report to document the selection of data for the safety assessment, known as the data report, will also be upgraded. In addition, SKB has developed analytical models for radionuclide transport which have been shown to largely reproduce the results obtained from numerical models. The advantage of the analytical models is that probabilistic calculations can be carried out with considerably less calculation capacity. All of the proposed improvements, compared with SR 97, will be specified in the method report that will be published later this year.

In RD&D Programme 2001, SKB presents results regarding certain aspects of risk analysis which can be considered to be a supplement to SR 97. SKB shows, among other things, that the exact shape of a parameter distribution is of minor importance since the results are largely affected by the central value and distribution measure. Certain parameter correlations have also been studied and have been found to have a very limited impact. SKB has also supplemented the uncertainty analyses in SR 97 with rank correlation coefficients.

Comments by the Reviewing Bodies

In the view of the Royal Institute of Technology, Stockholm (KTH), SKB's system description is unsatisfactory and SKB's selection and elimination of scenarios should be more clearly justified. In particular, KTH points to the problem of including unlikely although not improbable scenarios.

The local safety committee at Oskarshamn nuclear power plant considers that the safety assessment must not become too scientific in focus and that such factors as basic considerations behind the choice of scenarios must also be included. The committee emphasizes the importance of ensuring that the safety assessment is formulated in such a way so that it can provide answers to the public's questions.

In SOS-Tierp's view, "risk analysis" should be the general term for the evaluation of the long-term evolution of the repository, rather than "safety assessment", which is the case at present.

SOS-Tierp also considers that expertise in scenario analysis must be broadened so as to apply social scientific and behavioural expertise, particularly in order to develop the intrusion scenarios. Referring to previous regulatory reviews, SOS-Tierp also raises the question of the performance of the buffer and backfill after intrusion. SOS-Tierp also points out that SKB must not develop analytical tools for radionuclide transport at the expense of the further development of the numerical models.

In SSI's view, based on the stated goals of RD&D Programme 2001, is that SKB has taken into account the most important comments from SSI and SKI's joint evaluation of SR 97. The authority is positive to the fact that SKB has started work on making the descriptions of biosphere processes systematic, by using the same method as for engineered and natural barriers. With respect to scenario selection, SSI considers that the link to probability, the weighing up of scenarios and the evaluation of scenario uncertainty are issues that SKB should clarify in the method report (2002).

SSI points out that SKB does not necessarily have to conduct a complete probabilistic assessment. SKB should rather clarify the handling of combined deterministic and probabilistic calculations. Furthermore, in SSI's view, SKB should present an overall strategy for risk analysis, in connection with the next safety report. Particularly urgent issues are formal procedures (expert judgement) for quantifying parameters that are difficult to measure, the use of maximum conditioned risk and average risk as well as alternative safety indicators.

SKI's Evaluation

SKI agrees with SSI that SKB has largely taken heed of the most important viewpoints from the joint regulatory review of SR 97. According to SKI, an important portion of the remaining issues surrounding the safety assessment are related to the quality assurance requirement, which means that SKB should plan and clarify its objectives in this area. SKI expects that SKB's method report will clarify certain issues but judges that the work on improving quality assurance will have to continue until the time that an application for permission to construct the repository is submitted. Examples of quality aspects that SKI will follow up in connection with the review of SKB's safety assessments are:

- That an updated process report should contain scientific material that is as established and complete as possible.
- That the assumptions and modeling tools used in the scenario analysis are consistent with the process report descriptions.
- That the selection of scenarios are based on a systematic handling of events and processes that can affect the repository.
- That the documentation and verification of modeling tools and codes are adequate from the quality assurance standpoint.
- That the content of an updated data report is traceable to empirical results and the documentation from site investigations.
- That expert judgements upon which parameter selection is based, handling of individual processes, selection of conceptual models etc. are documented in as complete a manner as possible.

Another important aspect of quality assurance is the control of the reproducibility of particularly important calculations in safety assessment. Over the next few years, SKI intends to develop and improve the documentation of its own calculation models and codes which will be used as a basis of checking the reproducibility of SKB's results.

SKI's regulations and general recommendations on safety in connection with the disposal of nuclear material and nuclear waste entered into force on April 1, 2002 (SKI, 2002a; SKI, 2002b). These have implications for the characteristics of the barrier system and how these are to be demonstrated. SKI's regulations and general recommendations broach a number of aspects of SKB's safety assessments, such as scenario selection, time-scales, treatment of uncertainty etc., that SKB must take into account.

SKI notes that a number of reviewing bodies raise the issue of how scenarios that involve human intrusion and human actions should be handled in SKB's future safety assessments. In SKI's view, the ambition level for and objective of the analysis of this type of scenario should be discussed in the framework of a dialogue between SSI, SKB and SKI.

SKI is positive to the fact that SKB is planning to prepare validity documents for the most important consequence analysis models. However, in SKI's view, SKB should also carry out an inventory of detailed process models that support consequence analysis calculations and overall conclusions in the safety assessment. In SKI's view, simpler quality assurance documents should also be prepared for other models besides those used for consequence calculations.

SKI is positive, as is SSI, to the fact that SKB has developed and evaluated analytical solutions to equations that describe radionuclide transport. The fact that the results from the analytical solutions are in good agreement with the numerical calculations opens up new possibilities to apply, in a simpler manner, extensive probabilistic calculations. However, SKB's report on safety assessment does not deal with the more difficult and more basic issue of how representative SKB's numerical method of describing radionuclide transport can be considered to be, the impact of abstraction errors in connection with the characterization of the geosphere with a few effective parameters as well as the comparison with transport models which cover more details of the transport path geometry. SKI assumes that SKB will continue to work on these issues within the framework of research projects as well as safety assessments (see also 4.6).

In SKI's opinion, the sensitivity analyses that SKB describes are useful and probably reflect a generally correct view of the critical parameters in the KBS-3 system. However, this does not mean that they do not have to be applied with a great deal of caution, since the sensitivity analyses are affected by the many conceptual simplifications that have been employed. SKI encourages SKB to adopt a minimum common quality standard to all parameters regardless of their sensitivity in this context as well as, if possible, to conduct sensitivity analyses based on more detailed process models in order to obtain a more extensive basis for allocating priorities.

SKI notes that many of the reviewing bodies are interested in following SKB's safety assessment work but are concerned that SKB's report will be difficult to understand and too technically oriented. In SKI's view, at an early stage SKB should develop and then update a transparent and easy-to-read version of the safety report. To be useful, this report should be as consistent as possible with the technically detailed parts and should describe, in detail, the basic problems of demonstrating the long-term safety of the repository.

3.3 SKI's Overall Evaluation of Safety Assessment

With respect to the safety assessment work to be conducted over the next few years, SKI particularly emphasizes the following points:

- SKB's capacity to conduct safety assessments for disposal should be reviewed internationally.
- A plan for the quality assurance of forthcoming safety assessment should be prepared.
- SKB should develop procedures for, and document the use of preliminary safety assessment results to provide feedback for further site investigation work.
- SKB's work on preparing safety assessments should be integrated with the development of engineered barriers and repository design.
- The safety report should be supplemented so that it can not only be read by experts but also by readers without specialist background knowledge.

4 Research on Long-term Safety

In this chapter, SKB presents viewpoints on SKB's overall priorities for research on long-term safety, as reported in Chapter 3 of RD&D Programme 2001. Under the sub-headings of spent fuel, canister, buffer, backfill, geosphere and the Hard Rock Laboratory, SKI evaluates SKB's corresponding chapters – Chapters 4-8 as well as Chapter 12 – of RD&D Programme 2001.

4.1 Introduction

The description of different subject areas in RD&D Programme 2001 largely follows the structure that SKB has already established in the process report. The following parts of the repository system are each described separately:

- Fuel.
- Canister.
- Buffer.
- Backfill.
- Geosphere.

SKB starts each section with a description of the work on characterizing the initial state, which is considered to be the deposition time for the description of the fuel, canister, buffer and backfill. Subsequently, the processes that can affect the long-term development of each sub-system are described. In turn, each sub-system is divided into the THMC structure that SKB has developed, which comprises radiation-related processes (R), thermal processes (T), hydraulic processes (H), mechanical processes (M), chemical processes (C) as well as radionuclide transport.

SKB presents, in the form of a matrix, priority issues for the initial state and long-term processes (divided into THMC structure sub-systems; Tables 3-1 and 3-2; SKB, 2001) to be investigated in the forthcoming three-year period. With respect to the initial state, it is primarily the geosphere which is the object of particular attention since SKB plans to start site investigations shortly. Examples of long-term processes that will be specifically studied are fuel dissolution, corrosion and canister deformation, resaturation of the buffer and gas transport. In the case of the geosphere, the processes are groundwater flow, reactivation in connection with seismic activity, microbial processes and matrix diffusion.

In SKI's opinion, in RD&D Programme 2001, SKB has developed a significantly improved structure for the reporting of research on the initial state of the repository and on long-term properties. By relating the programme structure to the basic structure of the Process Report, the necessary conditions are created for integrating research and safety assessment in a clearer manner than before. This is expected to facilitate the updating of the process report which SKB has said that it will carry out prior to forthcoming safety assessments. SKI recommends SKB to use a similar structure for future RD&D programmes.

In SKI's opinion, SKB's overall prioritization of research on the long-term safety of the engineered barriers and the geosphere (as expressed in Table 3-1; SKB, 2001) are largely suitable in relation to the needs of the safety assessment. The background to this assessment is the result of the review of SR 97 (SKI, 2001).

Since the nuclear waste management issue has entered a tangible phase which assumes that well-defined goals can be reached and reconciled within a relatively tight timetable, there are greater demands that the authorities and SKB should conduct an effective dialogue which involves both overall strategic issues and technical and scientific detailed issues. Therefore, in SKI's opinion, the importance of regular information meetings will increase. SKI therefore assumes that information meetings within the areas of safety assessment and research surrounding long-term safety as well as engineered barriers will be held once or twice a year. SKI has also proposed a structure of follow-up meetings to reconcile reviews of RD&D programmes and safety assessments. These meetings, which are being arranged for a small circle of experts who are involved in the work, will cover the following topics:

- Canister.
- Spent fuel and near field.
- Buffer and backfill.
- Scenarios and safety assessment methodology.
- Radionuclide transport.

Meetings for site investigations as well as system analysis and safety assessment are also covered by the consultation between SKB, SSI and SKI that the Government has decided upon.

SKI, like SSI, is positive to the fact that SKB in RD&D Programme 2001 summarizes particularly important comments from previous reviews. However, prior to forthcoming RD&D programmes, SKB should check that all of the regulatory comments that are dealt with are also explicitly specified in the programme report.

4.2 Spent Fuel and Radionuclide Chemistry

In this section, SKI evaluates SKB's report on fuel which corresponds to Chapter 4 of RD&D Programme 2001.

SKB's Report

During the previous period, SKB's experiments focused on studies of how hydrogen gas can reduce oxidized species formed during radiolysis at the fuel surfaces. The results show that fuel dissolution is very limited when hydrogen gas is present. SKB considers that this can be explained by the fuel matrix's activation of the hydrogen gas which enables a reduction of species such as O_2, H_2O_2 and UO_2^{2+}. The lowest measured dissolution rates are consistent with non-oxidizing solutions of the very low-soluble U(IV) matrix. Higher dissolution rates, which are measured under anoxic conditions without hydrogen gas, can be explained by oxidative dissolution of UO_2(s), caused by radiolysis and, to a certain extent, the oxidation of UO_2(s) from the leakage of oxygen from the environment.

SKB states that studies of fuel dissolution are a priority area for the forthcoming three-year research period. The importance of the area can be related to the need for showing, in a safety assessment, that the fuel has an important radionuclide barrier function which has been incorporated into the fuel matrix. Prior to future safety assessments, SKB intends to analyze the value of the proof provided by results obtained with the aim of proposing defensible

models for fuel dissolution. Further empirical work in the form of leaching experiments with spent nuclear fuels in autoclaves and flow cells are planned as well as in situ experiments using the CHEMLAB probe.

SKB is also planning to prepare an improved database for the most rapid form of fuel dissolution, instant release, using new technology. The radionuclide inventory calculations for all fuel types will also be reviewed and uncertainties associated with certain nuclides that are difficult to determine will be investigated. Long-term changes in geometry and structure will be studied within the framework of an EU project.

SKB has studied redox processes for actinides in UO_2(s) and iron oxides. The aim is to understand retention processes in a damaged canister. In order to include these effects, further work on characterizing and understanding the formation of corrosion products and secondary minerals is necessary. A related problem is that there is only a limited quantity of information available on tetravalent actinide dioxides, and this will therefore be a topic for further study during the forthcoming RD&D period. Prior to future safety assessments, new solubility calculations are being planned, similar to those reported in SR 97 (Bruno et al., 1997).

Comments by the Reviewing Bodies

Chalmers Institute of Technology would like to see further research work on basic actinide chemistry. Chalmers considers that the existing basis of knowledge is insufficient, particularly in the case of plutonium chemistry at higher pH values.

Chalmers also considers that SKB should plan experiments with an experimental canister of spent nuclear fuel. This would enable the corrosion propensity in a real radiation environment, the effect of heating on materials strength and other possible unknown radiation effects to be studied in a real environment.

Chalmers points out that the analysis of criticality conditions could be supplemented by scenarios that include incorrect loading (possibly fresh fuel) in a canister. Umeå University considers that further research to establish safety margins to criticality in the encapsulated fuel ought to be important.

SKI's Evaluation

In SKI's opinion, SKB's fuel programme has shown positive progress over the past few years and has largely been conducted in a manner that can be considered suitable in relation to the needs of the safety assessment. SKB is probably correct to allocate relatively sizeable resources to characterize and improve its understanding of the long-term dissolution rates of the fuel under conditions that almost agree with possible disposal conditions. It could be an advantage if long-term safety can be demonstrated with barrier functions close to the source, such as a very limited fuel dissolution.

In SKI's view, the results that SKB so far has reported provide a necessary basis for the development of a credible and realistic fuel model, which allows for a significant barrier function for radionuclides in the fuel matrix. However, it should be pointed out that recently obtained results, such as results concerning the capability of hydrogen gas to halt fuel dissolution, must still be considered to be preliminary. In SKI's opinion, a considerable degree of caution is warranted before newly acquired knowledge is applied in a safety

assessment. The safety assessment should, as far as possible, be based on established knowledge which has been obtained through the verification of scientific experiments and through the evaluation and comparison of several independent interpretations and theories.

In connection with the review of SR 97, SKI and SSI considered that the interpretation of the results from models describing the near field (damaged canister and fuel dissolution) were too categorical and did not adequately take into account model and parameter uncertainties (SKI, 2001; Grambow, 2000). Therefore, it is important for SKB to pursue its work on improving process models to explain its empirical results. The basic requirement for the extrapolation of empirical results to long time-scales is that a process model can be shown to be able to explain results obtained and that this is perceived as credible. Furthermore, other possible explanations must be eliminated (or considered to be alternative conceptual models in the safety assessment evaluation).

The further development of process models includes such aspects as improved quality control of kinetic data for individual reactions, improved representation of phase interfaces, the handling of the structural degradation of the fuel and the representation of gradients from the spent fuel. Furthermore, it should be possible to describe the quality assurance of databases and computer programs.

SKI sees certain risks arising from primarily focusing the fuel programme on issues surrounding the role of the hydrogen gas in oxidant consumption. This approach is also connected to SKB's damaged canister model (see Section 4.3). The fuel model should be so general that it can, if necessary, be adapted to other fuel types of fuel damage besides minor initial damage (such as damage caused by seismic movements, stress corrosion or human action). SKB should study how the partial pressure of hydrogen gas, and the resulting fuel dissolution, are affected by various degrees of exposure (to groundwater) and canister and buffer damage. SKB should, itself, also question whether it is possible to include, for very long time periods, the hydrogen gas formed by corrosion of the insert. It is possible that the available iron might be used up or that the corrosion rate might drop to a level that is insignificant in this context.

The impact of geochemical conditions on fuel dissolution provides a link to site-specific conditions, rough estimates of the long-term geochemical evolution (see Section 4.6.5) and possibly the porewater composition of the bentonite (Arthur and Zhou, 2001). Even if SKB's report shows that the impact of redox has been dealt with in detail, in SKI's view, a discussion of the impact of other groundwater chemical parameters (salinity, pH, carbon concentrations etc.) and an analysis of whether or not these have been adequately covered by the experimental programme are lacking.

The quantitative measure of fuel dissolution which probably has the greatest effect on the risk analysis is the estimated inventory of instant release for critical nuclides (I-129, C1-36, Se-79 etc.). Therefore, SKI is satisfied that SKB has taken the initiative to improve the empirical basis of these estimates.

With respect to the thermodynamic calculations of the solubility estimates that SKB is planning, SKI reiterates that uncertainty and sensitivity analyses are an essential part of the analysis that must be reported (Ekberg, 2000). Furthermore, SKB must ensure that all quality issues relating to database management have been taken into account (for example, Arthur, 2001).

SKI is positive to the fact that SKB is continuing to evaluate the uncertainties in its assessment of criticality. However, SKI agrees with SKB that criticality is not probable providing that adequate fuel burnup has been achieved and that there is no change in geometry.

4.3 Canister

In this section, SKI evaluates SKB's description of canister research, which corresponds to Chapter 5 of RD&D Programme 2001.

4.3.1 Initial State

SKB's Report

SKB's description of the initial state of the canister is included in the geometry variable that includes initial damage in the seal. SKB has started a research programme in order to, in an initial phase, determine acceptance criteria and, in a later phase, work towards the qualification of non-destructive testing equipment. Future safety assessments should contain assumptions of initial damage that are more directly linked to the results for the development work on manufacturing models and methods for non-destructive testing.

Another variable is temperature, and the further work concerning temperatures in the near field is described in connection with fuel (Section 4.1.4 in RD&D 01) and in connection with the canister (4.2.5 in RD&D 01). The emissivity of the copper is of crucial importance for the temperature distribution in the canister and future studies will provide a basis for formulating the design requirements of the canister surfaces.

Comments by the Reviewing Bodies

SSI states that SKB, in future safety assessments, should describe the evolution of all canisters, even canisters with damage that is smaller than that specified by the preliminary acceptance criteria, and evaluate their importance for long-term radiation protection. SSI also notes that SKB states that the development of criteria for acceptance testing is to be achieved in a dialogue with the authorities. SSI considers that the development of criteria for acceptance testing should firstly be conducted between those who are working with safety assessment issues and method development at SKB, and, secondly, in consultation with SKI and SSI.

Uppsala University agrees with SKB's evaluation that the emissivity of the copper surface is of decisive importance for heat distribution in the canister. The University points out that emissivity is critically dependent on how clean the surface is, and this is very likely to change as the surface becomes increasingly contaminated with impurities.

SKI's Evaluation

In its review of RD&D Programme 98, SKI found that SKB had not shown that, with available methods for testing, it could reach the criterion of a maximum of 0.1 % damaged canisters. In RD&D Programme 2001, SKB presents a plan for how acceptance criteria are to

be developed. SKB also states that the experience from the trial welding will provide information on welding defect types and frequencies. SKI agrees that this is the correct approach to adopt. However, SKI reiterates that acceptance criteria must be specified for allowable defects in the copper shell and welds as well as in the cast inserts. Consequence analyses will show what happens if there are more and/or larger defects than those specified by the acceptance criteria. However, the effects of smaller defects should be analyzed in order to demonstrate the sensitivity of the system. SSI also makes this point. In SKI's opinion, with respect to future safety assessments, there not only should but must be a strong link between safety assessment input data, established acceptance criteria and test statistics from non-destructive testing. SKB states that work will be conducted jointly with representatives from safety assessment, research and method development. SKI is very positive to this approach.

SKI would like to see a more detailed description of the studies of emissivity and temperatures in the canister. However, SKI is positive to the fact that SKB is planning to use such studies in order to develop design requirements for the canister surfaces. As Uppsala University states, the possible change in emissivity over time should also be taken into account.

4.3.2 Deformation of the Cast Iron Insert

SKB's Report

Previous calculations of the materials strength of the cast iron insert have shown that the canister can withstand 45 MPa (design basis in RD&D Programme 98) without collapsing, when using the material from the table for the selected cast alloy (EN-GJS-400-15). New calculations that use materials data from the insert manufacturing trials have shown that canisters that can withstand the higher design load from SR 97 (80 MPa) cannot always be manufactured.

SKB plans to perform new materials strength calculations as new materials data are obtained. Damage resistance calculations will be performed to define permissible defects in the casting. SKB may also consider manufacturing trials using other cast alloys. New calculations for canister behaviour in connection with shear movements in the rock will also be conducted. However, this assumes that new materials data for bentonite will have been obtained. SKB will also investigate the safety factors that will apply to the canister insert design basis.

Comments by the Reviewing Bodies

The Mehedeby-Orrskog Group and SOS-Älvkarleby are concerned that the manufacturing of the cast iron insert is associated with materials strength problems and difficulties in achieving an even and high quality. In the view of SOS-Tierp, it is also a matter of concern that the materials strength requirements applied in SR 97 cannot always be fulfilled. The safety assessment must therefore be revised on the basis of the design basis specified in RD&D 98.

SKI's Evaluation

In SKI's opinion, it is very important that SKB should perform new calculations for the mechanical strength of the canister, where all components are reviewed, such as:

- That the materials data actually obtained from manufactured inserts are used

- That updated materials data for bentonite are used
- That design basis loads are consistently chosen with the scenario selection (loads during glaciation)
- That permissible defects are defined (on the basis of consequence analyses)
- That the rupture criterion in connection with shear movements should be reviewed.

Calculations and reasoning concerning uncertainties in materials data, defects and loads must show that there are adequate margins so that the canister does not collapse or shear. When this is done, a discussion on safety factors can be conducted. However, such a discussion should not be basically used to determine the canister design basis.

In view of the scope of this work, SKB needs to ensure that the timetable for the work is reasonable and that adequate resources are allocated.

4.3.3 Deformation of the Copper Canister

SKB's Report

SKB intends to perform model calculations for realistic load cases as new creep data for canister and lid become available. The theoretical studies will continue over the next year. However, these studies are expected to be completed within a three-year period. Studies of the creep properties of the base metal and weld metal (from both electron beam welding and friction stir welding) are underway.

With respect to the impact of phosphorus on the creep properties of copper, theoretical studies show that copper sulphide precipitation is the most probable cause of embrittlement. Phosphorus competes with sulphur for vacancies and lattice defects. Empirical studies show that creep ductility increases at concentrations of up to 30 ppm of phosphorus. However, higher concentrations do not have a greater impact.

SKB describes pierce and draw and roll forming along with welding as an alternative manufacturing method for copper canisters (in addition to extrusion). The development of the weld methods is described along with possibilities for improving results.

Comments by the Reviewing Bodies

SOS-Tierp cannot discern, from reading Section 5.2.5, how the research will handle the conclusion of SR 97 which states that the corrosion products lead to a pressure increase that results in the stretching and rupture of the copper shell.

SKI's Evaluation

SKI's previous recommendation to SKB to show how a simplification (by assuming plastic collapse instead of creep) of the model for the deformation of the copper canister impacts on the results still holds. Alternatively, a more realistic material model can be used, together with creep data for both the base metal and the weld, from canisters manufactured in accordance with SKB's selected methods.

In SKI's opinion, SKB's description of the various alternative manufacturing methods for the copper tube (extrusion, pierce and draw or roll forming and welding) do not adequately deal

with the issue of grain size (and distribution). Roll forming can result in a very large grain size on the outer surface of the canisters. With the pierce and draw method there is a risk that repeated heating will result in a finishing grade that is too low with resulting large grains or an uneven grain size. In SKI's view, SKB should show, through simulation, calculations etc. (and at a later stage through the verification of the grain size in the finished tubes), that an adequate finishing grade is reached in the entire tube and right through the copper thickness, regardless of the manufacturing method.

