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International Expert Review of Sr-Can: Safety Assessment Methodology

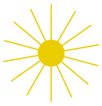
External review contribution in support of SSI's and SKI's review of SR-Can

Budhi Sagar et. al

STATENS KÄRNKRAFTINSPEKTION
Swedish Nuclear Power Inspectorate

Statens strålskyddsinstitut
Swedish Radiation Protection Authority

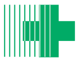
SSI's Activity Symbols



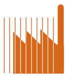
Ultraviolet, solar and optical radiation
Ultraviolet radiation from the sun and solariums can result in both long-term and short-term effects. Other types of optical radiation, primarily from lasers, can also be hazardous. SSI provides guidance and information.

Solariums
The risk of tanning in a solarium are probably the same as tanning in natural sunlight. Therefore SSI's regulations also provide advice for people tanning in solariums.

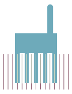
Radon
The largest contribution to the total radiation dose to the Swedish population comes from indoor air. SSI works with risk assessments, measurement techniques and advises other authorities.



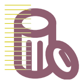
Health care
The second largest contribution to the total radiation dose to the Swedish population comes from health care. SSI is working to reduce the radiation dose to employees and patients through its regulations and its inspection activities.



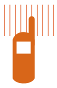
Radiation in industry and research
According to the Radiation Protection Act, a licence is required to conduct activities involving ionising radiation. SSI promulgates regulations and checks compliance with these regulations, conducts inspections and investigations and can stop hazardous activities.



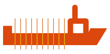
Nuclear power
SSI requires that nuclear power plants should have adequate radiation protection for the generalpublic, employees and the environment. SSI also checks compliance with these requirements on a continuous basis.



Waste
SSI works to ensure that all radioactive waste is managed in a manner that is safe from the standpoint of radiation protection.



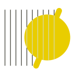
Mobile telephony
Mobile telephones and base stations emit electromagnetic fields. SSI is monitoring developments and research in mobile telephony and associated health risks.



Transport
SSI is involved in work in Sweden and abroad to ensure the safe transportation of radioactive substances used in the health care sector, industrial radiation sources and spent nuclear fuel.

Environment
"A safe radiation environment" is one of the 15 environmental quality objectives that the Swedish parliament has decided must be met in order to achieve an ecologically sustainable development in society. SSI is responsible for ensuring that this objective is reached.

Biofuel
Biofuel from trees, which contains, for example from the Chernobyl accident, is an issue where SSI is currently conducting research and formulating regulations.



Cosmic radiation
Airline flight crews can be exposed to high levels of cosmic radiation. SSI participates in joint international projects to identify the occupational exposure within this job category.

Electromagnetic fields
SSI is working on the risks associated with electromagnetic fields and adopts countermea-sures when risks are identified.

Emergency preparedness
SSI maintains a round-the-clock emergency response organisation to protect people and the environment from the consequences of nuclear accidents and other radiation-related accidents.

SSI Education
is charged with providing a wide range of education in the field of radiation protection. Its courses are financed by students' fees.

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Swedish Nuclear Power Inspectorate

Foreword

The work presented in this report is part of the Swedish Nuclear Power Inspectorate's (SKI) and the Swedish Radiation Protection Authority's (SSI) SR-Can review project.

The Swedish Nuclear Fuel and Waste Management Co (SKB) plans to submit a license application for the construction of a repository for spent nuclear fuel in Sweden 2010. In support of this application SKB will present a safety report, SR-Site, on the repository's long-term safety and radiological consequences. As a preparation for SR-Site, SKB published the preliminary safety assessment SR-Can in November 2006. The purposes were to document a first evaluation of long-term safety for the two candidate sites at Forsmark and Laxemar and to provide feedback to SKB's future programme of work.

An important objective of the authorities' review of SR-Can is to provide guidance to SKB on the complete safety reporting for the license application. The authorities have engaged external experts for independent modelling, analysis and review, with the aim to provide a range of expert opinions related to the sufficiency and appropriateness of various aspects of SR-Can. This report presents an international expert evaluation of the safety assessment methodology used in SKB's SR-Can assessment. It is one of three parallel reviews by international expert teams, which have been undertaken to support the regulatory review by SKI and SSI. In addition to this review, separate teams were established to review SKB's handling of information from the site investigations and the representation of the engineered barrier system (EBS) in the safety assessment.

The conclusions and judgements in this report are those of the authors and may not necessarily coincide with those of SKI and SSI. The authorities own review will be published separately (SKI Report 2008:23, SSI Report 2008:04 E).

Björn Dverstorp (project leader SSI)　　Bo Strömberg (project leader SKI)

Förord

Denna rapport är en underlagsrapport till Statens kärnkraftinspektions (SKI) och Statens strålskyddsinstituts (SSI) gemensamma granskning av Svensk Kärnbränslehantering AB:s (SKB) säkerhetsredovisning SR-Can.

SKB planerar att lämna in en ansökan om uppförande av ett slutförvar för använt kärnbränsle i Sverige under 2010. Som underlag till ansökan kommer SKB presentera en säkerhetsrapport, SR-Site, som redovisar slutförvarets långsiktiga säkerhet och radiologiska konsekvenser. Som en förberedelse inför SR-Site publicerade SKB den preliminära säkerhetsanalysen SR-Can i november 2006. Syftena med SR-Can är bl.a. att redovisa en första bedömning av den långsiktiga säkerheten för ett KBS-3-förvar vid SKB:s två kandidatplatser Laxemar och Forsmark och att ge återkoppling till SKB:s fortsatta arbete.

Myndigheternas granskning av SR-Can syftar till att ge SKB vägledning om förväntningarna på säkerhetsredovisningen inför den planerade tillståndsansökan. Myndigheterna har i sin granskning tagit hjälp av externa experter för oberoende modellering, analys och granskning. Denna rapport redovisar en internationell expertgranskning av den metodik för säkerhetsanalys som använts i SKB:s säkerhetsredovisning SR-Can. Det är en av tre parallella internationella expertgranskningar som SSI och SKI organiserat som stöd för myndigheternas egen granskning. De två övriga internationella expertgrupperna har granskat SKB:s användning av data från platsundersökningarna respektive hanteringen av de tekniska barriärerna i säkerhetsanalysen.

Slutsatserna i denna rapport är författarnas egna och överensstämmer inte nödvändigtvis med SKI:s eller SSI:s ställningstaganden. Myndigheternas egen granskning publiceras i en annan rapport (SKI Rapport 2008:19; SSI Rapport 2008:04).

Björn Dverstorp (projektledare SSI) Bo Strömberg (projektledare SKI)

Contents

Summary

In 2006, SKB published a safety assessment (SR-Can) as part of its work to support a licence application for the construction of a final repository for spent nuclear fuel. The report represented the culmination of work conducted by SKB over several years, focusing on the goal of making the licence application in late 2009. Results from the SR-Can project have been documented in several reports, with the main technical report being TR-06-09, published in October 2006.

The purposes of the SR-Can project were stated in the main project report to be:

1. To make a first assessment of the safety of potential KBS-3 repositories at Forsmark and Laxemar to dispose of canisters as specified in the application for the encapsulation plant.

2. To provide feedback to design development, to SKB's research and development (R&D) programme, to further site investigations and to future safety assessments.

3. To foster a dialogue with the authorities that oversee SKB's activities, i.e. the Swedish Nuclear Power Inspectorate, SKI, and the Swedish Radiation Protection Authority, SSI, regarding interpretation of applicable regulations, as a preparation for the SR-Site project.

To help inform their review of SKB's proposed approach to development of the long-term safety case, the authorities appointed three international expert review teams to carry out a review of SKB's SR-Can safety assessment report. Comments from one of these teams – the Safety Assessment Methodology (SAM) review team – are presented in this document. It is expected that these will be considered, alongside those from the other two teams, by the regulatory authorities in developing their own view of SKB's approach. As the three teams conducted their reviews independently, the reader is encouraged to read the reports of all the three teams in order to obtain a fuller picture of the overall evaluation.

The SAM review team's scope of work included an examination of SKB's documentation of the assessment ("Long-term safety for KBS-3 Repositories at Forsmark and Laxemar – a first evaluation" and several supporting reports) and hearings with SKB staff and contractors, held in March 2007. The hearings provided an opportunity for the review teams to discuss the SR-Can safety assessment with the authors and contributors to SKB's work.

As directed by SKI and SSI, the SAM review team focused on methodological aspects and sought to determine whether SKB's proposed safety assessment methodology is likely to be suitable for use in the future SR-Site and to assess its consistency with the Swedish regulatory framework. The team was requested to make recommendations regarding what, if any, revisions may be needed by the time a licence application is made for repository construction. No specific evaluation of long-term safety or site acceptability was undertaken by any of the review teams.

SKI and SSI's Terms of Reference for the SAM review team (Appendix 1) requested that consideration be given to, and recommendations made on, the following issues:

- Strategy for safety demonstration and structuring of different arguments in the safety case, including allocation of safety to different barriers, expression of confi-

dence, use of risk and other safety indicators, quality assurance, optimisation, etc.;

- Traceability and transparency aspects and the suitability of the report hierarchy;
- Methods to demonstrate completeness and the handling of FEPs;
- Selection of scenarios in relation to regulatory guidance and the role of function indicators;
- Methods for handling uncertainties;
- Methods for consequence calculation and presentation of risk results.

SKB considers that the structure and methodology presented in SR-Can will be very similar to that used in SR-Site, although they point to many areas where more detailed treatment might be expected. Thus, a key aspect of the SAM review team's evaluation of methodology was to consider whether the structure and approach is appropriate to fulfil regulatory requirements. The team also decided to identify areas where further elaboration appears to be necessary, or would be useful for comprehension.

The SAM review team recognises that SR-Can is a significant piece of work, building on several decades of safety assessment methodology development, each major step of which has been documented by SKB and reviewed by the regulatory authorities or other organisations. This particular step of SKB's methodology development is especially important as it presents the final opportunity for the authorities to influence the content of the actual licensing submission safety case, SR-Site, currently scheduled for release in late 2009.

In broad terms, the SAM review team concludes that, through SR-Can, SKB has made an excellent job of evaluating the long-term safety of their proposed spent fuel repository, according to requirements for compliance demonstration established by the Swedish regulatory authorities. There appear to be no major gaps in the methodology itself, although there are a number of places where the thread of argument can only be traced with some difficulty. The major part of the team's commentary therefore relates to areas where clarity could be improved, where there is a need for more information to be provided, and where it is considered that the structure of the assessment might usefully be amended for SR-Site, in order to support a robust and convincing overall safety case.

In this context it is worth recognising that a long-term safety case needs to provide a broad, integrated view of the various issues that will support the further refinement and development of confidence in post-closure safety performance for the repository (IAEA, 2006; NEA, 2004). Although the focus of the evaluation presented here was on the methodology for safety assessment, it is evident from the review team's terms of reference (not least the reference to SKB's "strategy for safety demonstration") that SKI's and SSI's interests extend beyond the structure and composition of the assessment itself. By itself, safety assessment is but one thread of the wider strategy for building confidence in implementation of KBS-3 for deep disposal, which also includes ongoing R&D, engineering demonstration, monitoring and inspection, management systems, etc. It is the linkage between such issues and the safety assessment in relation to building an integrated safety case that is perhaps one of the weaker aspects of SR-Can. This underlines the importance of framing the assessment itself, its inputs and outputs, within the wider context of what will be required to support the licence application.

In view of the above, and the fact that SKB has acknowledged that some further development work remains to be done, the SAM review team believes that it remains a challenge for SKB to conduct and present a safety case of suitable quality within the currently proposed timescale for delivery of the SR-Can assessment and the 2009 licence application.

1 Introduction

1.1 Background

In Sweden, the nuclear power industry is responsible for managing and disposing of all radioactive waste generated by its plants. To meet this responsibility, the owners of nuclear power plants formed Svensk kärnbränslehantering AB (SKB, or the Swedish Nuclear Fuel and Waste Management Company). Starting in the 1970s, SKB has developed a system for management and disposal of various types of radioactive waste. The system includes a ship for transport, a repository for operational waste (SFR) and a central interim storage for spent fuel (CLAB). Through its research, SKB has developed a basic concept of a deep geological repository in Swedish crystalline bedrock for the permanent disposal of spent fuel. This Swedish concept has become known as KBS-3.

The reference KBS-3 concept is depicted in Figure 1. Its primary components are a copper canister with cast iron insert encapsulating the spent nuclear fuel, and emplacement of the canisters in disposal holes, surrounded by a bentonite backfill, at a depth of about 500 m. A number of variants of the reference KBS-3 concept (including the possibility of horizontal, rather than vertical, emplacement of the canisters) continue to be studied. Formal legal consent for SKB's disposal plans, including a decision on a repository site, has not yet been given. However, SKB is currently conducting detailed surface-based site investigations in two Swedish municipalities, Oskarshamn and Östhammar

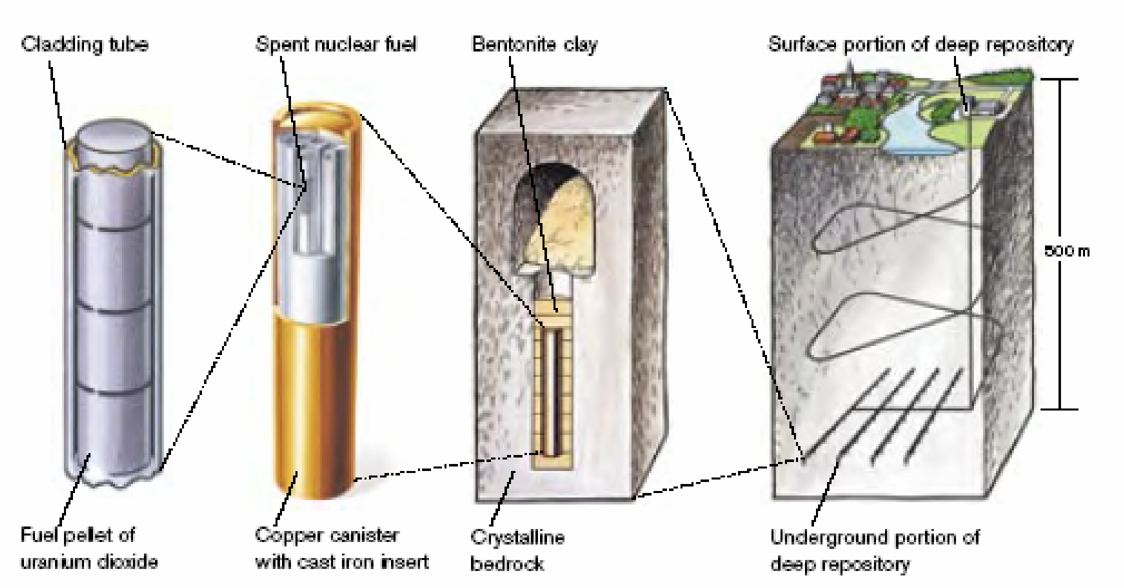

Figure 1: The KBS-3 concept for disposal of spent nuclear fuel (picture from SKB)

SKB plans to submit a licence application in late 2009 for the construction of a geological repository at a preferred site. The licence application will be supported by a range of technical documentation, including assessments of post-closure safety for a disposal facility based on the KBS-3 concept (SR-Site). Although the final decision on SKB's application will be taken by the Swedish government, regulatory responsibility for licensing lies with the authorities, the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Authority (SSI). SKI and SSI will therefore conduct a thorough review of SKB's safety case and supporting technical assessments.

SKB has undertaken the SR-Can project (SKB, 2006a) as a demonstration of its approach to long-term safety assessment for regulatory compliance purposes. Indeed, it is expected that the long-term assessment presented in SR-Site will be based on a methodological approach that is broadly the same as that adopted for the SR-Can assessment. However, it is expected that more information will be available by the time of licence submission from the site investigation programmes, alongside other aspects of environmental impact assessment, to support the selection of the preferred site and to underpin safety demonstration.

The aim of undertaking the SR-Can study has been to provide an opportunity for SKI and SSI to review and comment on SKB's proposed approach before it is used in support of a formal licence application. The intention is therefore that the authorities' response should indicate where revisions may be necessary prior to completion of SR-Site.

Within the SR-Can report, SKB presents its assessment approach as a further development over that used in previous published safety assessments for the KBS-3 disposal concept, including SR 97 (SKB, 1999) and the Interim SR-Can report (SKB, 2004). In developing the proposed approach, SKB has responded to review comments and suggestions from the authorities (SKI and SSI, 2001; SSI and SKI, 2005), and those of international review groups appointed to evaluate SR 97 (NEA, 2000) and the Interim SR-Can report (Sagar et al., 2004).

Three new international review teams were appointed by SKI and SSI in 2006 to carry out a review of the SR-Can documentation. This report presents the conclusions of one of those teams, the Safety Assessment Methodology (SAM) review team. The constitution of the SAM review team and its terms of reference are described in Appendix 1. Comments from all three of the teams will be considered by the regulatory authorities in developing their own response to SKB's SR-Can reports.

1.2 Review Scope and Methodology

Members of the SAM review team were individually selected by SKI and SSI based on their qualifications and experience (Appendix 2). In conducting the review, a primary consideration has been the recognition that the SR-Can report is primarily intended to be a description and illustration of approach and methodology, using interim data from the site investigations, rather than a comprehensive safety case. Whilst it sets out SKB's intentions regarding strategy for demonstrating compliance with regulatory requirements, and includes results from the application of modelling tools, no firm conclusions are drawn regarding overall acceptability of the concept or the identification of a preferred site.

The role and scope of work of the SAM review team were established by the authorities (Appendix 1). In particular:

"The review teams should evaluate the methods and basis for SKB's safety assessment and compare with the corresponding state-of-the-art used in other countries. The international perspective on SKB's safety assessment work provided by the review teams will be a significant input to the authorities own review of SR-Can... The first review team should include an assessment of SKB's compliance (or rather possibility to comply at the time of SR Site) with the above mentioned regulations and guidelines."

Specifically, therefore, the SAM review team has evaluated SKB's safety assessment methodology in terms of its suitability for compliance demonstration and in relation to international approaches.

The SR-Can main report (SKB, 2006a) provides an overall view of SKB's approach to safety assessment. The methodology itself is limited to assessing the long-term safety (or post-closure safety) of the proposed KBS-3 repository concept; the pre-closure or operational safety of the encapsulation plant and the repository is not considered. The Interim Main Report is structured to reflect a "systems" or "safety assessor's" view, such that the distribution of topics and the level of detail broadly follow the 10 steps (pages 50 of the main report) that constitute the methodology. SKB's outline representation of the methodology is reproduced in Figure 2.

The way in which the main report is structured did not easily lend itself to its division among the review team members according to specific technical areas; all five members therefore reviewed the entire report and then focused attention on those parts that best corresponded to their individual experience and expertise. Portions of the various supporting documents were reviewed by individual members of the SAM review team as required.

The first step in SKB's 10-step methodology for safety assessment (see Figure 2) is the processing of features, events and processes (FEPs) for consideration in the safety analysis. One of SKB's supporting reports (SKB, 2006b) describes the FEP analysis procedures, as well as the software tool used to document the outcome of the analysis and the methods by which the FEP database is maintained. Biosphere FEPs were excluded from the published version of the database.

The second step of SKB's assessment methodology involves description of the initial state of the repository and its environment. A more detailed description of the assumed state of the fuel and engineered components of the system immediately after deposition, according to design basis adopted for the SR Can assessment, is described in the Initial State report (SKB, 2006c).

Next, in Step 3, a description of the factors and assumptions relating to external conditions that influence the evolution of the disposal system, according the three main categories: "climate related issues", "large-scale geological processes and effects" and "future human actions". The handling of these factors is described in separate supporting documents (SKB, 2006d; 2006e; 2006f). In parallel with this (Step 4), all the processes identified within the disposal system that are considered relevant to its long-term evolution are identified. In support of SR-Can, supporting process reports have been developed for the fuel and canister (SKB, 2006g), buffer and backfill (SKB, 2006h) and geosphere (2006e). A corresponding process report for the biosphere was described by SKB as being under development, but was not available as an input to the review (see Section 6.1.2 of the SR-Can main report).

The remaining steps in the methodology are presented and described in the Main Report itself (SKB, 2006a). However, supporting information relating to the assessment is also collected together in key supporting documents. Input data used in the safety analysis are described in the Data report (SKB, 2006i). A separate supporting document is also provided which summarises the models used to support the assessment (SKB, 2006j).