The fine grain size which is often obtained through extrusion has led to questions regarding the level of impurities in the copper material and their possible segregation to the grain boundaries. The effect of grain size on the creep properties has been accorded a lower priority. If SKB chooses methods for tube manufacturing that can result in a large or uneven grain size, it will be necessary to show that segregation of impurities in the grain boundaries does not occur or that any segregation that does occur will not lead to a deterioration in creep properties. It is believed that the segregation of sulphur impurities in the grain boundaries both reduces the creep ductility and leads to embrittlement.

Furthermore, in SKI's opinion, the issue concerning the creep rupture limit of the copper remains, including any impact of phosphorus on this parameter.

4.3.4 Corrosion of the Cast Iron Insert

SKB's Report

Anaerobic corrosion of the cast iron has been studied in experiments and the corrosion rate is very low and independent of both the hydrogen gas pressure and the concentration of Fe^{2+}. This indicates that the corrosion rate most likely is determined by the transport properties in the layer of corrosion products on the surface.

In its continued programme, SKB intends to characterize the corrosion products that are formed upon contact with relevant groundwater compositions from the site investigations and with systems containing bentonite. SKB also states that new knowledge has emerged concerning the speciation of iron corrosion products interacting with U(VI).

With respect to galvanic corrosion (in oxygen-free water), SKB states that the corrosion rate will double at first, corresponding to the increase in the area of water reduction (available copper surface).

SKI's Evaluation

SKI considers SKB's continued programme of characterizing corrosion products to be reasonable. However, SKI reiterates its recommendation to SKB to continue work on developing a detailed basis for quantifying the corrosion of the cast iron in the case of a hole in the copper. This work should take into account the local environment in the small gap between the cast iron insert and the copper shell with any effects of, for example, carbonate and sulphide on the composition of the corrosion products and the possibility of aerobic corrosion due to water radiolysis. Any effects on the corrosion rate due to the metal connection between copper and cast iron (galvanic corrosion) and transport properties inside and around a damaged canister should also be included. Furthermore, SKB should clarify whether U(VI) formation of corrosion products on the cast iron must also be taken into

consideration. The extent of work needed in the area depends on the importance of the model for the damaged canister and the way in which it is used in the safety assessment.

4.3.5 Corrosion of the Copper Canister

SKB's Report

SKB has compiled thermodynamic data for copper (Puigdomenech and Taxén, 2000) and, in co-operation with Posiva, has summarized the state of knowledge in copper corrosion (King et al., 2001). The studies of the conditions for microbial corrosion have continued and will continue until 2004. However, nothing has so far emerged to contradict SKB's previous conclusion that sulphate-reducing bacteria are not active in compacted bentonite (with the density that bentonite will have in the deposition holes).

SKB is planning a series of further studies of copper corrosion, including field experiments at Äspö, to investigate local corrosion supplemented by laboratory studies of anaerobic copper corrosion in water with a high saline content, as well as studies of grain boundary corrosion in weld metal. Furthermore, SKB is planning experiments to determine the time-scale for the evolution of reducing conditions in the bentonite and to identify the mechanisms behind oxygen consumption in pure bentonite and in the copper/ bentonite system.

In co-operation with Posiva, SKB has studied the risks of stress corrosion in the presence of aluminum ions in reducing environments. The results indicate that there is no risk of stress corrosion under these conditions. Furthermore, SKB notes that, since tensile stress is a necessary condition for stress corrosion and the canister is under external overpressure, it is hardly likely that stress corrosion would lead to rupture through the canister wall. An investigation of crack growth during stress corrosion indicates that there is a threshold for the stress intensity in order for stress corrosion cracking to grow.

Comments by the Reviewing Bodies

In the view of Chalmers Royal Institute of Technology and Lund University, the issue of how radiation affects corrosion needs to be better investigated. In SSI's opinion, the effect of a very higher secondary electron flux in the water or hydrogen gas-filled cavities and at the interface between the canister and the water should be included in a review of processes that can affect the engineered barriers.

SKI's Evaluation

SKI is very positive to the fact that SKB has summarized the state of knowledge within copper corrosion. SKI previously stated, in its review of RD&D Programme 98, that the next step must be to apply this knowledge in the safety assessment and in the design basis work which will lead to the determination of the design basis for the copper thickness.

SKI agrees with SKB that further research on microbial processes is necessary and that the central issue is whether the microorganisms can survive. SKB's current programme for this research covers the period of 2001-2004. Whether additional research is necessary must be decided when results from the current programme have been obtained.

SKB's other planned work on field experiments and laboratory experiments should reduce uncertainty regarding copper corrosion. However, in SKI's view, there are issues that need to be further investigated, primarily the properties of copper oxide films and, in particular, the impact of chloride and sulphide ions (Hermansson and Eriksson, 1999; Hilden et al., 1999) and the impact of concrete on copper (saline alkaline water). In its compilation on copper corrosion, SKB mentions this. However, SKI would like to see plans for further work.

As SKI has previously shown with rough estimates, certain parts of the canister's surface area will be subjected to tensile stresses, even if the copper canister as a whole is under external overpressure when subjected to loads in the repository. Experience from the nuclear power industry has shown that, even at very low stress intensities (far below previous threshold values), stress corrosion has occurred (Andresen et al., 2001). Therefore, SKI considers that the issue of stress corrosion must be treated in another manner than by discussing stress intensity, namely that SKB must show that the canister will not be present in an environment that can cause stress corrosion in the copper or take into account stress corrosion in the analysis of canister lifetime.

In conclusion, SKI would like to see an account of how SKB intends to handle the spread of corrosion rates and canister lifetimes in the safety assessment.

4.3.6 Evolution of a Damaged Canister – Processes and Integrated Studies

SKB's Report

SKB has studied corrosion rates for steel and cast iron as well as the mechanical pressure buildup of corrosion products. The first experimental results indicate a non-existent expansion. The experiments will continue with the characterization of corrosion products, studies of corrosion in the presence of bentonite and corrosion in more aggressive environments as well as corrosion under gamma irradiation. Related to the model of the damaged canister is the fact that SKB is also planning work on improving the understanding of gas transport through bentonite.

Comments by the Reviewing Bodies

Stockholm University, Department of Geology and Geochemistry, points out that molecular hydrogen which is formed in connection with the corrosion of the iron insert can very well be used as a substrata of autotrophic microorganisms, which could result in the formation of acetate. This could have different types of safety-related significance and more research in the area is therefore considered to be important.

SKI's Evaluation

In SKI's opinion, SKB's previously reported model for the damaged canister shows that even a damaged canister has an important barrier function. On the other hand, the authority is skeptical to too literal an interpretation of the quantitative data obtained from the modeling of the damaged canister (for example, Takase et al., 1998) and to the direct integration of the data into a consequence analysis (see SR 97; SKB, 1999). In SKI's opinion, there is a danger that partly speculative safety functions will be mixed with safety functions that rest on solid and relatively unambiguous theory (such as solubility limitations) and for which there is a considerable body of documentation, experimental data and extensive international

experience (such as sorption). In relation to more established safety functions, SKB's model for a damaged canister is currently not considered to be a key argument for the demonstration of the long-term safety of a repository. However, in a qualitative perspective, the model of the damaged canister increases the confidence in the significant safety margins in the KBS-3 system and the very low probability of early releases even from initially damaged canisters.

An important technical objection against the damaged canister model is that it assumes that corrosion processes can be predicted for 100,000 years. Short-term experiments are of limited value for such time-scales, since the chemical and physical properties of the corrosion products may very well have changed considerably over long time-scales. In turn, this can impact on the rate-limiting mechanisms. Bearing in mind the complexity of the system and the long time-scales, SKB must be able to provide very good basis for defending a linear extrapolation of measured corrosion rates. Additional uncertainties associated with the model for the damaged canister are the limited knowledge of hydrogen gas transport through a saturated bentonite buffer. As SKB itself points out in RD&D Programme 2001, full-scale experiments are probably required to understand the scale dependencies and the relevance of experiments on a smaller scale.

Another technical difficulty is the problem of predicting how copper is slowly deformed over very long time periods. SKI would like to see a description of the work that can be done to determine the creep ductility of the copper canister, which should be the design basis process when calculating the copper shell rupture time.

4.3.7 SKI's Overall Evaluation for the Canister

In RD&D Programme 2001, SKB presents a plan of how acceptance criteria are to be prepared and of how the experience from the trial welding will provide information on types and frequencies of defects that can arise during welding. In SKI's opinion, with respect to future safety assessments, there not only should but must be a strong link between safety assessment input data, established acceptance criteria and test statistics from non-destructive testing. SKB states that work will be conducted jointly with representatives from safety assessment, research and method development. SKI is very positive to this approach.

In SKI's opinion, it is very important that SKB should perform new calculations for the mechanical strength of the canister, where all components are reviewed. Calculations and reasoning concerning uncertainties in materials data, loads and defects must show that there are adequate margins to so that the canister does not collapse or shear. In view of the scope of this work, SKB needs to ensure that the timetable for the work is reasonable.

In SKI's opinion, issues relating to the structure of the copper and the mechanical properties that are linked to this require attention. The most important aspects of this concern the modeling of the creep process, the determination of the creep rupture limit of the copper, including the phosphorus insert's impact on the rupture limit as well as the grain size (and distribution) obtained and any impact on the segregation of impurities to the grain boundaries. The latter will be particularly important if the copper tube is manufactured through roll forming or pierce and draw, which generally results in a larger and more uneven grain than manufacturing by the extrusion method.

SKI is very positive to the fact that SKB has summarized the state of knowledge within copper corrosion. SKI previously stated, in its review of RD&D Programme 98, that the next

step must be to apply this knowledge in the safety assessment and in the design basis work which will lead to the specification of the copper thickness. SKI agrees with SKB that further research on microbial processes, the properties of the copper oxide films and, particularly, the impact of chloride and sulphide ions, as well as the impact of concrete on copper (saline alkaline water) is necessary. However, SKI would like to see an account of how SKB intends to handle the spread of corrosion rates and canister lifetimes in the safety assessment. Furthermore, in SKI's view, the question of stress corrosion in the copper canister cannot be dismissed with reasoning concerning stress intensity. SKB must show that the environment around the canister cannot cause stress corrosion.

In SKI's opinion, SKB's previously reported model for the damaged canister shows that even a damaged canister has an important barrier function. On the other hand, SKI is skeptical to too literal an interpretation of the quantitative data obtained from individual modeling work and to the direct integration of the data into a consequence analysis. This opinion has been previously stated by SKI. In particular, SKB should take into account the uncertainties associated with a linear extrapolation of measured corrosion rates and the limited knowledge of hydrogen gas transport through a measured bentonite buffer. SKI agrees with SKB's statement that full-scale experiments will probably be required to understand the scale dependencies and the relevance of smaller scale experiments.

4.4 Buffer

In this section, SKI evaluates SKB's account of the buffer that corresponds to Chapter 6 of RD&D Programme 2001.

To make the review easier to read, in Section 4.4, SKI has chosen not to follow SKB's structure in RD&D Programme 2001. In Sections 4.4.2-4.4.10, SKI describes SKB's report as well as SKI's evaluation without sub-headings. Review comments from the Waste Network, the Waste Network Association, SOS-Tierp and SSI are presented in 4.4.1. Other sections are reviewed under the sub-headings, "SKB's Report", "Comments by the Reviewing Bodies" and "SKI's Evaluation".

4.4.1 Introduction

SKB starts off by specifying the requirements on the buffer as presented in RD&D Programme 98 and subsequently summarizes the properties of MX-80 bentonite which, according to SKB, fulfills these requirements. In SKI's view, a specification is lacking of the gas permeability in relation to the pressure build-up inside the buffer as well as requirements on the chemical composition given by retention properties and long-term properties in different environments.

The Waste Network doubts the superior properties of the bentonite in preventing radioactive substances from spreading from the canisters to the groundwater in the surrounding bedrock.

To summarize the opinion of the Waste Network Association, the section on the buffer is among the clearest in the entire report to show SKB's and, in general, the nuclear industry's complete lack of a professional attitude to the disposal of nuclear waste.

SOS-Tierp lists a long series of viewpoints on the buffer, including:

- SKB's claim that a 1 cm settling of the canister over a period of 100,000 years must be subjected to a broader scientific review,
- SOS-Tierp questions SKB's claim that the groundwater cannot result in erosion of the buffer and colloid formation, bearing in mind the fact that the repository is planned to be located in a discharge area,
- since the swelling process is expected to be uneven, SKB should not assume that advection is *not* the dominant transport mechanism,
- with respect to SKB's planned long-term experiments, SOS-Tierp questions whether it will be possible to draw statistically-guaranteed conclusions from the experiments.

SSI would like to see a systematic analysis of how the short-term evolution of the buffer can affect its long-term properties, for example, with respect to uneven or slow resaturation, deposition damage and chemical impact from the groundwater. In SSI's view, the results from this analysis are necessary to guide the development of the design basis and acceptance criteria, for example, for deposition holes.

4.4.2 Choice of Buffer Material

Under this heading, SKI presents its evaluation of Sections 6.1.2, 6.1.6, 6.1.12 and 6.1.13 in RD&D Programme 2001.

SKB refers to investigations on other buffer materials besides a smectitric clay such as MX-80. It is not stated explicitly, but implicitly (SKB, 1999) that at least clays of a saponite type and with high concentrations of smectite mica (Friedland clay) could be feasible alternatives. According to the investigation, these alternatives could be superior to MX-80 in certain respects (for example, with respect to rheological properties), although not in others. The purpose of SKB's further work in this area is stated as finding correlations between composition and functional properties so that these can be the basis of selection criteria in connection with the selection and purchase of buffer materials.

SKI realizes the value of the correlations that SKB is planning to develop and strongly recommends that SKB pursue these plans. However, SKI questions whether it is adequate to have theoretical correlations for the characterization of these, in spite of all of the complicated material. It would be valuable for the optimum alternatives to be clarified, especially with respect to the mechanical properties. SKB should, as soon as possible, decide which large-scale experiments will be necessary to confirm the theoretical correlations. SKI particularly emphasizes the difficulties that can arise unless clearly defined, justified alternatives for the buffer material are developed prior to repository licensing.

With respect to the occurrence of other minerals and the occurrence of primarily organic impurities in the clay, SKI considers that it is important for SKB to develop acceptance criteria since these criteria may have as large an impact on the selection of buffer material supplier as the concentrations of the minerals that constitute the desirable properties of the clay.

4.4.3 Water Content

SKI presents its evaluation of Section 6.1.7 in RD&D Programme 2001 under this heading.

The water content of the fabricated blocks are important for manufacturing, ease of handling and desirable short-term properties as well as for thermal conductivity and time to water saturation. SKI assumes that these factors have been taken into account and that the possibility of long-term wetting in connection with, or after, block emplacement will be exhaustively treated in the forthcoming research programme.

4.4.4 Mechanical Interaction of Buffer-Backfill

SKI presents its evaluation of Section 6.2.8 of RD&D Programme 2001 under this heading.

The buffer can swell and expand into the deposition tunnel backfill which could lead to a lower density and load-baring capability of the remaining buffer in the deposition hole. SKB is conducting both experimental work and modelling within the area.

According to SKI, it is important for this work to be conducted at a rate that allows the results to be used to determine design basis conditions for the backfill and deposition holes in time.

4.4.5 Heat Transport

SKI presents one review statement and SKI's evaluation of Section 6.2.3 and parts of 6.2.12 of RD&D Programme 2001 under this heading.

Stockholm University, Department of Physics (SU), emphasizes the importance of the full-scale experiments with heat conductivity and water uptake and raises the question of what will happen if the results of these experiments are not satisfactory. SU considers that supplementary short-term experiments on a laboratory scale should be conducted to confirm whether the ongoing full-scale experiments are moving in the right direction.

With reference to the authorities' comments to SR 97, SKB emphasizes the difficulty of describing thermal conductivity in the unsaturated buffer. SKI agrees that the thermal conductivity in the saturated state is of less interest from the standpoint of research.

Section 6.2.12 deals with SKB's programme to identify simultaneous water uptake and thermal conductivity in an unsaturated buffer. SKB refers to the international project DECOVALEX which was co-ordinated by SKI where these issues were the subject on detailed studies. SKB considers the results to be valuable although improved models for mechanical and hydraulic processes are desirable in certain cases. SKB also states that the calculation models so far used for linked THM processes in unsaturated bentonite have been found to be inadequate to describe the formation, condensation and transfer of steam in a physically correct manner. A programme for the evaluation of different models will therefore continue over the next few years. Furthermore, SKB will conduct full-scale studies at Äspö as well as laboratory experiments. The latter will be carried out to study various mechanisms in detail.

In SKI's opinion, an understanding of the processes for water uptake by the unsaturated buffer is of fundamental importance for confidence in the performance of the buffer in the

repository. SKB should channel substantial resources into resolving this issue which cannot continue to be unresolved prior to repository licensing. The time to full water saturation is also decisive for the time that the buffer is exposed to such high temperatures that its long-term properties can be affected. Mineral alterations such as cementation and connected deterioration of mechanical and other safety-related properties can occur during this early phase. These difficulties have been known for some time and it is now high time that SKB conducts experiments on different scales and develops physical-chemical models that can provide an answer to as yet unresolved issues in this context, for example, with respect to the state of the water in a highly compacted buffer and its sorption on different minerals. SKI wonders how this can be achieved in the short period of time that, according to SKB's programme, remains before an application is submitted for permission to construct a repository. This issue is particularly important if full-scale experiments at Äspö should not give the intended results or if they should fail in another way. Furthermore, in SKI's opinion, the laboratory experiments that are planned should also investigate possible mineralalterations.

4.4.6 Gas Transport

SKI's evaluation of Section 6.2.6 of RD&D Programme 2001 is presented under this heading.

SKB recognizes that knowledge of the transport of gas in a compacted buffer is inadequate. This applies to both the structure of the gas conducting cavities and the necessary overpressure to start transport. Furthermore, SKB states that experiments so far conducted indicate that the clay must expand in order to allow transport. In SKI's view, this must be interpreted as though material surrounding a deposition hole must expand to allow for transport, which is a process that has so far not been analyzed. The impact of gas production and gas transport on the buffer, backfill and rock in the near field, in this context, would have to be clarified in the safety assessment.

In SKI's opinion, the issue of gas transport in the buffer is of such a nature that if this is not resolved within the next three years, it could impact on SKB's programme, primarily on the timetable but also on the canister design.

SKB states that it will not have any time to conduct repository-scale experiments within the next three-year period. In SKI's view, this is an indication that SKB has not allocated this issue sufficient attention. According toSKI, it is particularly important that full-scale experiments as well as experiments on other scales should be started and evaluated within a shorter period of time than three years if SKB is to keep to its timetable.

In its programme, SKB mentions nothing about the extensive work on gas transport that is being conducted internationally, for example, within EU's research programme. Since SKB needs useful results very soon, SKB may need to conduct independent work in this area to achieve its goal more rapidly than would be the case with ongoing international projects.

4.4.7 Swelling and Osmosis

SKI's evaluation of Sections 6.2.7 and 6.2.15 of RD&D Programme 2001 are reported under this heading.

The clay minerals in the buffer and backfill can take up and bind water. The resulting swelling primarily has a positive effect since it seals cracks and heterogeneities. In certain cases, it can also have a negative impact, for example, in connection with uneven swelling around a canister and swelling that leads to the penetration of the buffer in the deposition tunnel backfill. The swelling pressure decreases with an increase in porewater salinity (an osmotic effect) and can change if the salinity of the groundwater changes with time. Chemical reactions between the clay and porewater can also lead to a reduction in swelling pressure and volume.

In SKI's opinion, SKB has good insight into these processes and the research programme conducted together with POSIVA can provide valuable results. To all appearances, swelling and osmotic effects are of more critical importance for the backfill than for the buffer. SKI assumes that the experiments and model studies included in SKB's programme on swelling and osmosis will be designed with this in mind.

4.4.8 Montmorillonite Alteration

SKI presents its evaluation of Section 6.2.17 under this heading.

SKB refers to the review of SR 97 and other documents and states that it is in agreement with the authorities thatalteration, at an early stage, at high temperatures (cementation) is a more important question than illitization. SKB also refers to investigations of Kinnekulle clay and hydrothermal treatment of bentonite clay at 110 °C which confirm this.

SKB also reports studies of bentonite stability at high pH (ECOCLAY) and future studies of thermal effects in the Spanish BARRA project. Alternative buffer material can also be a topic for long-term stability studies, according to SKB.

SKI considers that SKB's programme is ambitious in terms of depth and, in principle, covers the necessary processes for an evaluation of the long-term properties of the buffer clay. At the same time, in SKI's opinion, due to the structure of the programme, it is difficult to clearly discern how work priorities are being allocated among the different areas. In SKI's view, alteration processes at an early stage should still be given a high priority. Autoclave experiments can, for example, need to be supplemented in order to better understand cementation and other impacts under more realistic conditions.

4.4.9 Colloid Release – Erosion

SKI presents its evaluation of Section 6.2.19 of RD&D Programme 2001 under this heading.

Since the comments put forward in SKI 1999 and, in connection with the review of SR 97, SKB has renewed its efforts to better understand colloid formation and the transportation of radioactive substances with colloids. SKB has commissioned bentonite erosion studies with different ion strengths and flow rates. According to SKB, these experiments will be completed in a larger project, COLLOID, which will be conducted at Äspö.

In SKI's opinion, SKB has now taken the necessary initiatives to advance this issue. However, it is still not clear how the importance of colloidal transport should be handled in the safety assessment (see also Section 4.6.6).

4.4.10 Developments under Saturated Conditions

SKI presents its evaluation of Section 6.2.9 and 6.2.23 in RD&D Programme 2001 under this heading.

SKB primarily refers to the ongoing LOT experiments (Long Term Test of Buffer Material) at the Äspö Hard Rock Laboratory. According to SKB, the aim of the experiments is to evaluate models and hypotheses concerning changes of physical and mineralogical properties in the buffer. These experiments are intended to be conducted on a full scale and for times of up to one, five and 20 years. Since RD&D Programme 98, two one-year experiments have been completed. According to SKB, an overarching conclusion is "that no degrading processes, with respect to buffer performance, were found in most of the bentonite as a consequence of water saturation and heating for one year".

In SKI's opinion, the ongoing experiments are valuable and necessary in order to reach more definite conclusions regarding the buffer properties before an application for permission to construct a repository can be evaluated. In this context, SKI reiterates that SKB may need to consider supplementing these experiments if delays arise as a result of experimental mishaps (cf Section 4.7).

SKI also emphasizes the importance of SKB's continued work on the development of an integrated chemical model for the buffer and, above all, on a THM model for water saturated conditions. Such a model is necessary, especially in order to determine the mechanical interaction between the buffer and canister (cf Section 4.3.2) and the canister's settling in the buffer.

4.4.11 Colloid Transport through Bentonite

SKI presents its evaluation of Section 6.2.19 in RD&D Programme 2001 under this heading.

SKB's Report

In accordance with SKI's comments in its evaluation of SR 97, SKB considers that the impact of colloids should be evaluated for cases where the buffer does not perform as intended. SKB also notes that colloids in the near field are important and not as well studied as the natural colloids. To evaluate the filtering capability of the bentonite clay, SKB is conducting experiments on the diffusion of organic colloids in a compacted bentonite buffer. The focus is on the importance of the pore geometry to diffusion as well as the possibility of radionuclide transport with colloids.

Comments by the Reviewing Bodies

SSI recalls that SKI and SSI, in their review of SR 97, pointed out that SKB should evaluate the impact of colloids in cases with a damaged buffer. In SSI's view, it is unclear how SKB will deal with this issue in its research programme.

SKI's Evaluation

In SKB's opinion, organic colloids diffuse through bentonite at almost the same rate as negative ions (for example, I^- and Cl^-) and the colloids move somewhat faster at high ion

strengths. In SKI's opinion, in its further studies of colloid transport through the buffer, SKB should investigate the importance of this process for the safety assessment as well as whether the same phenomenon applies to inorganic colloids.

SKI notes that the erosion of the buffer material that could be caused by the groundwater flow along the edge of the buffer is not mentioned/discussed in the RD&D programme. This erosion can lead to a production of colloid carrier particles for radionuclides and, thereby, facilitate radionuclide dispersion.

4.4.12 Water Transport under Unsaturated Conditions

SKI presents its evaluation of Section 6.2.4 in RD&D Programme 2001 under this heading.

SKB's Report

In SKB's opinion, the quality of input data and models used in the calculations of water transport at unsaturated conditions is sufficient to conduct a satisfactory analysis of the hydraulic evolution in the base scenario. However, at the same time, SKB recognizes that the precision of the calculations would improve with improved knowledge of the hydraulic properties surrounding individual deposition holes, something that is only expected in connection with the actual repository construction. Furthermore, laboratory experiments have been conducted which indicate another type of behaviour in the water saturation process than has so far been assumed.

In order to improve knowledge of the processes and to improve the models that describe resaturation, SKB states that a number of research programmes are in progress:

- THM model studies, unsaturated conditions.
- Full-scale experiments in the Äspö Hard Rock Laboratory.
- Supporting laboratory experiments for the modelling of full-scale experiments.
- Laboratory experiments on unsaturated bentonite for a better understanding of hydro-mechanical processes, for example, the impact of pressure on the pore water pressure, hydraulic conductivity in unsaturated bentonite as well as water redistribution through vapour transport in a temperature gradient.
- The full-scale FEBEX II experiment in the Grimsel Laboratory.

SKI's Evaluation

In SKI's view, the critical question within this area is the resaturation of the buffer. In order to obtain a good understanding of the resaturation process, in its review of SR 97, SKI noted that the links between the thermal, mechanical, chemical and hydrological processes need to be further studied. Furthermore, SKI noted that unambiguous experimental data in support of SKB's assumptions concerning the saturation process are lacking. In SKI's opinion, based on its review of the present RD&D Programme, these comments have not been adequately investigated and, therefore, must still be dealt with.

Furthermore, in SKI's view, the consequences of an uneven or long buffer resaturation should be investigated as well as how the buffer is affected by the heating that occurs as a result of heat transport from the canister. A further question that SKI considers that SKB should investigate is how the buffer is affected by contact with groundwater with high saline

concentrations. SKB should also describe how it will ensure an adequate water flow to the buffer. With respect to the planned full-scale experiments, SKI considers that SKB must clarify what it expects to achieve from the experiments within a reasonable period of time.

SKI is aware that SKB has conducted a study of how the canister is affected by uneven wetting. However, it is difficult for SKI to judge the relevance of SKB's conclusion that the mechanical integrity of the canister is not affected, since SKI has not had access to the internal report to which SKB refers.

4.4.13 Radionuclide Transport – Processes in the Buffer

The evaluation of sections 6.2.13, 6.2.14, 6.2.16, 6.2.24, 6.2.25, 6.2.26 of RD&D Programme 2001 is presented under this heading.

SKB's Report

SKB describes various transport and reaction processes that contribute to the radionuclide transport through the buffer:

- Advection.
- Various diffusion mechanisms.
- Sorption.
- Colloid transport.

Advection and colloid transport is expected to be able to occur only during the resaturation process. Under saturated conditions, diffusion is expected to be the most important transport mechanism. The buffer's original ion content on clay particle surfaces can be replaced by other types of ions through sorption and ion-exchange. In SKB's view, the area of advection no longer requires further research, development or demonstration.

SKB notes that radionuclide transport through the buffer occurs with different *diffusion mechanisms*. Certain cations may have high diffusivities and it is believed that a possible explanation can be found in surface diffusion theory. This process is handled in the safety assessment by postulating higher diffusivity values for cesium, strontium and radium. SKB is to carry out further laboratory experiments to investigate the partially unexpected (for substances that demonstrate surface diffusion) results from the experiments in the Äspö Hard Rock Laboratory.

In SKB's view, detailed knowledge of *sorption* in bentonite is not of critical importance for the performance of a KBS-3 repository. Consequently, SKB does not intend to conduct its own studies in the area.

SKI's Evaluation

SKI questions whether it is correct to describe the *surface diffusion process* by postulating higher diffusivity values for cesium, strontium and radium. Therefore, SKI proposes that SKB should use more than one model to describe the surface diffusion process and, thereby, handle model uncertainty. Furthermore, SKI considers that SKB should report the way in which the results from the experiments are partly unexpected for substances that show surface diffusion, or at least refer to a document where this is reported.

To clarify conceptual uncertainties, SKI proposes, in its review of SR 97, that SKB should, in parallel, evaluate several different methods of estimating how the pore water composition in bentonite develops in the short and long term. However, it is not clear, in this RD&D Programme, how SKB intends to take this comment into account. SKI also questions SKB's way of rejecting the *sorption process* in the way that has been done.

4.4.14 SKI's Overall Evaluation of the Buffer

In SKI's opinion, as much attention has not been focused on the role of the buffer in a repository for spent nuclear fuel as on the other two main components of the KBS-3 method: the rock and the canister. This could give the impression that the buffer is of subordinate importance, which is incorrect; the repository cannot function effectively without an effective buffer. This primarily applies to the buffer in its role of protecting the canister.

In SKI's view, it is difficult, on the basis of SKB's description to judge each area individually, since deficiencies within one area often have an impact on or a link to several other areas. One example is that chemical changes that have been achieved, due to thermal effects (poor thermal conductivity) can impact on the mechanical properties.

SKI has not found, in the areas that SKB describes, that there is support for anything that would seriously contradict the premise that a buffer with acceptable properties can be developed. SKB's buffer programme appears to be comprehensive and shows a good understanding of relationships between initial properties and long-term processes. However, SKI questions whether the work that, in SKB's view, remains to be done can be accomplished within the time left before repository licensing, if SKB's timetable is to be followed.

This primarily applies to the development of a validated model for combined heat and water transport in the unsaturated buffer and to gas transport in the saturated buffer. In both of these cases, the need for experiments on different scales is anticipated, including some full-scale long-term experiments. Studies of the buffer's mechanical/rheological properties are of similar importance, especially bearing in mind the choice of material, the buffer/canister/rock interaction and the interaction with the backfill in the deposition tunnel.

Another essential issue which, in SKI's opinion, must be resolved before a licence application is submitted, is the choice of an optimum buffer, taking into account various properties and the availability of materials.

Among the chemical properties and processes, SKI particularly draws attention to the question of cementation during an early (unsaturated) phase and the fact that knowledge must be obtained concerning the importance of this process to other properties (mechanical, hydraulic) that are important for long-term safety.

4.5 Backfill

In this section, SKI evaluates SKB's account of the backfill, which corresponds to Chapter 7 of RD&D Programme 2001.

As is evident from SKB's report, there is a considerable overlap between the treatment of the buffer and the backfill. Only points that are of particular importance for the backfill are dealt with below.

4.5.1 Choice of Backfill

SKI evaluates sections 7.1.6, 7.1.11, 7.1.12, 7.1.13 and parts of 7.2.2 of RD&D Programme 2001 in this section.

SKB's Report

For a long time, SKB's main alternative for the backfill was crushed rock mixed with some tens of per cent of bentonite. SKB has been aware of the deficiencies of such a backfill composition, particularly its sensitivity to increases in the salinity of the groundwater. This could lead to a decrease in swelling (phase separation) and an increase in the flow porosity of the material. One way of avoiding this would be to use a material that, in principle, comprises 100 % clay, although not necessarily bentonite. One such an alternative is Friedland clay. SKB has commissioned investigations to determine its suitability as a material for the buffer and the backfill.

Comments by the Reviewing Bodies

SSI emphasizes the importance of the long-term performance of the backfill and its link to operations-related issues. The need for long-term experiments must be identified, especially if it is a question of using pure clay as an alternative to SKB's main alternative, which involves 15-30 % of bentonite mixed with crushed rock. Therefore, inSSI's view, SKB must clearly state, in a strategy document, how and at what rate issues of this type need to be clarified.

SKI's Evaluation

SKI shares the view of SSI and other reviewing bodies that the issue concerning the choice of a suitable backfill material must be resolved within a reasonably good time before the licensing of the repository for spent nuclear fuel. Necessary tests of such a material must be carried out on different scales and under relevant conditions. This area was also identified by SKB as a prioritized research area in SR 97. However, the backfill tests, involving mixtures of crushed rock and bentonite, which are being conducted by SKB within the framework of the Backfill and Plug Test field experiment, are not adequate. This is also evident from SKB's programme, where further experiments with other materials, including Friedland clay, have been announced. SKI recommends that SKB should rapidly determine the requirements that must be made on the backfill material so that, prior to licensing, data and methods can be developed that show how these requirements are fulfilled, for example, with respect to materials choice, application method and control methods.

4.5.2 Integrated Studies

Under this heading, SKI's presents its evaluation of primarily sections 7.2.2 and 7.2.13 of RD&D Programme 2001.

SKB's Report

Under the heading "Integrated Studies – Composition and Function" (Section 7.2.2 of RD&D Programme 2001), SKB largely presents all essential information concerning the backfill programme. In the previous section, SKI has highlighted the fundamental importance of the issue of the choice of backfill material. Otherwise, from SKB's description, it is difficult to distinguish points that do not belong to this heading with respect to the backfill programme. SKB describes the research within the Backfill and Plug Test field experiment. This work has many purposes:

- testing different materials and compaction tests
- testing backfill performance and mechanical interaction with the rock
- flow testing.

SKB also states that the studies of alternative materials will continue.

Comments by the Reviewing Bodies

The Waste Network questions SKB's claim that there is no risk of liquefaction with the buffer and backfill densities that will apply with the KBS-3 concept.

The Mehedeby-Orrskog Group emphasizes the groundwater salinity and its importance for backfill performance. In the view of the Group, RD&D 2001 does not provide any clarity on these risks and whether they can be averted. SOS-Tierp also considers that it is a major problem that the backfill performance deteriorates already at relatively low saline concentrations and this is a problem because SKB will demand very high salinities (10 %) in order to exclude a drilling site from further studies.

SSI also broaches the issue of the impact of salinity on the hydraulic properties of the backfill and the importance of this factor for the selection of backfill material, see above.

SKI's Evaluation

Under this heading, SKI would like to emphasize that the results that have so far been obtained from experiments with crushed rock and bentonite mixtures must also be obtained for alternative materials. The work must focus on obtaining a material that withstands any future changes in groundwater salinity and retains its sealing function. In this context, in SKI's opinion, it could be of interest to also take into account the initial saline concentration of the backfill. However, above all, in SKI's view, there is a limited time remaining, according to SKB's plans, until repository licensing, in relation to the time needed for experiments on different scales that may be necessary for alternative backfill material.

With respect to the issue of buffer and backfill liquefaction in connection with seismic movements, SKI shares SKB's opinion that this does not appear to be a problem, especially since SKB will have full control over the composition of the material. This issue, like many

other factors, must be taken into account before the material and repository design are ultimately chosen.

4.5.3 Water Transport

SKB's Report

The properties of the backfill are primarily determined by its composition and the groundwater salinity. SR 97 identified the backfill function as a priority research area which needs to be better investigated. Since RD&D 98 and SR 97, SKB has conducted tests at the Äspö Hard Rock Laboratory where the backfill properties, under both saturated and unsaturated conditions, have been studied and a material model also developed. As a result of the research conducted at Äspö, SKB has been able to determine the negative pore pressure as a function of the water ratio and the bentonite content as well as the hydraulic conductivity as a function of the water saturation and bentonite content. These relationships are necessary to be able to describe the water saturation process in the backfill.

Comments by the Reviewing Bodies

SOS-Tierp maintains that, by siting the repository in a discharge area, there is a risk that the backfill tunnels will become the very link between the repository and the biosphere that SITE-94 warned against.

SKI's Evaluation

In SKI's opinion, the understanding of the backfill function is of considerable importance for the evaluation of repository safety and, therefore, SKI is positive to the fact that SKB, since SR 97, has considered this to be a prioritized area. However, SKI emphasizes that an understanding of this issue is still incomplete and that the area should also continue to be prioritized. The interaction between the backfill and buffer must also be taken into account, since water saturation in the buffer is affected by backfill performance.

4.5.4 Integrated Modelling – Radionuclide Transport in the Near Field

SKB's Report

SKB reports that it has improved the COMP23 computer model since SR 97, so that it is now considerably faster and requires less memory. An analytical approximation to COMP23 has also been developed and it shows that the agreement between the numerical model for the SR 97 calculation cases are fairly good. SKB states several purposes of developing an analytical model:

- To facilitate rapid preliminary probabilistic calculations.
- To improve the understanding of the transport phenomenon.
- To rapidly and simply focus on dominant nuclides and the most important parameters in the transport models.
- To validate and verify the numerical models.
- To allow more involved persons access to tools that do not require specialist training in user interfaces, use of mainframe computers etc.

SKB's research programme entails attempting to develop a more realistic description of radionuclide transport between the buffer and the rock. It also entails expanding COMP23 in order to allow for the calculation of simultaneous diffusion and advection in the backfill.

With respect to the quantification of the *sorption processes* in the backfill, sorption coefficients for radionuclides in the backfill are calculated by weighing together K_d values for the bentonite and rock in proportion to the backfill composition. In SKB's view, at present, further research, development or demonstration is not necessary in this area.

SKI's Evaluation

SKI questions whether it is possible to obtain an improved understanding of the transport phenomenon by using a simple analytical model. Furthermore, SKI considers that it is not possible to use the analytical model to validate and verify the numerical model. SKI notes that SKB, by simultaneously stating that the "numerical models will always comprise the 'yardstick' and be the most important calculation tool for radionuclide transport", contradicts itself.

SKI also notes that it is not clear how SKB has handled the authorities' demand for a clearer report on and documentation of models, data and results. Furthermore, SKI notes that it is not clear whether SKB, besides improving the COMP23 model in terms of rapidity and memory requirements, has also improved the description of the transport and reaction processes included in the model.

Finally, with respect to the handling of the sorption process, SKI lacks a justification of SKB's conclusion that the determination of the K_d value does not require additional work.

4.5.5 SKI's Overall Evaluation – Backfill

To an even greater degree than the buffer, SKB has not paid as much attention to the backfill as it has to the rock and canister. However, the backfill is a condition for ensuring that the buffer performs as intended and that the near field rock does not short circuit as a barrier against the groundwater flow.

SKI's general comments on properties and processes in the backfill and on SKB's report are the same as for the buffer.

An essential issue that must be resolved before an application can be submitted is the ultimate choice of a suitable clay component in the backfill material.

The ongoing studies of the THM properties of the backfill, within the framework of the ongoing Backfill and Plug Test at the Äspö Hard Rock Laboratory, are also important. SKB should, in time, ascertain how useful the results of these experiments are, bearing in mind the choice of material and the interaction with the buffer in the deposition holes.

With respect to chemical properties and process, SKI emphasizes the impact of penetrating saline groundwater on the hydraulic properties of the backfill.

4.6 Geosphere

In this section, SKI evaluates SKB's report on the geosphere which corresponds to Chapter 8 in RD&D Programme 2001.

4.6.1 Heat Transport

SKB's Report

According to SKB, heat transport does not require additional research since SKI, according to SKB, considers that the calculations in SR 97 show that the design condition (a maximum of 100 degrees C on the canister surface) can be met by regulating the quantity of fuel or the distance between the canisters.

According to SKB, heat generation has no bearing on safety. SKB mentions that the authorities (SKI, 2001a) consider that the link between the THMC processes in the buffer need to be further studied to be able to describe the saturation process.

SKI's Evaluation

In their review of SR 97, SKI and SSI considered that the links between the early THMC evolution in the buffer need to be further investigated since the long-term properties of the buffer can also be affected by the environment and the processes to which they have been subjected at an early stage.

In SKI's view, the simplified assumptions for calculations should be clarified. The maximum temperature closest to the canisters are underestimated since the heat source is more extensive in a large-scale model compared with the model used for the calculation of the canister distance and thermal load. This has also been stated by SKI's consultants, Goblet and de Marsily (2000).

Furthermore, in SKI's opinion, supported by consultants Goblet and de Marsily, even if SKB has studied the THMC links, SKB has not updated these links with the latest temperature calculations. The chemical aspects, in particular, need to be further studied.

4.6.2 Groundwater Flow – Recharge and Discharge Areas

A recently published SKI report, written by two consultants from the USA (Voss and Provost, 2001) on behalf of SKI, has been the focus of attention by the NGOs and the Municipality of Tierp. Several organizations and opinion groups interpret the authors' conclusions in the report to mean that a coastal siting of the repository would be the worst possible alternative.

SKB's Report

According to SKB, the largest uncertainties surrounding the understanding and modelling of the groundwater flow are associated with the natural heterogeneity of the rock. This means that a statistical approach must be used for modelling and implies scaling problems in connection with the evaluation of field measurements.

SKB states that criticisms against SR 97 and RD&D Programme 98 have been dealt with. NAMMU and Darcy Tools are to be used during the site investigations for both site understanding and safety assessment (described in two SKB reports on PLU, SKB, 2000 and 2001a). Discrete models will also be used to improve the understanding of how a repository can be optimized with respect to design or safety.

Comments by the Reviewing Bodies

In its review statement, the Waste Network points out that SKI's consultants, Voss and Provost (USGS; US? Geological Survey), with relatively simple calculation models have shown that suitable and unsuitable areas for the siting of a nuclear waste repository can be identified on the basis of defined siting criteria. The Waste Network also considers that the results show that it is entirely possible to, already in this relatively simple manner, determine which areas are better or worse with respect to risks for radionuclide migration (radioactive substances) in the groundwater flow. The Waste Network's interpretation of conclusions presented in the report is that coastal areas should be avoided.

In the view of the Swedish Anti-Nuclear Movement, Oskarshamn – referring to Voss and Provost's report – SKB's choice of trial drilling sites are among the worst possible from the standpoint of safety and environmental protection.

The Mehedeby-Orrskog Group considers that, on the basis of Voss and Provost's report, it is absolutely necessary and natural for the entire site selection process to be redone from scratch.

The Swedish Society for Nature Conservation, Uppsala County, refers to SKI's own preface in the consultants' report, where SKI states that SKB has not adequately investigated the importance of recharge and discharge areas in site selection and, therefore, considers it to be a basic requirement that this aspect should be taken into consideration before the site investigation phase starts. The Society therefore considers it to be a basic requirement that aspects presented in Voss and Provost's report should be taken into account before the start of the site investigation phase.

SOS-Tierp considers that RD&D Programme 2001 confirms how vital it is that the recharge and discharge areas' importance to long-term safety should be further investigated before site investigations start. Further site alternatives and feasibility studies in the interior of the country must also be added to the process in order to achieve the necessary credibility.

SSI considers it to be positive that SKB is now planning to prepare a better basis for determining the importance of recharge and discharge conditions and salinity conditions in the selection of sites for investigation. In SSI's view, it is also important for the analyses to be designed so that they shed light on the selection of sites for investigation and so that the Hultsfred siting alternative can be considered in a more satisfactory manner than was the case in the RD&D Programme 98 Supplement.

The Municipality of Tierp considers that Voss and Provost's report shows that there are considerable safety-related differences with respect to the hydrological barrier, depending on whether the repository is sited in a groundwater recharge or discharge area. The Municipality also notes that all of the sites that have now been proposed for trial drilling are located within the discharge areas for the groundwater and this could mean shorter transport times for radionuclides, which is generally considered to be unfavourable.

Uppsala University maintains, in its review statement, that the advantages offered by siting the repository in suitable bedrock in a recharge area, with long transport times and flow paths to the biosphere, should be taken into account from the standpoint of long-term safety.

SKI's Evaluation

In SKI's opinion, which was also stated in the review of SR 97, the use of a stochastic continuum model on the site scale has not been adequately justified. SKI supports SKB's work on rectifying this situation within the framework of the forthcoming site investigations.

In its reviews of RD&D Programme 95 and RD&D Programme 98, SKI requested a clearly account of the geoscientific advantages and disadvantages of an interior and of a coastal siting of a repository for spent nuclear fuel as well as the consequences for long-term safety, for example, the importance of recharge and discharge areas. This resulted in the preparation of the "North-South/Coastal-Interior" report (Leijon, 1998).

In order to obtain further data, SKI's consultants, Voss and Provost (2001) conducted their own analyses on behalf of SKI. Their study shows that, if the problem is considered solely from the perspective of transport times (flow times) and transport paths (flow paths) through the bedrock, there may be potential advantages to an interior siting above the highest shoreline.

However, a long series of factors affect the evaluation of the long-term safety of the repository and the issue of the impact of the choice of site on the expected retardation of radionuclides in the geosphere is only one of these. One issue that is at least as important is whether there can be site-distinguishing properties that affect the condition of isolating the fuel in the copper canister. Another important issue is that of the dissolution that can be expected when assessing the radionuclide dose that has reached the biosphere. With respect to the hydrogeological assessment, SKI believes that the following factors should be taken into consideration: the heterogeneity of the rock and the occurrence of fractures and/or fracture zones that form rapid flowpaths with short transport times to the biosphere, the chemical and mechanical properties of the rock, the impact through future climate changes as well as the occurrence of local discharge areas in the interior and the uncertainty surrounding what will be the recharge and discharge areas in the future. If all relevant factors are taken into account, it cannot be stated with certainty which site is most suitable without first conducting site investigations. However, a certain uncertainty will always exist since the heterogeneity of the rock will make it difficult (if not impossible) to characterize the properties of the bedrock in detail.

In this context, it is important to emphasize that the results from Voss and Provost's studies were available already at the time of SKI's review of RD&D Programme 98 Supplement and was therefore taken into account in SKI's review of SKB's site selection.

In both RD&D Programme 2001 and in an ongoing consultation between the authorities and SKB prior to the site investigations, SKB has announced that it intends to conduct a research project on recharge and discharge areas as well as the biosphere-geosphere link. The project will also encompass regional simulations of the groundwater flow.

In SKI's opinion, it is very important for this study to be conducted. Furthermore, SKI emphasizes that the most important aspect concerning the issue of recharge and discharge areas at this phase of the Swedish nuclear waste management programme is the geoscientific understanding of hydrological processes. Since Voss and Provost's report deals with conditions at Hultsfred and Oskarshamn, SKI believes that it would be most logical if SKB, in its own study, also clarified the hydrological conditions in the Småland region.

4.6.3 Fracturing - Reactivation

SKB's Report

In SR 97, SKB uses the term *fracturing* to refer both to new fracturing and the propagation of existing fractures. Two potential impacts on safety have been identified: direct mechanical impact on canisters and impacts in the form of changes in flow conditions.

SKB states that the understanding of how the process (fracturing) is to be handled from the standpoint of calculations is deficient. Theoretical models of fracturing and fracture propagation exist. However, the knowledge of how these can be effectively converted into useful calculation models is deficient.

The reactivation process, as described by SKB in SR 97, refers to both shear and normal movements which are important for safety from the mechanical as well as the hydromechanical standpoints. SKB provides an extensive description of mechanical and hydromechanical effects relating to the scenarios in SR 97. In SKB's view, the process will not result in canister damage as long as no deposition holes are intersected by long fractures and as long as the specified canister criterion of 10 cm shear also applies in the future.

SKB plans to examine and evaluate the results of the past 10 years within rock mechanical modeling in order to identify gaps in knowledge. Not only will SKB evaluate the reactivation process, it will also evaluate all issues that may be of importance for the repository design and long-term safety. SKB plans to initiate programmes to identify mechanically (or thermomechanically) induced changes in the near field rock and the far field permeability which can be allowed from the standpoint of the safety assessment.