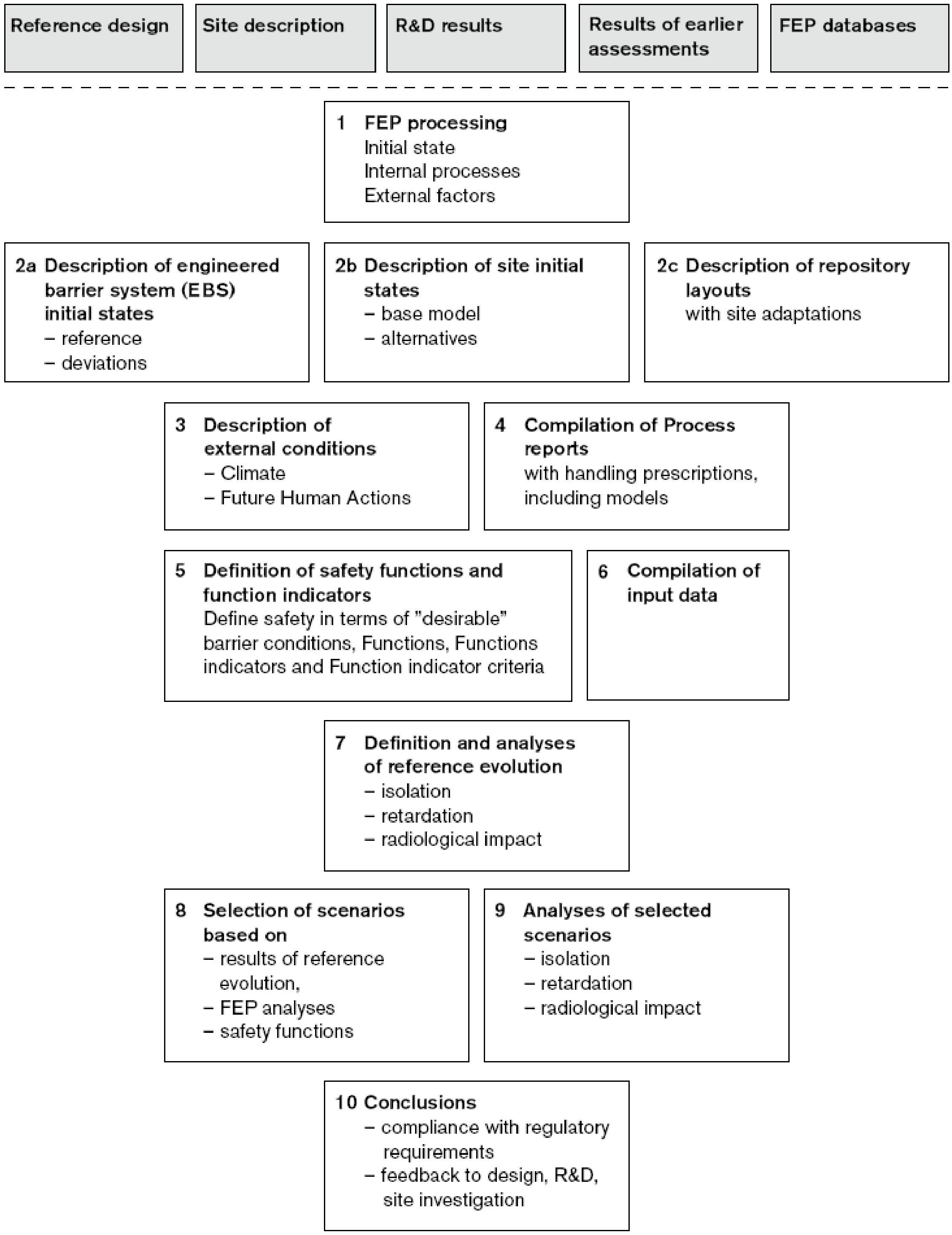

Figure 2: An outline of the 10 main steps of the SR-Can Safety Assessment Methodology. The boxes at the top above the dashed line are inputs to the assessment (SKB, 2006a)

The SAM review team did not have time to examine the many technical reports and papers referenced in either the main report or the various supporting documents. These more detailed technical documents are likely to have a bearing on various aspects of the forthcoming SR Site assessment, for example through providing justification for data and assumptions adopted in the safety analysis. However, the focus of the SAM review team’s work was on the methodology applied, rather than on specific results and conclusions reached in the Main Report or the detailed judgments made in the supporting documents. The SR-Site documentation will need to provide a fully traceable and comprehensive audit trail so that the Swedish authorities can trace key lines of evidence relied on in the safety analysis to the relevant supporting information.

In the weeks following receipt of the documents provided in November 2006, members of the review team undertook an initial appraisal of their contents and prepared written questions seeking further information and clarifications on a range of topics. These questions were compiled by the SAM review team and transmitted to SKB by the authorities on 19 January 2007. SKB provided written answers to these questions prior to the hearings in Stockholm, which took place on 20-22 March.

The three review teams met in Stockholm on the eve of the hearings, in order to coordinate their activities and their approach to the meetings with SKB. To the extent possible, the overlap of topics among the groups was minimised through the development of key ‘themes’, which were identified so as to ensure that maximum value could be gained from the hearings themselves. Each review team was assigned a full day for their hearing, which provided an opportunity for discussion of the SR-Can documentation, the team’s initial questions and SKB’s responses to those questions. Information gathered during this exchange, including SKB’s responses to the questions, has been taken into account in the review reported here.

The SAM review team discussed its preliminary findings on the day following the hearings. A complete version of the draft review report was transmitted to SKI in draft form on 18th June 2007. This, in turn, was submitted to SKB for verification of any factual inaccuracies. The final version was prepared taking into account a small number of suggestions from the authorities, as well as minor revisions initiated by review team members.

The remainder of this report presents the consensus comments and recommendations of the IRT. Section 2 describes the SAM review team’s assessment of SKB’s methodology against the six main areas of interest that had been identified by SKI and SSI in the terms of reference (Appendix 1), as well as some additional comments relating to broader issues raised by the review. The review team’s key recommendations are highlighted in bold typeface within the text so that these can be seen within their context. Section 3 then summarises the main findings, collecting together the recommendations arising from the review team’s work for ease of reference.

2 Review Findings

As requested by SKI and SSI, the SAM review team has focused on the methodological approach and structure defined by SKB for the SR-Can assessment. Issues identified by the authorities as being particularly important in the terms of reference for the review (Appendix 1) were:

- Strategy for safety demonstration and structuring of different arguments in the safety case, including allocation of safety to different barriers, expression of confidence, use of risk and other safety indicators, quality assurance, optimisation, etc.;
- Traceability and transparency aspects and the suitability of the report hierarchy;
- Methods to demonstrate completeness and the handling of FEPs;
- Selection of scenarios in relation to regulatory guidance and the role of function indicators;
- Methods for handling uncertainties; and
- Methods for consequence calculation and presentation of risk results.

In what follows, each of the above issues is considered in turn. In addition, some reflections on topics that do not easily fall under any of the above are provided under the general heading of “broader issues relating to compliance demonstration”.

2.1 Strategies for Safety Demonstration and Structuring of Arguments

Contributions of Barriers to Long-term Safety

In order to gain confidence in the projected long-term performance of the overall repository system, the contribution of the primary or important barriers need to be clearly and systematically explained. Two aspects of barrier contributions need to be discussed:

i. the relative contribution to safety performance (risk reduction) made by individual barriers in postulated scenarios, including the main or reference scenario; and

ii. the ‘protective capability’ of each barrier, this being the potential contribution that a barrier can make to the isolation and containment function of the disposal system through time, even though it may never be called upon to do so. Such analysis helps to demonstrate the ‘reserve’ capacity, or ‘robustness’, of the overall system, which is not necessarily evident in standard total system performance assessment calculations.

As noted in Section 10.10 of the SR-Can main report (SKB, 2006a), the regulations of the Swedish authorities require that both kinds of analyses should be included in a safety report.

The SAM review team understands that the primary barriers and their roles, as presented in the safety assessment described in the main report, include as a minimum: (a) the waste form (slow dissolution of fuel); (b) the iron canister insert (mechanical strength); (c) the copper canister shell (corrosion resistance); (d) the bentonite buffer (flow resistance and sorption, support for the canister); (e) the deposition hole (isolation from flow and mechanical disturbance); (f) the tunnel backfill (flow resistance and sorption); and (g) the host rock (dilution, sorption, isolation and Eh control).

The analysis of barrier functions described in Section 10.10 appears to be a good start but it could in principle be extended in a systematic manner to include analysis of the contributions to overall performance made by all the important barriers. For example, the analysis of barrier contributions might start by considering the implications of having all but one barrier not functioning, and then proceed to combinations of barriers as represented in Figure 10-53 (page 451 of the SR-Can main report).

More generally, it would be advantageous if SKB were to present, in a more transparent manner, the contribution to actual risk reduction and potential risk reduction capacity, from each individual barrier for a range of conditions. This can be illustrated by considering the risk assessment for the main scenario, which is discussed in Section 12.2.2, with reference to the results for Forsmark and Laxemar shown in Figures 10.42 and 10.43, respectively. It might be concluded that the small difference between the near-field and the far-field dose curves in these two figures indicates, in the absence of other explanation, little or no contribution of the geosphere barriers, which in turn may suggest that the most important control is the assumed low dissolution rate of spent fuel (as indicated in Table 10-10). How would the mean annual effective dose curve change if one particular barrier (such as the waste form) did not function as expected? Similar questions might be raised in relation to results obtained for the container corrosion scenario (Figures 12 14 and 12-15) for the container corrosion scenario. A low dissolution rate of waste form is a positive contributor to repository safety but an assessment calculation based on such a rate potentially obscures the protective capability provided by other barriers.

The SAM review group therefore recommends that SKB provides (i) a clear delineation of the barriers associated with the disposal system, (ii) a transparent analysis of the contribution of each barrier to isolation and containment for a range of conditions, and (iii) a systematic analysis of barrier capability for at least the main scenario but possibly also for other scenarios.

Results of such analyses will help to inform the selection of assumptions, models and data underpinning different aspects of the safety case for more detailed analysis and regulatory review.

Use of Safety Function Indicators in Safety Demonstration

Safety function indicators for repository components/subsystems are defined by SKB as attributes that can be measured or calculated. The safety function indicators are expected to meet certain quantitative criteria during the normal evolution of the repository. If all (or a necessary subset of) components/subsystems meet these criteria during the lifetime of the repository, then, in theory, there should be no release of radioactivity and the repository will be absolutely safe. However, alternative evolutions of the repository may lead to scenarios where one or more of the criteria are not met, which might result in release and non-zero risk.

It was noted in the international review team's evaluation of the Interim SR-Can report (Sagar et al., 2004) that SKB's development and use of safety indicators as part of its analysis of long-term system performance offers an innovative and helpful way of describing safety and safety performance for different components of the disposal system. Although satisfying the criteria assigned to safety function indicators does not necessarily mean that risk targets will be satisfied, or indeed that the criteria are necessary in order to meet regulatory limits, such an approach (coupled with the type of analysis discussed above) is in principle capable of supporting the demonstration of margins of confidence in the contribution of different barriers to long-term safety performance. In any case, safety function indicators are able to provide a complementary strand of quantitative analysis for presentation alongside the development of standard release/pathway/receptor models, as part of the overall strategy for safety demonstration, contributing to the multiple lines of reasoning that lend confidence to long-term safety arguments.

SKB's presentation of the overall spent fuel repository safety concept and the safety functions provided by different components of the system is, however, currently rather hard to follow. For example, the specific safety functions that are central to the SR-Can safety assessment are not actually listed in Chapter 7 of the SR-Can main report (SKB, 2006a); they are only traceable through Figure 7-2 (page 191).

The SAM review group therefore recommends that SKB provides in SR-Site a clear presentation of safety functions and corresponding safety function indicators, linked to a straightforward presentation of the underlying safety concept.

This sort of presentation – provided at an early stage in the safety analysis – would have several advantages, being linked to the wider need for a robust and convincing overall safety case. For example, it could be useful in linking understanding of safety functions to the development of safety assessment scenarios (e.g. the extent to which alternative scenarios may compromise specific functions) and investigating their implications for isolation and containment, measured in terms of dose and risk. It would thereby support general traceability in presentation of the safety analysis. The SAM review group also believes that there may be potential for a more explicit link to be drawn between safety function indicators and the discussion of best available technology and design optimisation (see Section 2.7 below).

Expression of Confidence

Expressions of confidence in the conclusions that can be drawn from different components of the safety analysis are scattered throughout the entire SR-Can main report as well as in supporting documents; a summary discussion is provided in Section 13.3.5. In general, the elements that lead to confidence in the safety analysis – and thereby the overall safety case – include:

- the development, documentation and implementation of a clear methodology for safety assessment;
- the provision of adequate arguments to support key modelling assumptions;
- the collection of sufficient high quality data to meet the needs of the methodology;
- the proper interpretation of data to support the use of one or a few alternate conceptual/mathematical models;
- the characterisation of parameter uncertainties;
- the use of models that have been tested and validated;

- the presentation of model results in a traceable and transparent manner;
- demonstration of the robustness of the system;
- development and documentation of multiple lines of reasoning to support the findings of the safety analysis;
- demonstration that regulatory requirements are met.

Many of these elements are present in the SR-Can main report but some need strengthening.

The staged approach to performance assessment illustrated in Figure 2-1 of the SR-Can main report is broadly similar to methodologies used within other national programmes, albeit with some differences. As noted above, one of the primary differences would seem to be the concept of safety function indicators and the assignment of 'success criteria' or target values to them (Step 5). As noted previously, however, it is difficult to trace through the methodology to understand how safety function indicators have been used in developing the assessment. For example, it is the understanding of the SAM review team that SKB has developed scenarios, at least in part, from consideration of the likelihood and possible implications of different ways in which key safety functions might be violated (i.e. the safety function indicators may fail to achieve their target values). However, Step 8 of the methodology (as indicated in Figure 2-1) suggests that scenarios are constructed from consideration of FEPs. We suggest that the primary role played by the safety functions in constructing scenarios should be emphasized in step 8 while acknowledging the confirmatory role of FEPs.

This also underlines the importance (as part of confidence building) of providing an unambiguous, traceable description of how the assessment methodology is implemented. Developing confidence in projections of system performance and long-term safety is a fundamental role played by the systematic approach to safety analysis. As such, SKB's approach to confidence building probably deserves to be highlighted 'up front' in discussion of the methodology itself, rather than as an apparent afterthought in the conclusions.

No specific recommendations are made by the SAM review team on this particular point. Clearly, however, the acceptability of disposal plans are as much based on the confidence in the overall safety case, including the outcome of the safety analysis and its links to broader aspects of the programme and related supporting arguments. By itself, safety assessment is but one thread of the wider strategy for building confidence in implementation of KBS-3 for deep disposal, which also includes ongoing R&D, rigorous application of quality assurance/control, engineering demonstration, monitoring and inspection, management systems, etc. A key aspect of traceability in developing a robust, integrated safety case is therefore in drawing convincing links between such issues and the safety assessment; this is an aspect of the assessment that has been identified by the SAM review team as illustrating an opportunity for further development in SR-Site. Some specific aspects of such confidence building are discussed under relevant sub-headings elsewhere in this review.

In addition, it is considered that arguments other than numerical risk calculation, including considerations such as robustness of design, barrier capability held in reserve, knowledge gained from natural analogues etc. could usefully be expanded as part of a strategy focusing on the development of the overall post-closure safety case, as opposed to simply the presentation of the long-term safety assessment.

System Safety Indicators

In accordance with SSI and SKI regulations, including the accompanying guidance and recommendations, SKB has used the "*annual risk of harmful effects after closure*" (SSI, 1998) as the primary safety indicator for the overall repository system. The SSI regulation defines risk as "*the product of the probability of receiving a radiation dose and the harmful effects of the radiation dose*". Except for the final risk summation (cf. Section 2.6 below), SKB has chosen to present annual effective doses as the final outcome of the calculation cases for several scenarios. For cases where probabilistic calculations were carried out, mean values of calculated annual effective doses were presented, sometimes together with additional statistics.

The SAM review team considers that, although the presentation of mean values and their use for the risk calculations is apparently compliant both with the Swedish regulations and with generally accepted practice, a more extensive presentation of characteristics (e.g. percentiles, ranges) of the distributions of dose obtained by probabilistic calculations would contribute to a more effective communication of the results of the analysis and associated uncertainties.

Furthermore, for building confidence in safety assessment, SKI regulation (SKI, 2002) seeks the application of system level safety indicators that are complementary to dose and risk, especially for timeframes beyond 1,000 years after repository closure. Suggested examples of such indicators include "*concentrations of radioactive substances from the repository which can build up in soils and near-surface groundwater or the calculated flow of radioactive substances to the biosphere*". In Section 2.9.3 of the SR-Can main report, SKB discusses options for the choice of such complementary indicators and associated yardsticks[1] for assessing the significance of model projections based on those indicators. In particular, reference is made to the indicators recommended by the EU SPIN project, those identified in Finnish regulations and studies performed on behalf of IAEA and SKI/SSI. SKB has decided to compare calculated activity fluxes to the regulatory criteria defined by the Finnish regulator STUK. In addition, for one of the sites (Laxemar), calculated radionuclide concentrations have been compared against naturally-occurring ones in the vicinity.

Internationally, the use of such complementary indicators is often recommended in order to overcome some of the perceived problems associated with having to define an evolving biosphere, within which the migration and accumulation of radionuclides – and assumed behaviour of human beings in that environment – determine the estimate of dose or risk for the long-term future. The SAM review team considers that the complementary indicators for system performance reviewed in SR-Can reflect the current state-of-the-art. However, some of the proposed system safety indicators have problems associated with the definition of appropriate yardsticks, especially for artificial radionuclides where there are

[1] We use this term here to avoid the confusion introduced through terms such as 'criteria' in relation to alternative system safety indicators. As a general rule, with the exception of constraints applied by STUK in the Finnish regulatory context, regulatory criteria do not exist for such cases. It is also important to recognise that the 'indicator' is the predicted quantity derived from the safety assessment models (e.g. calculated radionuclide concentrations) – the value against which such results may be compared in order to comment on their significance is then a 'yardstick' or 'benchmark' for comparison purposes (cf. the final sentence of Section 2.9.3 in the SR-Can main report).

no corresponding natural concentrations or fluxes for comparison. The options explored by SKB for complementary indicators are thus believed to be those that are presently available; however, the review team is of the opinion that better explanation and justification could probably have been provided for the choices that SKB finally made.

Nevertheless, SR-Can has adopted a fairly limited interpretation of the use of complementary indicators of safety, largely by restricting their application to evaluations of the projected safety performance of the system as a whole. It would not be unreasonable to acknowledge that the sub-system safety function performance indicators developed by SKB might themselves also be considered as 'alternative' indicators in the broader context of developing multiple lines of reasoning to support the safety case. Moreover, the SAM review team considers that more use could potentially be made of natural analogues, particularly when considered in the context of broader safety case development and presentation. For example, safety arguments would potentially be enhanced by a consolidated discussion of how comparisons with information on natural materials and processes have underpinned the safety assessment (i.e. not only 'natural analogues' for radioactive transport but also the broader understanding of, for example, climate evolution and natural geochemical fluxes over the last million years). In addition, there is potential scope for a rather more extended comparison against natural geosphere and biosphere concentrations of radionuclides than is presented in the SR-Can main report. In the latter respect, SKB notes that their present analysis covers only the reference evolution scenario, but that other scenarios could be readily evaluated using such indicators.

The SAM review team therefore recommends that SKB further develops the use of natural analogues in SR-Site, not only in relation to providing yardsticks for assessing the significance of projected radionuclide fluxes, but also in support of general arguments regarding environmental evolution.

In summary, the review team is of the opinion that SKB's use of complementary system safety indicators is broadly compliant with the state-of-the-art. Moreover, the use of such indicators has the potential to add to overall confidence in the safety analysis. It should, however, be noted that the Finnish regulatory criteria for activity release were derived from site-specific data on radionuclide fluxes and on reference biosphere models. It may therefore be appropriate to consider whether these are entirely appropriate, or if there is a need to derive and justify particular yardsticks for application in the Swedish (or, indeed, site-specific) context.

Quality Assurance

The SAM review team considers that quality assurance/control in relation to the assessment programme is more formalised now than it was at the time of Interim SR-Can report (SKB, 2004). For example, it is understood that SKB has developed a quality assurance plan in accordance with ISO 9001:2000. However, as noted in Section 2.8 of the SR-Can main report (SKB, 2006a) and as was discussed during the hearings, this plan has only been partially implemented to date. This is disconcerting for a programme that is advanced to the point where a licence application (i.e. based on SR-Site) is planned to be submitted within less than three years.

Full implementation of a quality assurance/quality control plan is an important ingredient of generating confidence in the safety case. Objective evidence that data collection, including the gathering of expert judgments, model/code development and analyses were undertaken according to specified quality assurance procedures is essential to assure that there is a process for identifying and addressing errors in the assessment. Section 13.3.7 of the SR-Can main report indicates that several aspects of the QA plan, including the review of central documents, FEP management, and procedures for documenting essential information have been implemented. Nevertheless, the SAM review team was surprised to find that no measures are available (e.g. trends of findings from internal auditing and surveillance) to indicate how well these aspects of the quality assurance plan are being implemented.

The SAM review team recommends that SKB gives high priority to full implementation of the Quality Assurance plan, including routine surveillance and auditing to gauge the effectiveness with which it has been deployed within the assessment programme.

Because at least some of the SR-Site assessment may be based on historical data, models and analyses, SKB should also consider how these aspects of the assessment will be qualified prior to their use in support of a licence application.

There are several assumptions made in the safety assessment (especially with respect to the initial state of the engineered system) that will clearly depend upon the application of a rigorous quality control program during canister production and repository construction. For example, the initial states of the copper canister and buffer are assumed to have uniformity of properties, which can only be obtained in the presence of a strict quality control programme. Detailed knowledge of manufacturing processes may be required for developing a practical quality control program. At the current stage of the programme, SKB has assumed that such a quality control program can be developed and implemented in order to ensure that characteristics of the canister and buffer will be as stipulated.

The SAM review team believes that SR-Site is likely to require a stronger proof of concept (or in other words, a basis for the belief that attainment of the assumed properties is feasible), in order to ensure that the assessment does not depend on unsubstantiated critical assumptions.

2.2 Traceability and Transparency and Suitability of the Report Hierarchy

Suitability of Report Hierarchy

As indicated in Table 2-1 and Figure 2-2 of the SR-Can main report (SKB, 2006a; page 53), the SR-Can report hierarchy consists of three main levels. The first two levels are represented by the main report and the main supporting references (as discussed in Section 1.2, above). At the lowest level, this information rests on the support of a large number of additional references, including SKB research reports and publications on specific issues. This hierarchy is closely related to SKB's assessment methodology, although there is no one-to-one relationship between assessment steps and reports.

SR-Can is, however, to be seen in a broader context of the repository development programme, as illustrated in Figure 1-3 of the main report (page 47). R&D activities, such as site investigation, as well as research on, and development of, engineered repository components, provide information that is used in the assessment. For example, it is noted in Section 2.2.1 of the SR-Can main report that the site-descriptive models and the site-adapted repository layout are fundamental inputs to the assessment. At the same time, it is expected that feedback from the assessment takes place to inform the direction of future RD&D activities.

The SAM review team considers that, given SKB's assessment methodology, the three-level reporting hierarchy is in principle an appropriate approach for documenting the safety assessment. However, following the hearing with SKB, a view was reached by the reviewers that SR-Site would be more coherent if it were accompanied by a separate summary presentation of how long-term safety is provided by the disposal system. This should be supported by a clearly presented sensitivity analysis that identified key data and assumptions. SKB presented the results of some later sensitivity studies at the hearing in Stockholm and subsequently (letter dated 28 March 2007) provided additional information to the authorities on the intended scope of the SR-Site sensitivity analyses. The concept of a separate chapter within the SR-Site main report, showing how each system component contributes to safety under different circumstances seemed to be broadly concurred with by SKB.

Based on the experience gained from reviewing SR-Can, as well as the outcome of discussions and presentations at the hearings, two additional elements are suggested for consideration with a view to structuring documentation of the SR Site assessment:

- The overall safety concept and main results from the safety analysis should be summarised in a short summary technical report for a broader, but nevertheless technically-informed audience. The summary at the beginning of the Main report could serve as a blueprint for such a report but would need to be supplemented by more contextual information as well as a clear presentation of the main safety arguments and key outstanding uncertainties. As an aid to understanding, a 'road map' of the overall safety case strategy should also be provided up front.
- The review team found it sometimes hard to extract information on specific issues that are central to how the methodology is implemented (e.g. uncertainty management and sensitivity analysis, and the approach to scenario construction and risk summation) since such information was sometimes spread over several sections of the SR-Can main report. It would be useful, as a guide to readers, to create dedicated sections or chapters on such cross-cutting issues, including relevant summaries of the process followed at key points, even if this might be perceived as disturbing the reporting sequence as presently adopted in the main report. The use of boxes, appendices or annexes, supported by visual aids pointing towards relevant sections of the main and/or supporting reports, might be appropriate means for minimising such a disturbance.