Comments by the Reviewing Bodies

Gothenburg University (GU) notes that there is considerable evidence that the *reactivation* of fractures occurs. GU also states that it is almost impossible, with present-day knowledge, to quantify, in general terms, the respect distance between fracture zones and the repository. Therefore, GU recommends that site-specific investigations should be conducted in the selected investigation areas where the status of existing fractures is investigated and possible methods for dating tectonic events are applied. This should result in a tectonic model based on field observations. This also includes the determination of the possible geometry of tectonic lenses, their extension and their previous history, with the aim of using this information for future scenario prognoses.

GU also proposes that, based on the known age of an area and its tectonic history (such as parts of western Sweden), studies should be conducted of fracture frequency, fracture orientation and fracture mineralizations supplemented by dates, in other words a natural analogue. In GU's opinion, such a study would at least give a rough indication of how

common reactivation is and the extent to which new fractures and fracture orientations are created within a limited area over a long period of time.

The Mehedeby-Orrskog Group considers that it is positive that SKB is studying post-glacial faults and measurements of movements in the major Lansjärv fault at the boundary between Norrbotten and Lappland, in order to understand fracture formations in rock.

SOS-Tierp notes that SKB, in SR 97, did not take into account the fact that future faults can occur along new lines (new fracturing) and that SKB should, therefore, conduct a new safety assessment and introduce a scenario where seismic activity leads to canister rupture.

Stockholm University's Unit for Paleogeophysics & Geodynamics (SUEPG) points out that, with respect to *fracturing*, new fractures and fault lines can arise where none have previously existed. SUEPG also states that the risk assessment described in SR 97, based partly on the prediction of future seismic movement frequencies and partly on a method for the calculation of the mechanical effects of individual movements in the form of the reactivation of rock fractures is incorrect and misleading (SUEPG refers to the Boda Project).

SUEPG also asserts that the possibility cannot be excluded that seismic movements can cause new fracturing and states that observed seismic movement frequencies cannot be extrapolated for 100,000 years into the future. SUEPG maintains that much that was previously stated in the earthquake scenario and the tectonics scenario (in SR 97), must now be considered to be pure falsification. SUEPEG also considers that SKB's statement about "siting the repository in relation to major deformation zones" appears to be based upon considerable underestimates of the seismic effects and risks.

The Geological Survey of Sweden (SGU) states that the new formation of post-glacial faults and the reactivation of existing fracture systems should be a function of the distribution of the ice cover thickness. Therefore, SGU considers the ongoing study concerning the dating of fracture zones to be important in order to be able to distinguish between purely glacially-related deformation zones and tectonic zones which are formed and reactivated in connection with geological events in a pre-glacial time.

The Swedish Research Council questions SKB's assumption that future seismic events will exclusively occur along existing fractures. The Council maintains that it should not be possible to exclude the possibility that movements within the next 100,000 years will occur along new lines within some section of the Swedish bedrock. Furthermore, the Council states that further research should therefore be devoted less to prediction and more to the character and depth of possible movements.

SKI's Evaluation

In SKI's opinion, it is important for SKB to channel resources into developing useful calculation models for *fracturing* – both new fracturing and the propagation of existing fractures.

In their review of SR 97, the authorities questioned the correctness of the assumption that future seismic events would exclusively occur along existing fracture zones (*reactivation*) and stated that the possibility of future fault movements occurring partly along new lines must be taken into account.

SKI notes that SKB's evaluation that the risk in the tectonic scenario has been overestimated is probably correct, since the assessment was based on friction-free fractures in the rock.

In SKI's opinion, the comments and requirements presented in the review of SR 97 still apply. Based on SKB's planned research activity within the area of fracturing and reactivation, it would seem as though answers to several questions will be provided, possibly with the exception of the canister damage criterion (see below).

In its review of RD&D Programme 98, SKI noted that SKB needed to clarify which knowledge was adequate and which additional work was required with respect to regional plastic shear zones and the implications of siting in or near to such zones (tectonic lenses). Since SKB, in RD&D Programme 98 Supplement has not reported any actual experience (scientific reports) that new fracturing will not affect a tectonic lens, SKB must now show that the lens at Forsmark will not be affected by a future glaciation. GU also emphasizes the importance of determining the geometry, length and previous history of any tectonic lenses, and of applying this information in scenario prognoses.

SKI notes that RD&D Programme 2001 does not include a reference for the claim that the process of thermomechanical loads will not result in canister damage on condition that no deposition holes are intersected by long fractures and on condition that the specified canister criterion of a 10 cm shear, continues to apply. In SKI's opinion, SKB must now show that the canister can withstand the stresses than can result from thermomechanical loads. In addition, the impact of the heat pulse on the fracture system in the form of permanent changes in the fracture system and, thereby, flow conditions should be further investigated.

In SKI's opinion, it is positive that an earthquake's impact on underground constructions is now being documented. After this study has been completed, SKB's assumption that the impact on the repository depth is negligible should either be confirmed or disproved.

SKB indicates that the result from the investigations of the Boda Caves in the Iggesund area (SUEPG's investigation area for post-glacial seismic movements) is a result of glacial erosion processes (Wänstedt, 2000). In SKI's opinion, it is probably more correct to refer to this phenomenon as banking, which Carlsten and Strålhe (2001) have done in their SKB report. However, additional studies are necessary before the earthquake theory can be dismissed.

4.6.4 Time-dependent Deformations and Erosion

SKB's Report

In this case, deformations are those that occur due to slow continuous load changes (related to large-scale tectonic movements) and those (creep movements) that are due to the inherent time-dependent deformation properties of the rock mass. The conclusions of SR 97 are that stress growth does not result in deformations that can damage the canister. SKB also notes that there is a poor understanding of creep movements in the rock.

According to SKB, erosion is of subordinate importance. However, there is uncertainty concerning how deep erosion can occur in deformation zones. SKB also considers that the erosion in coastal areas has been low. In order to clarify the extent of the erosion process, SKB intends to initiate an investigation into this issue.

Comments by the Reviewing Bodies

The Geological Survey of Sweden (SGU) agrees with SKB that the erosion process is not of importance for the long-term safety of the repository within the next 100,000 years.

The Swedish Research Council questions SKB's plan to continue its investigations concerning erosion, stating that it is less likely that SKB will plan to site a repository in deformation zones and fissure valleys where glacial erosion is deeper than in the surrounding environment.

SKI's Evaluation

SKB notes that the canister can become damaged if the deposition holes are intersected by fractures that are several hundred metres in length. Therefore, in SKI's opinion, SKB must ensure that long fractures cannot be allowed to intersect a canister hole. Neither can short (1-10 m) fractures be allowed to intersect a canister hole if it leads to high flows.

Furthermore, in SKI's opinion, in addition to the GPS network that has been established in the Laxemar region, SKB should consider whether the area that includes the Äspö Hard Rock Laboratory should not also be used to measure deformations in the form of creep movements in the rock. In this case, SKB could form an opinion of creep movements depending on the fact that the rock excavation (Äspö Hard Rock Laboratory) is essentially larger in comparison with unaffected bedrock (Laxemar).

In SKI's opinion, in spite of SGU's and the Swedish Research Council's comments reported above, it is positive that SKB is investigating long-term erosion since SKI can note that long-term erosion of the geosphere has not been dealt with in SR 97. If SKB's interpretation of the Boda cave phenomenon (see Section 4.6.3) is correct, namely, that this is a case of glacial erosion, in SKI's opinion, this shows that erosion can be relatively extensive, even in coastal areas.

4.6.5 Geochemistry

SKB's Report

In connection with site investigations, the characterization of geochemistry and groundwater composition is one of the most important aspects. Research that is required to interpret this information focuses on relevant chemical and physical processes as well as the possibility of being able to model these in a quantitative framework. SKB's report concentrates on a discussion of the following processes (SKB, 2001):

- Advection and mixing.
- Diffusion.
- Chemical processes in the groundwater/rock matrix.
- Chemical processes in fracture minerals.
- Chemical processes with construction material.
- Colloid formation.
- Microbial processes.
- Reactions with gases dissolved in the groundwater.

In SKB's opinion, calculations to understand the mixing of different water types through groundwater flow is a key area within the interpretation of site data. Calculations with the aim of understanding the mixing conditions of water types, such as meterological water, glacial water, seawater, very saline groundwater (brines), is currently an established area. On the other hand, SKB has not yet managed to relate the calculations of mixing proportions to hydrological data.

Diffusion affects particularly stagnant groundwater (matrix water) that exists in pores without a link to conductive structures in the rock. SKB is planning, through numerical modelling, to study the conditions for the formation of brines (highly saline groundwater) which is in general almost stagnant.

With respect to chemical processes, SKB is planning to particularly study those that can affect resaturation after repository closure, as well as redox reactions between the groundwater and bentonite. Research on redox processes is considered to be largely concluded now that the REX project has been concluded (Puigdomenech et al., 2001). However, SKB will conduct certain calculations of the rock's capability to consume penetrating oxygen in connection with the melting of inland ice. Certain studies of the capability of microbes to buffer redox will also be conducted, even if the issue of the impact of the sulphate-reducing bacteria on the corrosion of the copper canister has now been given higher priority.

The chemical effect of the presence of concrete in the repository will be studied in co-operation with Posiva. With respect to colloids, a special project has been initiated which will focus on the potential of bentonite clay to form colloids as well as on the stability of the colloids and effects on radionuclide transport (see Section 4.6.6). Other processes that are mentioned, such as gas formation, methane ice formation and salt exclusion, may require individual research work.

Comments by the Reviewing Bodies

The Municipality of Oskarshamn and the local safety authorities at Oskarshamn nuclear power plant have focused on the issue of trapped oxygen which emerged from the public meeting with the GRAM consulting company in Oskarshamn in autumn 2001 (GRAM, 2001).

Stockholm University, Department of Geology and Geochemistry considers that SKB has not adequately investigated the possibility of the formation of acetate and other organic substances that act as complexing agents. Acetate can be formed by different microbial processes. Furthermore, it is believed that the composition of dissolved gases in deep groundwater deserves greater attention than SKB's programme indicates.

The Municipality of Tierp comments on the time-dependent aspects of chemical properties that are being measured in connection with site investigations, such as oxygen content and salinity.

Several reviewing bodies consider that it is highly justified to focus on the properties and barrier function of the rock, partly due to the fact that it is the final barrier before radionuclide dispersion to the biosphere (Municipality of Älvkarleby, SOS-Tierp, Municipality of Tierp).

SKI's Evaluation

In SKI's opinion, SKB has presented a geochemistry programme which is suitable, on the whole, and where the quality of the individual scientific projects is generally high. However, SKI notes certain deficiencies in how results from geochemical models, experiments and field measurements are integrated into the safety assessment (see below). The description of the focus and objectives of the geochemistry programme in the report on the site investigation programme is also somewhat unclear.

The geochemistry programme that SKB presents focuses on the idea that groundwater conditions at a repository site must comply with requirements that guarantee the integrity of the engineered barriers. Other aspects are reported as contributions to geoscientific understanding without any further details being provided. Furthermore, other aspects are not discussed in detail in connection with the specification of requirements or criteria for site evaluation (Andersson et al., 2000). Only a very brief description is included in SKB's planning for the site investigation programme (SKB, 2001a). SKI pointed out in connection with the review of the RD&D Programme 98 Supplement (SKI, 2001b) that the conditions that exist today are only an initial state and that there will be a subsequent evolution over 100,000 years that must be taken into account in the assessment of the integrity of the barriers. It is significant that SKB, during a site investigation phase, should have an understanding of the previous geochemical and hydrological evolution of a candidate site. This understanding contributes to the credibility of the safety assessment and is a possibility to judge whether hydrological and geochemical conditions will change in any decisive manner during the period of time that must be taken into account.

Therefore, SKI recommends that SKB should specify in detail the level of ambition that it will apply to geoscientific understanding and the objectives that must be attained in this area in order to achieve an adequate basis for decision-making on site selection and for an application for permission to construct a repository. It is important that SKB should form an opinion of groundwater age and turnover, for example, the possible occurrence of very young groundwater and traces of the origin and formation of salinity.

The most important geochemical issue, with respect to the long-term safety, is probably the stability of the groundwater chemistry over a glaciation cycle and, perhaps, in particular, groundwater salinity. This is a site-specific issue that cannot be evaluated until the required site data have been obtained. To evaluate this issue, paleohydrological information obtained must be utilized and combined with, for example, time-dependent groundwater modelling where density-dependent effects must be accorded particular attention. SKB should present calculations on how the salinity can change for scenarios that involve extensive climate changes over long periods of time. These prognoses should then form the basis of assessments of the long-term performance of the barrier system etc. The report on geochemistry in a 100,000 year perspective (SKB, 2001b) provides an excellent summary of the state of knowledge which should be useful as a basis for interpreting data from the site investigation programme.

The issue of whether oxygenated glacial meltwater can reach repository depth has been discussed in previous RD&D programmes and reviews (SKB, 1998b; SKI, 1999). Since previous RD&D programmes, SKB has submitted its final report on the REX project and reported additional results from model studies as well as field investigations. SKI's interpretation (of SKB 2001c and other documents) can be summarized as follows:

- Depending on the concentration of reducing minerals (primarily pyrite and silicate mineral such as biotite) the Swedish bedrock should generally be able to consume penetrating oxygen without affecting the redox conditions of the deep repository.
- Oxygen consumption via bacterial processes, consumption of dissolved organic substances and reactions with dissolved gases can be even more effective. However, the effect is more difficult to prove for long time-scales as well as for changes in biosphere and hydrological conditions.
- Field studies aiming at understanding the impact of previous ice ages indicate that the penetration of oxygen has been limited to a relatively shallow depth. However, no definite conclusions can be drawn since geochemical processes that may have been affected by the oxygen supply are reversible.
- Model studies indicate that oxygen is consumed at shallow depths. However, this is not the case for a highly conservative but not unreasonable choice of parameters (the most difficult to control parameter choice concerns reactive surfaces for reducing minerals and heterogeneity for flow paths and minerals).

The implications of these conclusions for the safety assessment should be that a scenario with unchanged redox conditions at repository depth can be considered to have a low probability of occurrence. However, since this case cannot be reasonably excluded, in SKI's opinion, it is important that the engineered barriers' capability to withstand oxygen supply is illustrated. The safety philosophy for the KBS-3 method focuses on copper canister integrity and this means that the reporting requirements are most strictly applied to processes that can jeopardize canister integrity. In RD&D Programme 2001, SKB mentions but does not discuss in detail oxygen consumption in connection with the resaturation phase. This case also needs to be described. However, it should be easier to handle since the conditions are better understood. A third possibility is that oxidizing conditions are created by radiolysis at the fuel surface. However, this case is only possible if the repository contains damaged canisters (see also Section 4.2).

The importance of the redox conditions in the repository is clearly illustrated by the fact that previous international peer reviews have focused on this issue (OECD/NEA, 2000; GRAM 2001). In SKI's opinion, future safety assessments must deal with these issues clearly and in depth. SKI also assumes that SKB, within the framework of site investigations, is studying traces of previous occurrences of oxygen at different depths with the same methodology that it previously reported for Äspö and Klipperås.

In order to model geochemical processes with various equilibrium programs described in RD&D Programme 2001, it is necessary to have a good knowledge of quality issues relating to thermodynamic data. SKI assumes that SKB will use a common and quality-assured set of thermodynamic data for all calculations which are reported in future safety assessments.

4.6.6 Radionuclide Transport

To investigate the effects of a possible leakage of radionuclides from the repository after closure, a number of transport and retention-related mechanisms must be taken into account. In its report on radionuclide transport in the geosphere, SKB has focussed on:

- Advection and dispersion.
- Molecular diffusion and matrix diffusion.
- Sorption.

- Speciation.
- Colloid transport.

SKB's Report

SKB notes that the concept of the flow-wetted surface is of decisive importance for *matrix diffusion* and that it is associated with significant conceptual uncertainties. In accordance with this, SKB's research programme involves further simulations with discrete fracture network models with the aim of improving the understanding of flow-related transport parameters such as the flow-wetted surface. A research project has also been initiated with the aim of being able to measure rock diffusivity directly in the field. In SKB's opinion, a mutual consensus should be established between the parties involved concerning how retention/matrix diffusion is handled in mathematical models as well as how and what data should be measured in the field.

SKB considers that it has investigated certain mechanisms for the *sorption* of radionuclides in detail. The result of studies of sorption mechanisms are reported in a Ph.D. thesis (Jakobsson, 1999). SKB's research programme will entail continued studies of sorption mechanisms on mineral surfaces, as well as further demonstration experiments at Äspö (using the CHEMLAB probe) to clarify the importance of redox processes for sorption.

Since studies are now available that indicate that *colloids* can have a greater importance for radionuclide transport than was previously expected (for example, the study at Nevada Test Site in the USA, which indicates that plutonium is transported sorbed on colloids rather than dissolved in the water phase; Kertsting et al., 1999), SKB states that further research within the area is required if colloidal transport is to be incorporated into the model chain of the safety assessment. However, at the same time, it must be possible to handle colloids separately. An experimental demonstration project is also being planned where the formation of colloids from the bentonite buffer is to be investigated with the aim of studying, under which conditions colloids are formed and are stable. Some model development work is also being planned to roughly quantify the importance of colloidal transport for safety and, if there is a need, the idea is to incorporate colloidal transport into the calculation chain.

Comments by the Reviewing Bodies

Gothenburg University believes that SKB, by measuring electric conductivity to investigate the matrix diffusion process, may have obtained misleading results (in the form of diffusion rate and diffusion distance). Instead, it is proposed that SKB should place greater importance on natural analogues which can be described on the basis of studies of existing fractures, for example, with the help of impregnation methods, water doping and microstudies, which will provide scope for a pessimistic assumption concerning the part of the rock that comprises an active volume in the event of leakage.

In the opinion of the Royal Institute of Technology (KTH), studies of the possible importance of the *colloids* for a repository should be conducted until conclusive conclusions have been reached. Like KTH, SOS-Tierp would like to see the issue of the importance of colloid transport for radionuclide transport thoroughly investigated. KTH also considers that the risk of buffer erosion and colloid release must be included in future safety assessments.

Furthermore, KTH considers that natural isotopes and anthropogeneous substances (such as CFCs) should be utilized to study the transport and retention properties of the bedrock. Stockholm University, Department of Physics, considers that SKB, in future safety assessments, should deal with conceptual uncertainties in radionuclide transport modelling simultaneously with parameter uncertainties, by using more than one transport model for the near field, the geosphere and the biosphere.

Stockholm University, Department of Physics, also states that it is important that the relationship between the water flow and the geometry of large fractures (*the specific wet surface*) should lead to new knowledge during the forthcoming period in order to be able to reduce uncertainties in input data to certain models for geosphere transport, which are used in the safety assessment. Furthermore, the Department points out that SKB has not clearly stated whether the work that it is planning to conduct is on a par with the issue in question.

SOS-Tierp considers that a comparable alternative to the KBS-3 method is necessary, since there is no consensus in the research community concerning radionuclide retention.

In SSI's opinion, SKB, in connection with the development of methods for safety assessment, should develop its analysis of radionuclide transport in the interface between the geosphere and biosphere, in order to be able to present a credible safety assessment in connection with an application.

SKI's Evaluation

In its review of SR 97, SKI made the judgement that SKB should develop the interpretation of *flow-wetted surface* as well as methods that provide the necessary field data to support its use. In its review of RD&D Programme 98, SKI considered that measurement methods for transport properties should be developed. In its review of this RD&D Programme, SKI notes that SKB has planned to deal with previous comments in a satisfactory manner. However, SKI considers that SKB should clearly describe how, in the site investigations, it intends to measure relevant properties since, in SKI's opinion, there are considerable uncertainties concerning how to measure properties that determine the effect of the *matrix diffusion* and since it is unclear how the effective diffusion depth in the intact rock adjoining a fracture plane is dependent upon different measurable units. Due to these unclear points, SKI considers that SKB should conduct process-oriented studies of matrix diffusion in both fracture-filling material and intact rock.

In its review of SR 97, SKI noted that the K_d values that had been utilized may have had too narrow an uncertainty interval which, in turn, has affected the choice of the pessimistic value in the assessment. In SKB's opinion, these uncertainty intervals can best be estimated when a greater understanding of the basic mechanisms determining *sorption* has been obtained. Furthermore, SKI stated in its review of RD&D Programme 98 that both a good process understanding as well as a relevant database of K_d values for the needs of the safety assessment are required. SKI would like to see a description of how the criticism/questions from the authority has been dealt with by SKB as well as an account of the new knowledge that has emerged from SKB's detailed studies of sorption mechanisms and information on whether SKB plans to use/incorporate this new knowledge into future safety assessments.

SKI would also like to see sorption studies on site-specific material, in order to be able to quantify the site-specific importance of the sorption process with a greater degree of certainty.

Furthermore, in SKI's opinion, the surface-complexing method needs to be further developed to be useful in assessing K_d values. It should be possible to use this method to investigate the importance of the pore water composition as well as the specific mineral composition.

SKI's opinion that SKB should investigate the importance of sorption kinetics for radionuclide transport through fractured rock is supported by research results from the SKI consultants Wörman and Xu (Xu and Wörman, 1999). In their evaluation of SR 97 (SKI, 2000) Wörman and Xu state that it is not clear how conservative K_d values can compensate for sorption kinetics, surface diffusion or other deficiencies in the process description. In its review of this RD&D Programme, SKI notes that these points are still unclear.

In SKI's opinion, SKB, in future safety assessments, should include the effect of the rock's heterogeneity and the resulting variability in the properties that determine the retention of radionuclides in the rock (mineral composition, porosity, share of exposed mineral surfaces). Research results from the SKI consultants, Wörman and Xu (Xu et al., 2001) show that this effect could be considerable.

On behalf of SKI, a group of researchers from Galson Sciences Limited have conducted a model study concerning the potential importance of *colloids* in safety assessments. Preliminary results indicate the importance of kinetics and the fact that colloid transport could be important, also for Swedish conditions. SKI's previously expressed view - that SKB should acquire a deeper understanding of the processes that determine colloid transport/mobility (see SKI's review comments on SR 97; SKI, 2001a and RD&D Programme 98; SKI, 1999), in order to subsequently, and in a relevant manner, also incorporate this process into its safety assessment – is still valid. In SKI's opinion, the site-specific colloid concentrations must be studied in connection with the forthcoming site investigations.

4.6.7 Integrated Modelling – Radionuclide Transport

SKB's Report

In SR 97, SKB modelled radionuclide transport using the FARF31 numerical model. Since SR 97, an analytical approximation to FARF31 has also been developed, which SKB will use for preliminary probabilistic calculations in future safety assessments as well as other purposes.

SKB is conducting research at the Äspö Hard Rock Laboratory. Several experiments are being conducted to improve an understanding of the transport and retention of radionuclides in fractured rock (TRUE experiments). The empirical data are then being compared with models of the rock to determine the extent of agreement.

SKI's Evaluation

In its review of SR 97, SKI noted that the FARF31 model, which is used by SKB to model radionuclide transport, should be compared with more detailed process models and that a more detailed report of simplification errors should be presented. Furthermore, a better documentation of conceptual assumptions and mathematical formulations was requested as well as a report on scientific support for the model. SKI also pointed out that SKB should

consider whether FARF31 should be developed to incorporate variable penetration depths for matrix diffusion.

In its review of this RD&D Programme, SKI has found that SKB's activities within the area are adequate and that SKB is acting upon SKI's previous comments in a satisfactory manner.

If the TRUE experiments show that retention can only be described in the context of transport in a three-dimensional network of fractures, SKI considers that SKB should describe the simplification errors that can result from an application in the three-dimensional FARF31 model.

4.6.8 SKI's Overall Evaluation of the Geosphere

In SKI's opinion, simplifications of temperature calculations that have been applied should be better clarified. The maximum temperature closest to the canisters has been underestimated since the heat source is more extensive in a large-scale model, compared with the model that SKB has used for the calculation of canister distance and heat loads.