The SAM review team is also of the opinion that, taking into consideration the key role that will be played by SR-Site in support of a licence application, the broader picture of an overall safety case should be made evident in a structured approach for its documentation. This implies that more definitive links will need to be made between the SR-Site assessment and its role in the broader context of ongoing R&D, site characterisation activity and engineering work on repository design and canister fabrication. In particular, there is a need to ensure that information flows between these programme components are well understood, and the way that they combine to provide multiple lines of evidence for safety is mirrored in an overall reporting structure.

For example, although SKB has used sensitivity analyses (and 'what if' calculations) within SR-Can to illustrate safety functions and develop the overall safety assessment, at some point these types of analysis will have to be considered for use in design and safety (risk) optimisation. Factors such as canister thickness, buffer thickness and repository depth all have both safety and design implications. At the current level of safety scoping, sensitivity studies can be used as a relatively blunt tool, but we expect that when they are used for system optimisation they might need to be more refined. The authorities might wish to consider how and when (presumably between SR-Site and subsequent more detailed design development) this type of interaction could best be presented to them. We comment elsewhere on the role of risk optimisation and BAT.

The review team also believes that there is benefit to be gained from the authorities indicating their expectations concerning the structure of documentation in support of the licence application as soon as possible. For example, it can be expected that clear links will need to be drawn between the safety analysis reported in SR-Site and other documents, such as the planned general discussion of Best Available Technology and Optimization, Engineering Design, Construction Methods, Monitoring and Performance Demonstration, Pre-closure and Worker Safety, and Quality Assurance and Quality Control.

Traceability and Transparency

The SR-Can main report follows the main steps of SKB's assessment methodology and, in doing so, provides a reasonably clear account of the way safety has been assessed by SKB. It is, however, sometimes less clear where certain evidence (e.g. data or distribution functions) comes from. Attempts made by members of the SAM review team to trace information through the report hierarchy back to its sources were not always successful. In addition, the ways in which certain cross-cutting issues are documented do not always provide a clear picture of these issues. As noted above, this applies to, for example:

- the relationship between the reference evolution and the choices made for the definition of scenarios;
- the handling of uncertainties by means of scenario definition, definition of calculation cases (e.g. in the frame of sensitivity analyses), probabilistic or deterministic analyses etc; and
- the way in which risk summation has been carried out.

The SAM review team did not make any significant effort to check the traceability of specific data values provided in the SR-Can main report back to their sources. Nevertheless, a check was made on a very small sample (two parameters) defined in Table 10-3 for the "growing pinhole" calculation case, by tracing their derivation back to the data report. One of these parameters was the 'Time between onset and complete loss of transport resistance in canister', which is indicated in Table 10-3 as having a triangular distribution (min = 0, max = 105, mode = 105 years). We wanted to understand how this distribution was derived, and identified several pages devoted to this particular parameter in the Data report (SKB, 2006i). However, the text was unable to provide a clear rationale for the particular triangular distribution. In fact, the Data report indicated that the experts thought that this parameter was best described by a uniform, rather than triangular, distribution. During the hearings, SKB stated that the safety assessment results were insensitive to this parameter, so the parameter distribution is not important. That this is the case is not apparent from the main report, as there is limited exploration of sensitivity of dose/risk outputs to specific parameter distribution functions. Greater attention towards ensuring traceability and a more transparent documentation of parameter sensitivity in the main report will help in better understanding of the results and add to confidence in them.

The SAM review team recommends that SKB develops a procedure (perhaps as part of the Safety Assessment Quality Assurance programme) to check the traceability of parameter assumptions and to conduct a reasonable sample check to provide a suitable level of assurance.

Because many of the parameter distributions used in the assessment, as well as formulation of alternate conceptual models (e.g. the flow models), are based on informally-elicited expert opinion, it is important to describe how the potential biases in the experts' opinions were factored in (e.g., by narrowing or broadening the range of uncertainty, or by placing the most probable value at a different location, etc.). The SAM team also understood that in some cases the SR-Can project team needed to interpret the outcome of expert elicitations in order to arrive at the parameter values actually used in safety assessment. For these cases, it is especially important to document the SR-Can team's interpretation and associated rationale.

The SAM review team recognises that there are multiple audiences for a safety assessment and the wider safety case that it supports. It is therefore possible that SKB may have to produce versions of the documentation suited to specific audiences. However, in order to improve the readability of the report from the perspective of a technical audience (including the authorities), the following would be helpful:

- minimising the use of acronyms and provision of a list of those that are eventually used;
- use of simpler figures or provide a fuller explanation of their content;
- presenting figures at a size such that all text can be easily read;
- illustrating the assumed repository foot print in relevant diagrams where appropriate;
- repeating the definition of certain terms used throughout the report (such as Q1, Q2 and Q3) or alternatively use of easily recognisable names;
- including a list of figures and tables in the Table of Contents;
- using references to supporting documents that are as specific as possible (e.g. to particular pages or sections of the document, rather than simply the overall report); and
- providing a glossary for key technical terms associated with the assessment methodology.

An added consideration is the general linguistic style adopted in presenting the assessment. Where assertions are made – e.g. "*there is no reason to expect that...*" – it is important that appropriate justification is provided, either through reference to supporting materials, or (in the case of more fundamental arguments critical to the analysis) through the reporting of evidence within the main document itself. So far as possible, specialised terms (including, and perhaps more importantly, well-known terms) should be used consistently. One example in the SR-Can main report is the discussion of 'scenarios', which is somewhat confusing (particularly given that the approach is somewhat novel) because of a failure to distinguish between ‘failure modes’ of key safety functions and overall ‘assessment scenarios’.

2.3 Methods to Demonstrate Completeness and the Handling of FEPs

The SAM review team believes that, compared with other approaches, FEPs have only a limited role in the SKB methodology in deriving scenarios to describe possible evolutions of the system, and that, instead, an increased role has been assigned to the safety function indicators at the level of the important components of the system. This is considered reasonable, given that the primary objective of the proposed repository system is containment with the greatest emphasis on the engineered barriers (i.e. waste form, copper canister, iron insert, buffer, and deposition hole). SKB postulates that, if these barriers, or at least a minimum subset of them, meet their assigned safety function indicator criteria, then the repository system will achieve its objective of containing the radioactivity of the spent fuel within the near field and the geo- and biosphere will be unaffected.

Completeness of FEP List

It is the understanding of the review team that most of the FEP analyses underlying SR-Can were undertaken in earlier stages of SKB’s programme. The FEP list has evolved as a result of the R&D work undertaken by SKB over decades as well as of double-checks with existing FEP lists, most notably the NEA FEP database. Interaction matrices, as instruments for handling relationships between single FEPs, were also developed earlier in SKB’s programme. The newly-established SR-Can FEP catalogue can thus be seen as an update of previously produced results, mostly through “restructuring, differentiation and lumping” (SR-Can Main report, section 3.3), rather than in terms of content. Probably the most important recent findings are related to the occurrence and implications of spalling at the walls of deposition holes.

It is beyond the resource available to the review team to make a definitive judgment regarding the completeness of the list of FEPs that has been selected for use in SR-Can. Given the continuous work, over decades, that has been subject to several reviews and checks, the review team believes that there ought to be reasonable assurance that the FEP list is consistent with the state of science and technology and the key safety functions that are analysed in the assessment. Nevertheless, it was disappointing that the biosphere report was not available at the time of the review. In the opinion of the SAM review team, this appears to reflect the ongoing uncertainties regarding the status of the biosphere modelling work (see Section 2.6, below). Moreover, the example of spalling shows that there is always the possibility of new knowledge which has to be taken into account and that final or definitive answers on completeness issues are hard to obtain.

A comprehensive FEP catalogue provides essential support for understanding and modelling the system. Traditional approaches for scenario derivation are also strongly based on FEPs. However, the SAM review team is of the opinion that SKB’s scenario construction method, which is based on consideration of safety functions rather than ‘bottom-up’ FEP processing, also ensures the comprehensiveness of the scenarios considered in the assessment, with the result that less burden than usual is placed on issues related to FEP completeness. In practice, it would seem that the role of the FEP list in SKB’s safety assessment is to act more as a check list; that is, to audit the models and assigned safety functions to ensure that important features, events and processes are not excluded.

Sufficiency of Arguments for FEP Screenings

Tables 6.4.1 through 6.4.5 provide an enumeration of screening of processes with arguments for screening out certain processes. We suggest that an explicit linkage of these processes with the safety function indicator criteria be established and that the screening arguments should be based on the potential effect on these indicators. Some of the arguments in these tables for screening are obvious and clear (e.g. where a process cannot occur because of the design while others are based on simplified assumptions). The SAM review team recommends that the arguments for screening out some of the processes be strengthened in the SR-Site report. A discussion of the potential cumulative effect of screened-out processes could also be usefully included, especially for processes that are neglected based on judgments regarding their low consequence.

Link of FEPs to Scenario Definition

SKI and SSI requested that consideration should be given in this review to the role of FEPs in scenario definition within SR-Can. However, as previously noted, SKB’s method for scenario definition is based on the safety function indicators of primary components of the repository and not on FEP analysis. Combinations of failure modes for safety functions are used to define scenarios, while gradual changes in performance as well as environmental change are handled within the scenarios, rather than as separate scenarios.

The transition to ‘top-down’ approaches for scenario definition based on safety functions (rather than ‘bottom-up’ methods based on FEPs) is now becoming apparent within a number of national programmes. This is related to the intent of achieving comprehensiveness of the scenario set by focussing on scenarios that are relevant to demonstrating safety, rather than attempting to identify a ‘full’ or ‘complete’ list of scenarios, many of which might be largely irrelevant. All these programmes have reached a certain maturity and therefore well-developed FEP lists are already available.

In such a context, FEP lists are then usually used as confirmatory tools, rather than as the basis for scenario development itself. Hence they are effectively used after the fact to check that nothing important has been missed from the analysis, to ensure that there is sufficient knowledge of influences in scenario-defining failure modes for the system, as well as to audit the assessment models (including the representation of gradual change) for different scenarios. Provided that the safety functions are appropriately defined (i.e. all significant components are defined, together with the safety-significant functions of these components) then the SAM review team believes that SKB’s method of scenario definition is reasonable and credible.

In the understanding of the SAM review team, therefore, SKB links FEPs and functional approaches to scenario development through descriptions for the initial state of the repository and the processes acting within the system. The development of process reports, based on a standardised format for each system component, including influence tables and process tables, are the most important tools for guiding this work and for documentation. The process tables give information about, and reasons for, decisions surrounding how processes are handled in the assessment (e.g. about including or neglecting processes in modelling). Linkage of the processes to numerical modelling (namely to the Assessment Model Flowcharts AMF), as well as to the definition of the reference evolution (and thus to scenario development), is further established and documented in dedicated tables. With this approach, it is evident that SKB has accounted for the suggestion in the international review of the Interim SR-Can report (Sagar et al., 2004) that there should be a better-documented linkage between FEP processing and AMFs.

The connection of the rather descriptive FEP processing to issues central to performance and safety assessment (i.e. the safety functions), and hence to scenario definition, is provided by the FEP chart. The SAM review team considers that development of the FEP chart is an important methodological advancement in terms of how FEP processing is accounted for in a scenario definition methodology based on safety functions. Clearly, owing to the complexity of the issues at stake, the diagram format in its printed form has certain limitations with regard to readability (illustrated by the fact that SKB has chosen not to show a considerable fraction of the influence lines in the printed version). Within SR-Site, SKB might wish to consider providing a read/print-only electronic version of the FEP chart for review purposes. Such an electronic version could also provide links to the underlying process tables mentioned above, if this were found to be necessary and useful.

2.4 Selection of Scenarios in Relation to Regulatory Guidance

Scenario Identification

As noted above, the SAM review team understands that the scenario identification process adopted by SKB within SR-Can is based on seeking to define a set of failure modes that is comprehensive with respect to possible violations of key safety functions, rather than being 'complete' in the strong sense of the word. The review team considers this approach to be sufficient and effective in the context of a safety analysis.

Based on a reference evolution of the system environment, with two main variants (according to two different climate evolutions), a main scenario is defined. Three failure modes for the canister (corrosion, isostatic pressure, shear movement) and three modes for the buffer (advection exceeding the one assumed for main scenario, transformed buffer, frozen buffer) are then identified as potential causes for a violation of safety functions, and thus as potentially initiators for alternative scenarios.

Assuming this list to be comprehensive, this approach leads to a set of 'on/off' combinations (i.e. scenarios), where the switching 'on' (intact) or 'off' (failed) of a particular safety function represents the only defined states of these systems. Most of the 'on/off' combinations are discarded from the final risk summation, based either on arguments of low likelihood or on physical arguments, the latter in some cases leading to the recognition that certain scenarios can effectively be subsumed by others in terms of their potential consequence. Nevertheless, for illustration purposes, some of the discarded scenarios – as well as an additional failure mode for the canister (the 'growing pinhole') – were numerically analysed within SR-Can.

In addition, postulated human intrusion scenarios are being studied for which, by definition, the question of completeness does not apply.

In the opinion of the SAM review team, this procedure can be considered an effective basis for scenario identification. The fact the procedure itself is not yet fully mature, however, would seem to be reflected in the fact that there is clear room for improvement with regard to the documentation of scenario development and the screening procedure for system 'failure modes'. In particular, because of the 'on/off' nature of the combinatory process, issues related to the gradual and overlapping evolutions of failures are not very clearly described (one example being the analysis, and eventual screening out, of the combination of shear movement and corrosion failure modes for the canister).

The SAM review team therefore recommends that a formally more rigorous description is provided of the exploration of scenarios through combinations of sub-system 'failure modes'. This should ensure that clear consideration is provided for the treatment of the gradual and/or overlapping development of different failure modes. It should also be supplemented by a terminology that is more consistent than the one currently used, especially in order to avoid confusion of failure modes with scenarios.

Relationship of Analysed Scenarios to Compliance Demonstration

According to the SAM review team's reading of the relevant documents, Swedish regulations require the following with regard to scenario analysis:

1. According to SKIFS 2002:1, the method for scenario selection should be reported and the set of scenarios considered should include a main scenario that "takes into account the most probable changes in the repository and its environment". In addition, SKI's recommendations (SKI, 2002) request the analysis of less probable as well as of residual scenarios, the latter having an illustrative character with regard to the demonstration of barrier performance and being similar to the 'special scenarios' mentioned in SSI guidance.

2. SSI regulations (SSI, 1998) and the supporting guidance (SSI, 2005) anticipate the (probability-weighted) combination of scenarios for the demonstration of compliance with the risk criterion. Consequence evaluation should be "based on a set of scenarios that together illustrate the most important courses of development of the repository, its surroundings and the biosphere." A range of conceivable climate evolutions should be considered.

3. SSI guidance specifies requirements concerning the nature of human intrusion scenarios to be considered (SSI, 2005). According to SKI regulation (SKI, 2002), the consequences to humans involved in intruding into the repository should be explored as 'residual' scenarios.

As noted above, the SAM review team understands that, within SR-Can, SKB has defined a main scenario and climate variants in a manner that can be considered in accordance with regulatory expectations. Alternative evolutions to the main scenario were derived on the basis of a 'failure mode' analysis for different safety functions of the disposal system, as described above and, based on likelihood considerations, categorised these alternatives either as 'less probable' or 'residual'. Only the former were included in the risk summation. Some of the discarded failure mode combinations, as well as some other evolutions, were handled as 'residual' scenarios and studied within SR-Can in order to explore and demonstrate the performance of certain barriers (e.g. release limitation based on slow dissolution of the fuel) and hence the robustness of the system. The review team is of the opinion that this approach is consistent with regulation. The same applies to SKB's treatment of human intrusion; however, the SAM review team has some reservations with regard to how such scenarios have been documented, as noted below.

Future Human Actions

Section 12.10 of the main report (SRB, 2006a) presents SKB's evaluation of future human actions (FHA) and their implications for long-term safety performance of the disposal system. The discussions of rock cavities, tunnels and mining (at Forsmark) are essentially qualitative and assert that such actions are of no relevance to system performance. However, the supporting arguments for such judgments were not readily traceable. Much of the justification appears to be based upon a series of reports by Svensson, which were not available at the time of our initial review. Unfortunately, none of the quantitative evidence from these studies has been brought forward into the main report to support the assertions and, without properly argued presentation of the use of these flow studies, it is not possible to judge qualitative statements such as "is assessed as limited", "there is no reason to expect" and "would thus not likely affect".

The SAM review team recommends that SR-Site deals in more depth with the justification for the assigned status of those FHA scenarios that may have implications for the long-term safety performance of the disposal system.

Use of Sub-System/Component Function Indicators in Scenario Analysis

As noted earlier, the question about whether or not a function indicator violates the associated criterion is central for the linkage of FEP processing to modelling and scenario analysis.

The SAM review team considers that the – then innovative – approach presented in the Interim SR-Can report (SKB, 2004) has been successfully further developed, especially with regard to the use of the indicators in the definition of scenarios but also by modifying the list of indicators in some cases and by more systematically assigning them to the safety functions. In accordance with the recommendations of the international review of the Interim SR-Can report (Sagar et al., 2004), it was noted that choices for indicators and thresholds are now better justified. In building an integrated safety case, however, there remains the need to demonstrate with reasonable assurance that these thresholds will actually be achieved in practice.

In the opinion of the SAM review team, further development of this positive, and so far unique, method is possible with a view to the establishment of stronger links between engineering design and optimisation work to safety analysis. This could potentially be achieved by making the relationship of function indicators to design criteria clearer and more explicit.

2.5 Methods for Handling Uncertainties

Uncertainty Management

In response to the regulatory request for reporting about uncertainty management, SKB states in Appendix A1.1 of the SR-Can main report (SKB, 2006a) that section 2.7.3 provides a "plan for the management of uncertainties" and hints at further elaboration in sections 10.11, 11.5, and 12.7.

Section 2.7.3 (page 60) distinguishes between system uncertainty, conceptual uncertainty, and data uncertainty. This categorisation is somewhat different from the one suggested in SKI's regulatory guidance but, in the view of the SAM review team, is no less sensible nor less comprehensive. Exceptions are that uncertainties concerning the models used seem not to fall under one of these categories and that spatial variation or variability is only implicitly introduced later in the chapter when probabilistic calculations are introduced.

SKB then states that system uncertainty (mainly being linked to comprehensiveness issues) is mainly addressed by appropriate FEP management and (albeit under the separate heading "Scenario selection") through scenario development using failure mode analysis based on safety functions and function indicators. For conceptual uncertainty and data uncertainty, the main report refers to the Process and Data reports, respectively, and to the standardised formats for describing uncertainties as well as to associated review processes and QA measures.

Uncertainties in modelling are handled under a separate heading, with reference being made to the SR-Can Model Summary report. In the opinion of the SAM review team, the issues named in the model report (i.e. suitability and applicability of codes, development process, verification, validation, other means of confidence building) would have been worth exploring in more detail in section 2.7.3 of the SR-Can Main report. Similarly, discussion of the handling of uncertainties under the heading "Integrated handling of uncertainties" in Section 2.7.3 is very general and lacks a specific description of the strategy or a motivation for it.

More generally, the SAM review team considers that, given its central role in framing the approach taken to a fundamental aspect of the safety analysis, section 2.7.3 is lacking concrete information about uncertainty management. In part, such information can be found in subsequent parts of the report (e.g. in section 11.5 where – still at a rather general level – the handling of system, conceptual, and data uncertainties within the several scenarios is explained). Information is further supported by section 10.11 where choices concerning the handling of uncertainties by means of deterministic or probabilistic approaches are explained and statements are made about which of the considered failure modes or scenarios have been propagated to the risk summation. The latter is further explained under the heading "*Canister failure due to corrosion*" in section 12.7.

Apart from these sections, which are referred to by SKB in the Appendix, the review team found more case-specific information about the handling of uncertainties in different elements of the safety assessment, especially regarding the balance between probabilistic assessments, deterministic calculation cases and sensitivity studies, in sections 9.2, 9.3, 9.4, 10.5, 10.6, 10.7, 10.8, and 12.7.2. This scattering of information throughout the report made it rather difficult to achieve a clear view regarding the comprehensiveness and appropriateness of uncertainty management.

Notwithstanding the difficulties described above, the SAM review team is of the general opinion that uncertainties critical to safety have, in general, been appropriately handled within SR-Can. In so far as could be ascertained, given the way in which issues are distributed throughout the main report, choices made concerning assessment methods seems to be sensible, with sensitivity and bounding calculations providing assurance about the robustness of the system. Where appropriate and necessary, alternative modelling assumptions were tested. It is, however, less clear whether parameter distribution functions were always derived appropriately and to what extent the effects of possibly arbitrary choices for such functions were explored. There are also deficiencies with respect to the traceability of information from research, site investigation, and engineering that is used in the assessments.

For SR-Site, the review team strongly recommends the creation of a central register of uncertainties, containing

- **a description of the uncertainty under question and a motivation (based on the safety concept) for addressing it;**
- **a thorough description of the methodological means of assessing the uncertainty qualitatively and/or quantitatively;**
- **the basis for the assessment coming from research, site investigation, or engineering work (including the basis for choices of parameters or distribution functions);**
- **results of the assessments and their evaluation; and**
- **conclusions concerning further work.**

The development and reporting of such a register is one of the cross-cutting issues regarding centralised reporting recommended in Section 2.2 of this review report.

Estimation of Model/Parameter/Scenario Uncertainties

Model uncertainty is handled by defining alternate conceptual models with their own set of parameters. The SAM team believes that the SKB methodology of not assigning probabilities to these alternate models but carrying forward the most pessimistic conceptual model is conservative from the perspective of risk estimates. It is a reasonable approach because the model uncertainty is not always separable from parameter uncertainty and assigning probabilities to models independent of their parameters might well lead to inconsistencies. However, explicit demonstration that a pessimistic model has been selected should be provided in documentation of the safety assessments. Such a demonstration should show at what level (e.g. overall dose, geosphere flux, near field release) the pessimism has been assessed.