In SKI's opinion, it is important that a study should be conducted on the issue of recharge and discharge areas, since this is an important aspect of the geoscientific understanding of hydrological processes. SKI considers that it would be most logical if SKB, in its planned study, clarified the hydrological conditions in Småland firstly and, secondly, those in Uppland.

In SKI's view, SKB still has to show that canister integrity is maintained in connection with thermomechanical loads.

In SKI's opinion, SKB should compile and report the body of experience that exists to support the assumption that any new fracturing will not affect a tectonic lens in connection with a future glaciation.

In SKI's opinion, it is justified that SKB should investigate the long-term erosion of the geosphere since an investigation of erosion effects during several glacial cycles has not been previously reported by SKB. In SKI's view, there are indications that erosion can be relatively extensive, also in coastal areas.

In SKI's opinion, SKB has presented a geochemistry programme which is suitable, on the whole, and where the quality of the individual scientific projects is generally high. However, SKI notes certain deficiencies in how results from geochemical models, experiments and field measurements are integrated into the safety assessment.

In SKI's opinion, perhaps the most important geochemical issue with respect to long-term safety is the stability of the groundwater chemistry during a glaciation cycle and, in particular, the salinity of the groundwater. SKB should, therefore, report calculations of how the salinity can change for scenarios that involve extensive climate changes over long periods of time.

In SKI's opinion, future safety assessments must treat the above issues, clearly and in detail. SKI also assumes that SKB, within the framework of site investigations will study traces of previous occurrences of oxygen at various depths with the same methodology as previously reported in the case of, for example, Äspö and Klipperås.

With respect to the quantification of the matrix diffusion process, SKI considers that SKB should clearly describe how it intends to measure relevant properties in the site investigations. In SKI's opinion, there are considerable uncertainties surrounding how properties that determine the effect of *matrix diffusion* should be measured. it is unclear how the effective diffusion depth in the intact rock adjoining a fracture plane is dependent upon different measurable units.

SKI would also like to see sorption studies on site-specific material, in order to be able to quantify the site-specific importance of the sorption process with a greater degree of certainty. Furthermore, in SKI's opinion, the surface-complexing method needs to be further developed to be useful in assessing K_d values. SKB should also investigate the importance of sorption kinetics for radionuclide transport. Finally, SKB, in future safety assessments, should include the effect of the rock's heterogeneity and the resulting variability in the properties that determine the retention of radionuclides in the rock.

4.7 Äspö Hard Rock Laboratory

In this section, SKI evaluates parts of SKB's report on the Äspö Hard Rock Laboratory which corresponds to Chapter 12 of RD&D Programme 2001.

SKB's Report

SKB's four stage goals, reported in RD&D Programme 98, have now been replaced by an RD&D programme with the overall purpose of testing models for the barrier performance of the rock in order to:

- improve the scientific understanding of the deep repository's safety margins and to provide data for assessments of the long-term safety of the repository
- obtain the specific data that are necessary in order to supplement data from the site investigations before an application for permission to site a repository is submitted
- clearly describe the geosphere's role for the different barrier functions: isolation, retardation and dilution.

The overriding goals that determine SKB's work are:

- to obtain a basis for future safety assessments of candidate sites
- to obtain a basis for the preparation of a detailed characterization programme.

In SKB's opinion, described models of geology, geohydrology and geochemistry concerning the Äspö volume have been found to provide an adequate basis for the planning of the site investigations. SKB has no plans to expand the Äspö Hard Rock Laboratory during the forthcoming six-year period, unless new needs arise.

Comments by the Reviewing Bodies

SOS-Tierp and SOS-Älvkarleby consider that the number of canisters in the series of experiments in the prototype repository is too small, which means that it is questionable whether any statistically supported conclusions can be drawn from the experiments.

In SSI's view, the final results from planned long-term experiments in the prototype repository will not be completed until five years after SKB plans to start repository operation. Consequently, it is of central importance that SKB, already at this stage, should clarify the purposes, and expectations of the experiments and the evaluation criteria that will be used. SSI also states that SKB also needs to consider supplementary experiments to provide, among other things, a better statistical basis for the conclusions that must be drawn from the experiments.

Stockholm University, Department of Physics, wonders what will happen if SKB, after the experiment (in the prototype repository) reaches the conclusion that the results are not satisfactory. The Department also states that, if SKB finally chooses medium-long holes as a final disposal concept, it is not obvious that it will be possible to generalize conclusions from isolated holes in the prototype repository to the new concept.

SKI's Evaluation

In SKI's opinion, the Äspö Hard Rock Laboratory is a very important resource for SKB, both in terms of research on long-term safety performance and in terms of the development of disposal technology under realistic conditions. In SKI's opinion, SKB has made considerable progress with respect to these aspects, as a result of the activities at Äspö. It is important that the activities at the Laboratory should not be given a lower priority and that quality should not deteriorate as new field objects are added during the site investigation phase.

For obvious reasons, SKB's long-term experiments are of particular importance for the long-term planning of activities at the Äspö Hard Rock Laboratory. Experimental mishaps and deviation could lead to results being delayed for many years. The implications of such delays must be considered. SKI recommends that SKB should review the long-term experiments that have been initiated at the Hard Rock Laboratory and investigate whether they need to be supplemented or increased so that there are margins for possible future mishaps.

One important issue in this context is the resaturation phase for both the buffer and the backfill. The experiments at Äspö play an important role in confirming that the level of knowledge in this area is adequate. SKI agrees with SSI that SKB must clarify the expectations for the experiments and the evaluation criteria that will be used. The importance of this is emphasized by the fact that several other reviewing bodies also deal with this issue (SOS-Tierp, SOS-Älvkarleby, Stockholm University, Department of Physics).

SKB states that no expansion of the Äspö Hard Rock Laboratory is currently being planned, unless new needs arise. In SKI's opinion, the Laboratory could be used to demonstrate gas transport through the buffer on a full scale (hydrogen gas formed from corrosion of the iron insert). The SR 97 safety assessment included far-reaching interpretations of this process in spite of the fact that there is no evidence that the knowledge of gas transport that has been achieved through laboratory-scale experiments is adequate.

New needs can naturally arise if SKB continues to work on variations of the KBS-3 method, such as horizontal deposition. Another backfill alternative involving natural clay instead of bentonite and crushed rock has been discussed and may also have to be demonstrated on a full scale. In order for these alternatives to be considered realistic, and without, for this reason, postponing the process for several decades, SKB may need to make a decision on the demonstration of these, and possibly other alternatives, relatively soon.

5 Biosphere

In this section, SKI evaluates SKB's description of the biosphere which corresponds to Chapter 9 of RD&D Programme 2001.

SKB's Report

The description and calculation of the dispersion of radioactive substances in the environment is necessary in order to be able to assess the consequences of disposal. The estimated consequences are the basis for the judgement of compliance with regulatory requirements as well as for comparing different technical solutions and siting alternatives with each other. SKB emphasizes that to achieve credible calculations, the biosphere must be realistically described. The reason is that oversimplified models can lead to an overestimate of consequences which, in turn, can result in an incorrect allocation of priorities in connection with repository construction.

SKB formulates the overall goal of the biosphere programme as "to describe, based on modern scientific knowledge, the most important processes in the biosphere from a radiological point of view and to provide sufficient scientific support to assess the environmental consequences of constructing and operating a repository."

SKB's biosphere programme comprises both field investigations and laboratory experiments and modelling.

Comments by the Reviewing Bodies

The Mehedeby-Orrskog Group considers that the knowledge about swamps and wetlands should be considerably improved, as specified in SKB's RD&D programme, and that this should have been done before the sites for site investigations were proposed. In the light of this and other factors, the Group considers SKB's selection of a site in Tierp to be unacceptable.

In the view of the Swedish Environmental Protection Agency, programmes should be developed to distinguish natural variations in the environment from those caused by a repository.

In SOS-Tierp's opinion, SKB's models do not deal with the entire ecosystem. Furthermore, SOS-Tierp considers that SKB, in its biosphere modelling, uses dilution as a starting point in a way that is not compatible with modern environmental awareness. Furthermore, SOS-Tierp considers that the biosphere scenarios must clarify the effects of different types of leakage and that it is particularly important to clarify the effect of speculative intrusion into the repository.

SSI is the reviewing body that has submitted the most comments on SKB's biosphere programme and the basic evaluation is that SKB is conducting methodical and ambitious work. However, in SSI's opinion, SKB should:

- describe the importance that the biosphere has for the final selection of a repository site and how the biosphere is assessed in the safety report
- prepare a timetable which states how much progress needs to be made in the biosphere work prior to the full site investigations.

In addition, in SSI's view, SKB needs to present more detailed plans or state its position more clearly on the following areas:

- documentation of processes included in the interaction matrices
- modelling of transitions between ecosystems, as a result of, for example, land elevation or climate changes
- the process-based system-ecological model development and its importance for the design of the full site investigations
- how environmental protection will be ensured and handled in the safety assessments and site investigation programme
- radionuclide transport in the interface between the geosphere and biosphere.

Stockholm University, Department of Physics, states that SKB, in recent years, has conducted considerable work with respect to the importance of the biosphere for long-term safety. The Department considers that it is necessary to develop a model which includes the interface between the geosphere and biosphere.

In the view of the Swedish University of Agricultural Sciences (SLU), SKB's biosphere programme can be successful if there is knowledge both about the relevance of the models used and of the input parameters that are to be used. SLU states that there is an obvious risk that the experimental radioecology will completely disappear in Sweden as a result of a lack of resources. The lack of experimental competence can lead to the use of deficient input parameters in the models. Therefore, SLU suggest that SKB should support groups focusing on experimental radiological research.

In the opinion of Uppsala University, SKB's systemecological approach is good. The University points out that there are several different types of nature in the areas that could be considered for repository siting and that a weakness in the RD&D Programme is that relatively little work seems to focus on how the different types of nature are to be linked. Furthermore, the University states that the littoral zone is not mentioned to any great extent by SKB. However, the University acknowledges that this could be a question of definition. SKB should clarify this.

SKI's Evaluation

Like SSI, SKI's overall evaluation is that SKB's biosphere programme is both methodical and ambitious. However, considerable work remains before the overall goal of performing credible consequence calculations in the safety assessments has been reached. Therefore, SKI supports SSI's opinion that SKB should continue to detail its plans with respect to model development and field studies, namely determining which data have to be collected during the site investigation phase. One example is the interface between the geosphere and biosphere.

SKI notes with satisfaction that SKB has started different inventories, control programmes etc. and has therefore begun its work on baseline measurements. According to SKB's report, this work will also provide a basis for distinguishing between natural variations in the environment from those that are caused by a repository, which is a factor that the Swedish Environmental Protection Agency has also highlighted.

SSI's regulations concerning the final disposal of spent nuclear fuel and nuclear waste (SSI FS 1998:1) contains requirements that the environmental impact must also be assessed. In RD&D Programme 2001, SKB does not specify any concrete plans for how it intends to do this. SKB primarily refers to the work being conducted in the FASSET EU project which is being managed by SSI. SKI shares SSI's opinion that SKB should present detailed plans prior to the full site investigations.

In RD&D Programme 98, SKB stated that the analysis and evaluation of alternative safety indicators, which supplement dose and risk, were goals for biosphere research. Examples of such safety indicators can be concentrations and flows of radionuclides. Both SKI and SSI considered it to be essential that these plans should be completed. SKI notes that RD&D Programme 2001 does not mention alternative safety indicators at all. In its statement to SKI, SSI also noted that SKB did not deal with this issue. In SKI's opinion, it is important for SKB to realize the plans that were described in RD&D Programme 98.

Finally, in SKI's view, it is positive that SKB intends to publish, to a greater extent, results in international journals. This will contribute to the scientific peer review of its research.

6 Climate Evolution

In this chapter, SKI evaluates SKB's report on climate evolution which corresponds to Chapter 10 of RD&D Programme 2001. Sections 3.7 and 9.9 (RD&D 01) also deal with issues relating to climate evolution. According to SKB, Chapters 5 to 8 deal with a number of climate-related issues in the process descriptions that are not covered by the report in Chapter 10.

Climate changes can be expected, with considerably certainty, in the timescale of over one hundred thousand years to be covered by the safety assessment of the deep repository. A good understanding and description of climate changes and their impact on repository performance is therefore necessary in a safety assessment. Knowledge of the changes that have occurred at a site for a repository through history is an important factor in the geological, hydrological and geochemical understanding of the long-term evolution of the site. This knowledge is important to take into account when describing future climate conditions and their impact on a repository.

SKB's Report

In RD&D Programme 2001, SKB noted that expected climate changes will not only impact on the biosphere but also on the bedrock, down to repository depth. This type of change must therefore be included in an assessment of long-term repository safety. In this context, SKB refers to SR 97 and the specific climate scenario.

SKB identifies several areas that must be further studied, such as possible climate variations, the development of permafrost, the relationship between ice loads and ice movements, the link between hydraulic and mechanical development as well as the large-scale tectonic changes. SKB also deals with issues concerning how climate changes during the post-glaciation stage in turn impact upon the repository properties, such as the mixing of groundwater of different origins, canister strength, buffer erosion in connection with groundwater compositions that are extremely low in iron and the evolution and performance of the backfill. In this report, the latter issues are dealt with in Sections 4.3-4.6.

SKB is studying the link between hydraulic and mechanical processes as well as their impact on the conditions in the near field of a deposited canister within the BENCHPAR EU project. SKB is also planning to develop a conceptual model that describes the hydraulic conditions under an inland ice cover.

Comments by the Reviewing Bodies

In the opinion of the Waste Network Association, there is no question that nuclear waste should not be deposited in groundwater-conducting crystalline bedrock, taking into account future glaciations.

The Mehedeby-Orrskog Group emphasizes that future climate changes, in connection with the glacial state, can radically change the repository's protective capability by damaging or destroying the engineered barriers. Examples include effects of earthquakes, changes in hydraulic conductivity and water chemistry at the repository.

SOS-Tierp notes that SKB has not taken into account ice-free periods during glaciations with a more extensive permafrost. SOS-Tierp also points out that the effects of a deep permafrost must be clarified. SOS-Tierp also notes that SKB, in RD&D Programme 2001, itself points out that climate changes that affect the bedrock down to repository depth are very likely to occur in the future.

SOS-Älvkarleby and SOS-Tierp question whether SKB, with the plans reported in RD&D Programme 2001, will be able to show how future glaciations can affect a repository.

In the opinion of Stockholm University, Department of Physics, SKB needs to determine how the information on the climate processes will be introduced into the safety assessment methodology.

Stockholm University, Unit for Paleogeophysics & Geodynamics (SUEPG) considers that methane ice can theoretically be formed almost wherever inside the rock that fractures and cavities are present. According to SUEPG, the conversion from solid methane ice into gas can occur in the form of an explosion. SUEPG states that there is no unambiguous proof that such conversions through explosions have occurred, but mentions the Boda caves as an example where this phenomenon may have occurred in combination with major earthquakes. In SUEPG's view, SKB has not taken into account important information from the Boda Project.

In the opinion of Stockholm University, Department of Geology and Geochemistry, a deep repository in solid rock is a very unlikely place for methane hydrate formation (methane ice), even if methane hydrate can occur close to the surface under certain conditions.

SSI is positive to the fact that SKB is planning to collect data and to develop models to improve the understanding of climate-related issues. SSI points out that SKB's choice of coastal sites places considerable demands on the reporting of climate impact and on the role of the biosphere. Therefore, SKB should, according to SSI, evaluate its research on the future of the Baltic Sea, and the importance of sea-level changes for the radiological consequences (for example, the release of radionuclides previously accumulated in sea sediment).

SSI points out that the biosphere has a vital place in the safety report and, particularly, the issue of whether releases will occur to a marine or terrestrial environment. SKB must consider whether counting on a dilution of radionuclide releases in the way assumed by the climate scenario in SR 97 is defensible. Therefore, SSI would like SKB to develop methods to be able to perform expert judgements for the selection of climate scenarios.

Furthermore, in SSI's opinion, SKB's research on the future of the Baltic Sea should include an evaluation of the impact of a release into the Baltic Sea which leads to enrichment of the sediment and the importance of this in the perspective of the possible fluctuations of the shoreline. SSI also states that the separate report required by SSI's regulations for the first thousand-year period, should also contain an assessment of possible climate variations during this period.

SKI's Evaluation

In SKI's opinion, it is important that activities within the climate area should be accorded high priority. It is somewhat surprising that SKB has not made more progress in its planning, since according to information provided by SKB, after SR 97 and RD&D Programme 97,

further work was based on the comments made in connection with the regulatory reviews of these documents.

In SKI's opinion, RD&D Programme 2001 lacks a plan for how SKB intends to conduct research in this area and SKI would like to see clearer goals and timetables. Furthermore, the work needs to be put into a larger perspective which better illustrates when RD&D results need to be produced, bearing in mind the needs of the work on, for example, site evaluations and safety assessments.

One of SKB's conclusions from SR 97 was that climate-related changes should not affect repository safety. However, the authorities questioned whether SKB had presented adequate material to support this conclusion. The authorities also commented on the fact that SKB did not analyze alternative climate evolution in greater detail. The report in RD&D Programme 2001 indicates that SKB has taken heed of these comments, although it does not provide any details of how they will be dealt with. SKI would like SKB to present detailed information on future research and development work.

SKI completely shares SSI's opinion that the future position of the shoreline and its impact on groundwater conditions and the biosphere is an important safety and radiation protection issue for a repository in a coastal region. SKB's selection of two coastal sites in its programme will therefore involve more stringent demands on future descriptions of climate effects on the repository, the rock and the biosphere.

In RD&D Programme 2001, SKI notes that SKB describes additional investigations into the land elevation process, including the impact on the shoreline position, the geohydrology and the groundwater composition. SKB also intends to, in an integrated manner, link the climate evolution in a 100,000 perspective with studies of the large-scale tectonic evolution. SKI questioned the tectonic scenario as presented by SKB in SR 97, since the seismic activity that can be expected in connection with a deglaciation phase was not taken into account. SKI is therefore very positive to the fact that SKB, in this respect, has taken note of the opinions from the review of SR 97. In SKI's view, it is important that this work should be started as soon as possible, and SKI is interested in receiving information about SKB's detailed plans.

In SKI's opinion, it is important for SKB, in its assessment of the importance of the greenhouse gas for climate evolution, to also clarify and assess it over a longer time-scale, for example its impact on the start of the next glaciation or permafrost evolution.

Permafrost evolution and its importance for the safety of the deep repository is to be studied within the framework of a joint project to be conducted by Finland, Canada and Great Britain. In SKI's opinion, it is positive that SKB is planning co-ordinated efforts to investigate issues on the depth of the permafrost at different time periods. However, the information in RD&D Programme 2001 is not adequate for a judgement to be made as to whether SKB's current plans are suitable.

In its review of RD&D Programme 98, SKI considered that it was positive that much of the knowledge development within the area is international. However, this does not prevent SKB itself from taking up the Swedish/Scandinavian conditions within the framework of its own project.

In SKI's opinion, SKB needs to clarify the importance of the meltwater production at the bottom of an inland ice cover and its importance for hydrology and groundwater chemistry. SKI emphasizes the importance of SKB considering the best way of developing reliable melt models.

SKI's Overall Evaluation of Climate Evolution

For a coastal repository, the future position of the shoreline and its impact on the groundwater conditions and biosphere are an important safety and radiation protection issue. SKB's choice of two coastal sites in its programme will, therefore, mean that the authorities must place considerable demands on future descriptions of the impact of the climate on the repository, the rock and the biosphere.

In SKI's opinion, RD&D Programme 2001 is lacking a clear plan of how SKB intends to conduct research in the area of climate evolution. SKI would like to see clearer goals and concrete timetables.

7 Natural Analogues

In this section, SKI evaluates SKB's description of natural analogues, which corresponds to Chapter 11 of RD&D Programme 2001.

SKB's Report

For some years, SKB has been involved in international projects concerning natural analogues. These projects provide information that supplements laboratory experiments and site investigations. The advantage of natural analogues is that they enable processes to be studied that have occurred over much longer periods of time than can be followed in laboratory experiments. The processes that the analogues have focused on have, as a rule been in progress for time periods that are comparable with the expected lifetime of the repository. However, the disadvantage is that boundary conditions and other conditions that have affected the processes throughout this period are difficult to assess. Therefore, data from analogue studies can often not be used directly in a safety assessment. On the other hand, according to SKB, it is not uncommon for safety assessment models to be tested on natural analogues. In RD&D Programme 2001, SKB has compiled, in tabular form, examples of natural analogues that have been used to study processes of importance for repository safety assessments. SKB has actively participated in about a half of the studies.

Comments by the Reviewing Bodies

Gothenburg University (GU) states that many times it is impossible to extrapolate results from laboratory experiments to the long time-scales that apply to a repository. Therefore, GU considers that natural analogues (that are preferably "site-specific") should be accorded greater importance when assessing future processes in a deep repository.

The Royal Institute of Technology, Stockholm (KTH) considers that methods for the interpretation of data from natural analogues should be prioritised.

Stockholm University, Unit for Paleogeophysics & Geodynamics states that research on natural analogues, in SKB's case, is a one-sided search for data that can support SKB's own assumptions.

Uppsala University (UU) proposes a much stronger focus on testing and calibration of models with the help of field studies. In UU's opinion, most of the important issues can be investigated in the field (with supplementary laboratory studies), such as the migration of relevant radionuclides in the bedrock at a depth of several hundred metres, the migration of nuclides in surface water, the impact of glaciation and permafrost, the impact of major earthquakes and faults. The University thereby considers that SKB's programme for natural analogues should be expanded to include ongoing natural processes in a global perspective.

SKI's Evaluation

In RD&D Programme 98, SKB considered that the goal of the studies of natural analogues was to test assumptions and models used to assess the long-term safety of a repository. In RD&D Programme 98 , and in other contexts, SKI has proposed a more general direction whereby natural analogues focus on issues within the safety assessment without necessarily aiming to validate models and codes. Experience shows that it is difficult or impossible to

describe, in quantitative terms, the evolution of the natural analogues due to the uncertainties surrounding the original state and boundary conditions. Furthermore, the environment does not always adequately agree with that expected in the repository. The expectation that safety assessment models could be validated in this way was perhaps exaggerated.

The outlook is better if analogue studies are used to assess the completeness of process descriptions, namely, to show that no essential parts of the conceptualisations used are missing. Studies of natural analogues can also be a pedagogical tool for understanding the evolution of geological systems over long periods of time and can contribute to the knowledge of individual processes. The description provided in RD&D Programme 2001 indicates that SKB's evaluation of the value of analogue studies now agrees with SKI's. However, in RD&D Programme 2001, SKB could have better justified its selection of natural analogues.

SKI notes that SKB (according to RD&D Programme 2001; Section 2.1.1) will describe the role of the natural analogues in future safety assessments in the method report announced by SKB.

SKI has noted that most of the projects in which SKB is currently involved are reaching completion. There is a considerable risk that the reduced extent of analogue studies will mean that both the commitment and expertise required for further analogue studies will be completely depleted. SKI considers this to be a problem since there are few possible alternatives to acquire knowledge of long-term geological, hydrological and geochemical changes of importance to final disposal. SKB should uphold continuity and should, therefore, ensure some form of continued work within the area of natural analogues.

In RD&D Programme 2001, SKB has outlined a research programme which involves the completion of major ongoing analogue projects as well as further work on materials analogues for copper, bentonite and concrete in particular. SKI is positive to SKB's proposed activities in the area of material analogues. In SKI's view, SKB should also consider whether studies of anthropogenous analogues can contribute anything further (objects and structures made of copper, concrete, cement manufactured by human beings through time).

SKI knows that discussions are in progress to start, within the framework of an EU-funded project, a review of already completed analogue projects. The goal would be to find out whether already known information on processes that are important for the assessment of repository safety can be utilized in a better manner, or be obtained through supplementary field experiments. In SKI's opinion, SKB should consider the possibility of participating in this project in order to continue to actively acquire new knowledge.

SKI's Overall Evaluation on Natural Analogues

In SKI's opinion, SKB should give high priority to studies of material analogues in its further planning work. Furthermore, SKB should consider whether additional work is required to better utilize the information that already exists from completed projects or consider the value of supplementary field experiments on these sites.

8 Methods for Site Investigations

In this section, SKI evaluates SKB's report on methods for site investigations (PLU) which corresponds to Chapter 13 of RD&D Programme 2001. Sections 9.12 and 12.5 also deal with issues linked to PLU of the biosphere and investigation data as well as site-descriptive models.

SKB's Report

According to SKB, in RD&D Programme 98 Supplement, an overall account was given of SKB's programme prior to the site investigation phase and additional details are therefore not provided in RD&D Programme 2001. Instead, in the report in RD&D Programme 2001, SKB focuses on the ongoing development of important investigation methods and measurement systems. Data management, the construction of site-descriptive models and the exchange of information between investigation, design and safety assessment are other parts clarified by SKB in RD&D Programme 2001.

Comments by the Reviewing Bodies

Gothenburg University (GU) considers that site-specific investigations should be conducted in the selected investigation areas and that the status of existing fractures should be investigated (such as fracture reactivation) and possible methods for dating tectonic events should be applied. In GU's view, this will result in a tectonic model based on field observations that can be used for prognoses of, for example, future scenarios.

The Municipality of Oskarshamn and the local safety committee at Oskarshamn nuclear power plant would like SKB to clarify the link between the safety assessment, geological site selection criteria and site investigations.

Stockholm University, Department of Physics, states that the site-specific biosphere data that will be compiled should be made easily available for research within biosphere modelling.

Stockholm University, Department of Geology and Geochemistry expresses the importance of conducting geochemical measurements at an early stage before the system has been disturbed.

Stockholm University, Unit of Paleogeophysics & Geodynamics emphasizes the importance of knowing the paleoseismic history in the site investigation areas in question.

SSI underlines the importance of SKB prioritising R&D on the collection of biosphere data. In SSI's view, baseline measurements and the selection of reference areas should be conducted at an early stage in the process. SSI intends to follow up the questions related to site investigations within the framework of the consultation process between SKB, SKI and SSI.

The Municipality of Tierp considers that a clearer account of requirements and criteria with which SKB intends to comply should be established before further investigations involving test drilling are started. The Municipality also raises the question of the properties of the rock in a long-term perspective, for example, how the chemical properties change (oxygen and salinity) over time.

Uppsala University (UU) points out the necessity of measuring induced micro earthquakes in connection with intrusion into the rock. This monitoring should be started in good time (1-2 years), prior to the start of the intrusion, in order to determine the background activity. According to UU, micro earthquakes registered in the seismological network can be used to increase the conceptual understanding of creep movements in the rock. This is preferably done with a simultaneous interpretation of these micro earthquakes and data from strategically located extra GPS stations in addition to the National Land Survey's GPS network.

UU also proposes that, within the framework of the site investigations, both recharge and discharge should be investigated by deep drilling. For example, it is important to also investigate the recharge areas in the coastal areas such as Östhammar.

The Science Research Council considers that SKB, already at the initial stage, should establish a GPS network in the areas where the site investigations are to be started. This should be done bearing in mind the importance of long measurement cycles and in order to demonstrate any long-term movements along existing fracture zones.

The Municipality of Östhammar assumes that the site investigation programme will be conducted in accordance with previously reported planning, namely in at least three municipalities or three sites.

SKI's Evaluation

In connection with SKI's review of the RD&D Programme Supplement 98, a number of views were presented on SKB's plans relating to site investigations. In this context, SKI refers exclusively to SKI's review statement (SKI, 2001). Important viewpoints on the site investigation phase specified in the statement are now being taken into account in the prioritisation of work within the framework of the ongoing consultation process between SKB, SKI and SSI. SKI also assumes that important viewpoints on the site investigation phase, submitted with respect to RD&D Programme 2001, will be followed up within the framework of the consultation meetings.

SKI notes that, for the time being, SKB's site investigation programme has reached a very intensive phase, where general plans and programmes are to be converted into concrete activities, such as quality-assured site-specific programmes. This places high demands on SKI and SSI, since within their respective areas of regulatory competence, they must be able to continuously follow and review SKB's plans. Some of the accounts in RD&D Programme 2001 (Chapter 13) are already out-of-date and have now been replaced by more detailed activity plans.

For example, SKI has already stated that the characterization of geochemical conditions should be allocated a very high priority in the initial phase of undisturbed conditions. A high resolution of geochemical information in time and space is critical for data to be translated into geoscientific knowledge. SKI has also expressed the importance of traceability and quality assurance concerning data management in the field and in SKB's databases.

SKI has an advisory group (INSITE) comprising international experts in important areas for site investigations within SKI's area of responsibility. The advisory group will follow SKB's site investigation programme and advise SKI. In order to provide relevant viewpoints during

the different phases of the process, the group needs to continuously be kept updated of the status of SKB's work.

SKI aims to achieve a breadth of scope in its basis for decision-making in the review of different issues as well as depth with respect to issues that require specialist knowledge. Issues treated within INSITE will be followed up within the framework of the consultation meetings with SKB, including through a series of special INSITE meetings arranged for the purpose of acquiring knowledge within different areas.

9 The Repository

In this chapter, SKI evaluates SKB's report on the deep repository which corresponds to Chapter 14 of RD&D Programme 2001.

SKB is planning to compile existing design-related information. The starting point of this work is society's demands on the safety and protection of man and the environment as expressed in Swedish legislation and international agreements.

Acceptance Testing, Variations of KBS-3, Method - Development and Demonstration

SKB's Report

In the work on the design basis, requirements are being established for the components of the deep repository (canister, buffer) and different repository parts (deposition holes, deposition tunnels, other rock cavity areas etc.).

Acceptance testing aims at judging whether the design basis requirements can be met. In order to take advantage of experience gained from the Äspö Hard Rock Laboratory (prototype repository) and site investigations, SKB anticipates that the development of acceptance criteria and methods for acceptance testing can be conducted in stages and in parallel with the design and optimization of the facility as well as the acquisition of in-depth knowledge of the site in question.

Under the heading of acceptance testing, SKB mentions the design basis for deposition holes, including the reporting of methodology for the acceptance or rejection of canister deposition positions.

In the JADE (Jämförelse Av Deponeringsmetoder) Project, SKB has compared *variations of KBS-3* and found vertical emplacement (KBS-3 V) of canisters to be the reference design. KBS-3 medium-long holes (MLH) are judged to be better from the perspective of environmental impact (less rock excavation) and cost. SKB states that considerable work is required for the MLH concept, primarily to develop the deposition method, machinery and other equipment. SKB is not planning to conduct any work of its own with respect to demonstration in the Äspö Hard Rock Laboratory. SKB states that the reason is that it does not wish to change the boundary conditions for ongoing experiments.

Full-face boring of tunnels and the boring of 13 deposition holes have been conducted at the Äspö Hard Rock Laboratory and good results have been obtained. In SKB's view, there will still be scope for freedom of choice with respect to methods for the excavation of deposition tunnels and deposition holes after deposition has started.

The some 100 manufactured bentonite blocks (50x165cm) with a natural water ratio (10%) and an elevated water ratio (17%) have been manufactured by uniaxial pressing. SKB plans to conduct isostatic pressing of blocks and rings with a diameter of 100 cm.

A prototype of a canister deposition machine has been developed to gain experience from the design, manufacturing and operating of such a machine.

SKB states that the quantity of chemical substances in the form of stray materials that will be brought into the repository is small in relation to the natural material of the repository, with the exception of calcium if cement is used for bottom levelling of deposition holes.

No later than when the repository is closed, SKB is planning to seal boreholes by filling them with bentonite or cement. Sealing methods have been developed within the Stripa project. The further development of existing methods for short boreholes and new development of methods for deep boreholes will be conducted in the Äspö Hard Rock Laboratory during the forthcoming six-year period.

Comments by the Reviewing Bodies

In SSI's review statement to SKI, SSI states that SKB, according to SSI's regulations, needs to describe the way in which the disposal system has been optimized with respect to radiation protection. SSI also maintains that the choice of entrance into the repository (access ramp or shaft) will have considerable importance for system design and can also be of importance for the long-term protective capabilities of the repository. According to SSI, the depth of the repository also affects the long-term protective capabilities of the repository.

In its review statement on RD&D Programme 98 Supplement, SSI also stated the need for SKB to perform an analysis where the impact of the repository depth on the protective capabilities is compared to costs, constructability etc. SSI also considered that, in addition to this, SKB should conduct further work on different variations of horizontal deposition (such as medium-long tunnels) compared with vertical deposition.

SKI's Evaluation

In SKI's opinion, the repository performance requirements that have not yet been determined, must be complied with no later than by the time a licence application is submitted, in accordance with the Act on Nuclear Activities. SKI shares SKB's opinion that it is necessary for a breadth of variation and a certain freedom of choice with respect to repository design to be included in the licence.

In previous reviews (RD&D 92), SKI has requested a report on the importance of the repository depth. SKB has partly satisfied this in a report in 1996 (SKB, 1996) where it describes the advantages and disadvantages of different repository depths. In its report, SKB states that, taken as a whole, the disadvantages outweigh the advantages and that the study does not show any important reasons to consider greater repository depths than those assumed in KBS-3 and related studies. SKI finds that the report only clarifies technical aspects. Economic aspects of the repository depth and long-term safety are not discussed.

SKI still would like to draw to SKB's attention the fact that it needs to more clearly assess the implications of the negative factors: increased temperature, higher rock stresses, greater need for reinforcement, higher water pressure, increasing groundwater salinity and possible deterioration in the buffer performance due to salinity, mean for long-term safety.

SKI shares SSI's view that there are also a number of positive factors that emerge in connection with a siting of the repository at greater depths, including a lower hydraulic conductivity, longer transport routes, a lower hydraulic gradient and lower groundwater flux. Furthermore, there is a lower risk of human intrusion and impact from glaciation or permafrost at greater repository depths. With respect to the repository depth, SKI and SSI note, in summary, that it is important for SKB to detail its plans to evaluate the importance of the repository depth, access alternatives down to the repository depth and alternative variations on the repository design.

With respect to access alternatives, there are SKB reports that describe the alternatives although SKB has not adopted a position regarding which alternative it wishes to prioritise. SKI notes that if the ramp and/or shaft alternatives both, through an analysis, can show that they comply with the long-term safety requirements, it is understandable if SKB wishes to retain freedom of choice in order to adapt the alternatives to local conditions at the selected sites.

In SKI's opinion, inflow to the deposition holes is one of the most important acceptance criteria that SKB must determine no later than when an application for permission to conduct a detailed characterization is submitted. SKI also questions whether it is adequate to base conclusions concerning bentonite resaturation, which depend on the water inflow, on only two tests (two holes terminated after 5 years, the other four after 20 years, according to SKB's plan) in the Äspö Hard Rock Laboratory. If anything fails in the holes, it will be necessary to break off the other experiments earlier, that is before 20 years. SKI has commented on this criterion in previous RD&D reviews (see also Section 4.7)

A two-level repository has been discussed in various contexts, although no detailed analysis and evaluation of this alternative has been reported by SKB. Consequently, such an evaluation could now be justified if it is found that the volume of the single level repository design that is being considered in the limited lens in Forsmark is inadequate.

With respect to SKB's plans for the medium-long holes (MLH) alternative, SKB reported late in the review process an RD&D programme for a KBS-3 repository with horizontal deposition which both SKI and SSI find to be satisfactory. Already at the time of the review of RD&D Programme 95, SKI proposed that SKB should demonstrate MLH in the Äspö Hard Rock Laboratory. However, at that time, SKB wished to await the results of the FEBEX tests in the underground laboratory in Grimsel in Switzerland.

In SKI's opinion, the reasons reported by SKB in RD&D Programme 2001 for not disturbing ongoing experiments is too weak a justification for refraining from demonstrating the deposition method based on the medium-long hole concept in the Äspö Hard Rock Laboratory. If SKB wishes to keep the alternative open and to provide SKI with data to approve the method, a demonstration of the deposition methods is required. However, in a newly published SKB report (SKB, 2001), it seems that SKB has re-evaluated its decision concerning the demonstration of the method in the Äspö Hard Rock Laboratory.

In SKI's opinion, the fact that SKB is investigating alternative methods for bentonite blocks and rings is laudable, since isotatically pressed blocks will probably be more homogeneous in the structure than uniaxially pressed blocks and rings and, thereby, can more easily meet high quality demands.

If SKB encounters problems in connection with a separate deposition of the bentonite and canister, it should prepare to develop methods and equipment for the simultaneous deposition of the canister and the bentonite. This alternative also results in larger deposition tunnels and, thereby, greater rock excavation.

SKB mentions three types of backfill: bentonite + crushed rock, bentonite + quartz sand or only crushed rock. SKI can note that, in the latest cost estimates (SKB's plan for 2001), SKB mentions natural clay as an alternative (variation) to the backfill where SKB probably means German Friedland clay. In SKI's opinion, the cost estimate plan and the RD&D programme must be in phase with each other.

SKB does not consider operating seals to have any function in terms of long-term safety. Similarly, SKB should investigate why the concrete plugs (including a deep niche in the rock) in the Backfill and Plug Test in the Äspö Hard Rock Laboratory do not comply with the sealing requirements. In SKI's opinion, it is a credibility issue for SKB that it can demonstrate to the public, municipalities, regulatory authorities etc., that the applied technology performs satisfactorily.

SKI notes that SKB does not mention the possible need and consequences of cement/concrete as a bottom plate or detachable sleepers for the rails of the deposition machine in the tunnels. However, SKB mentions the use of cement in the bottom of the deposition holes. In SKI's opinion, it is important that SKB should investigate the impact of the cement/concrete on the bentonite which SKB hopefully will do within the framework of the joint project with Posiva and through its participation in the ECOCLAY II EU project.

SKB does not want to have to be concerned about the positioning of the boreholes during the site investigations and is therefore developing methods for borehole sealing. In SKI's opinion, it is probable that it will not be possible to completely exclude the failure of any sealing or that erosion processes will open up flowpaths in old borehole sites. Therefore, SKI recommends that SKI should maintain some form of respect distance between boreholes and deposition holes.

10 Transport, Safeguards and Physical Protection

In this chapter, SKI evaluates SKB's report on transport, safeguards and physical protection, which corresponds to Sections 14.6 and 14.7 of RD&D Programme 2001.

10.1 Transport

SKB's Report

SKB states that there is a tried and tested transport system for spent nuclear fuel and nuclear waste and that the regulations for the transport of hazardous goods are based on international agreements. The need for transport during the construction and building phase is described. SKB states that the encapsulated fuel will be transported from the encapsulation plant to the repository in a special transport cask which, filled with canisters and with a frame, weighs about 75 tonnes. A feasibility study of the transport cask for canisters has been conducted in co-operation with Germany. The mode of cask transportation could be sea, rail or road. The mode of transportation varies depending on the siting of the encapsulation plant in relation to the repository. Various alternatives are described for the selected feasibilty study municipalities.

Comments by the Reviewing Bodies

In the view of the Royal Institute of Technology, Stockholm (KTH), in the light of the events of September 11 in the USA, it is important to analyze the transports from the standpoint of physical protection. International experience shows that the transports are particularly vulnerable.

In the opinion of the Mehedeby-Orrskog Group, RD&D Programme 2001 lacks an account of how radiation from the transport casks affects the environment in connection with road transportation. Furthermore, the Group considers that the transportation of nuclear waste should not be conducted through populated areas and presents a line of reasoning concerning radiation from the transport casks to support this view. The Group also rejects the idea of transporting nuclear waste by rail.

In the view of the Group, a transportation accident in the Tierp area could lead to severe consequences for society. Furthermore, the Group believes that the radioactive contamination of transport casks and frames is a recurring problem. The Group goes on to state that that total weight of a transport cask with frames and railroad carriage corresponds to 90 tonnes, which is stated as the maximum permissible weight on the east coast railway track. In view of this, the Group does not consider that safety margins should be provided for the total weight. This stretch of track is reported to be exposed to a considerable amount of traffic.

The Swedish Environmental Protection Agency considers that research on sustainable transportation of radioactive waste to the disposal sites should be included in SKB's RD&D Programme.

In the view of SOS-Älvkarleby, the dose rate from the transport casks containing encapsulated fuel results in health risks and, consequently, such transportation should not be allowed to occur through populated areas. Furthermore, SOS-Älvkarleby considers that due to

the transport weight of the package with the accompanying frame as well as the railroad carriage, there are no weight margins for the specified stretch of track. SOS-Älvkarleby also considers SKB's transportation investigation to be incomplete.

The Municipality of Älvkarleby states that transportation issues are only dealt with on two of a total of about 300 pages of the main report and also considers that the transportation issue is highly topical since it considers that an effective solution to this issue is a prerequisite for a deep repository in Tierp. The Municipality does not agree with SKB that the transportation of spent nuclear fuel and nuclear waste by rail is a tried and tested technology and that practical experience exists both in Sweden and in other countries. Furthermore, the Municipality is not satisfied with SKB, on the one hand stating that there is a considerable need for freight, but on the other hand, not wishing to describe routes and transport until it prepares an EIS prior to the submission of an application to conduct a detailed characterization of a site. The Municipality would like SKB to provide a description of transportation logistics at an early stage.

SKI's Evaluation

SKI notes that several reviewing bodies consider that transportation has been given a cursory treatment in SKB's programme in the form of a very limited report amounting to two pages of text. SKI understands this view. In the RD&D Programme, SKB refers to a final report concerning a feasibility study in Älvkarleby and the planned EIS that will be prepared in connection with site investigations.

In SKI's view, it would have been useful if transportation had been described in greater detail in the main report since the issue is of considerable public interest. At the same time, SKI finds that the current transportation system for spent nuclear fuel and nuclear waste has been efficient and that it is suitable. The system is characterized by the fact that transportation usually occurs by sea with a ship that is specially designed and built for the purpose (M/S Sigyn). A non-coastal siting of a repository would mean that transportation must be achieved by rail and/or by road. In SKI's opinion, heavy transports with a 75-tonne transport cask, including the frame, conducted by road or rail, are very vulnerable to disturbances such as demonstrations. This will also place considerable demands on the load-bearing strength of the roads or railroad.

However, transport packages that will be certified as fissile-classed B packages, will be designed to withstand severe accidents. The mode of transportation can have a considerable impact on public acceptance of a specific repository site. SKB's main report does not contain a reference for the feasibility study on the transport cask for canisters.

SKI notes that it is the Swedish Rescue Services Agency and the Swedish Maritime Administration which issue the applicable regulations for the transport of hazardous goods and not the IAEA as SKB states. However, the regulations are largely based on the IAEA's recommendations.

Furthermore, SKI notes that an assumption cannot be made, in the way that SKB does, that the current system for monitoring, communication and accident preparedness can be applied to future transportation to a repository. This issue will be particularly important if the repository is located in the interior of the country, namely if longer land transportation is

necessary. Therefore, SKI recommends SKB to carry out studies of experience from other countries.

SKI's overall evaluation is that the transportation problem is described in an acceptable manner in the RD&D Programme, bearing in mind the uncertainties concerning where the repository is to be located. However, some form of desirable allocation of priorities for possible transport modes for the canisters could have been presented in the report and the protection issues could have been more clearly dealt with.

10.2 Safeguards and Physical Protection

Through its ratification of the Non-proliferation Treaty in 1970, Sweden made a commitment to implement safeguards in accordance with the IAEA's regulations. The Non-proliferation Treaty gives the IAEA the right to inspect facilities in Sweden to verify that the country's declared inventory of nuclear materials is correct. It is SKI's task to ensure that Sweden complies with the requirements.

Following Sweden's membership of the EU in 1995, the Euratom Treaty entered into force. This Treaty gives the Euratom Safeguard Office the right and duty to inspect Swedish facilities where nuclear materials are used. The supplementary protocol to the IAEA's safeguards agreement has been ratified by Sweden but has not yet entered into force. This gives IAEA extended rights to information and inspections. The aim of the safeguards activities is to ensure that nuclear materials are not diverted for arms purposes and when the supplementary protocol has entered into force, to also ensure that no non-declared nuclear development/activities are conducted in Sweden.

Based on the nuclear legislation, SKI has promulgated regulations (SKIFS 1998:1) whereby measures for physical protection are to be adopted at nuclear facilities. The measures aim at protecting the facility from unauthorized access, sabotage or other impacts that can result in a radiological accident as well as preventing the theft of nuclear materials or nuclear waste.

SKB's Report

SKB states that the approach to safeguards for disposal etc. is connected to the draft safeguards policy for disposal that the IAEA's SAGOR task force prepared in 1998. Within the IAEA, it was noted that a closed repository has to be subjected to nuclear materials control as long as a corresponding control is conducted in other areas. International work is in progress to define requirements on the safeguards system in a closed repository.

In its report, SKB states that, already at this time, established systems exist for the physical protection of both nuclear facilities and the transportation of irradiated nuclear fuel. Furthermore, SKB considers that these systems can be applied to future transportation between CLAB, the encapsulation plant and the repository. The same line of reasoning is also advanced for the protection of the encapsulation plant and the repository.

Comments by the Reviewing Bodies

The Waste Network states that SKB underestimates the risk of human intrusion into the repository and terrorist attacks against nuclear facilities.

The Swedish Anti-Nuclear Movement, Oskarshamn, states that if the repository is co-sited with a nuclear power plant, this will increase the risk (for terrorist acts) at both facilities.

The Royal Institute of Technology, Stockholm states that, in the light of the events of September 11, improbable but nevertheless not impossible scenarios must also be included in the assessment, which the discussion concerning increased protection for Swedish nuclear power plants has clarified.

The Mehedeby-Orrskog Group notes that transportation is vulnerable to sabotage. In the view of the Group, weapons with a directed explosive action could damage the barriers in a cask to the extent that radioactive leakage occurs.

Umeå University considers that the strong police presence (15,000 policemen) in connection with previous transports of spent nuclear fuel/nuclear waste in Germany shows that the radioactive waste must be disposed of.

SKI's Evaluation

In SKI's opinion, the areas of safeguards and physical protection are described in very general terms in the main report. The future repository will, in principle, contain the irradiated nuclear fuel from the entire Swedish programme (including certain MOX fuel). This is a major source term that is in a class of its own. Therefore, SKI maintains that high demands must be made with respect to safeguards for the fissile material and to physical protection of the material. This applies to the entire chain from CLAB, via the encapsulation plant, to the repository. In SKI's opinion, it is of particular importance that these aspects should be considered at an early stage in the process, since experience shows that it is very expensive to undertake a subsequent modification of facilities etc. to take into account these factors. SKI also agrees with the reviewing bodies which assert that road and rail transports are more vulnerable to sabotage than sea transports.

In SKI's view, an analysis should be conducted based on the protection needs for the encapsulation plant and the repository as well as the transports that will have to be conducted, depending on the siting of the encapsulation plant and the repository. In the light of the fact that two completely new types of facilities are involved, SKB should, at an early stage, clarify the measures needed to protect the facilities from sabotage and to protect the fuel from theft.

SKI's conclusion is that SKB must describe how it intends to organize research and investigations on how safeguards and physical protection are to be arranged at the new types of facilities concerned. In the case of the encapsulation plant, the results must be reported in connection with the application for permission to construct the facility.

11 Encapsulation

In this chapter, SKI evaluates SKB's reporting on encapsulation which corresponds to Chapter 15 of RD&D Programme 2001.