Parameter uncertainty in SR-Can is largely treated by assigning triangular probability distributions to most parameters. Even though the SAM review team has not reviewed the background for each and every parameter, it is our general understanding that the parameter probability distributions were based on an informal elicitation of expert opinions, which were then moderated by members of the SR-Can team responsible for model implementation. The logic and rationale of which expert (or SR-Can team member) said what and why is not documented, which means that it is not transparent how personal biases were accounted for in the final accepted distribution. The SAM review team believes that it may not be necessary to document each and every parameter to the same level of detail. However, once a thorough sensitivity analysis is completed and a small subset of important parameters is identified, it would be appropriate that the rationale for this subset should be revisited and more fully documented.

The SAM review team recommends that SKB seeks to improve the documentation of how critical model parameters are identified through sensitivity analysis, and provides a more thorough audit trail to justify value assignments for those parameters.

Based on the description in section 11.3 of the Main Report, the SAM review team believes that SKB handles scenario uncertainty by defining four scenario categories: (i) the main scenario and its variants; (ii) scenarios based on loss of safety functions (less probable scenarios); (iii) residual scenarios (also based on safety function failures, but considered to have much lower likelihood of occurrence); and (iv) future human action scenarios. The usual practice of assigning probabilities to scenarios when calculating total risk is not followed. To estimate total risk, the main scenario and all but one of the 'less probable' alternative scenarios propagated into the risk summation are assumed to have a probability of one. This is clearly a pessimistic approach and it is possible only because the repository system is robust and has significant safety margins. The SAM review team recognizes the difficulty in assigning probabilities to 'very low probability' scenarios as part of a risk calculation and agrees that the approach adopted by SKB is sufficient for compliance demonstration.

Propagation of Uncertainties

The SKB modelling strategy does not include coupling of detailed process models; instead, parameter uncertainties are propagated using a simplified analytic model. This analytic model has been verified by comparing its results to those from more complex numerical models. Such a strategy of using simplified models for safety assessment is quite common in various national programs although not universally so and is adequate provided that the simplified models are properly verified and validated. This would involve checking at least parts of the simplified model to ensure that the essential features of the detailed process model are adequately reproduced. The SAM review team understands that SKB plans to complete verification and validation of the analytical model used for system-level probabilistic analysis by the time of the SR-Site.

Sensitivity Analyses and Feedback to Design/Site Investigation

Some sensitivity analyses are presented in SR-Can but, in the view of the SAM review team, these are far from complete. In response to questions raised during the initial period of the review, additional sensitivity analyses were developed by SKB and presented during the hearings. SKB also provided a write-up and a published paper justifying the use of the standardized rank regression coefficient method for sensitivity analysis, following the hearings. The SAM review team agrees that the standard rank regression coefficient method is appropriate for the condition where the model results depend monotonically on parameters. However, it is not uncommon for any sensitivity analysis method to produce false results as such methods are unable to differentiate the effects of various unequal assumptions. SKB's sensitivity analysis results should therefore be carefully interpreted in light of the combination of pessimistic (with varying degree of pessimism) and realistic (with varying degree of realism) assumptions that are made during model development and parameter value assignment. It is recommended that consideration is given to the application of more than one sensitivity analysis method in order to provide to assurance that the results can be properly interpreted. Some deterministic sensitivity analyses are reported in the SR-Can main report (i.e. Section 10.6.5) and are helpful in understanding the system.

During the hearing, in their sensitivity presentation, SKB noted that uncertainty in the likelihood of a significant seismic event was a key factor in determining estimates of overall risk, primarily because shear failure of the canister is the dominant contributor to risk in earlier timeframes. This sensitivity is not immediately apparent from the treatment of seismic hazard in the main report, indicating either that the sensitivity analyses are not fully described or that there is a lack of transparency in the linkage of such analyses to reporting on key parameter assumptions. In light of such sensitivity, the SAM review team recommends that a clearer trace is provided for assumptions that underpin the risk contribution associated with this scenario in SR-Site.

The SAM team therefore recommends that SKB considers using other methods of sensitivity analyses to properly interpret the results. A more comprehensive presentation of sensitivity analyses (as agreed during the hearing), ensuring that attention is properly drawn to key factors, would also be appropriate.

R&D Plans for Managing and Reducing Uncertainties

The review team is of the opinion that sections 13.5 to 13.7 of the SR-Can main report (SKB, 2006a) provide a reasonable description of issues remaining to be resolved in design and site investigation, according to the outcome of the safety analysis. Sensitivity studies with respect to (e.g.) layout options and choice of backfill material have been carried out in an appropriate way to inform such issue identification. The priorities defined appear to be consistent with the results of the safety assessment. Major challenges would seem to be:

- justification for the assumptions used in the assessments concerning canister properties, in particular of the weld, by appropriate engineering means and quality controls;
- further development of the criteria used for acceptance or rejection of deposition holes, their justification and application; and, on a related issue, but more broadly
- the development of an approach to feed the findings of site investigation and knowledge obtained during construction (namely with regard to fractures and deformation zones as well as to rock mechanics) into engineering and construction work.

The latter seems to apply especially to Laxemar. The time schedule for meeting these challenges appears to be tight. One should also be aware that design specifications for a number of engineered components (tunnel plugs, backfill materials for cavities other than deposition tunnels, bottom plates in deposition holes, borehole seals) remain to be thoroughly defined.

Section 13.8 of the main report identifies issues for further R&D based on the outcome of the safety assessment. According to the maturity of the Swedish programme, the number of such issues is rather limited and the SAM review team considers the description given by SKB to be generally adequate. Obviously, the problem of buffer erosion is a key factor with regard to safety, whilst the rather new issue of spalling seems to have less impact on overall safety performance. Hence a major challenge, also with regard to the time schedule, is the need for R&D work on buffer erosion. This seems to be all the more important given that (according to the assessment reports) SKB's description of the planned programme with regard to this issue appears to suggest that the work is not yet particularly mature.

2.6 Methods for Consequence Calculations and Presentations of Risk Results

Methodology for Risk Calculation

The SSI regulation (SSI, 1998) defines annual individual risk as the central quantitative indicator for providing overall system safety assurance. This has a number of implications for the safety assessment methodology. The issue is referred to in section 2.9.2 of the SR-Can main report (SKB, 2006a):

"*In principle, the product of dose consequences and likelihoods of all possible future evolutions of the repository should be weighed together and presented as a time-dependent risk. The spectrum of possible evolutions is, however, very wide and cannot be captured in a detailed sense … The usual approach taken in safety assessments, and also in SR-Can, is to work with scenarios and variants that are designed to capture the broad features of a number of representative possible future evolutions. Together, these are intended to give a reasonable coverage of possible future exposure situations. Conditional risks are calculated for each scenario and variant and these are then weighed together using the probability for each scenario/variant. Furthermore, each variant, represented by a specific calculation case, may be evaluated probabilistically in order to determine the mean exposure given the data uncertainties for the particular variant.*"

As stated in section 11.1 of the SR-Can Main report, the scenarios to be considered in the risk summation should be mutually exclusive and cover together the whole space of reasonable future evolutions. In the understanding of the SAM review team, the risk summation was carried out by SKB for each of the sites under consideration as follows:

- The issue of completeness is addressed by basing the summation on the assumption that scenarios for which no safety function is failed lead to zero release and can therefore be excluded from the risk summation.
- In order to address SKI guidance, a main scenario with the two climate variants is defined by SKB (investigating climate variants is a regulatory requirement from SSI). The scenario comprises the failure modes of canister corrosion and buffer advection (limited to the extent estimated for the reference evolution), while all other failure modes were put aside based on low likelihood considerations. For the two sites, conditional risks for the base case variants are derived from mean annual effective doses obtained as an outcome from probabilistic calculations. The difference between the two climate variants in terms of calculated risk is, however, negligible. Consequently, the (somewhat higher) conditional risks for the base variant were considered as being representative for the overall main scenario.
- As potential causes for a violation of safety functions, three failure modes for the canister (corrosion, isostatic pressure, shear movement) and three modes for the buffer (advection exceeding the one assumed for main scenario, transformed buffer, frozen buffer) are identified. These modes, as well as their combinations, are potential causes for scenarios to be considered in the risk summation. Based on the characteristics of the KBS-3 system, however, SKB excludes most of the failure modes and potential combinations either by arguments based on low likelihood or by physical reasoning. Apart from the main scenario, the only scenarios remaining for risk summation are those ones relating to corrosion and shear failure.
- SKB calculated the conditional risk for these scenarios derived from mean annual effective doses obtained from probabilistic calculations.

– SKB was also in the position to quantify likelihoods of occurrence for the shear failure mode: different values for the two sites were derived on the basis of earthquake probabilities, fracture detection probabilities and probabilities for fractures intersecting canisters, under the assumption that the criterion for deposition hole rejection is respected.

– Since the copper corrosion scenario and the main scenario are mutually exclusive, the higher consequence from the copper corrosion scenario was taken as an upper estimate for the risk contributions from both scenarios without taking any credit from likelihood considerations. SKB took, however, credit for the likelihood of shear failure by multiplying it by the mean annual dose in the risk summation. For early times (in the order of some 10,000 years) the consequences of shear failure dominate the overall risk, while later periods, the contribution from copper corrosion becomes dominant.

The SAM review team is of the opinion that SKB's method for risk calculation is appropriate and – apart from the conceptual problems associated with forecasting the biosphere for the timeframes under consideration (see below) and the impossibility of accounting for the unforeseeable (i.e. scenarios nobody has so far thought about) – capable of providing an appropriate, conservative estimation of annual individual risk arising from the repository. The SAM review team believes that the basis for excluding scenarios from the risk summation is reasonable – the only difficulties arising with regard to communicating the reasons for excluding the combination of the shear movement and the corrosion failure modes for the canister (cf. section 2.4 above). The way that the issue of potential risk dilution is handled is also satisfactory.

In the opinion of the SAM review team, it is often problematic to assign likelihoods of occurrence to scenarios. In the only case this has been done by SKB, however, the basis for the choice of likelihoods appears reasonable.

The SAM review team is, however, less satisfied with the way in which the methodological approach to risk calculation has been presented by SKB (cf. the recommendations on reporting under Section 2.2 above).

Presentation of Risk

Apart from the above mentioned difficulties of presenting the approach to risk calculation, the review team is of the opinion that the presentation of the results of the analysis is generally appropriate. Nevertheless, as previously noted, the review team considers that more complete information about uncertainty bandwidths surrounding the mean annual doses that are the basis for risk calculation (or about other distribution features of the results of probabilistic analyses) would been have useful and informative as a guide to making sense of the results of the assessment, even if not explicitly required by Swedish regulation. Such information was presented in a small number of cases but not throughout the whole analysis.

Biosphere Assessment

A further implication of the emphasis on risk in SSI regulations is that it requires a biosphere model to be an integral element of the overall safety assessment. In the absence of explicit guidance on assumptions that should be made for the purposes of dose calculation, SKB has developed its own methodological approach. It is not the role of the SAM review team to comment in detail on the assumptions that underpin SKB's biosphere assessment models; however, it is relevant to comment on the part played by the biosphere in the overall methodology, not least because SKB's approach appears to involve complexity, and not yet fully mature (as evidenced by the fact that comprehensive model and FEP documentation was not available at the time of the review). Moreover, experience suggests that the results of biosphere assessment calculations can vary considerably – potentially by several orders of magnitude – depending on key assumptions regarding the nature of the environment into which radionuclides emerge, and the relationship of human activities, habits and diet, to exploitation of that environment.

The general framework for biosphere assessment appears to have been given considerable thought, and a substantial modelling hierarchy has been defined. The approach involves an extensive description of present-day local ecosystems (environmental studies) and associated conceptual models (assessment biospheres). One key aspect of this approach is the systematic consideration of what has become widely known as the 'geosphere-biosphere interface' and its evolution through time. SKB's modelling hierarchy provides a site-specific and time-dependent analysis of the influence of near-surface hydrological features on the dilution of radionuclide flux emerging in groundwater and hence the spatial extent of any release that might occur.

However, the precise connection between the two tiers of modelling (in particular, how the former can reasonably be expected to inform the latter, given the uncertainties that exist with respect to the precise nature of the future biosphere systems) is unclear. What appears to be missing, at least in the SR-Can documentation, is a clear understanding of how information is transmitted between different tiers of the modelling hierarchy – providing justification for the assessment models that are used; for example, in terms of how radionuclide transfer models for all relevant radionuclides can be defined on the basis of site data and understanding expressed in the ecosystem models, rather than the more traditional approach based on bioconcentration factors. The suggestion is that there should be a seamless transition between the two steps; in practice, however, this currently appears to remain more of an aspiration than a traceable process. Indeed, the data and assumptions that underpin the models for derivation of the landscape dose factors that were eventually used in the risk calculations remains obscure.

One output from the more complex approach, based on consideration of productivity from different ecosystems, is its use by SKB to inform discussion of how the average dose might vary according to increasing population size, for a given combination of landscape objects (e.g. Figure 10-4 on page 389 of the main report). Whilst such information can be informative as part of a general discussion of the potential significance of forecasts of individual dose derived from the assessment models, however, it says little about the nature of the diet etc. that will determine key exposure pathways for different radionuclides. The source of key data and parameters necessary for dose assessment is not clearly indicated.

The comments made by the international review team at the time of the Interim SR-Can report (Sagar et al., 2004) therefore remain appropriate here. Based on the discussions at the hearing in March 2007, it is evident that the timescales for SR-Site are placing considerable pressure on the development of SKB's biosphere assessment approach to a sufficient level of maturity and robustness.

The SAM review team therefore believes it is a matter of priority for SKB to define clearly its overall strategy for the development of fit-for-purpose dose assessment tools (models and parameter values) for SR-Site, consistent with both SSI's re-

quirements for risk calculation and the overall objectives of the wider safety assessment.

Transitional States

In presenting its long-term radiological impact estimates, SKB has adopted a relatively simple approach that omits the detailed effects on flow and transport (and other aspects of system behaviour) of time-dependent transitions between environmental states. The SAM review team accepts that this makes the system behaviour easier to follow and is an effective way of showing how loss of safety functions could affect performance. However, there is a residual concern that this simplification (which amounts to the application of selected, constant conditions, rather than a smoothing over transitions between states) could miss some potentially magnifying effects or feedbacks that might occur in the course of evolution of, say, the climate and surface environment (potentially over short periods of some hundreds to thousands of years). Such effects could in principle have an impact on engineered barriers or on the flow and geochemical field in and around the repository.

The SAM review team does not believe that it would be either feasible or effective to attempt a fully time-dependent analysis, but we suggest that SKB should present an argued assessment of whether any such transitional impacts might exist that could have significant effects on performance. The current adoption in SR-Can of a detailed climate transition model for one glacial cycle, together with SKB's plans to develop a time-dependent groundwater flow model, could provide a useful basis for such considerations. We also note SKB's stated intention (Section 9.4.6, p. 335 of the main report) of carrying out a more comprehensive study of groundwater flow during the permafrost conditions for SR-Site.

Very Long Timescales

The authorities' regulations are explicit in terms of the quantitative information that SKB should present to demonstrate compliance with long-term safety requirements and, in SR Can, SKB has adhered to these. Because SR-Site will be viewed as underpinning SKB's statement of the long-term safety case for spent fuel disposal, it can be expected that documents – and particularly the assessment results they present – will be read by a range of stakeholders, not only by the regulatory authorities. Consequently, both SKB and the authorities need to consider how the reports will be perceived by other readers and the messages that they will communicate (note: we comment elsewhere on the structure and presentation of safety reports).

SR-Can shows a rising dose curve at the end of the assessed period (one million years). In discussion with SKB, it was acknowledged that this leaves an open question as to how very long-term impacts might develop – that is to say, how 'bad' the impacts might be in the far future. In response to questions, SKB produced some simple estimates of far-future doses, based on extending the time period for the release calculations already presented. The estimates from these (inevitably) speculative calculations (c.4 mSv/yr) are in the order of natural background exposures. We accept that these calculations are highly stylised and the uncertainties in the assumptions may render the result not to be particularly meaningful. Nevertheless, we believe that both SKB and the regulators ought to be concerned with showing stakeholders, in some way, the likely ultimately 'fate' of the repository – essentially, that SKB should be able to make the case that the repository will not represent an exceptional hazard in the natural environment at any time in the future. If the calculation of groundwater releases and consequent exposures is not considered meaningful, then alternative ways should be found of expressing long-term hazard potential.

For SR-Site, we therefore suggest that SKB should discuss and illustrate this theme more fully. SKB already notes in SR-Can that the radiotoxicity of the spent fuel diminishes to the level of natural uranium ore after some 100,000 years or so. It is reasonable to expect that the repository will remain at depth for many millions of years (i.e. will not be exposed as a result of erosion, even by many successive future glaciations), but this needs to be explained and discussed. More use could also be made of information on the behaviour and evolution of uranium ore deposits in analogous environments/depths and the known radiological impacts that they have in the surface environment.

2.7 Other Issues Related to Methodology and Compliance Demonstration

Initial State Verification

The validity of SKB's safety case depends critically on the capability to encapsulate and emplace the spent fuel and the associated engineered barriers in a manner that meets the defined expectations of quality and material/rock properties assumed in the definition of the 'initial state' of the system (SKB, 2006c). To date, there has been only limited testing of EBS emplacement (the prototype repository project at Äspö) under trial conditions. At present, SKB is also assessing an alternative, horizontal, emplacement scheme (i.e. KBS-3H, as opposed to the vertical deposition holes (KBS-3V) assumed in SR-Can), whose engineering practicality remains unproven (although this will not be part of the licence applications in 2009-10). Chapter 6 of the Initial State report briefly introduces components of vertical deposition holes and handling steps that are clearly only at the conceptual stage. So far as we are aware, no container and EBS emplacement and quality confirmation tests have been carried out under simulated, remote, active-handling conditions. Eventual repository operation will require repeated deposition of EBS and containers, to rigorous standards, on almost a daily basis over many years.

It may be that this issue is more appropriately dealt with by the authorities elsewhere than under the current review of SR-Can, but it is important to point out that the ability to build the repository 'as specified' is a fundamental foundation of the safety case. Critical assumptions are made in SR-Can (and, we assume, will also be made in SR-Site) on the basis that the system can and will be engineered to assumed specifications. The SAM review team believes that it would be inappropriate for licensing to be completed without a clear and comprehensive plan and timetable for early, full-scale engineering demonstrations and quality confirmation tests of KBS-3V under simulated active handling conditions being presented to the authorities. Such demonstrations could make use of both surface and existing underground facilities and consideration should be given to carrying them out in the next few years.

It would be useful to link a requirement for such demonstrations with a requirement for a clear statement of intent with respect to the initial stages of repository operation. Consideration might be given to testing some safety-relevant aspects of performance related to the achievement of assumed 'initial state' conditions by disposal of a small number of containers in a separate, instrumented and monitored region of the repository. Any remaining issues (at that time) associated with (e.g.) thermal spalling and hydraulic and chemical aspects of resaturation could be investigated and data gathered to refine performance evaluations. The results could also be used to inform future operational decisions or design amendments, both of which would fall within the regulatory system. Such an approach to demonstration at the repository site itself would also help to lend confidence to the feasibility of implementation (and any necessary updating of the safety case and underlying assumptions) when SKB is confronted with the actual situation underground at the chose site.

Meanwhile, for SR-Site, the SAM review team recommends that SKB should discuss in a focused manner the feasibility of achieving the assumed initial condition and means for assuring that they will achieved.

Impact of operational measures on long-term safety

A specific requirement of SKI's regulations (§8 of SKIFS2002:1) is that the implications of operational measures (including those taken to facilitate monitoring) should be taken into account in the demonstration of long-term safety. This aspect is not adequately discussed in the SR-Can, and there is no clear link as yet between long-term and operational safety measures. It is the impression of the SAM review team that operational features will need to be developed to a level such that any potential impacts of operational features on long-term safety can be identified and discussed in a sensible manner.

Design Optimisation and BAT in Repository Development

The SSI and SKI regulations both include requirements related to optimisation and the use of best available technique (BAT). SKB has approached this issue cautiously, pointing out that it is not primarily a matter for a safety assessment. Nevertheless, SR-Can devotes several pages (Section 13.3.4) to discussing the background and exploring how it could be applied to the engineered barrier system and repository layout.

Since BAT came to prominence in the EU Integrated Pollution Prevention & Control (IPPC) Directive in 1996, there have been a number of definitions of what is meant, both in general terms and more specifically by 'best', 'available' and 'technique'. However, BAT has been described as simply a 'label' expressing overall aspirations, and as a result its precise implications are referred to by some as a being something of a 'moving target'. This underlines the importance of developing a clear understanding between implementers and regulators of the practical implications of this requirement, especially as the point is reached when regulations are actually being applied.

It was clear in our discussions during the week of the SKB hearings that there is a pervasive lack of clarity on this matter. SR-Can notes that it is often difficult to distinguish between optimisation and BAT. The SSI regulatory guidance (SSI, 2005) is not very helpful on this matter – it is generalised, setting no clear targets or requirements – and it seems that SKB, the authorities and members of the independent review teams have a range of views of what is meant by BAT and how it relates to the requirement for optimisation with respect to calculated risk.

Since the SSI regulations call for application of BAT already at the time of siting and design, it seems important to have (a) a better indication of what a requirement for BAT actually means in the current context of geological disposal of spent fuel and what is implied by "*the most effective measure available…which does not entail unreasonable costs*" (SSI, 1998) and (b) a better idea of how central an element of compliance BAT might be.

Notwithstanding the need for such clarification in relation to regulatory compliance, the SAM review group believes that reflection on the principle of optimisation, coupled with SKB's approach to the use of safety function indicators, suggests one potential way forward on this matter. Specifically, there may be potential for a more explicit link to be drawn between safety function indicators, the definition of the initial state of the repository engineered system, and the discussion of BAT and optimisation. If the buffer, for example, is assigned safety function indicator criteria in terms of density and permeability, this suggests that it would be appropriate to consider what technologies are available to achieve these properties and to explain why a particular technology has been selected as the basis for design.

In general, the safety function indicators are different from design criteria or the design basis, although for some components the two may be the same. An example of where the two are different is the thickness of the copper canister: the safety function indicator criterion for this attribute is 'greater than zero' during the regulatory period (one million years), whereas the design basis (i.e. the initial manufactured thickness) may be 5 centimetres. As a general rule, the logic supporting definition of the design bases is not discussed in any detail in SR-Can, although the discussion in Section 13.4 of the main report (SKB, 2006a) appears to imply a relationship between design criteria and the safety function indicator criteria. In the example of copper thickness, it might be imagined that the minimum required thickness at the time of disposal ought to be closely related to the length of time that it is supposed to satisfy its safety function indicator criterion, i.e. not to corrode completely in one million years.

The SAM review group recommends that SKB should provide a clear description in SR Site of design criteria and their relationship to safety function indicator criteria.