11.1 Canister Design

SKB's Report

A basic, preliminary version of the design basis for the canister has previously been presented by SKB (primarily in Werme, 1998). An evaluation of the knowledge of copper corrosion in deep repository conditions has also been summarized (King et al., 2001).

The reference design is a pressure-bearing insert of nodular iron with a steel lid and an outer corrosion barrier of copper. In the reference design, the thickness of the copper is 50 mm, and this is also the thickness used for testing manufacturing methods and for optimizing the detailed design of the canister. Canisters with a wall thickness of 30 mm will be manufactured for testing in order to provide experience of both manufacturing and sealing methods for such canisters. This knowledge will be a basis for any subsequent decisions concerning changes in wall thickness.

Comments by the Reviewing Bodies

The Waste Network Association questions how it can be possible to guarantee with any kind of credibility that the canister will hold for 100,000 years. Furthermore, the Association considers SKB's description of the copper thickness required to be unclear.

The Waste Network Association considers that it is necessary to draw attention to the fact that SKB is gradually reducing the copper thickness of the canister and replacing it with less durable and cheaper material such as cast iron.

SKI's Evaluation

In its review of RD&D Programme 98 (SKI, 1999), SKI stated that the preliminary design basis as described in Werme (1998) has a good basic structure, but that it needs to be justified to a greater extent through consequence analyses in the repository safety assessment. SKI assumes that SKB will take this into account when developing the design basis for the entire repository and that the experience from the work on the preliminary requirements on the canister will be utilized.

As before, SKI agrees with SKB that there are advantages and disadvantages to a more thin-walled (30 mm) copper shell with respect to manufacturing, sealing and control methods. In SKI's opinion, the possibility of using a more thin-walled copper canister must be demonstrated by results from manufacturing and consequence analyses in the safety assessment (particularly with respect to corrosion) showing that the canister complies with the performance requirements.

11.2 Canister Manufacturing and Assembling of Canisters

SKB's Report

SKB describes the situation for canister manufacturing, canister assembling and the planned canister factory in Sections 15.2, 15.3 and 15.4 of the main report and in a status report (Andersson, 2001).

The development work concerning tube manufacturing has concentrated on the manufacturing of seamless tubes (by the extrusion or pierce and draw processing methods) even if SKB states that roll-formed and longitudinally welded tubes can probably be developed into an applicable alternative for tube manufacturing.

With respect to the manufacturing of the cast inserts, SKB has used several different foundries, and connected to this, different casting methods, different types of casting moulds etc. Experience from trial manufacturing has indicated uneven quality and partially low mechanical strength compared with the current specification. Further work focuses on manufacturing inserts with a more even quality and, if necessary, greater materials strength, to be achieved through possible changes in the casting methods and alloys. Together with new materials strength calculations (see also Section 4.3.2), this will provide a better opportunity to specify materials strength requirements.

In two previous studies (Burström, 2000a and 2000b) SKB has presented a preliminary design for a canister factory, with separate finishing lines for cast iron inserts and copper shells. The studies include a preliminary evaluation of machinery, premises and personnel needs as well as a cost estimate.

Comments by the Reviewing Bodies

The Mehedeby-Orrskog Group considers that SKB's chapter on encapsulation confirms that there will be many major difficulties for a long time with respect to obtaining an acceptable quality of canister, joints, tools and tests. SOS-Älvkarleby is concerned about the same point. SOS-Älvkarleby and SOS-Tierp point out that a complete canister has not yet been manufactured.

The Municipality of Oskarshamn and the local safety committees at Oskarshamn nuclear power plant assert that the development of the copper canisters along with the choice of manufacturing and welding methods is the most critical component of the KBS-3 method. Therefore, for the Municipality, it is important for SKI to follow, evaluate and report how this development work is progressing.

Stockholm University, Department of Physics, points out that the adequate welding of the large?and massive copper canisters is till an engineering challenge and that with the roll-forming method, the length of the total welds is considerably extended and, thereby, also the probability of weld defects.

SKI's Evaluation

In SKI's opinion, SKB provides a good summary of the development of the canister manufacturing methods in its status report.

With respect to the manufacturing of copper tubes, SKI's concerns about the grain size and distribution that can be obtained with roll-formed tubes remain, even in the light of the further development of the method for roll-formed and longitudinally welded tubes. In this case, SKI agrees with SKB that the manufacturing would probably be simplified by using a thinner-walled tube. Furthermore, in SKI's opinion, the question of grain size and distribution is at least as relevant to the manufacturing of seamless tubes, and particularly relevant to the manufacturing of pierce and draw pressed tubes which have a lower degree of finishing than extruded tubes, see also Section 4.3.3 concerning grain size. In its continued work, SKB should more clearly compare the advantages and disadvantages of the various methods in order to produce seamless tubes, such as the impact of heating in several stages in connection with draw and pierce pressing, the impact on tubes (and bottoms) in connection with pierce and draw processing with integrated bottoms etc.

SKI is positive to the fact that SKB is using modelling work (of the manufacturing of copper tubes and has now also planned further studies of the lid and bottom) at the Royal Institute of Technology, Stockholm in order to support the work on optimizing the design of tools, forging and extrusion temperatures, ingot size etc.

SKB's experience from the manufacturing of cast inserts and, particularly, from the material specimens studied, has indicated uneven quality and a possibly too low materials strength. In SKI's opinion, the planned material/inserts?is reasonable. However, SKB should verify, to a greater extent, the mechanical properties of the work by investigating some manufactured inserts in greater detail. As mentioned in Section 4.3.2, in SKI's opinion, SKB needs to ensure that the timetable for this work is reasonable and that adequate resources have been set aside.

The canister factory will not be a nuclear facility but will nevertheless be a vital link in the chain, since high demands are made on the canister, both from the standpoint of operations and long-term safety. In SKI's opinion, SKB's planning work has not so far shown any serious deficiencies with respect to the canister factory. However, SKI points out that the design of the factory must also be updated in connection with changes in manufacturing method or canister design. In a commissioned study (Lundin et al, 2001), SKI has evaluated SKB's proposal for canister manufacturing and recommends that SKB continue to study possible changes in the method for copper tube finishing and blasting of inserts as well as the allocation of tasks with respect to determining what work is to be conducted by suppliers and what work is to be conducted in the canister factory, since this can increase the quality of the canisters delivered.

SKI once again emphasizes, as do several reviewing bodies, that a critical issue for the technical feasibility of KBS-3 is that there should be methods for sealing and control that can be applied to series manufacturing. This means that an adequate number of full-size canisters must be manufactured, sealed and controlledand these must be found to comply with the requirements postulated in the long-term safety assessment.

11.3 Welding Technology

SKB's Report

SKB is continuing the development of electron beam welding for both sealing welds for lids and bottom welding. Projects for sealing welds in both 50 mm and 30 mm copper tubes are expected to be completed at the end of 2004.

SKB describes how bottoms are welded in TWI's high vacuum chambers, with both horizontal and vertical electron beams and states that the latter has shown better results. Friction Stir Welding (FSW) is also specified as a possible alternative. The further development must show which method is the most reliable.

In the last three-year period, SKB has developed FSW and states that the process can probably be developed into a useful method for copper canister welding. Experience has so far shown that tool materials, tool parameters and a series of different process parameters are the factors that determine the results. A remaining question is how the problem with the exit hole (from the rotating tool) should be dealt with. FSW is also specified as a possible alternative to roll-forming and longitudinal welding of copper tubes.

Furthermore, SKB states that the final process of manufacturing and sealing canisters must be qualified. A programme for qualification will be developed until the time has come for the application for permission to construct the encapsulation plant to be submitted while the qualification of the methods is to be conducted in connection with the commissioning of the plant.

Comments by the Reviewing Bodies

In the view of Stockholm University, Department of Physics, one issue that should be clarified is whether the "friction head" that must be of a harder material than copper does not give off impurities that diffuse into the copper (in addition to the oxygen from the air).

Lund University and Uppsala University point out that there is no planned research on how the impact of the welding on the material affects the corrosion properties.

SSI considers that a co-ordinated evaluation of the results from the different welding experiments is lacking. In SSI's view, there is a lack of clarity in the description of the development work on canister manufacturing since the account given in the status report for canister manufacturing (Andersson, 2001) provides another view than that presented in RD&D Programme 2001.

SKI's Evaluation

SKI's opinion is that the development of the welding technology has made considerable progress over the past three-year period with respect to FSW. SKI considers SKB's plans to develop new equipment in the Canister Laboratory at the same time as the development work continues at TWI to be a very suitable stage. In SKI's opinion, the documentation of both the development that has been achieved (in connection with the Canister Laboratory and improved bottom welds at TWI) and the planned work on electron beam welding is far too

limited and recommends SKB to compile the results achieved as soon as possible. SSI also presents comments on the lack of clarity in the evaluation and continued plans.

SKB states that welds that have been produced will be evaluated using metallography and non-destructive testing. However, like Stockholm University, Department of Physics, SKI emphasizes the importance of investigating the weld joints produced by FSW in order to establish whether foreign particles (originating from the tools) or oxidation occur. Investigations of the material composition and the occurrence of impurities in the weld joints should be included.

SKI's views on the qualification of the canister sealing are largely the same as those for the qualification of the non-destructive testing methods.

11.4 Non-destructive Testing

SKB's Report

Most of the practical work on developing methods for non-destructive testing is being done at the Canister Laboratory. The testing of welds is being conducted using three different methods to detect different types of defects: radiography reveals pores (discontinuities with volume), ultrasonic testing reveals weld joint defects (without volume) and eddy current testing reveals near-surface discontinuities. Furthermore, at Uppsala University, research projects are in progress on ultrasonic testing.

SKB plans to subject the non-destructive testing methods to qualification. This will be accomplished in two stages. In connection with the application to construct an encapsulation plant, the qualification will focus on technical justifications. In connection with its submission of an application for permission to operate?the plant, SKB intends to qualify the methods for non-destructive testing based on ENIQ Recommended Practice 4 (European Network for Inspection Qualification).

Comments by the Reviewing Bodies

The Waste Network Association states that, based on SKB's description, it is evident that a number of canisters that are not leaktight will be deposited in the repository.

SKI's Evaluation

SKB describes the work on developing the methods for non-destructive testing by presenting an overview of the methods and a short list of ongoing research and development projects. SKI would like to see a single document compiling results and experience so far obtained and recommends that SKB prepare such a document as soon as possible. The document would be valuable to SKB in guiding further work so that adequate knowledge and technology is available at the time that an application for permission to construct an encapsulation plant is submitted and in providing SKI with a better basis for evaluating SKB's development work.

SKI agrees with SKB that the process for the non-destructive testing of copper canisters must be qualified. However, the qualification methodology mentioned in RD&D Programme 2001, with details in ENIQ's document, must be adapted for the non-destructive testing of canisters,

since it has actually been developed for the recurrent testing of mechanical devices in nuclear power plants. The development of the methodology is to be accomplished in relation to clearly defined qualification goals and the level of safety that is to be achieved via qualification, especially since the scope of practical demonstrations is limited to a few defects and is far from adequate to be able to evaluate the performance of the non-destructive testing system with any certainty. A necessary condition for qualification is also knowledge of possible defects that can occur as well as acceptance criteria for these defects. This is a further reason why the work on acceptance criteria must be given a high priority.

SKI has also found that the infrastructure for conducting the qualification of testing systems for the copper canisters is not clear at present. SKI can mention, in comparison, SQC Kvalificeringscentrum's activities concerning mechanical devices in nuclear facilities, where SKI supervises SQC's work. SKI recommends that SKB provide a clearer description of who will conduct the qualification and of the infrastructure for qualifications. Furthermore, SSI considers that it is risky that SKB is underestimating the time that qualification will take and would like to point out that the results from qualification, for example, if a non-destructive testing method does not provide the desired results, can affect the design of the encapsulation plant at a late stage.

11.5 Canister Laboratory

SKB's Report

The development work at the Canister Laboratory is primarily directed towards the development of electron beam welding and non-destructive testing. In 2002, SKB plans to install/build?new equipment for testing FSW. The Canister Laboratory is also an important resource for demonstrating encapsulation technology.

SKI's Evaluation

In SKI's opinion, the Canister Laboratory is a considerable asset for SKB, where technology can be developed and demonstrated on a full scale. SKI is positive to ensuring that new equipment for FSW isinstalled/built. However, in SKI's opinion, it is important for SKB to find a suitable means of documenting and utilizing the experience gained in the Laboratory, especially bearing in mind the tight timetable for the submission of an application for permission to construct an encapsulation plant.

11.6 Encapsulation Plant

SKB's Report

The main alternative for the siting of the encapsulation plant is adjacent to the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB) in the Municipality of Oskarshamn. The advantages of such a siting are the opportunity of utilizing the experience of fuel handling that the CLAB personnel have and the fact that several of the existing systems and facility components at CLAB can be utilized. Transportation will be resolved more easily since only encapsulated fuel will need to be transported. However, there will be an increase in the number of transports. The most important difference compared with an encapsulation plant

located at another site than adjacent to CLAB is that all handling will be dry (no pools will be available) and the fuel will have to already be sorted when it is received.

The design of the facility will be achieved in several stages where the planning stage (Phase D) will be the basis for the application for permission to construct the encapsulation plant. SKB states that there is a certain amount of flexibility with respect to possible future changes in canister design. The facility must also be prepared to be supplemented by equipment for handling long-lived low and medium-level waste. At the construction phase, there is scope in the layout for equipment that can be required for safeguards.

The encapsulation process comprises several stages where the canisters are delivered from the canister factory and the fuel is collected from the storage pools at CLAB. The fuel then undergoes control and is dried, placed into canisters, which are then sealed. The welds are finish-machined and control is carried out by non-destructive testing. SKB also provides a general description of how rejected welds can be segmented (using a milling machine), how damaged fuel is to be handled and how interim storage of filled canisters can be arranged.

In terms of special development work, SKB mentions the development of a new calorimeter (supplemented by gamma probes) in order to obtain more reliable measurements of residual heat and a study of the consequences for the layout of the encapsulation plant if FSW is chosen as a welding method.

SKB provides a brief description of the handling of damaged fuel in CLAB and in connection with transportation to the encapsulationplant.

Comments by the Reviewing Bodies

The review statements from the local safety committee at Oskarshamn nuclear power plant and from the Municipality of Oskarshamn reiterate the Municipality's previous demands that the disposal programme must have made sufficient progress that an application for permission to conduct a detailed characterization has been handled by the authorities and the Government before the Municipality reaches its decision on an encapsulation plant. The County Administrative Board, Kalmar, points out the importance of the temporal links between the encapsulation plant and the repository and states that SKB must clearly declare when decisions will be made for the different parts of the disposal system.

SSI would like to see an evaluation of the effects that different siting alternatives and the design (of the encapsulation plant and canister factory) can have on long-term safety and radiation protection.

SKI's Evaluation

SKI agrees that the co-siting of an encapsulation plant with CLAB has many advantages (in the same way as in the review of RD&D Programme 98; SKI, 1999). In its review, SKI emphasized the importance of a systematic analysis of siting aspects and SKI views SKB's proposal to describe the advantages and disadvantages of the EIS that will be submitted in connection with a licence application as entirely reasonable.

Since there are still a relatively large number of stages in the encapsulation process that have not yet been finalized (welding method, non-destructive testing methods, residual heat

measurement, safeguards measurement methods etc.), in SKI's opinion, it is particularly important for there to be flexibility in the design of the facility. SKB should consider supplementing the planned study of the impact of the replacement of the welding method with similar studies of the uncertainties in the choice of non-destructive method testing, residual heat measurement etc. In this context, the impact of any changeover to canisters for horizontal deposition must be clarified.

The question of the physical protection of the encapsulation plant is not dealt with by SKB in the section on the encapsulation plant. In the light of the fact that it is a completely new type of facility, SKI considers that the protection issues must be investigated at an early stage in order to be included in the design basis of the facility. It is particularly important to analyze whether and how the events of September 11, 2001 have affected the need for protection (see also Section 10.2).

In SKI's opinion, a more detailed description must be obtained for deviant types of fuel (damaged fuel, fuel residues, MOX-fuel etc.) and how this affects both the canister design, handling in the encapsulation plant as well as the long-term safety.

SKI shares the view of the Municipality of Oskarshamn, the local safety committee at Oskarshamn nuclear power plant and the County Administrative Board, Kalmar, that the link between the encapsulation plant and the repository is important. In SKI's opinion (SKI, 1996 and SKI, 2001), a condition for permission to construct an encapsulation plant is that a safety assessment for the repository should also be included in the licence application. Furthermore, in SKI's opinion, a repository should be approved by the authorities before SKB starts the encapsulation of spent nuclear fuel. This means that detailed characterizations must be completed and that SKB must be have been granted permission to start deposition in the repository.

11.7 Safeguards

SKB's Report

The encapsulation plant is to comply with requirements on safeguards from both Swedish and international safeguards authorities. At the design stage, this will be ensured by giving scope to equipment in the layout. The facility will be designed so as to make it difficult to divert nuclear substances. Both the canisters and the transport casks will have a unique identity which can be visually controlled.

CLAB is currently one MBA (Material Balance Area). The intention is for the encapsulation plant to belong to the same MBA in order to facilitate the administrative handling.

SKI's Evaluation

SKI would like to see a more detailed description of methods to verify fuel prior to encapsulation. Internationally accepted requirements do not exist. Consequently, SKB must be the driving force, with SKI's support, behind the development of such requirements and the acceptance by the IAEA. It is an advantage in achieving IAEA acceptance, if Sweden and Finland, which are at the same planning stage, have equivalent methods.

In SKI's opinion, several methods may have to be combined to achieve a reliable verification. In the application for permission to construct the encapsulation plant, the method or methods must be described as well as how the fuel will be handled in the case where documentation and measurement results provide different information. SKB must also describe how the IAEA will be given the opportunity to conduct independent verification. The temporal aspects of the IAEA's verification and handling of fuel where the evaluation provides an uncertain result must be clarified.

SKI does not agree with SKB that the encapsulation plant and CLAB must necessarily belong to the same MBA. In SKI's opinion, SKB should investigate this issue further. SKI would like to ensure that SKB is aware that the IAEA and Euratom will probably have viewpoints on the MBA structure.

11.8 SKI's Overall Evaluation of Encapsulation

In SKI's view, SKB's work on encapsulation is largely being conducted in a suitable manner. However, in SKI's view, SKB should, to a greater extent than before, identify the critical issues in order to obtain adequate data for the application to construct the encapsulation plant.

SKI views the ongoing work with the design basis for the repository, and the acceptance criteria for the canister, as very important. In SKI's opinion, any delays arising in this work can delay other parts of the canister work because this work should determine the direction of many activities and because it may have to be revised after the consequence analyses that must be conducted in order to show that the design basis and acceptance criteria are adequate.

With respect to the design and manufacturing technology for canisters, in SKI's view, the grain size of the copper tube is also a relevant issue for pierce and draw-processed tubes (which was previously stated with respect to roll-formed tubes) with its lower degree of finishing than extruded tubes. However, as before, SKI agrees that there are both advantages and disadvantages of using a thinner-walled (30 mm) copper tube. SKI is positive to SKB's overall approach to the work on manufacturing methods and materials strength calculations for the cast iron insert. However, in SKI's view, SKB must ensure that adequate time has been set aside for this.

SKI recommends that SKB should, as soon as possible, compile into a single document, results and experience obtained from the work on non-destructive testing. SKI agrees with SKB that the non-destructive testing process must be qualified. However, SKI notes that the proposed qualification methodology must be adapted to non-destructive testing of copper canisters and that an infrastructure for conducting qualification is currently lacking. Furthermore, in SKI's view, there is a risk that SKB will underestimate the time needed for qualification as well as the results that may be obtained.

In summary, SKI would like to emphasize that a critical issue for the technical construction feasibility (of the KBS-3 method) is that SKB can show that there are methods for the sealing and control of canisters that are suitable in connection with series manufacturing. This means that an adequately large number of full-size canisters must be manufactured, sealed and controlled and these should be found to comply with the requirements of the long-term performance assessment.

12 Alternative Methods

In this chapter, SKI evaluates SKB's description of alternative methods which corresponds to Chapter 16 of RD&D Programme 2001.

Introduction

The Act (1984:3) on Nuclear Activities stipulates a comprehensive research and development programme. The term "comprehensive" could be interpreted as meaning that the programme must cover all aspects of science and technology that are of importance for a safe disposal. However, the Ordinance (1984:14) to the Act states that the evaluation of the programme must also take into account alternative handling and disposal methods. Therefore, the term "comprehensive" also includes comprehensiveness with respect to alternative methods. In SKI's opinion, the programmes so far presented have complied with this requirement.

Prior to the review of RD&D Programme 98, several of the feasibility study municipalities expressed uncertainty with respect to the issue of method choice. This was largely due to the fact that the authorities were previously cautious in stating their opinion on method choice, bearing in mind that the Act does not give any clear decisions regarding when the requirement on adequate comprehensiveness can be expected to be met. SKI and SSI therefore jointly presented their view on how the method choice issue could be handled within the framework of the system analysis requested by the Government in its decision on RD&D Programme 95 (SKI dnr. 5.8-971083, SSI dnr 6220/1994/97, from March 5, 1998). The full impact of this work was only seen in the RD&D Programme 98 Supplement, which resulted in a statement by the Government, in its decision on the Supplement, that the KBS-3 method should apply as the basis for planning the site investigations. However, at the same time, the Government stated, in accordance with SKI's review statement, that a method can only be ultimately approved in connection with a future position on licence applications.

The Environmental Code also stipulates the reporting of alternative methods along with a justification of the chosen method. Such a special, and already previously noted requirement is the reporting of the resulting scenario if the planned disposal is not realized, known as the zero alternative.

There are therefore three requirements on alternative reporting: one under the Act on Nuclear Activities and two under the Environmental Code. The review of RD&D Programme 2001 primarily concerns whether the proposed programme is adequate to comply with the requirements on alternative reporting in connection with licensing.

SKB's Report

SKB starts off by stating that it is "pursuing a main line with a system based on a deep disposal in accordance with the KBS-3 method." However, SKB states that, at the same time, it is working on following and supporting the development of two alternatives: *partitioning and transmutation* (S&T) as well as *deposition in deep boreholes*.

Partitioning and Transmutation

In short, the aim of transmutation can be considered to be that of converting long-lived atomic nuclei into short-lived nuclei through neuron irradiation. In this way, the radiotoxicity of the high-level waste can be reduced so that, for example, after 500 years it is on the same level as that of the spent nuclear fuel after 100,000 years. However, the end-product will still need to be disposed of in geological formations. Transmutation can be achieved in nuclear reactors, of the conventional type and in accelerator-driven systems. The energy that is released through fission can be utilized and the surplus used for electricity generation, for example. Research is being conducted on different suitable systems. However, the accelerator system is the focus of interest.

Prior to the transmutation of long-lived substances in spent nuclear fuel, they must be separated from uranium and fission products through reprocessing and a refined separation of various substances. This separation must be very efficient and only very small quantities of long-lived radioactivity may be included in the waste streams so that there is some gain from the standpoint of radiation protection. In the area of separation, a relatively large amount of work is therefore in progress.

SKB starts off by reporting the costs of different partitioning and transmutation research programmes:

- France: USD 600 million in 15 years (1991-2006).
- Japan: tens of millions of USD per year.
- USA, (Advanced Accelerator Applications): USD 68 million for 2001 (some relating to the nuclear arms programme).
- EU, Fifth Framework Programme: EUR 26-27 million in five years (1998-2002).

A study in the USA reports the following costs for a programme adapted to existing light-water reactors in the USA; over a period of 120 years the total costs would amount to about USD 110,000 million (development USD 11,000 million for 30 years, facilities USD 50-60,000 million, operation USD 500 million per year for 90 years).