The licensing authorities should also consider which design criteria or function indicator criteria ought to be included as licence conditions, especially if it is not possible to demonstrate achievability at the time of licence application.

3 Conclusions and Recommendations

The SAM review team is of the opinion that the methodology for safety assessment (as summarised in the 10 steps presented in SR-Can) is, for the most part, mature, appropriate, and fit for purpose. Certain elements – not least the systematic approach to scenario development through consideration of sub-system failure modes, based on exceeding safety function indicators – are state-of-the-art and SKB can indeed be considered as being at the forefront of developments in this area. In addressing requirements for regulatory compliance, SKB's approach to risk calculation is considered by the review team to be appropriate and (subject to clarification of the basis for undertaking the necessary radiological exposure calculations) to be capable of providing a suitable, conservative estimation of annual individual risk arising from the repository.

There appear to be no major gaps in the methodology, although there are a number of places where the thread of argument can only be traced with some difficulty. In places, the impression is given that time pressures meant that lines of reasoning associated with particular methodological steps were sometimes developed as the report was written, with no opportunity for consolidation ahead of publication. There is a need to collect together and consolidate certain aspects of the methodology, not only to provide a clearer exposition of how the different pieces fit together in a logical fashion, but also to ensure that there are no gaps in logic and consistency of approach.

Apart from the deficiencies on particular points referred to in the recommendations that follow, together with some problems related to reporting, the SAM review team considers that SR-Can provides a good blueprint for a safety assessment to be undertaken as part of a licence application. The team nevertheless believes that such a license application will require rather more in the way of framing the assessment and drawing clear links between the work reported by the assessment team and other components of the repository project. There has to be a clear audit trail demonstrating how the data and assumptions used in the assessments are based on results from R&D, site investigation, and engineering work. Moreover, there is also scope for improving the discussion of how R&D, site investigation, and engineering work in turn has taken advantage from, and will continue to be informed by, the assessment work. The review team believes that SKB should make an effort to ensure that the necessary links between these programme components are efficient and that they will be made evident in the documentation for the license application.

3.1 Recommendations for SKB

- For SR-Site it is recommended that SKB provides (i) a clear delineation of the barriers associated with the disposal system, (ii) a transparent analysis of the contribution of each barrier to isolation and containment for a range of conditions, and (iii) a systematic analysis of barrier capability for at least the main scenario but possibly also for other scenarios.

- In presenting SR-Site, the overall safety concept and main results from the safety analysis should be summarised in a short summary technical report for a broader, but nevertheless technically-informed audience. This could reasonably include a clear presentation of safety functions and corresponding safety function indicators. As an aid to understanding, a 'road map' of the overall safety case strategy should also be provided up front.

- As a guide to readers, it would be useful to create dedicated sections or chapters (and/or suitable inserts, illustrations, text boxes, etc.) on key cross-cutting issues that run through the assessment as a whole. Such topics include uncertainty management and sensitivity analysis, and the approach to scenario construction and risk summation. Relevant summaries of the strategy followed in the assessment could helpfully be presented at key points.
- As part of the development of multiple lines of reasoning in support of its safety case, it is suggested that SKB could further develop the use of natural analogues in SR-Site, not only in relation to providing yardsticks for assessing the significance of projected radionuclide fluxes, but also in support of general arguments regarding environmental evolution.
- SKB needs to give high priority to full implementation of the Quality Assurance plan within the framework of its safety assessment activities, including routine surveillance and auditing to gauge the effectiveness with which it has been deployed within the assessment programme. This should include consideration of how historical data, models and analyses will be qualified prior to their use in support of a licence application.
- A procedure should be developed by SKB (perhaps as part of the safety assessment Quality Assurance plan) to check the traceability of parameter assumptions and to conduct a reasonable sample check in order to provide a suitable level of assurance.
- A formal description should be provided for the approach of developing scenarios through combinations of sub-system 'failure modes'. This should ensure that clear consideration is provided for the treatment of the gradual and/or overlapping development of different failure modes. It should also be supplemented by a terminology that is more consistent than the one currently used, especially in order to avoid confusion of failure modes with scenarios.
- SR-Site should deal in more depth with the justification for the assigned status of FHA scenarios that may have implications for the long-term safety performance of the disposal system.
- A central register of uncertainties should be created for SR-Site, incorporating:
    - a description of the uncertainty under question and a motivation (based on the safety concept) for addressing it;
    - a thorough description of the methodological means of assessing the uncertainty qualitatively and/or quantitatively;
    - the basis for the assessment coming from research, site investigation, or engineering work (including the basis for choices of parameters or distribution functions);
    - results of the assessments and their evaluation; and
    - conclusions concerning further work.
- SKB should seek to improve the documentation of how critical model parameters are identified through sensitivity analysis, and provide a more thorough audit trail to justify value assignments for those parameters.

- SKB should considers using a range methods for sensitivity analysis, together with a more comprehensive presentation of their results to ensure that attention is drawn to key factors influencing the outcome of the safety assessment.
- It has become a matter of priority for SKB to define clearly its overall strategy for the development of fit-for-purpose biosphere assessment tools (both models and parameter values) for SR-Site, consistent with both SSI's requirements for risk calculation and the overall objectives of the wider safety assessment.
- Given the critical importance of assumptions regarding key aspects of the initial state of the engineered systems, the SAM review team believes that SR-Site is likely to require a stronger basis for the belief that attainment of the assumed properties is feasible. SR-Site should therefore include a focused discussion of the feasibility of achieving the assumed conditions and means that will be adopted for assuring that they will be achieved.
- SKB should provide a clear description in SR-Site of design criteria and their relationship to safety function indicator criteria.

3.2 Recommendations for Licensing Authorities

- SKI and SSI should insist that evidence is provided of the implementation of an appropriate QA program in relation to SKB's safety assessment activities.
- The SAM review team believes that it would be inappropriate for licensing to be completed without a clear and comprehensive plan for necessary demonstrations and confirmation tests, especially in relation to achieving the assumed 'initial state' conditions in the repository.
- SSI (in particular) should consider extending its guidance on BAT, perhaps through opening out the discussion more broadly, to ensure that it is practically oriented towards making meaningful design choices. It is also relevant to differentiate between BAT in relation to a particular site and design concept for licensing purposes, and the wider issue of optimisation in terms of the overall deep disposal programme (choice of concept, siting, etc.).
- SKI and SSI should consider how SKB's design or safety function criteria might be effectively incorporated as licence conditions, especially if it is not possible to demonstrate achievability at the time of licence application.
- SKI and SSI should negotiate an outline of the expected content of the licence application, showing how safety assessment is expected to relate to the wider safety case, as well as other components of the ongoing repository programme.

4 Acknowledgements

All members of the team have contributed to the report and are collectively responsible for its content. The team would like to express its thanks to SKI and SSI for help in supplying information needed for the review, and to SKB for its co-operation in the open discussions during the hearings that took place on March 20-22, 2007.

5 References

IAEA (2006). *Geological Disposal of Radioactive Waste – Safety Requirements*. IAEA Safety Standards Series WS-R-4, International Atomic Energy Agency, Vienna, May 2006.

NEA (2000). *SR 97: Post-closure Safety of a Deep Repository for Spent Nuclear Fuel in Sweden. An International Peer Review*. Nuclear Energy Agency, OECD, Paris.

NEA (2004). *Post-closure Safety Case for Geological Repositories – Nature and Purpose*. Nuclear Energy Agency, OECD, Paris.

Sagar B, Bailey L, Bennett D, Egan M J, Röhlig K-J (2004). *International Peer Review of Swedish Nuclear Fuel and Waste Management Company's SR-Can interim report*. SKI Report 05:02, SSI report 2005:02, December 2004.

SKB (1999). *SR 97 – Post-closure safety, Main report Volumes I, II and Summary*. SKB Technical Report, TR-99-06, Svensk kärnbränslehantering AB, November 1999.

SKB (2004). *Interim Main Report of the Safety Assessment SR-Can*. SKB Technical Report TR 04 11, Svensk kärnbränslehantering AB, August 2004.

SKB (2006a). *Long-term Safety for KBS-3 Repositories at Forsmark and Laxemar – A First Evaluation: Main Report of the SR-Can Project*. SKB Technical Report TR 06 09, Svensk kärnbränslehantering AB, October 2006.

SKB (2006b). *FEP Report for the Safety Assessment SR-Can*. SKB Technical Report TR 06 20, Svensk kärnbränslehantering AB, November 2006.

SKB (2006c). *Initial State Report for the Safety Assessment SR-Can*. SKB Technical Report TR 06 21, Svensk kärnbränslehantering AB, November 2006.

SKB (2006d). *Climate and Climate-related Issues for the Safety Assessment SR-Can*. SKB Technical Report TR 06 23, Svensk kärnbränslehantering AB, November 2006.

SKB (2006e). *Geosphere Process Report for the Safety Assessment SR-Can*. SKB Technical Report TR 06 19, Svensk kärnbränslehantering AB, November 2006.

SKB (2006f). *Handling of Future Human Actions in the Safety Assessment SR-Can*. SKB Technical Report TR 06 24, Svensk kärnbränslehantering AB, November 2006.

SKB (2006g). *Fuel and Canister Process Report for the Safety Assessment SR-Can*. SKB Technical Report TR 06 22, Svensk kärnbränslehantering AB, November 2006.

SKB (2006h). *Buffer and Backfill Process Report for the Safety Assessment SR-Can*. SKB Technical Report TR 06 18, Svensk kärnbränslehantering AB, November 2006.

SKB (2006i). *Data Report for the Safety Assessment SR-Can*. SKB Technical Report TR 06 25, Svensk kärnbränslehantering AB, November 2006.

SKB (2006j). *Model Summary Report for the Safety Assessment SR-Can*. SKB Technical Report TR 06 26, Svensk kärnbränslehantering AB, November 2006.

SKI (2002). *The Swedish Nuclear Power Inspectorate's Regulations concerning Safety in connection with the Disposal of Nuclear Material and Nuclear Waste (including General Recommendations concerning the Application of the Regulations)*. SKIFS 2002:1, March 2002.

SKI and SSI (2001). *SKI's and SSI's Joint Review of SKB's Safety Assessment Report, SR 97*. SKI Report 01:04, Swedish Nuclear Power Inspectorate; SSI Report 2001:03, Swedish Radiation Protection Authority, January 2001.

SSI (1998). *The Swedish Radiation Protection Institute's Regulations on the Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste*. SSI FS 1998:1, September 1998.

SSI (2005). *The Swedish Radiation Protection Authority's Guidelines on the Application of the regulations (SSI FS 1998:1) concerning Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste*. SSI FS 2005:5, September 2005.

SSI and SKI (2005). *Review of SKB's Interim Report of SR-Can: SKI's and SSI's Evaluation of SKB's Up-dated Methodology for Safety Assessment*. SSI Report 2005:13, Swedish Radiation Protection Authority; SKI Report 2005:40, Swedish Nuclear Power Inspectorate, July 2005.

Appendix 1: Instructions for the Review Team

SKI's and SSI's guidelines for this review, as recorded in the Terms of Reference provided to members of the team, are reproduced below.

"The Safety Assessment methodology review team should address the following questions:

- Is the safety assessment methodology appropriate for the future SR-Site and consistent with the Swedish regulatory framework?
- If not what revisions would be needed?

The following methodological areas are of particular interest:

- Strategy for safety demonstration and structuring of different arguments in the safety case, including allocation of safety to different barriers, expression of confidence, use of risk and other safety indicators, quality assurance, optimisation, etc.
- Traceability and transparency aspects and the suitability of the report hierarchy
- Methods to demonstrate completeness and the handling of FEPs
- Selection of scenarios in relation to regulatory guidance and the role of function indicators
- Methods for handling of uncertainties
- Methods for consequence calculation and presentation of risk results

The chairman of the group should in consultation the other team members and also SKI/SSI present a more detailed specification of key areas for review work within the group. This has to be accomplished well in advance of the submission of written questions to SKB. In order to ensure continuity, this review team is partially based on the team of experts who conducted the international peer review of SKB's SR-Can interim report. The work within in this review group should to some extent be able to build on the outcome of this previous work.

The respective chairs of INSITE and OVERSITE (i.e. Chapman and Wilmot) have been included in this group so that the experience from the several years of review work within these two groups can be utilised also in this context. These two experts are expected to complement the other review team members and to have a relevant background and expertise since awareness of the key concepts in safety assessment is a basis for judging the needs within site characterisation. However, the contribution of Chapman and Wilmot will be smaller than for the other team members, since they also have other engagements in the SR-Can review."

Appendix 2: International Peer Review Team Members

Budhi Sagar (Center for Nuclear Waste Regulatory Analyses) (Chairman)

Budhi Sagar is President of the Center for Nuclear Waste Regulatory Analyses (CNWRA), at the Southwest Research Institute in San Antonio, Texas. He has B.S. and M.S. degrees in Civil Engineering and a Ph.D. degree in Hydrology, with over forty years of professional experience that includes teaching, researching and consulting. Dr Sagar is the primary representative with the US Nuclear Regulatory Commission (USNRC), which is the sponsor of CNWRA, representing the USNRC at the meetings of the OECD/Nuclear Energy Agency Integration Group for the Safety Case. He provides overall direction for conducting technical assistance work and research activities of the CNWRA, assures efficient manpower utilisation, controls budgets and schedules, and assures quality of work. Dr Sagar is the author of several numerical models and has published over 100 papers and reports related to various aspects of repository safety assessments. He was Chair of the International Review Team for SKB's SR-Can interim report and has previously participated as a peer reviewer for nuclear waste programmes in the UK, Korea and Canada.

Michael Egan (Quintessa Limited) (Secretary)

Michael Egan is a consultant specialising in the design, review and implementation of assessment studies in support of long-term radioactive waste management, with a particular focus on the way that different types and sources of information are used to inform the development of a safety case. He trained in Physics and worked briefly as a teacher before starting a career and environmental assessment research and consulting. During this time, Michael has led environmental audits and reviews world-wide, from Indonesia to Russia, Eastern Europe and the Middle East. A major theme of this work has been the effective understanding of environmental risk information and its interpretation alongside other important factors, including priorities identified through stakeholder involvement, as part of a transparent decision making process. This includes guidance in the development of systematic approaches to long-term safety assessment for radioactive waste disposal, technical reviews on behalf of SKI and SSI, and development of guidance on environmental options appraisal for UK regulators. He was secretary of the International Review Team for SKB's SR-Can interim report and recently played a significant role as a facilitator in support of the assessment and options appraisal programme conducted by the UK Committee on Radioactive Waste Management.

Klaus-Jürgen Röhlig (Gesellschaft für Anlagen- und Reaktorsicherheit mbH - GRS)

Klaus-Jürgen Röhlig is the deputy head of the final disposal department at GRS. He graduated as a mathematician and received his PhD degree in 1989. Dr Röhlig joined the Gesellschaft für Anlagen- und Reaktorsicherheit mbH in 1991, initially working on hydrogeological modelling and numerical simulation of fluid flow and contaminant migration. During the following years, his work broadened to other fields and more general methodological considerations linked to the post-closure safety case for radioactive waste repositories. He worked as a project manager for technical advice to the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety in the field of post-closure safety for radioactive waste management and is now involved in the development of safety criteria and regulatory guidelines for radioactive waste disposal. He is a member of the core group of the OECD/Nuclear Energy Agency Integration Group for the Safety Case of radioactive waste repositories. He was a member of the NEA review teams for "Dossier 2001 Argile" and "Dossier 2005 Argile" produced by the French National Agency for Radioactive Waste Management as well as of the International Review Team for SKB's SR-Can interim report. In December 2006, Klaus-Jürgen Röhlig was offered a professorship for repository systems at the Technical University of Clausthal, which he has recently accepted.

Neil Chapman (Independent Consultant)

Professor Neil Chapman has a PhD in geology and is Chairman of the ITC School of Underground Waste Storage and Disposal in Switzerland. He is Research Professor of Environmental Geology at the Department of Engineering Materials, University of Sheffield (UK), Programme Director of the Arius Association (Switzerland), and an independent consultant in radioactive waste management. He has 30 years' experience in the scientific and strategic aspects of deep and shallow disposal of radioactive wastes, including provision of advice at the highest level to industrial and governmental organisations in many countries (most recently, Italy, Japan, Germany, South Africa, Sweden, Switzerland, UK and USA). He is author/co-author of over one hundred papers and seven books on this topic. He has participated in numerous national and international committees concerned with the environmental impact of radioactive waste, in the technical management of internationally funded projects, and as a visiting expert. He is currently Chairman of the INSITE site investigation overview group for the Swedish regulatory authority, SKI, and a member of the International Technical Advisory Committee (ITAC) of the Japanese waste management organisation (NUMO).

Roger Wilmot (Galson Sciences Limited)

Roger Wilmot has a PhD in geology and is a Senior Consultant with Galson Sciences Ltd in the UK. He has over 25 years' experience in providing a broad range of research, consultancy and management services to a range of clients in the nuclear industry, starting with site characterisation work for the four potential UK sites for shallow waste disposal in the 1980s. Since then he has been involved in radioactive waste disposal programmes in the UK and other countries, with particular interest in the role of the surface environment in assessments, and the development of tools aimed at improving transparency and traceability in assessments and retaining corporate knowledge. Dr Wilmot has advised regulators and developers on strategies for considering future human actions and is currently working with the UK environmental regulators on revisions to their guidance on requirements for authorisation. He is Chairman of the Oversite overview group for the Swedish Radiation Protection Authority (SSI).

Appendix 3: Acronyms

BAT	Best Available Technique
FEP	Feature, Event and/or Process
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IRT	International Peer Review Team
NEA	Nuclear Energy Agency of Organisation for Economic Co-operation and Development
PDF	Parameter distribution function
SAM	Safety Assessment Methodology
SKB	Svensk kärnbränslehantering (Swedish Nuclear Fuel and Waste Management Co.)
SKI	Statens kärnkraftinspektion (Swedish Nuclear Power Inspectorate)
SR	Safety Report
SSI	Statens strålskyddsinstitut (Swedish Radiation Protection Authority)

Appendix 4: Questions by the Safety Assessment Methodology Review Team Before the Hearing and SKB's Answers

January 2007

Answers added by SKB February 2007

No.	Question
Overall methodology	
1.	**The description of Step 2 of the assessment methodology (Summary and Section 2.2 of the Main Report) identifies the times at which the Initial State of the system is described. For the fuel and engineered components of the repository, this is immediately following deposition, whereas for the geosphere and biosphere it is the natural system prior to excavation.** **How has SKB's methodology addressed potential inconsistencies associated with the fact that these descriptions are provided at different times (e.g. perturbations to the geological structure and groundwater system introduced by the repository)? It would have been helpful if a brief summary of key methodological issues was provided here (or in Section 4) rather than having to refer to the Geosphere process report.** This is addressed by documenting understanding of short-term geosphere processes in the Geosphere process report and then describing an integrated evolution of the excavation/operation phase in the main report, section 9.2. It is through this description of the integrated evolution that a consistent description is achieved. This is analogous to the handling of subsequent time frames, for which process understanding is documented in the process reports and an integrated evolution is described in the reference evolution in the main report. (An additional sentence in section 4.1 explaining the handling of short-term geosphere processes in the reference evolution could perhaps have clarified this further.)
2.	**How should we properly understand the difference between "reference evolution" (defined in Step 7 of the assessment methodology) and the Main scenario? The summary text for Step 8 notes that the two are "*closely related*", but it is not clear why (from a methodological perspective) it is necessary to differentiate between the two.** **Is it correct to suppose that the difference between the Reference evolution and Main scenario is that the former describes an *envelope* of possibilities for concepts, models and evolutions, whereas the latter is based on a *specific* assumption or decision, selected from this range, regarding how the system should be modelled (e.g. the choice of a particular hydrogeological model, or the assumption that thermally-induced spalling occurs. cf. Section 12.2.1)?**