SKB then briefly describes the international work in other countries:

- The EU's Fifth Framework Programme encompasses design studies of a research facility of 100 MW with construction start in twelve years and a facility cost of USD 1,200 million; the plan is also to use MOX fuel.
- For the EU's Sixth Framework Programme, a greater focus on partitioning and transmutation is recommended. However, this is an area where consensus has not been reached within the research community (due to the high cost, suspected low accessibility, radiation protection problems).
- Among the national programmes of interest, besides those already described initially, SKB mentions Switzerland, Belgium and the activity that is internationally funded in Russia.

Swedish partitioning research is conducted at the Department of Nuclear Chemistry at Chalmers Institute of Technology and, in an international perspective, through a joint EU project, PARTNEW. The research focuses on developing new and efficient extraction systems for the separation of lantanides and actinides. The extraction systems should preferably be

based on chemicals that can be incinerated without resulting ash formation, thereby contributing to keeping down the quantities of secondary waste.

Transmutation research is conducted at the Royal Institute of Technology (KTH), Stockholm and at Uppsala University.

Transmutation research at the Department of Nuclear and Reactor Physics, KTH, mainly focuses on ADS, within the areas of neutronics, burnup calculations, radiotoxicity as well as fuel and materials studies. Work is partially conducted within the framework of EU projects and the department is also co-ordinating the CONFIRM EU project, with respect to the use of plutonium-nitride fuel and testing of the fuel at the Studsvik R2 reactor. At the Department of Nuclear Safety, work is also being conducted within EU projects within the areas of technology, materials and safety issues in connection with the use of liquid metal as a coolant.

At the Svedberg Laboratory and the Department of Neutron Physics at Uppsala University, successful projects are being conducted for the measurement of neutron cross-sections at high energies. The activity is related to the HINDAS EU project.

Over the next three-year period, SKB intends to conduct research with about the same scope as at present. According to SKB, the focus should be on issues relating to safety, materials, process design and the composition of the waste streams.

Deposition in Deep Boreholes

SKB refers to the system analysis that was presented in October prior to the RD&D Programme 98 Supplement and the investigation into costs that KASAM requested in its review statement on RD&D Programme 98. According to SKB, the cost of developing the method to the same level would amount to about SEK 4,000 million and the programme would take thirty years to be completed. Considerable work would be needed within all areas, especially geoscience and deposition technology. SKB's overall conclusion is that there is nothing to indicate, at present, that a repository in deep boreholes would increase the level of safety or reduce the costs to deposit the spent nuclear fuel. SKB states that, in the future, it will follow developments within the area, since results and experience can also be useful for an understanding of the conditions in a KBS-3 type repository.

Comments by the Reviewing Bodies

The Waste Network considers that SKB still has not presented a credible method selection which is based on a comprehensive analysis of risks. The assessments made of the KBS-3 concept and alternatives indicated are not based on well-thought out performance criteria. Consequently, in the view of the Waste Network, the programme does not comply with the Environmental Code's requirements on alternative reporting.

The Waste Network Association emphasizes the basic problem of designing and siting a waste repository in groundwater-bearing rock regardless of repository depth. Instead, the Association insists that the depleted high-level nuclear fuel must be stored under surveillance until a method for safe disposal has been developed.

Chalmers Institute of Technology points out that partitioning and transmutation is not merely a waste management method but that the technical solution to the problem is connected to the

possibility of utilizing natural uranium and thorium in a much more efficient way than before for energy recovery.

The Royal Institute of Technology, Stockholm (KTH) considers that the alternatives of transmutation and deep boreholes are being given cursory treatment in RD&D Programme 2001 and emphasizes the importance of SKB continuing to support research on transmutation and especially the participation in international projects. According to KTH, this research also provides indirect support for the training of experts in nuclear technology, which is important, especially for the safety of existing nuclear power plants.

The Mehedeby-Orrskog Group considers that SKB's chapter on alternative methods is well structured. The Group maintains that partitioning and transmutation requires considerable resources and that it is therefore strange that, in this particular area, Sweden has not wished to participate in joint international or European work. The Group recommends that SKI, the Government and politicians should raise the status of this issue, which has been hitherto restricted to the municipal level and to a bygone technical generation, to the international level and the opportunities that this involves in terms of shared responsibility, sustainability and economic and technical innovation. Furthermore, in the opinion of the Group, a smaller repository may be needed in connection with transmutation, which is why the deep borehole alternative in the recharge areas is recommended.

The Municipality of Oskarshamn and the local safety committee at Oskarshamn nuclear power plant objects to the statement made by SKB in the introduction of Chapter 16 of RD&D Programme 01: "In practice, we in Sweden have already chosen the strategy of geological disposal of our spent nuclear fuel." The Municipality and the local safety committee fully support the Government's position in its decision on the RD&D Programme 98 Supplement and considers that the approach that it has already been decided how and where spent nuclear fuel and Sweden is to be managed must be counteracted.

SOS-Tierp maintains that there are so many large knowledge gaps surrounding the KBS-3 method and that, in accordance with the requirements of the Environmental Code, a comparable method alternative is lacking for the alternatives together to be able to provide a basis for planning site investigations. Furthermore, in SOS-Tierp's view, bearing in mind the need for democracy and the environmental legislative requirements on a comparable alternative method, it is not acceptable that SKB's RD&D programme on alternative methods should be reported only when SKB plans to submit an application for permission to site and construct a repository.

SSI describes its position on the need for different alternative method reports, which is largely in agreement with the introductory section of this chapter. In particular, SSI states that, according to the rules of the Environmental Code, the proponent must present alternatives. According to SSI's interpretation, the aim of this alternative reporting is primarily to be able to verify the main alternative, through comparison. SSI maintains that, in connection with decisions on detailed characterizations, it is important to contrast the KBS-3 concept with another method where the safety function has a different distribution than KBS-3. SKB should therefore conduct a safety assessment for deep boreholes based on existing data which SSI does not consider can be as reliable as those for KBS-3. SSI points out that such a comparison does not mean choosing between KBS-3 and deep boreholes but that it should lead to a more comprehensive and in-depth understanding of safety and the risk analysis for the proposed solution.

Stockholm University, Unit for Paleogeophysics & Geodynamics considers that the DRD method (Dry Rock Deposit) has not been adequately reported and that an adequate investigation should be conducted to do justice to the method and its developers.

The Municipality of Tierp considers that it is important that research on alternative methods should be continuous and goal-oriented and conducted at such a rate that a report can be presented in connection with the preparation of EIS for deep disposal.

Umeå University supports the present position, focusing on the KBS-3 method, providing that developments within a few other areas, such as partitioning and transmutation, are followed at the same time.

Uppsala University (UU) considers that SKB's reluctance with respect to the financing of activities within the partitioning and transmutation area can be strongly questioned, particularly bearing in mind that work in other countries is expected to increase considerably. According to UU, Sweden, with its relatively large share of nuclear power, should at least increase its efforts so as to match the work conducted within the EU.

In the view of the Science Research Council, it would be positive if SKB considerably increased its work within alternative methods so that it can be decided whether an alternative really does exist by the date that a decision is to be taken on the repository.

SKI's Evaluation

General Comments on SKB's Account of Alternative Methods

The Act on Nuclear Activities clearly stipulates disposal and that the nuclear power industry should provide and bear the cost of disposal. Naturally, the purpose of the stipulation is that it is indefensible to have a method that merely involves continued monitored storage of the nuclear waste and passes on the responsibility for the final management and disposal to future generations and, in principle, to other parties than the nuclear power industry. This responsibility must be borne by the industrial companies that have generated the waste.

If, first of all, the different types of nuclear waste are considered, it is only necessary to have an in-depth discussion on the management of the spent nuclear fuel. (The fact that, according to the Act on Nuclear Activities, spent nuclear fuel is only designated nuclear waste once it has been deposited in a repository is not taken into account). The reason is that all other types of nuclear waste, or rather their inventory of radioactive substances have to be disposed of in their existing form, although the waste may be given a suitable pre-treatment, taking into account the intended method of final disposal.

With respect to the management of spent nuclear fuel, only two possible *strategies* exist: disposal in the existing form (direct disposal) and reprocessing, possibly followed by partitioning and transmutation, and final disposal of the generated waste. Both of these strategies entail geological disposal as a final stage. Geological disposal can, if it is to be conducted in Sweden, only be designed as disposal in a tunnel system or borehole where the waste is maneuvered from the surface.

The above discussion shows that, as far as Sweden is concerned, geological disposal is involved in both strategies: partitioning and transmutation and direct disposal. SKB is correct to some extent in stating that "we in Sweden have already chosen the strategy of geological disposal". However, according to the description of the choice of method in connection with the supplement to RD&D Programme 98, partitioning and transmutation are not per definition included in the strategy of "geological disposal". Instead, this refers to direct disposal of spent nuclear fuel.

To a certain extent, the Municipality of Oskarshamn would be correct in maintaining that SKB's statement anticipates the ultimate choice of method. However, only to the extent that partitioning and transmutation are included in the possible alternatives. However, the arguments against this alternative have been clearly stated by the authorities in their review statements on RD&D Programme 98 and in the RD&D Programme 98 Supplement.

Nevertheless, SKI can agree with the Municipality of Oskarshamn that SKB's statement could be misinterpreted by those who are not familiar with these conditions to mean that the choice of method within the framework of the strategy of direct disposal based on geological disposal is already decided. In addition to SKB's main alternative, KBS-3, there are still a number of alternatives within this strategy such as very deep boreholes (VDH) and very long holes (VLH).

Another conclusion from the above line of reasoning is that the partitioning and transmutation strategy also complies with the legislative requirements in principle: it is a strategy that also leads to disposal. The research that SKB conducts within this area must therefore be considered to be relevant in the sense of the Act on Nuclear Activities, even if the current political opinion in Sweden does not agree with such a solution.

Partitioning and Transmutation

The evaluation of SKB's research within partitioning and transmutation is complicated by several factors:

- It is a question of extremely cost-intensive research and development where the Swedish funding will always be marginal.
- The driving force behind the development of a partitioning and transmutation system will be beyond the control of SKB and Sweden within the foreseeable future.
- Sweden lacks the political conditions for the application of partitioning and transmutation.
- There is still considerable uncertainty regarding if, and when functioning systems that meet reasonable requirements on efficiency will become available.

From the compilation of SKB's information on the cost of different programmes provided in Chapter16, it can be seen that the overall amount per year is estimated at USD 100-200 million. This can be compared with the US DOE's estimate which corresponds to about USD 350 million per year (for a period of 30 years). (The USDOE's figures apply for about 10 times more spent nuclear fuel than the Swedish programme, which also corresponds to about SEK 100,000 million).

The cost of work currently conducted on partitioning and transmutation in Sweden is estimated at SEK 5-6 million per year. However, in relation to Sweden's share of the world's

total nuclear capacity, this figure would be about 5-10 times greater in order to match the global work.

In SKI's opinion, the work that is currently being carried out is sufficient to actively follow and contribute to the international developments in a meaningful way. This is a minimum level that should not be reduced. However, if Swedish nuclear power had been in an expansion phase, a greater effort would have been justified.

In SKI's view, SKB's partitioning and transmutation programme has a suitable direction which covers everything from basic research to technical development. System and safety-related research as well as work on project co-ordination are particularly valuable since they provide a good insight into major international programmes at a reasonable cost.

Furthermore, SKI emphasizes that the research in partitioning and transmutation is one of the few areas in nuclear technology that can still attract young and committed researchers. The work that is being conducted in partitioning and transmutation in Sweden must therefore be considered to be a stage in the maintenance of expertise in nuclear subjects, particularly reactor physics and nuclear chemistry. This is also the reason why SKI also funds research in partitioning and transmutation for an amount of SEK 0.5 million per year.

Deep Boreholes

SKI agrees with SSI that deep boreholes are the alternative to the design of a geological repository that most deviates from the KBS-3 method. However, at the same time, in SKI's opinion, a number of questions must be answered before deep boreholes can be considered as an alternative in connection with licensing under the Environmental Code:

- To what extent should such an alternative be available, tried and tested and at what cost?
- How well must such an alternative meet important requirements of principle such as the requirement that there must be several barriers if it is a question of the disposal of long-lived, high-level waste?

In its review statement, SSI considers that SKB should prepare a safety assessment for this alternative and that this can be done using existing data. In SKI's opinion, it cannot, in that case, be a question of a complete safety assessment in the sense of KBS-3-type repositories. Under such conditions, SKI can support the idea of a limited safety assessment as a stage in a broader discussion on different alternatives, more or less in accordance with the opinions provided in SSI's statement.

However, in SKI's opinion, it is too early to adopt a position, at this stage, on alternatives for licensing under the Environmental Code. Such alternatives should be developed within the framework of the forthcoming Environmental Impact Assessment (EIA) work.

SKI's Overall Evaluation

The review of RD&D Programme 2001 primarily concerns whether the proposed programme is adequate to be able to meet the requirements on alternative reporting in connection with the licensing of the encapsulation plant and repository for spent nuclear fuel.

In SKI's view, the work currently being conducted on separation and transmutation is enough to follow and contribute, in a meaningful manner, to international development. However, in view of the current level of work in this area, this work should not be reduced. The work is also important for the maintenance and further development of national expertise which is required for the safe disposal of nuclear waste.

In its statement of opinion, SSI stated that SKB should prepare a safety assessment for the deep borehole alternative and that this could be conducted using existing data. In SKI's view, such a safety assessment would not be a comprehensive safety assessment in the sense that the term is used for repositories based on the KBS-3 method. Under such circumstances, SKI can support the idea of a safety assessment as a step in a broader discussion of different alternatives. In SKI's view, the need for and scope of a safety assessment for deep boreholes, should be discussed within the framework of the consultation process between SKB and the authorities that the Government decided on in 1996 and 2001.

13 Decommissioning of Nuclear Facilities

In this chapter, SKI evaluates SKB's description of the decommissioning of nuclear facilities which corresponds to Chapter 17 of RD&D Programme 2001.

With the closure of Barsebäck 1 in 1999, the planning for the future decommissioning of nuclear facilities has come into focus.

SKB's Report

SKB notes that the owner of a nuclear facility must ensure that it is decontaminated and dismantled to an adequate extent once it has been taken out of service. SKB is conducting general studies to ensure that technology and expertise are available and is performing cost estimates for decommissioning. The nuclear power plants are responsible for the planning, decommissioning etc. of their own facilities. The management of the waste is co-ordinated by SKB.

SKB's plan is that the nuclear power plants will be operated for a period of 40 years and then be decommissioned as soon as possible. However, no dismantling is to start as long as adjacent reactor units are in operation. A further condition for dismantling is that a repository for short-lived decommissioning waste should be ready and that there should be a capacity to store the long-lived waste.

SKB presents a general timetable, where the operation of SFR-3, the operation of the interim storage facility for core components and the dismantling of (the first) nuclear power plants will occur in 2014.

SKB's decommissioning and technology studies have primarily used data from abroad. In SKB's view, the technology for decommissioning exists and SKB needs to adapt it to Swedish conditions.

SKB expects that the dismantling of a nuclear power plant will take about 6 years and one to two years for the removal of the spent nuclear fuel. Waste volumes for long-lived waste are estimated at about 1,000 m^3 for a nuclear power plant.

SKB is following the work within the IAEA, OECD/NEA and EU within the decommissioning area. SKB's own development programme for the next six years within decommissioning will focus on methods for dry interim storage of core components, documentation within decommissioning, waste registration systems, dose calculations in connection with decommissioning, safety assessments etc.

Comments by the Reviewing Bodies

The Mehedeby-Orrskog Group considers that the question of the handling of core components and other long-lived waste from the decommissioning of nuclear power plants should be resolved before a decision is made on test drilling.

In its review statement to SKI, SSI maintains that the waste producers and SKB should review the entire chain from the producer of the decommissioning waste to the disposal of the waste.

The term “decommissioning waste” also includes inactive waste. The entire management chain should be visualized, and the quantification of the waste, the disposal or recycling should be described in detail. Furthermore, SSI would like to see dose estimates for decommissioning work as well as descriptions of the possible environmental impact of the activity on different decommissioning scenarios. Furthermore, SSI considers that the issue of long-lived waste management must be prioritized in the RD&D programme.

Of the other reviewing bodies, Stockholm University, Department of Physics states that the siting of long-lived decommissioning waste must be clarified before the licensing of a repository for high-level waste (spent nuclear fuel) has been decided.

SKI’s Evaluation

In SKI’s opinion, SKB is handling the issue of the decommissioning and dismantling of nuclear power plants in an ambitious manner. This is also reflected in SKB’s RD&D Programme 2001. In SKI’s view, technology is available abroad for the decommissioning and phase-out of facilities and this can be adapted to Swedish conditions. SKB’s plans to have a repository for short-lived decommissioning waste (SFR-3) ready by around 2015 have been accepted by SKI.

SKB’s view that nuclear power reactors in Sweden (apart from Barsebäck 1) are recommended to be operated for 40 years before they are decommissioned and dismantled as quickly as possible, is acceptable from a purely technical standpoint. However, since there are significant uncertainties associated with the financial and political variables, it is reasonable to request that it should be possible for all types of decommissioning waste to be placed in interim storage or to be disposed of already from 2015. With respect to long-lived decommissioning waste, which is intended to be deposited in the planned SFL 3-5 repository, SKI’s opinion is that it is reasonable to request that SKB should prepare a new safety assessment for SFL 3-5 within a ten-year period, which is what SKB has planned to do.

SKI notes that the long-lived waste, for logistic reasons, runs the risk of becoming a bottleneck in the handling in connection with a rapid close-down of a reactor in around 2015, unless the planning of an interim storage facility for this category of waste is started as soon as possible.

Furthermore, SKI shares SSI’s view that, the RD&D reports should more clearly state that it is the nuclear facilities, in their capacity of licensees (under the Act on Nuclear Activities) and waste producers, which have the overall responsibility for the dismantling of the facilities as well as for the management of the decommissioning waste. The licensees can only transfer this responsibility to a limited extent to SKB.

14 Other Long-lived Waste

In this chapter, SKI evaluates SKB's description of long-lived waste which corresponds to Chapter 18 of RD&D Programme 2001.

Introduction

In addition to the spent nuclear fuel, long-lived low and intermediate-level waste is managed. The intention is to dispose of this waste in SFL 3-5.

The different types of long-lived low and intermediate-level waste that must be managed can be divided into two main groups:

- Waste from maintenance and decommissioning of nuclear power plants, including certain reactor internals (core components).
- Long-lived waste from industry, research and health care.

SKB has not yet decided whether SFL 3-5 is to be co-sited with SFL 2, at SFR 1, or in a completely different location. According to SKB's timetable, this issue will not be resolved before around 2035.

SKB has studied two possible repository designs with either bentonite or gravel as backfill. The primary barrier to the transport of radionuclides is concrete enclosures.

SKB's Report

To obtain a better picture of the uncertainties associated with the radionuclide inventory of the waste, SKB will follow this up in a similar manner as for the SFR-1 waste.

SKB states three reasons for changing the original repository layout with a bentonite backfill to a layout with a gravel backfill. The first reason is SKB's sound experience from the construction, operation and safety assessment of the BMA rock vault in SFR 1. The second is that SKB would like to simplify the repository by having as few components as possible. The third reason is that the gas that can be formed could more easily leave the enclosure than if the bentonite barrier had been chosen.

SKB reaches the following conclusions from its preliminary safety assessment (SKB, 1999):

To reduce the uncertainties in the calculated environmental impact, research should particularly focus on the radionuclides that most contribute to the dose; in this case Cl-36 and Mo-93. Site-specific properties that are important for safety include the water flow at repository depth and the ecosystem from which releases can occur in the future.

SKBdescribes the processes that have been found to be of importance for the long-term barrier properties and that have been developed by SKB-supported research and by international investigations in the area:

- The leaching of the cement and concrete at a high pH. This has been studied in natural analogue studies, including in situ experiments in Jordania (Maqarin).

- Reactions between the leaching products from cement and the surrounding gravel backfill. In an international project, the British Geological Survey investigated how cement pore water has affected the rock.
- Steel and aluminum corrosion.
- Microbial degradation of organic material in the waste.
- Gas pressure buildup in the waste packages and concrete structures.
- Calcite and brucite precipitation.
- The alkaline degradation of the cellulose in the waste.

The following areas are prioritized in SKB's development programme for the next few years (2002-2007):

- Preparations for future safety assessments.
- Handling and storage of waste.
- Properties of the groundwater and concrete in the repository.
- The diffusion and sorption properties of the concrete at a high pH.
- The impact of organic substances as well as metal corrosion in the concrete.
- The impact of salt water on the concrete.

Comments by the Reviewing Bodies

The Waste Network would like to see a coherent safety assessment for SFL 3-5 waste.

The Mehedeby-Orrskog Group and SOS Älvkarleby would like to see a report of how SFL 3-5 waste will be managed before site investigations start.

In SSI's view, SKB should prepare a strategy document for the disposal of long-lived waste, which, for example, deals with issues relating to facility design and process understanding as well as the siting of the SFL 3-5 repository.

In SSI's opinion, SKB should also update its safety assessment for SFL 3-5 and evaluate alternative repository designs. Furthermore, SSI considers that SKB should prepare guidelines for the treatment and characterization of SFL 3-5 waste.

Stockholm University, Department of Physics, raises the question of the siting of SFL 3-5 and considers that this issue must be clarified before a decision is made concerning the licensing of SFL 2.

The Municipality of Tierp would like to see a description of the consequences that transportation of waste to SFL 3-5 involves.

In the opinion of the Municipality of Älvekarleby, it is important for SKB to state the requirements and criteria for a co-siting of SFL 3-5 and SFL 2.

The Municipality of Östhammar considers that SKB should expand its research on issues within the area of other long-lived waste.

SKI's Evaluation

SKI is positive to the fact that the present report is considerably more detailed compared to the report of SKB's research and development plans for the SFL 3-5 repository presented in RD&D Programme 98. In SKI's opinion, RD&D Programme 2001 lacks an overall account of the research projects and design studies which will be the basis of the safety assessment that will be based on site-specific data for the SFL 2 repository (2009).

SKB's description of what will be included in the future safety assessment must be considered to be limited and therefore difficult to evaluate. Therefore, in SKI's opinion, SKB should provide an account of this in the forthcoming RD&D programmes (RD&D 2004 and RD&D 2007).

At these times, SKB should provide a coherent report that justifies the design basis that must apply to the repository from the standpoint of long-term safety. Issues that must be clarified in greater detail include the choice of repository depth, separation distance between SFl 3-5 and SFL 2, backfill material, the principle of the hydraulic cage, the dimensions of the repository, the quantity of cement, the chemical composition of cement etc. Furthermore, SKB should state the requirements that must be made on a possible candidate site for it to correspond to the requirements on the proposed design of SFL 3-5 (SKI, 2001).

SKI is positive to the fact that SKB will follow up the uncertainties in the nuclide inventory of the waste and the quantities that can occur. SKI agrees with SSI that SKB should prepare guidelines for the characterization and treatment of the waste.

SKB's proposal to reduce the uncertainties in the estimated environmental impact from SFL 3-5 by concentrating on the radionuclides that contribute most to the dose (Cl-36 and Mo-93) is reasonable but SKB must make preparations to also study other nuclides. Since the preliminary safety assessment has not taken into account all of the uncertainties in a comprehensive manner, it cannot be excluded that other nuclides can also give a significant contribution. Furthermore, the repository design can have a certain importance for which radionuclides dominate the doses.

In SKI's opinion, SKB needs to present a better process model which describes the long-term degradation of concrete in comparison with that utilized in the preliminary safety assessment (SKB, 1999). A more detailed description of how saline groundwater affects the long-term properties of the concrete is also required.

SKB assumes that the concrete structure may have a number of cracks from the start and does not consider that this has a negative effect on long-term safety. In SKI's opinion, SKB should conduct an analysis that shows the size and the number of cracks that can be allowed in different time-perspectives without a substantial deterioration in the capability of the concrete to protect against radionuclide leaching.

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