	Yes, this is the difference between the two. The reference evolution is an instrument for gaining understanding of the system behaviour and benefits from not being too restrictively defined. The main scenario must, however, be more strictly defined in order to obtain a clear treatment of uncertainties in the set of scenarios. However, as evidenced by the cited section 12.2.1, there are only a few aspects of the evolution for which these restrictions were required. The difference is thus not considerable. **Is the "*base variant of the repository evolution*" (Section 11.3) synonymous with "*reference evolution*" (Section 9), or should we understand that there is some subtle difference between the two?** There are two variants of the reference evolution; the base variant assuming repetitions of the Weichselian glacial cycle and the greenhouse variant where the external conditions are assumed to be influenced by an increased greenhouse effect, see section 9.1 page 201 and section 9.1.1 pages 202-203 for details. (It would probably be helpful to add a sentence describing this in step 7 of the overview of the methodology in section 2.2.)
3.	**On p.58, Section 2.6 of the Main SR-Can Report, the use of expert judgments is described. It is stated that: (i) formal methods of expert selection are not used, and (ii) formal methods for elicitation are not used. In the absence of such formal methods, what approaches are followed by SKB in ensuring that differing expert judgments are (i) recorded and (ii) appropriately handled (i.e. factored into analyses). Can SKB please provide an example of a situation in which differing judgments were reconciled? To what level of detail is the reasoning (or rationale) behind expert judgment recorded? What QA procedure is applicable to obtaining and documenting expert judgments? Although the potential of bias in the "*most experienced individuals*" working in the project is acknowledged, it is unclear how such bias has been accounted for within the project.** There are a number of ways in which this is done. The template for documenting processes in the Process reports forces the author to discuss conceptual uncertainties systematically. Similarly, data uncertainties are systematically addressed in the Data report. The fuel dissolution (alteration) rate recommended for use in SR-Can was the result of several years' work by an international team of experts, as documented in /Werme et al, 2004, SKB TR-04-19/. Another example in SR-Can is the compilation of expert judgements regarding earth quake frequencies, see Table 9-5, p. 238 section 9.3.5 of the Main report (also used in section 9.4.5). All important material in the assessment has been review by external experts and review comments are addressed according to a formal and documented procedure when a report is finalised. Within the site modelling and safety assessment projects, issues of debate are often discussed in meetings, where a consensus view on what the needed uncertainty space needs to be is searched. Basically, if someone reasonably argues for wider distributions or additional alternatives – this widening of uncertainty is factored into the uncertainty

	estimates. Generally, the different arguments for the uncertainty range are documented – but not the actual discussion. A situation where our experts, after such discussion, fully disagree has never been accounted. There are in fact few situations where different expert opinions are encountered. However, sometimes a large spread of input data (e.g. regarding sorption) or models (e.g. hydroDFN models) is retained to reflect various possibilities. One example of considerable internal discussion is the hydrogeological model of Forsmark, where the hydro-modelling experts first only wanted to retain the DFN-option, but where the Site Characterisation team suggested this to be much more permeable than suggested by site data. After discussion we decided to also include the CPM model. In after thought this was wise – since new data suggest a hydraulic situation encompassed by the alternatives actually analysed.
4.	**While pessimistic handling of many uncertainties is possible (Main Report Section 2.7.3), can an analyst uniquely identify 'pessimistic' conditions in a complex non-linear system such as a repository system? Did SKB come across any cases where the identification of pessimistic conditions was problematic? Can examples be provided? What is the link between data (model parameter) uncertainties and raw data?** There are certainly examples of where pessimistic conditions can be identified and such where they can not. A higher earthquake frequency or probability of thermally induced spalling is negative for repository safety. A higher sorption potential is, however, an example of a condition that is not necessarily pessimistic. Overestimating scenario probabilities when these are difficult to quantify (and allowing the sum of scenario probabilities to exceed one) is another example of a pessimistic handling. Generally, distributions of data are provided in the SR-Can Data report. Pessimistic values are suggested only when there is confidence that this can be shown to be pessimistic, with motivations given in the Data report. (This is briefly addressed in section 2.3.7 of the Data report.) For example, sorption data for consequence calculations are derived as input distributions, meaning that a full range of data is considered in probabilistic calculations. (Note that low sorption values are described as "low" and not "pessimistic" in the Data report.) The link between raw data from the sites and parameter uncertainties is outlined in section 4.3.1 of the Main report. Raw data from the site are first assessed in a (comprehensive) site model (SDM). The implications for SR-Can are assessed in the SR-Can Data report. More generally, the Data report is the instrument for documenting the link between raw data and model parameter uncertainties.
5.	**Avoidance of human errors in modelling through the use of formal procedures is mentioned on p.62 of the Main Report. Where are these formal procedures described? What procedures apply to model validation (Section 2.8.2)? It appears from the Model Summary Report that at least some models and codes (e.g. Analytic Radionuclide Transport Model, Analytic Model for Advective Conditions) developed by SKB (ty-**

	pes 4a and 4b) lack documentation and verification at this time. **The terms verification and validation are both used in the Model Summary Report; how does SKB distinguish between these two?** "Avoidance of human errors" relates to user training and documentation reported in the Model summary report, no procedures have been developed to guarantee data handling etc. during calculations. It's correct that the two mentioned analytical models lack written documentation as code implementations. The models have been developed in MS Excel and the documentation appears in the spread sheet (all these calculations have been performed by the developer of the model). The analytical expressions are, however, fully documented in the references given in the Model Summary Report. Several of the cases calculated with the analytical models have also been performed using the fully documented numerical Compulink, as reported in the Main report, thereby further benchmarking the analytical models. In the Model summary report, verification deals with numerical uncertainty while validation deals with modelling uncertainty.
6.	**On p.62, Section 2.8 of the Main Report, it is stated that a QA plan has been developed but it has however been only partially implemented at this time. It is also stated that the full QA plan will be implemented throughout for SR-Site. How will data, models, tests, and analyses that were conducted in the past without implementing a full QA program (such as for SR-Can) be qualified for use in SR-Site, which is the basis for a formal licence application. Is there a QA procedure for data qualification, for example? Also, can SKB provide some statistics with respect to the implementation of the QA program? For example, SKB could provide a very brief summary of number of surveillances and audits conducted in the past year and some statistics of QA findings, e.g. number of non-compliances. Any trend analysis would also be helpful.** **How will SKB audit its QA system for SR-Site? Will this be an internal or a certificated external audit, or both?** The Data report, providing data qualification, has been produced in accordance with the QA-plan in SR-Can (similar routines were followed also in the earlier SR 97 assessment). The SR-Can procedures will be used also in SR-Site when updating the Data report. Models are qualified through the SR-Can Model summary report. An updated and expanded Model summary report will be produced for SR-Site. Most model calculations will be repeated/updated in SR-Site.

	There have been no QA audits in the past year, there are hence no statistics or trend analyses to present. The QA system for SR-Site will be audited according to the QA-plan for the Spent fuel project of which SR-Site is a sub-project. SKB is certified according to the ISO 9001:2000 and ISO 14001 standards. External audits are performed annually by the certifying organization. According to the ISO 9001 standard SKB has a programme for internal audits which is decided by the company management on an annual basis. In addition to that programme, the Spent Fuel Project management decide on further audits within the project.
7.	**Under 'Alternative Safety Indicators' (Section 2.9.3), reference is made to a number of different approaches (the SPIN project, STUK release constraints, and the Miller report for SKI/SSI). However, only the STUK indicators were used in SR-Can. Why was this approach selected and the others not chosen?** Not only the STUK indicators but also naturally occurring concentrations of radionuclides are used in SR-Can (see section 2.9.3 and further section 10.5.6). Generally, the discussed indicators are not independent. The SPIN radionuclide toxicity flux from the geosphere is similar to the STUK indicators since the latter have been derived taking radiotoxicity into consideration. The SPIN biosphere concentration indicator is similar to the biosphere concentration used in SR-Can. The cited Miller study also considers similar indicators and the IAEA work is in progress. The selected indicators for SR-Can are seen as one reasonable way of complementing the dose indicator. **More generally, the use of indications from natural analogues and observations in nature is managed unevenly in the reports. The climate report considers this line of evidence seriously, as does the Geosphere Process report, whereas the other Process reports do not. There is a tendency for the latter to mention that information could be available, without addressing what it is saying or being willing to handle the uncertainties inherent in this type of data. The impression is given that the authors do not believe analogue evidence is of any real value – in which case a reasoned discussion of this general position at the outset would be better than the shallow treatment repeated in each section.** **Does SKB intend to improve their treatment of this topic in SR-Site?** <u>Buffer and backfill</u>: For most processes in the Buffer & Backfill subsystem natural analogues are of rather limited value, since it is hard to find relevant observations. However, for some processes, eg montmorillonite alteration, data from natural analogues are used directly in the model validation, as described in the Buffer and backfill process report. <u>Fuel and canister:</u> For fuel and canister processes, natural analogues are applicable in only a very few cases. Natural analogues for zircaloy cladding, for example, must be treated shallowly since there are no natural analogues for zircaloy. This is the case for most of the fuel and canister processes. Where there are analogues, however, we feel that they have been treated appropriately. We see no obvious reason to improve the treatment of this topic in SR-Site.

	See also response to the very last part of question 17 from the EBS group.
Initial state of the repository	
8.	**In Section 4.1.2 of the Main Report it is noted that "*Other FEPs in the FEP catalogue concern the effects of an unsealed or abandoned or monitored repository. These issues are also propagated to the scenario selection in chapter 11, but are not further analysed in SR-Can. FEPs relating to effects detrimental for long-term safety caused by monitoring are excluded from further analysis since this type of monitoring will not be accepted.*"** **Is there any documentation (for example draft Quality Control plans) available concerning the planning/management of actions such as excavation, loading, closure, decommissioning and monitoring of the facility? Are there any specifications for what are considered to constitute required/acceptable actions and what would represent unacceptable actions during construction, operation and final closure of the facility?** No, but such documentation is planned to be included in the license application for the repository. **What exactly is meant by '*phased operation*' in the context of the KBS-3 repository, and how does it relate to the treatment of other FEPs (including those discussed above)?** The term refers to the fact that, at a given time, different parts of the repository will be in different stages of development (fully deposited and backfilled, backfilling in progress, deposition in progress, excavation in progress, excavation not yet started). This is preliminarily addressed in section 9.2.6 (referred to in Table 4-1 on page 81) and will require more attention in SR-Site.
9.	**SR-Site will primarily be based on surface-based data. Once SKB starts excavating, new data will become available. How will these new data be factored into safety assessment? Is it planned that the safety assessment presented in SR-Site should be updated? What will happen if new conditions are observed during operations?** There will be a new safety assessment when a licence to begin operation is applied for. That assessment will be based on data from the detailed investigation during excavation. Prior to that, evaluations of new data will be made and possibly also integrated safety assessments. The details of this programme remain to be established. Potential new conditions of relevance for safety observed during operations will be reported according to requirements in SKI's regulations.
10.	**How is canister tightness (Main Report Section 4.2.1, p.82) measured or quantified? Does this primarily refer to the integrity of the weld or does it also refer to initial material defects in copper shell and iron insert? Is the canister self-shielding? Does SKB propose to assess the surface conditions (e.g. including any damage during handling) of the canister after it has been placed in the deposition hole?** The canister seal weld as well as other parts of the canister assembly will be subjected to

	inspection using non-destructive testing methods. The canister is not self-shielding. Yes, SKB will assess surface conditions. Work on this in progress.
11.	**How much void space is present in the canisters? The Initial Sate report (e.g. p.29) does not give a total value, only some data on fuel pins. Also, what is the likely range of possible water contents of this void space? An upper bound of 600 g is presented (p.33) without explaining why.** The void volume in a BWR canister with fuel elements is about 1 m^3. The fuel will be dried and there should be very little water in the canister. The range of possible water contents of this void space is unknown. The upper limit of 600 g is based on estimates made by the crew designing the encapsulation plant.
12.	**Under discussion of minimal copper thickness in Section 4.2.4 of the Main Report (p.85), the following statements are made:** ***"Normal operation is defined as conditions where the observable parameters of the sealing process are within a defined "process window". The probability of detecting these defects is not taken into account. This omission is, however, of minor importance since i) the probability of detection for these defect sizes is fairly low and ii) these defects are acceptable, meaning that a possible detection would not lead to any corrective measures.*** ***If the sealing process parameters at any time lie outside the process window, the statistics of defect sizes referred to above cannot be taken as representative."*** **Can this be further explained, please? For example, it is not clear what is meant by the phrase "*these defects*".** "These defects" refer to those that could occur when operating within the process window, see SKB Report R-06-04 for further information. The most common defect is "joint line hooking". The vertical joint between the inside of the copper cylinder and the lid is bent towards the shoulder of the welding tool due to the materials flow around the tool during welding. They appear as crack-like flaws (< 10 μm) with a radial extension of a few millimetres.
13.	**What is the strategy for managing thermal loads in the repository? How will the canisters containing PWR, BWR and other fuel types (e.g., MOX) be located within the deposition tunnel to balance the heat output?** The current strategy is to select spent fuel elements in order to reach a heat output below but as close as possible to 1700 W per canister at deposition (see section 9.3.4 of TR-06-09 for a discussion on the relation to the temperature criteria). This implies mixing of old and newer spent fuel. Simulations have been made based on properties of existing spent fuel and current plans for future production. The simulations show that some canisters will not be completely filled at deposition. Hence, most canisters will have a heat output close to the maximum allowed and there are currently no plans to specifically locate different types of spent fuel in different areas. There are uncertainties concerning

	the properties, amounts and timing of future spent fuel and SKB does not consider it meaningful to optimize the system with respect to heat output at this point.
14.	**Much depends on the quality of the buffer. The description of buffer emplacement (Main Report p.87 and in Chapter 5 of the Initial State report) does not provide great confidence that SKB has found a feasible means of doing this without damage or degradation to the buffer or fiddly, difficult and uncertain techniques (e.g. plastic bag 'sealing bodies' at the bottom of deposition holes).** **Does SKB plan to carry out any full-scale demonstration tests of buffer and deposition hole management under simulated remote, active handling conditions, prior to submission of application for a construction license?** Full scale tests will be performed in the new bentonite laboratory at Äspö. The different techniques for temporary water protection will be developed and tested for different possible underground conditions (e.g different water inflow). The integrated test of simulated remote, active handling is not planned to be tested until after the application for a construction licence. The plans for how this will be made will be included in the application.
15.	**In Table 4-3 of the Main Report (p.86) some of the uncertainties in bentonite composition (mainly attributed to the analysis method) appear to be rather high by comparison with the measured values for the two bentonite types. Is it these sources that underpin the parameter values used in the SR-Can assessments, or are there additional sources? How relevant are such uncertainties for safety functions?** Bentonite is a geological term and refers to a natural material, which sometimes has a rather complex mineralogy in itself. The mineralogy of a commercial bentonite product is a matter of how careful the producer excavates the material and how they mix material from different sources in order to fulfil the specific quality demands of the particular product. The products may consequently vary somewhat both within and between different consignments. Determining the detailed mineralogy of a bentonite is not a straight forward single analysis, and a number of quite different analyses are usually used. There are even scientific contests regularly arranged in order to stimulate the development of techniques. So far, SKB has used XRD powder diffraction as the main tool, and the quantifications have been made by use of the Rietveld method. The mineralogical structure of the swelling clay part (montmorillonite) is calculated based on a chemical analysis of the clay fraction and analyses of the amount and type of charge compensating cations. The total mineralogical ensemble on the bentonite may then be calculated into a chemical composition, which is checked with the chemical analyses of the bulk material. There are significant uncertainties in the presented analyses as stated in the question, and according to the above, further variation may be present. However, the exact amount of swelling clay mineral is not crucial and secondary minerals and substances of special interest, such as sulfides and organic carbon, are determined separately in dedicated analyses.

	The values presented in table 4-3 are the source of input parameters. The data may be seen as an example of realistic quality demands on the bentonite rather than a specific and exact composition. The role of the uncertainties on the specific buffer safety functions is considered small.
16.	**The use of pumps to drain deposition holes is mentioned in Section 4.2.6 of the Main Report (p.87). What is the reliability of these pumps? What is the consequence if the pumps fail?** The reliability of the pumps will be investigated as a part of the development of the installation process. Alarms for pump malfunction will be used in the same way as for the installation of the Prototype repository. If the pumps malfunction they can be replaced quickly. If the pumps malfunction and are not replaced for a long period of time (depending on the water inflow rate) water could possibly pass the seal of the water protection, access the buffer and cause premature swelling. Worst case scenario is that the buffer swells so that the buffer density is affected. In this case the buffer would need to be replaced.
17.	**The Sicada data base is mentioned in Section 4.3.1 of the Main Report (p.95). Does this database include only quality assured data (on page 14, it is indicated that data are quality assured before entering into Sicada) or are the data it contains a mixture of quality assured and non-quality assured data? If the latter case, does the data base indicate the QA pedigree of each data set? Does this database also contain reliability (or uncertainty) estimates?** SICADA contains the results of field measurements – where the QA implies that measurement data with errors etc. have been corrected. SICADA also contains "meta-data" (i.e. data on how the measurement was made) or references to such data. Uncertainty of the data and evaluation/interpretation is part of the Site Descriptive Modelling and is presented in the Site Descriptive Model reports (SDM), see SKB R-05-18 (Forsmark) and SKB R-06-19 (Laxemar). Uncertainty in field data is an important part of the uncertainty estimates of the site parameterisation of the SDM work. Account is also made from various other sources of uncertainty (bias, lack of information, poor process understanding, neglect of couplings,… etc.) – and the overall findings of these uncertainty assessments are summarised in Chapter 12 of the SDM:s. The associated descriptions (with uncertainty) are stored in the "Simone Database". These (usually quantified) uncertainties form the site specific input to the SR-Can data report, which in turn assesses both the quantified and qualitative uncertainties and determines how this is to be quantified for the Safety Assessment application.
18.	**In discussion of groundwater flow at the Forsmark site (Main Report Section 4.3.2, p.108), it is stated that *"The analyses suggest that the flow field in the north-western part of the candidate volume is mainly local."* What exactly is meant by this statement? Is the boundary of the RFM029 domain also a hydraulic boundary?**

	The numerical models suggest that there is a discharge area immediately above this part of the repository, such that flow through the repository is generally directed upward toward the surface, and this situation continues into the future for the temperate period. The discharge area corresponds to an area of low topographic relief.
19.	**In discussion of groundwater composition at the Forsmark site (Main Report Section 4.3.2, p.111), it is stated that "*Hydrogeological simulations of the past evolution of groundwater composition show some agreement between simulated and measured hydrogeochemical data at depth, whereas poorer matches were obtained in the upper 100 m of the rock.*"** **Actually Figure 4-30 appears to suggest that such an agreement is visible for only 2 of the 4 boreholes, and only at depths of about 300 to 500 metres (measurements are lacking at these depths in the other two cases). At greater depths, measurements for only one borehole are visible (and apparently not in particularly good agreement with the calculated values). The "*poorer matches*" in the upper part of the model might presumably be related to the boundary conditions – it seems that zero salinity was assumed for the surface, which is not in agreement with the measurements. Is this correct?** No, it is not entirely correct. Figure 4-30 show the results of simulation of the past evolution considering the past shoreline displacement due to postglacial rebound sea level changes and the past variations in the salinity of the Baltic Sea that covered the candidate area until c. 1000 years ago. The applied boundary condition for salinity attempted to reflect this variation with an increase in salinity from the onset of the Littorina period (see Figure 4-28 in the SR-Can Main report) to a maximum of 12‰ at 4,500 BC and then a decrease in salinity towards modern salinity levels of the Baltic Sea from 3,000 BC (Figure 3-13 in R-05-18). When land emerges from the sea and onwards, infiltration of modern meteoric water was assigned as the top boundary.
20.	**With respect to the use of the Discrete Fracture Network (DFN) model, SKB acknowledges that its results don't match the observed fracture data (e.g. Figure 4-38 on p.123 of the Main SR-Can report). What is the impact of using DFN in SR-Can? The simulation seems to produce non-pessimistic results with respect to fracture frequency and trace length. Later (p.132), the need for better up-scaling for the F factor in DFN model is also acknowledged. Again what is the impact (i.e. the potential implications for safety margins) of using the DFN-model in its present form?** Generally regarding DFN-models, some uncertainties are large and the uncertainty descriptions provided in the SDMs needs to be improved as discussed in the *Data Report*, section 6.3. Since the publication of version 1.2 of the SDMs SKB has initiated subprojects with the sole purpose of decreasing the uncertainty and to improve the uncertainty description. The use of the FPI criteria dramatically decreases the consequences of DFN uncertainties as regards earthquakes (see also reply to INSITE Q 26). The matching of outcrop maps is not used as a primary calibration of hydrogeological DFN models for modelling flow and transport, i.e. for models resulting in flow-path statistics such as the F-factor. The primary data for the hydrogeological DFN will be fracture intensity and orientations of flowing fractures observed in hydraulic tests, such as the PFL-f tests, and to a lesser extent the intensity of potentially flowing fractures (i.e.

	open and partly open). This data will guide the development of a Hydro-DFN parameterisation to honour the intensity of open fractures, frequency orientation and magnitudes of fracture flows, which will indirectly calibrate unknown parameters such as fracture size distribution in seeking the correct connectivity characteristics. Outcrop data will only provide an independent comparison of the statistical models developed for the flowing fractures. We aim to further enhance the methodology and utilise a larger set of data for SR-Site. In terms of the Hydro-DFN models developed for SR-Can, there is nothing to suggest the models under-predict connectivity or flow-rates.
21.	**In discussion of the preliminary repository layout for the Forsmark area (Main Report Section 4.4.2, p.141) a depth of -400 m is assumed. However, no basis for this decision appears to be given. What might cause the choice of a -500 m depth instead?** **(Same question for the choice of -500 m or -600 m at Laxemar – Section 4.4.3)** At Forsmark the 500 m level was considered to have too high stresses. However, the repository depth at Forsmark is being reconsidered for the layout to be assessed in SR-Site. Careful evaluation of stress levels suggests a deeper repository would be feasible. The main advantage would be that the repository then could be located in the very low permeable rock found at depth below about about 350 m. At Laxemar, we start to see stress related problems below 500 m, and there is little other advantage of going deeper. See also the SR-Can feedback in repository level provided in section 13.6.8 of the SR-Can main report. There, we conclude that there is essentially no reason to reconsider the depths suggested in the D1 layout.
22.	**Also in Section 4.4.2 (p. 142) that following statement is made: "*It is also noted that the use of the FPC criterion to avoid deposition positions intersected by large fractures (see section 9.4.5), to be implemented in layout D2, suggests a degree-of-utilisation of around 90% /Munier 2006a/.*" Does this apply at both -400 m and -500 m depth? Is some kind of combination of both controls on the degree of utilisation (according to rock stability/potential water problems on the one hand and the FPC criterion on the other) necessary or foreseen?** The degree of utilisation due to FPC will be the same at both depths – at least according to our current understanding (DFN-model). In the updated Site Description to be used for SR-Site we are exploring depth (and other spatial) dependencies in the fracture data, but it is unlikely that we will see any trends below the more shallow first coupled of hundred m depth or so. In theory, there could be a need to balance different factors against each other, see our answer to your question 21.
23.	**For the Laxemar site (Main Report Section 4.4.3) the degree of utilisation associated with rock stability/potential water problems appears to be considerably lower than at Forsmark. Is this an intrinsic property of the site, or might the value for Laxemar increase with an extended database?** This is probably an intrinsic property – at least for the Ävrö granite in the northern part.

	However, we hope to reach higher levels of the degree of utilisation in the quartz-monzodiorite in the southern part of the site.
24.	**To what extent will the cost of repository construction vary according to the (actual) degree of utilisation available when the rock has been opened? Could the degree of utilisation become a significant factor in selecting a preferred site (for either cost or safety arguments)?** The total cost of deposition tunnels (including excavation and backfilling) is a considerable cost in repository construction. The cost, to a first approximation, is proportional to the length of deposition tunnels. Hence, with respect to the degree of utilization we get a cost related to the length of deposition tunnel per canister. The degree of utilization is one of the factors that could become significant in selecting a preferred site, particularly if the difference between the sites is considerable.
25.	**In discussion of Monitoring (Main Report Section 4.5, p.146) SKB suggests that post-closure monitoring decisions will be left to future generations. Has SKB considered what is feasible (with the current best available technology and optimisation considerations) and whether such monitoring poses any risk to the repository? Future generations may benefit from documentation of such considerations.** The results of SR-Can shows that the barriers in the KBS-3 repository can provide the required safety without monitoring or maintenance after the repository is closed. However, monitoring for safeguards purposes might be required and for this purpose satellite surveillance and/or seismic monitoring might be adequate. SKB's current monitoring strategy is outlined in R-04-13 but will be further developed as part of the programme for investigations during construction and operation. Monitoring will be performed during repository operation. The current intention is to dismantle monitoring installations during closure of the repository but these installations could of course remain if so decided at the time of closure. If they remain their possible effects on the safety of the repository has to be evaluated. To evaluate what is best available technology at this time does not seem meaningful considering that closure will occur some 50 to 100 years into the future.
Handling of external conditions	
26.	**What are the reasons for not discussing seismicity in Section 5.1 of the Main Report?** Section 5.1 deals with the external conditions of relevance for repository safety, in this case external phenomena of importance for the generation of earthquakes, i.e. plate tectonics. Plate tectonics is briefly mentioned in section 5.1 and further in the Geosphere Process Report (chapter 4). The impact on the repository, in terms of earthquakes in its near vicinity, is regarded as an internal event and is thus discussed in detail in connection with the analysis of the reference evolution in chapter 9. **Have the cumulative effects on the stability of buffer, canister, and backfill, of many small seismic events (e.g. M < 6) over long periods of time been analyzed?** No, in SR-Can, cumulative effects of earthquakes were not analysed. This issue will potentially be a subject for refinement in SR-Site.

	How are seismic events considered in facility design and during the operational phase? The probability of having damaging natural earthquakes during the construction phase is extremely low (Main Report Table 9-5, p. 238) and has, therefore, not been considered. Earthquakes induced by excavation activities are discussed on p. 209. **Large earthquake events are not expected (as stated on p.159); what is the largest earthquake event expected over a period of 1000 yr, 10 000 yr, and 1 000 000 years?** Earthquake probabilities are summarised in table 9-5, p. 238. The frequency decreases for each earthquake magnitude by a factor of, roughly, 10. That is, using e.g. Hora & Jensen, roughly $2.5\cdot10^{-4}$ earthquakes of M≥6, $2.5\cdot10^{-5}$ earthquakes of M≥7 and $2.5\cdot10^{-6}$ earthquakes of M≥8 are anticipated within a 1000 year period and area with radius 5 km. However, these estimates are based on averages from very much larger areas. It is e.g. doubtful if the prerequisites for M≥8 are fulfilled at the sites.
27.	**How is the effect of potential glacially-induced faulting estimated (Main Report p.150)?** This is addressed in the reference evolution, section 9.4.5, pages 319-334 (probability for canister failures) and further in section 10.7, pages 445-446 (dose consequences). The final assessment of this failure mode is done in the scenario "Canister failure due to shear movement", section 12.9, pages 508-513.
Handling of internal processes	
28.	**In Section 6.1.1 (p.154) of the Main Report it is noted that "*The deposition tunnel backfill has been included as a distinct system component, rather than being described together with the buffer as in SR 97. Also, the components "bottom plate in deposition hole", "plugs", "borehole seals" and "backfill of other repository cavities" have been added. The new components are, however, in general not crucially linked to safety, and processes reports for these have not been developed in SR-Can.*" Have any specific safety functions been described for these individual components of the engineered system? How is their role in the overall safety case analysed?** The other system components do not contribute directly to safety and it will be difficult to assign meaningful safety function indicator criteria to them. However, a certain performance from these components is needed in order for the barriers to fulfil their safety functions. Examples of this could be failed borehole seals that affect the geosphere transport or a bottom plate of an unsuitable material that would affect the buffer performance. It should be possible to include the performance (or lack of performance) of the "other system components" into the scenarios derived from the function indicators for the "real" barriers.
29.	**What exactly is meant by: "*Cautious to neglect an influence that may be significant, but cannot readily be quantified.*" (Main Report Section 6.3, p.156 – fourth bullet point).**

<table>
<tr><td></td><td> What is the logic behind this reasoning, and why does it have to be "readily" quantifiable? Can SKB provide examples of such neglected influences? Similarly, if many relatively small influences are neglected, is a check made that these don't add up to be significant in the sum? Can SKB discuss if the best available technology is not capable of quantifying these effects. This can be done by discussing the technologies considered and then rejected.
The fourth bullet point has an unfortunate formulation. It is meant to say that the analyst is cautious not to neglect an influence on the sole basis that the influence may be difficult to quantify. Furthermore, as this is not a reason for neglecting an influence it should not be on the bullet list, but rather as a sentence in the main text after the list. Only reasons mentioned in the first three bullet points have been used as motives for neglecting influences in SR-Can. </td></tr>
<tr><td>30.</td><td> Critical decisions on the safety relevance of particular processes appear to have been made at a fairly early stage in the analysis to avoid over-complexity in the models. This is evident from the following:
"The purpose of the process reports is to document the scientific knowledge of the processes to a level required for an adequate treatment in the safety assessment SR-Can. The documentation is, therefore, from a scientific point of view not fully comprehensive nor highly detailed, since such a treatment is neither necessary for the purposes of the safety assessment nor possible within the scope of an assessment." (Section 6.3, p.155)
"Also, all processes identified as relevant for long-term safety and documented in the Process reports have been considered with the aim of determining if a safety function relating to the process could be defined, ideally accompanied by an indicator and a criterion." (Section 7.2, p.182).
Is there a standard formalism by which decisions about the safety relevance of a process (for example, based on past modelling experience), and judgments about the adequacy of treatment in the safety assessment, are made and recorded? Are such records available?
There is no formalism in addition to that described in the main report section 6.3, i.e. a standardised format aiming at an adequate treatment in the safety assessment. This format includes a discussion of modelling and experimental studies. The judgements about the treatment in the safety assessment are also part of this documentation.
In what form are the supporting scientific studies documented and what is their QA pedigree?
The supporting scientific studies appear as references to the Process reports. These frequently take the form of publications in the open scientific literature or SKB technical reports. As for most scientific documentation, quality is assured through adequate peer review, but there are no general and formal requirements on the vast amount of references to the Process reports. However, as the process documentation is compiled by experts in the field that are also directly involved in the safety assessment, an additional element of quality assessment is added. </td></tr>
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31.	**It is stated on p.159 of the Main Report that alternative models and alternative approaches to simplification are used to "illustrate" conceptual uncertainty. Could SKB clarify how this type of uncertainty is accommodated in demonstrating (and not just illustrating) compliance with the risk criteria?** The model used for compliance demonstration will have to be the one that yields the highest consequences unless there is evidence that this model can be dismissed as not representing reality. There are relatively few cases where these situations with alternative conceptual models occur. One example in SR-Can is the importance of the conceptual uncertainty in groundwater flow models at Forsmark (CPM, different DFN-models), where the most pessimistic, i.e. the semi-correlated DFN model, is selected for the compliance demonstration. Another example is the three (crude) models for buffer erosion (no erosion, erosion according to an equivalent flow rate model and "immediately lost buffer"). The latter two yield very similar results and the unrealistic and most pessimistic third model was, therefore, used for the compliance demonstration. Both these issues are addressed in section 12.7.2 of the Main report.
32.	**In the process tables (e.g. Table 6-2 of the Main SR-Can Report), processes placed in the orange boxes are "*neglected subject to a specified condition*". Are the effects of these processes analysed at some stage in case the specified conditions are not met?** Yes, for example the effects of buffer erosion, subject to the condition that the concentration of divalent cations is below 1 mM, is prominent in SR-Can.
33.	**Can SKB clarify how "*integrated with other relevant processes*" (e.g. Table 6-3) is accomplished? How are thermal expansion of canister and insert, copper deformation from internal corrosion products, corrosion of cast iron insert, and galvanic corrosion integrated with other processes? Does this mean that each individual process is relatively unimportant?** It does not mean that the process in itself is unimportant. The integration is done in different way for different processes. The thermal expansion, for example, is strongly related to the thermal history of the canister (depends on the temperature). The rate of deformation of the copper shell depends on the rate of cast iron corrosion, which is caused by reduction of water (with a possible enhancement from the galvanic coupling to copper.
34.	**On p.163 of the Main Report, pitting is defined as uneven general corrosion. Are not the mechanisms entirely different? Wouldn't the rate of pitting corrosion be much faster than general corrosion?** The pitting corrosion is not defined as uneven general corrosion. The corrosion attack on the copper will have the appearance of uneven general corrosion. This appearance can be caused by continuous births and deaths of small pitting corrosion cells. The pit will die once it reaches a certain depth and new pit will be initiated.
35.	**Does the neglect of stress corrosion cracking (p.163) imply that the canister weld will be stress relieved?** No. It means that one or more of the prerequisites (e.g. tensile stresses, chemical agents,

	potential) for SCC will not be present and SCC, therefore, not initiate.
36.	**Earthquakes are reported as "not relevant" in Table 6-6 (p.169 of the Main Report).Has the possibility of earthquakes cracking the ice sheet during the glaciation period been considered?** No such analysis has been considered necessary. **Earthquake-induced fracturing is also neglected (p.170); what is the supporting evidence for this?** The creation of new fractures and propagation of old fractures has not been fully addressed in SR-Can and will be further developed for SR-Site. However, creation of fractures is discussed in the Process Report, section 4.4.4 (p. 101). Additionally, we find support in studies on earthquake effect on tunnels (TR-02-24) that indicate that the main deformation/fracturing occurs within or in the immediate vicinity of deformation zones. The effect of such deformation is reduced by the use of respect distances and FPI criteria.
Safety functions and safety function indicators	
37.	**On page 57 and later in Chapter 7 of the Main Report, the safety function indicators and criteria related to them are discussed. As indicated in our previous review of the Interim SR-Can assessment, safety function indicators are very helpful in communicating and understanding the safety case.** **It is evident that the SKB is reasonably confident of meeting or exceeding the criteria for the defined safety functions. It is also clear that the overall assessment of risk is based on this confidence of meeting these criteria. It, therefore, would make sense to acknowledge this in the licence as technical specifications. Technical specifications can also form the foundation for the authorities' program for surveillance and inspection. Does SKB expect these criteria to be included in a licence should the authorities decide to grant one, as "licence/technical specification" or "licence conditions"?** There are several examples in SR-Can where the criteria for the safety functions are *not* met. Most notably this relates to the contributors in the risk summation, i.e. canister failures due to corrosion following the creation of advective conditions in deposition holes and failures due to shear movements. Furthermore, these criteria are not the same as design criteria as elaborated in section 7.2, subsection "*Safety function indicator criteria are not the same as design criteria*". They are thus not suited for inclusion as "licence conditions". **The difference between specifying subsystem performance criteria in the regulations and specifying technical specifications in the licence should be noted. In particular: (i) regulatory criteria are proposed by the authorities while technical specifications are proposed by the licensee in its application, (ii) regulatory criteria apply in general to all sites and designs but the technical specifications are specific to a site and design, and (iii) regulatory criteria are non-negotiable while license/technical specifications are negotiable during the licensing process.** Comment from SKB to the above paragraph: It is primarily for the Swedish authorities

	to comment on these statements made by the review team. (There are no subsystem performance criteria in the regulations.)
38.	**In addition to criteria for safety function indicators, the SR-Can makes promises at certain places such in relation to implementation of the FPC rule (p.140 of the Main Report) or ensuring that fuel is of sufficiently low burnup (p. 160) (is there a waste acceptance criterion?), or in ensuring control on inflow to deposition holes (p. 219). Those that are significant to providing safety assurance (meeting the risk limit) should be identified and also included in technical specifications, in case SKB and the authorities agree to go in that direction.** Comment from SKB: This is a recommendation from the review team. See also our response to question 37. We also anticipate the need for developing more useful and stringent deposition hole acceptance criteria (see section 13.6.4 , p 549 in the Main report). Such criteria are under consideration for layout D2 and to be assessed in SR-Site.
39.	**The extent to which temporal and spatial dispersion of releases is seen as a safety function is not clear (in fact it is not mentioned!). Retardation is said to be a safety function and dilution not to be one. Could SKB clarify? At the same time, and more generally as a contribution to safety case development, it would be valuable to hear a clear statement of the overall Safety CONCEPT, which is not really spelled out as a separate item.** No need was seen for developing a definition of the term safety concept in SR-Can. Safety of the KBS-3 concept has been achieved according to the principles given in section 2.5.1. The safety functions in chapter 7 are used to evaluate safety over time and the corresponding indicators thus point to important safety related properties of the system. Temporal and spatial dispersion of releases are not defined as safety functions, but these phenomena are included in the evaluation of the retarding function of e.g. the geosphere, where they may also play a significant role. They are essentially captured by the safety function R2d, the aspect of favourable transport and hydrological and transport conditions in the rock related to sorption and diffusion. This is an example of a function where there is a certain degree of freedom to choose quantities for safety function indicator, see further subheading "Quantities for safety function indicators" in section 7.2.
40.	**Figure 7-2 of the Main Report brings together the safety functions, indicators and criteria. A key geosphere function is missing: the physical isolation (shielding and physical protection) that it provides between the waste and people and the environment. Also, R1 and R2 are styled as provision of favourable conditions, but not of stable conditions (like R3). Could SKB comment?** There is no deeper reasoning behind the choice of the terms "favourable" vs "stable" – other than that being stable is not sufficient if the condition is not favourable in the first place. Indeed, an important function of the host rock is to provide physical isolation, and this could have been included. In fact, an effort to include safety functions related to future human actions is on the "to do-list" for SR-Site. Apart from physical isolation, also the absence of minerals of potential economic interest could then be included.

41.	**SKB choose not to establish quantitative criteria for gas transport properties of the buffer (Main Report p.186), yet this topic was studied in depth for the SFR silo and could presumably be treated more quantitatively. Is this approach simply a reflection of SKB's knowledge status at SR-Can, or will the simplification be propagated into SR-Site?** Yes, the reason for not using a quantitative criterion is the lack of knowledge, or a problem to define the parameter which would define the criteria. It may be possible to define a maximum allowed gas pressure in the near field of the repository, which in turn would give a criterion for the gas transport properties of the buffer. This is the aim of the gas studies at SKB, but the full picture may not be available for SR-Site.
42.	**A similar point could be made about the presence of pyrite and other impurities in the buffer. Eventually SKB will need to have real acceptance criteria for buffer material. Has an attempt been made to take the SR-Can results and back-calculate a figure?** The amount of pyrite in buffer/backfill that is needed to corrode through the canister can easily be estimated with a simple mass balance. This would give an upper limit on what is acceptable as an impurity. However, an acceptance criterion would require some approach to a safety margin. A low pyrite content in the material is an advantage, but it is not the only factor in the selection of materials.
43.	**The buffer appears to be an important barrier for various reasons yet the treatment of piping/erosion processes is only at the "scoping" calculation stage. What are the plans in this respect for the SR-Site analyses?** Piping is one important process in the SKB R&D programme for the moment. It is of critical importance to understand the consequences of piping. However, the assessment in SR-Site will most likely be very similar to the one in SR-Can. The main improvement may be a reduction in uncertainty in data. Piping is a process with rather short duration and it is easy to make observations in both field and laboratory scale. The assessment approach is to make the best use of experimental observations. **Is vapour transport in the thermal period a potential mechanism for moisture contacting the canister?** Yes, before full water saturation of the buffer vapour transport is an important process in the entire buffer, but after full saturation there will be no vapour available for transport.
Compilation of input data and data uncertainty	
44..	**In Section 8.3 of the Main Report, it is noted that:** ***"These data are identified by sensitivity analyses of calculation results using preliminary input data ranges, often from earlier assessments. A number of calculation endpoints regarding both isolation and retardation have been considered and sensitivities of these to input parameter uncertainty have been determined."***

	The results of such sensitivity analyses are presented at several different places in the Main SR-Can report. Should the accounts presented in Sections 9.3.14, 9.4.10, 9.5.1 and 9.6.4, which describe the evolution of safety functions for different time periods and variants, be considered a comprehensive representation of the main findings from these sensitivity studies? Not only – also earlier findings e.g. from SR-97 are used in motivating sensitivities – as further described in relevant sections of the Data report. Findings from SR-Can will be used when judging importance of data in SR-Site data report.
45.	**In SKB's probabilistic analysis of canister inserts (TR-05-19), the probability of canister failure is shown to be very sensitive to the radius of outer corner and eccentricity of the iron insert. For example the failure probability (Figure 4-4 on page 27) for a load of 44 MPa varies from < 10E-16 to > 0.1 for an eccentricity of 5 mm to 15 mm. In safety assessment, the overall failure probability is assumed to be of the order of 10E-9.This assumes a high level of quality control in the manufacturing process. Has SKB studied the feasibility of such manufacturing processes?** Such studies are in progress. **Similarly, on p.87 of the Main Report, only one buffer out of 6,000 is expected to be defective with respect to density, again indicting a very high level of quality control including inspections, testing, and rejection of defective pieces. Is dynamic load due to seismic activity considered in deriving the design load? Would deformation create conditions suited for stress corrosion cracking?** The deformation will create tensile stresses in the copper. Tensile stress is a necessary by not sufficient condition for creating SCC.
46.	**Does SKB plan to test full scale canisters to verify the conclusions drawn from its mock-up tests (TR-05-18) with respect to the maximum strain and stress, which are shown to be strong functions of length of test specimen, e.g., the maximum strain increased by 27% as the specimen length increased from 1 m to 1.5 m. Further discussion is also needed with respect to reproduction of "end effects" in the tests.** At present we have no concrete plans for full scale testing. We have not identified a facility that could handle an object with the required size and weight. It is also questionable whether this would add anything. The probabilistic analysis and the mock-up tests showed both that we have a large safety margin to collapse for the load conditions anticipated in the repository.
47.	**What are SKB plans to include effect of creep into analyses? Creep may prove to be significant under the rather large static load. Also, SKB notes in the report on the mock-up tests (TR-05-18) that, in experiments, the onset of plasticity was at lower stresses than assumed in the calculations. Were experimentally measured data used to revise the calculation?** Creep will be included in the analysis of the strength of the canister. It should be poin-

	ted out, however, the maximum isostatic load is expected to be around 44 MPa (during a glaciation, otherwise 14 MPa) only and the insert will undergo no plastic deformation at this pressure. The maximum amount of deformation of the copper will be limited by the size of the gap between the insert and the copper tube. This deformation may be plastic or by creep depending on the rate of water saturation in the repository. Experimentally measured data were not used to revise the calculation.
48.	**The coefficient of variation (standard deviation/mean) of yield stress and ultimate strength of iron insets in TR-05-19 is taken as 0.022 (6/270) and 0.013 (6/478) respectively. This is significantly smaller than a coefficient of variation of 0.10 generally applicable to steels. This again points to a high degree of controls during the manufacturing of the inserts. What specific controls is the SKB planning to impose on the manufacturer?** These compression data were taken from the made measurements from different parts of the insert and were considered to be representative for the current insert production. At present SKB has preliminary technical specifications for the canister insert as well as a preliminary programme for inspection and testing. These can, of course, be modified as the development work for insert fabrication progresses. These include tensile testing, hardness testing microstructure evaluation, size and shape inspection, and non-destructive testing.
Analysis of reference evolution	
49.	**Where does eroded bentonite go to? The figures presented in Section 9.2.4 seem to indicate that there could be around 70 tonnes 'on the move' in a 500 m long tunnel. This is a large mass to accommodate.** The figures in section 9.2.4 relates to single wet deposition holes or wet sections of the backfill. It is unlikely that piping will occur all over the tunnel and in every single deposition hole. The eroded materials from the buffer will most likely end up in the voids in the backfill in the tunnel – piping in deposition holes will most likely occur before the hydrostatic pressure in the tunnel is restored. Piping in the deposition tunnel will occur before the tunnel plug is constructed. The lost material will likely end up in the drainage system in the main tunnels.
50.	**It is stated in Section 9.2.5 of the Main Report (p.218) that about 20% of deposition holes at Laxemar are expected to have inflow of > 0.1 l/min, with 2% having inflow of greater than 1 l/min. The inflow is proposed to be controlled by grouting the intersecting fractures. What is the effectiveness and stability of such grouts? That is, when would these grouts lose their function such that the fractures will be available for water flow? Is it feasible to implement the rejection criteria (Table 9-6) when the estimated percentages of rejected boreholes are so high? This also affects screening out the effects of M > 6 seismic events, which are estimated to have a 0.03 probability of occurring during the 120 ka (p.332 of the Main Report).** Grout is expected to work at least during the disposal phase (which is the key for assess-

	ing piping erosion)- but not to be durable in the long term, i.e. we are not taking any credit from grouting in the post-closure safety assessment part. As also observed grouting actually increases the number of holes with inflows above 0.1 l/min – compared to a situation with no grouting. This is probably due to the fact that grouting the more significant inflow routes would allow a higher groundwater pressure around the repository. Grouting is thus probably not an efficient means of enhancing degree-of-utilisation, but would be needed in the tunnel construction work. Table 9-6 shows impacts of very simple hydraulic criteria. They are, as we conclude both costly, inefficient and depends on the selected conceptual model to a large extent. Much more robust, effective and less costly criteria are needed – see section 13.6.4 of SR-Can main report. We are currently exploring how these should be formulated and verified.
51.	**Has SKB carried out any assessment of the combined impacts of possible saline water upconing, the presence of grout and the action of piping? Would this be a reasonable situation to address?** This question is somewhat hard to understand. Grouting is generally done to reduce the risk for piping. Saline water may increase the concentrations of eroded bentonite in the water in the pipe. This is considered in the estimates that are done in SR-Can. **On p.220 of the Main SR-Can report, several unsupported assertions are made about upconing. Where is the evidence to back them up?** In page 187 of TR-06-09 it is stated that salinities equivalent to 70 g NaCl/L are safe for the backfill function. This is based on the figures in sections 4.2.8 and 4.2.9. The upconing waters, as seen in Figure 9-92 have modelled salinities that are always less than 5%. This corresponds to about 52 g/L. The result therefore indicates that the salinities that may result from upconing are not high enough to affect negatively the properties of the buffer and backfill. **Similarly, there seems to be a key gap caused by lack of an analysis of resaturation rates in the deposition holes. SKB seems to be hesitant to carry this out, even for SR-Site (p. 243). What does SKB plan for this modelling work?** Plans are to carry out resaturation calculations for deposition holes and tunnels within SR-Site. It is only acknowledged that this is not an easy task for a real site involving spatial heterogeneity.
52.	**Is there significant space-time variability of microbial activity on sites that may affect the efficiency of their oxygen consumption (p.219 of the Main Report)?** Microorganisms respond to changes in the environment by changing their activity. This means that under stable environmental conditions, the microbial activity will be equally stable in a steady state situation. If something changes, for instance, if oxygen is intruding, the microbial ecosystem will react. The microbes will change their population composition and the corresponding activity from anaerobic metabolism to aerobic metabolism and they will consume the oxygen. Eventually, they will force the system back to the steady state the system started at: without oxygen. The only thing they require is an available electron donor and energy source. This can be methane, hydrogen or organic

	material. Consequently, the time-space variability in microbial activity will be nested within variation of environmental variables, in particular the distribution of electron donors and acceptors. For the parts of the system closer to the ground surface, organic matter is the main electron donor. The microbes act as buffers and they have a tremendous capacity to adapt to changing conditions. They will drive the system back to the steady state condition that is equal to the endpoint in the cascade of redox events that the system allows. In deep rocks, oxygen is limited, so the microbes will drive the system towards a redox level determined by other available electron acceptors, such as sulphate (sulphate reducing bacteria) and carbon dioxide (methanogens and acetogens). Reference *Madigan, M. Martinko, J. (2005) Brock Biology of Microorganisms, Prentice Hall.*
53.	**In discussion of the thermal evolution of the near field (Main Report Section 9.3.4, p.231) the following statement is made: "*When the peak canister temperature occurs, the temperature drop across the 5 mm gap between canister and buffer is around 10.4°C meaning that the buffer inner temperature is 80°C. The corresponding drop across the 30 mm gap between buffer and rock wall is just over 4°C, from 65 to about 61°C.*"** **How is it ensured that these values for the temperature drop remain valid over the calculation period?** Given that the different gaps remain open after the time of the temperature peak, the values for the temperature drop will scale with the canister power, i.e. the temperature drop values will decrease with time at the same rate as that power. If there is access to water, the gaps will begin to close and the values for the temperature drop will decrease faster. The given values can thus be regarded as upper bounds, which is appropriate since it needs to be demonstrated that a critical maximum temperature is not exceeded.
54.	**What evidence can SKB advance that the impacts of repeated glacial cycles are simply multiplicative? The risk assessment multiplies impacts of factors such as buffer erosion by 8 for the 1 Ma period. Does SKB consider this to be conservative, or could initial impacts over 100 ka weaken the EBS so that subsequent glaciations had an accelerated or magnified impact?** The buffer erosion and canister corrosion processes are described by mass balances in SR-Can and are both dependent on the water exchange in individual deposition holes. For the buffer erosion this is most likely conservative since the concentration gradient will decrease with the amount of lost buffer mass. The canister corrosion process is dependent on sulphide concentrations in the groundwater for which there are no evident time dependences.
Radionuclide transport and dose calculations	
55.	**What are the food habits of current inhabitants close to the sites? How do these compare with the assumptions adopted for the purposes of biosphere modelling?** The principal idea with the concept proposed in the SR-Can is to avoid any assumptions

	of food habits, except that humans need a certain amount of food to survive, corresponding to an intake of calories in 110 kgC/y as described in section 10.2.3 in the main report and further detailed in SKB –R-06- 82 and 83 chapter 7. This is the value used by ICRP in the internal dose models for a reference man (c.f. Avila and Bergström, SKB R-06-68). Today's consumption of local food by current inhabitants is much less than the potential food produced in the area, because humans generally buy their food in the supermarket, i.e. food transported from Brazil, New Zeeland or other places and only to a minor extent obtain food from the site due to centralised food trade in today's Sweden. Some items can be utilised from their own grounds e.g. potatoes, berries or some amounts of game. Estimates of this is found in /Miliander, S., et al (2004). Human population and activities at Simpevarp. Site description. SKB R-04-11. Miliander, S., et al (2004). Human population and activities in Forsmark. Site description. SKB R-04-10./ Especially in Forsmark it is hard to find representative inhabitants since there are no permanent households in the vicinity of the site. In the dose assessments it is assumed that individuals make maximal use of the environment. That means that all local production is used by local humans which maximises the intake of contaminated food and can capture some hypothetical extreme people at the site which grow their own potatoes, make their own beer, herd their own sheep and fish and hunt from the site. That type of habits has occasionally occurred historically at the site and cannot be excluded in the future /Jansson, U., U. Kautsky and S. Milliander (2006). "Rural landscape, production and human consumption: past present and future." Ambio 35(8): 505-512./ Details on how the radionuclide concentrations in food were calculated can be found in (Avila, 2006, SKB-R-06-81). See also answer to question 8 from OVERSITE.
56.	**Figure 10-4 is complex and needs better explanation. How is the number 1,173 derived? Are all the people depicted on the Y-axis assumed to be at high risk? Does the estimation of mean take the number of affected people into account?** Figure 10-4 is a complementary cumulative distribution function (CCDF), which shows the number of individuals (Y-value) that receive a dose above a given value (X-value). The steps in the derivation of the CCDF are given in section 5 of /Avila et al. 2006, SKB-TR-06-15/ and is summarised on pages 387-389 in the main report. The number 1173 is the size of the most exposed group defined in accordance with the SSI regulations. The size of the most exposed group is estimated by finding the fraction of the CCDF falling between the maximum dose and one tenth of the maximum dose and multiplying this fraction by the number of people in the population that can be fully sustained by the affected landscape (value of Y for X=0). All people depicted on the Y-axis are assumed to be maximally exposed from the affected landscape, although some will be more affected than others.

57.	**Can gas erode the buffer (p. 403 of the Main Report), especially at very high pressures?** There are no observations of any loss of bentonite in the experiments performed so far.
58.	**In making comparisons with the natural radionuclide content in the biosphere for the pinhole failure mode base case (Main Report Section 10.5.6) the text is rather hard to understand and more detailed explanation would be appreciated. For example:** – **The comparison was made only for Ra-226, since none of the other nuclides are present in appreciable amounts. What then is the reason for presenting Tables 10-6 and 10-7? Are they intended for use in comparisons for other scenarios?** No, they were included to present the information available for these types of comparisons. Also, it could be of interest to see the total content of naturally occurring radionuclides at the sites. – **Which result is shown for Ra-226 in figure 10-24? Is it a deterministic calculation or a mean or median of the probabilistic calculations? Is it based on the numerical or the analytical model?** This is the mean value of a probabilistic calculation using the analytical model. – **What is the reason for not presenting a Table similar to Table 10-6 for the Forsmark site? Are there no suitable data available?** Yes, at the time for the comparison, no data were available for Forsmark. **SKB has compared the flux of Ra-226 to the total amount of this radionuclide in the overlying regolith, noting that it is five orders of magnitude lower. Given the localised nature of releases, presumably a fairer comparison would be with the regolith in discharge areas. Has this calculation been made?** The discharge area is larger than the repository "foot" print and thus should give higher amount of natural Ra, moreover the Ra content in the rock and the remaining part of the upstream drainage area has been omitted. The purpose as stated above was to present another index for effects on the environment.
59.	**Has SKB carried out any simple sensitivity analyses for the Safety Functions? Those presented in Section 10 do not address the safety functions directly, or at least are hard to interpret. Consequently, Section 13 contains many unsupported assertions that would be easier to judge if there were diagrams showing, for example, sensitivity of calculated risk to canister thickness, buffer function longevity, number of canisters failed, etc. Can SKB show any information of this type?** Sensitivity to canister thickness was not calculated in SR-Can, but can readily be done using the expressions in Appendix B to the main report. This has now been carried out and the result is shown in Figure 1 below. The figure shows the effect of varying the canister thickness around the reference value of 0.05 m for the Forsmark advection base

case (Figure 10-42 in the main report). The risk contribution from the advection/corrosion scenario (not calculated here) is expected to vary in a similar manner. Note that no other consequences of an altered canister thickness (possibility of handling the canister at all stages prior to deposition, defect distribution when welding a different thickness, etc) have been looked into.

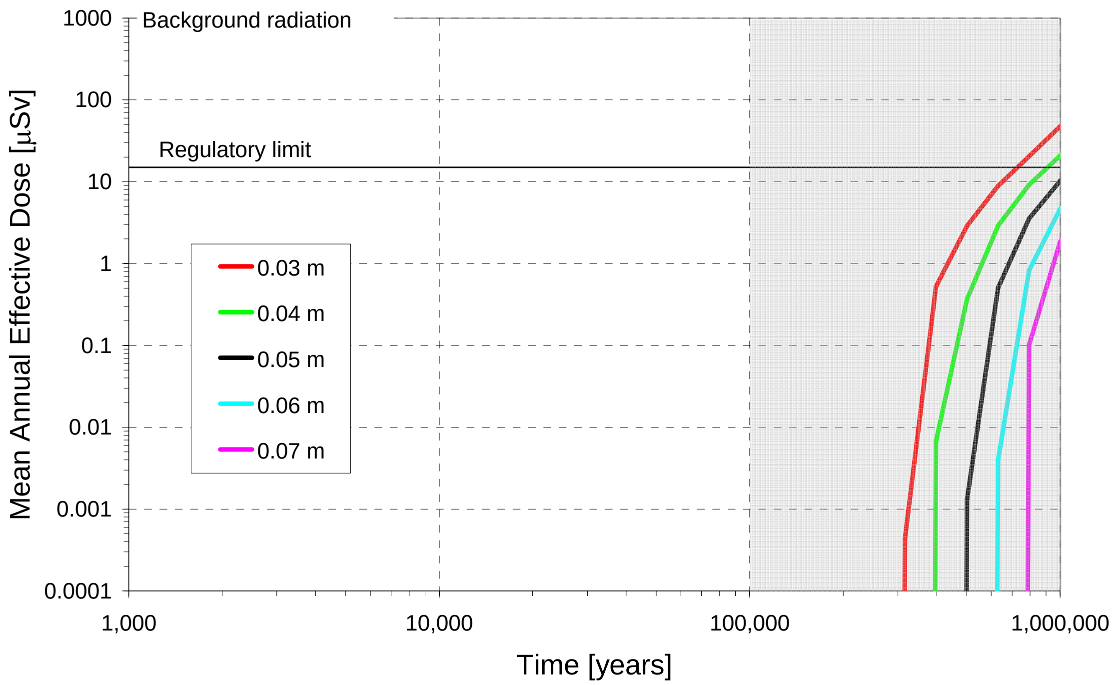


Figure 1. Dose from releases to geosphere for different canister thicknesses. 1,000 realisations of each case, analytical model.

Sensitivity to buffer longevity has been bracketed by the three cases considered: Immediate loss of buffer, buffer loss according to the crude Qeq-model and no buffer loss. As discussed in chapter 13 and elsewhere, the two former assumptions yield almost identical results, whereas the third implies that the risk contribution form the advection/corrosion scenario vanishes.

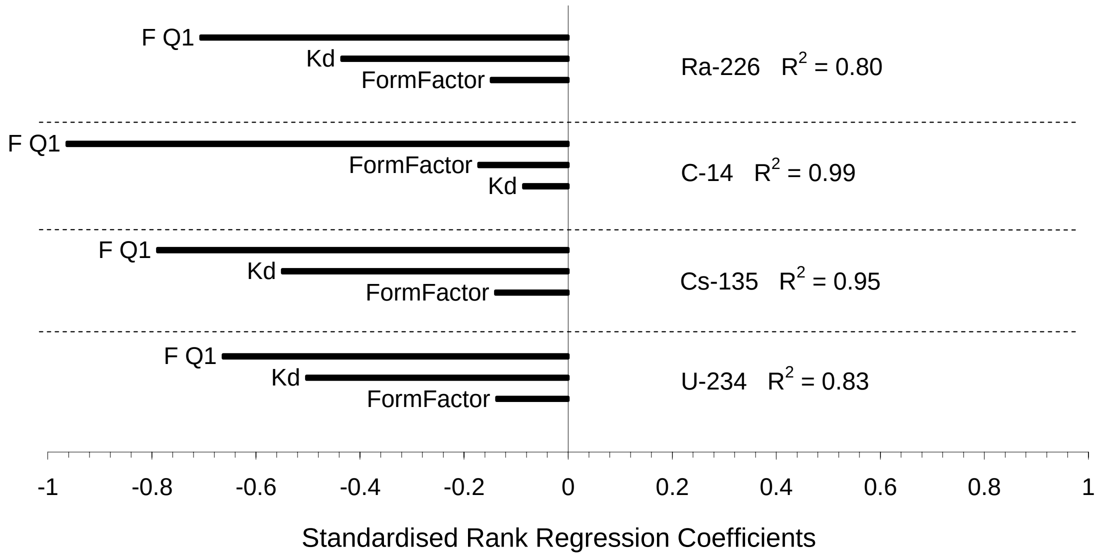
Sensitivity of mean dose to the number of canisters failed is proportional to the number of failed canisters if these are randomly located in the repository and if the failure mode is not related to the position in the repository (stylised pinhole and isostatic failure cases treated in sections 10.5 and 10.8, respectively).

Sensitivity of mean dose to the number of canisters failed is also proportional to the number of canisters failed if the failure mode is a shear movement since, in that case, no credit is taken for geosphere retention, see section 10.7.

60. **Results from probabilistic calculations for the growing pinhole failure case indicate (p.412 of the Main Report) that spalling in the deposition holes will strongly affect**

	flow and transport through path Q1.What is the reliability of predicting the timing and extent of spalling? The timing of the thermally induced spalling is related to the development of the heat load and the predictions are thus very reliable (within a couple of years). Regarding extent of spalling – see our answer to INSITE question no. 37. **On p.402, it is stated in relation to use of analytic (in contrast to numerical) model for Monte Carlo runs *"This would require more developed quality assurance procedures for the analytic model"*. Please explain the QA status of the analytic model.** This is described in the Model summary report, section 3.3. In particular the following excerpt from section 3.3.3 addresses the QA status: "No manual has been produced for the analytic model, and the code has been used only by the implementer. The Excel spreadsheets are not self-explanatory for an external user. A brief manual is to be developed for future assessments and the code is to be written such that it can be transferred to other users." It should, however, also be noted that a number of benchmarking exercises comparing the analytical and numerical models have been carried out over several years and yielding similar results. This is explained in the Main report and in the Model summary report section 3.3.2.
61.	**Most of the parameter distributions in Table 10-3 of the Main Report (p.406) are either triangular or log-triangular. This implies that a preferred value is known but not much else. Is that because of a lack of data at this stage of the project?** A triangular distribution also implies that we are confident about the range within which the real value should lie, and that we have a good idea about "a more likely value". We only see a need to reduce this uncertainty in distribution if there is reason to believe that the shape of the distribution is important.
62.	**In Figure 10-18 of the Main Report (p.412), does the dose curve based on near-field releases assume zero geosphere retardation for all nuclides or for just Ra-226 and I-129? It is a little surprising that other radionuclides do not show contributions to dose, if they are assumed to be mobile in the geosphere.** The near-field curve is the sum over all nuclides. Other nuclides than I-129 and Ra-226 do indeed cause doses, but not to the extent that they affect the sum dose appreciably. This is consistent with finding in earlier assessments of the KBS-3 system.
63.	**Is there a special reason for running 6,824 and 7,438 realisations for the two sites (p.412 of the Main Report)? The question is whether or not these are particular "special" numbers rather than choosing, say, 7,000 realisations.** These numbers refer to the calculations with the numerical models. 6,824 and 7,438 are the number of deposition holes in the hydrogeological simulation and are also the number of realisations used in the Compulink - FARF31 modelling tasks. The hydrogeological result for each deposition hole is sampled once, yielding a representative simulation of the ensemble of deposition holes at each site.

	The reason for having more positions in Laxemar is that a higher rejection ratio is expected. Figure 10-38 is used to judge whether the number of realisations are high enough to obtain stable results. For the Analytic Radionuclide Transport Model the number of realisations is 10,000. Also, LHS was used for these latter simulations.
64.	**In exploring some of the key uncertainties for the reference evolution (Main Report Section 10.5.7), was it the general strategy to base the analysis on probabilistic calculations using the analytical model in order to save calculation effort (with the exception of the cases where the numerical model seems to be more appropriate, e.g. changed near-field conductivities)? Was there a reason for using deterministic calculations in exploring the gas effect? Which model was used for the radium co-precipitation case?** Yes, it was the general strategy to use the analytical model to save calculation effort. The radium co-precipitation case was run with the analytical model. The nature of the gas pathway is different than the water pathway. The release of nuclides occurs as a pulse instead of a continuous flow. The main reason for the deterministic treatment was to simplify the evaluation of the importance of the process. The short cut of the geosphere in the gas pathway also makes a probabilistic treatment less interesting. However, it is fairly straightforward to include the gas pathway in the integrated radionuclide transport calculations if found necessary. **Only the mean value results are presented in the case of the probabilistic calculations. Were there any cases in which other features of the output distributions (namely range, shape, skewness) changed significantly compared to the base case?** This has not been investigated in detail, but the output data are available for such an analysis. **Is the 1½ order of magnitude difference in dose at million years in Figure 10-26 (thin black and green lines) wholly attributable to spalling in deposition holes? How many holes are assumed to have spalling in this calculation?** Yes, it is wholly attributable to spalling. All depositions holes are assumed to be affected by spalling. Note that spalling in all deposition holes is assumed in the base case (thin black line) and that this sensitivity case explores the effect of *excluding* spalling (thin green line).
65.	**In analysis of the retarding function of the geosphere (Main Report Section 10.5.9), the following statement is made "*The sensitivities of rock transmission distributions to their input parameters can be determined with the rank regression method used in section 10.5.4 for dose sensitivities*". Neither this analytical method nor, for that matter, any result of probabilistic sensitivity analyses is in fact presented in 10.5.4! Can an explanation please be provided? (In fact, the discussion of sensitivity analyses in Section 10.5.10 (p.431) seems to suggest that the sentence cited above may in fact be an**

	obsolete relict of the previous Interim SR-Can Report. Is this correct?). **In any case, it would be helpful to receive a more elaborate explanation of the results presented in 10.5.9 and of the lessons that can be learned from them.** These sensitivity analyses were left out due to time constraints and since they are not expected to provide appreciable new information in relation to the Interim report. (No, the quoted sentence is not an obsolete relict from the Interim report, but it should really read "discussed in section 10.5.10" rather than "used in section 10.5.4". The text referred to was originally part of section 10.5.4 and then moved to 10.5.10. Unfortunately, the reference was not updated.) Some SRRC-analyses have now been done and the ones for the transmission calculations for Forsmark are given in Figure 2 below. The results are quite similar to those in the Interim report in that uncertainty/variability of the F-factor of the rock has the highest influence on output uncertainty, followed by the Kd-value of the nuclide in question or the Formation factor (which expresses the uncertainty/variability of the effective diffusivity in the rock, see table 10-3 of the Main report and further the Data report, section 6.7). Further SRRC-results are given in the answer to OVERSITE question 4.  ***Figure 2. SRRC results for rock transmission at Forsmark.*** Lessons learned from the results in section 10.5.9: The Figures in section 10.5.9 show the distribution of geosphere transmissions over the ensemble of deposition holes at the two sites. The Figures demonstrate that a considerable fraction of the deposition holes (around 62% and 52% for Forsmark and Laxemar, respectively) are either not intersected by the fracture network, or intersected by fractures associated with such transport conditions that a release through this fracture never reaches the surface. (This is evident already from the hydrogeological analyses in section 9.3.6.) Furthermore, for both sites, non-sorbing nuclides like I-129 and Cl-36 are readily transferred through the geosphere. The transmission is similar for the two sites although the-

	ir hydrogeological properties are rather different. On the other hand, strongly (e.g. Pu-239) and weakly (e.g. Ra-226) sorbing nuclides are retarded more efficiently at the Forsmark site. This is an important reason for the lower doses in the base case for Forsmark than for Laxemar (Figures 10-16 and 10-17). Also, if the analyses had been carried out for all three hydrogeological models for Forsmark, the results would illustrate the differences between the models with respect to retention properties, but this was not done in SR-Can due to time constraints.
66.	**In the discussion of statistical convergence for the probabilistic calculations (Main Report Section 10.5.10, p.429) it is noted that "*For the analytic base-case simulations, there is a variation of about a factor of 2 in the mean value of the annual effective dose for 1,000 realisations and about a factor of 1.2 for 10,000 realisations, using Latin Hypercube Sampling (LHS) in both cases.*" What is meant by 'variation' here? Did the variation occur when comparing the results for several sets with 1,000 / 10,000 realisations for each set?** Yes, 5 cases were run for 1,000 and 5 for 10,000 realisations. (One run with 10,000 realisations takes about 20 minutes with the analytical model.)
67.	**What makes the growing pinhole failure mode (Main Report Section 10.5) conceptually different from the additional cases addressed in 10.10? Is it largely the degree of detail that is used to illustrate evolution within the canister?** **(This question is raised because the introduction to Section 10.5 reads very much like an introduction to a "what-if" case similar to those addressed in Section 10.10; nevertheless, the growing pinhole case is the one in which, compared to others, a considerable assessment effort was invested.)** The growing pin-hole case can indeed be regarded as a "what-if" case. The reasons for the rather elaborate analysis of this failure mode are stated in section 10.5 (and also in the introductory section 10.1): The pinhole case is suitable for elaborate analysis mainly because the buffer and the backfill and the entire ensemble of deposition holes contribute to retardation, and these components' roles for retardation can thus be elucidated. For the advection/corrosion and shear movement failure modes, the buffer and the backfill play very minor roles and only a very small fraction of the deposition holes contribute. Also, but less relevant, this failure mode has been prominent in SKB's earlier safety assessments.
Selection of scenarios	
68.	**In discussion of regulatory requirements and expectations, it is noted (Main Report Section 11.2, p.457) that "*SSI's General Guidance states ... "An account need not be given of the direct consequences for the individuals intruding into the repository." It is noted that this is contrary to SKI:s view, where these situations are included among the residual scenarios.*" Given this apparent contradiction, which approach was chosen by SKB and why?**

	The analyses of future human actions (FHA) in SR-Can only comprise the impact on the repository and doses to individuals of a family settling at the site after an intrusion into the repository have occurred. The analyses of FHA in SR-Can are mainly based on the analyses performed in the former assessment SR 97. SR 97 included doses to the intruders and to a family settling at the site after the intrusion. Apart from the impact on the repository and the assessment of risks and doses to the family, the authorities, both SKI and SSI, were satisfied with the management of FHA in SR 97. This is why SR-Can concentrated on the impact on the repository and doses to the family. A treatment in full agreement with the regulations would have to include doses to the intruders as a residual scenario, which could be done e.g. as a reference to the doses to intruders calculated in SR 97. These direct consequences should, however, not be included in the risk summation, in accordance with to SSI's regulations.
69.	**In discussion of risk summation for additional scenarios (Section 11.4.2, p.462) it is noted that: "*Risk contributions from scenarios that are independent are added, if combinations do not lead to higher consequences than the individual scenarios. If combinations may lead to higher consequences, the likelihood and consequence of such combinations are also assessed*".** **Does this mean an extra assessment is made of the combinations (in addition to the one for the single scenarios)? More generally, is there perhaps a formula or flowchart available to illustrate the verbal explanations for how the risk summation is undertaken?** Yes, there is an extra assessment for the combinations, see section 12.11.2. This rather short section focuses on the combinations not already covered in the preceding sections of chapter 12. Table 12-5 shows all the combinations considered in SR-Can. There is no flowchart of the requested type available. The risk summation made in SR-Can is in the end rather simple, and the procedure is maybe best illustrated by its implementation in section 12.12. **Epistemic and aleatory uncertainties are discussed on page 426 of the Main Report but not subsequently in discussion of the treatment of data uncertainties (e.g. p.465). What is the SKB methodology with respect to these? Is it to treat them separately or to combine them, and why?** In the data report there is an intention to trace the origin of uncertainty – and there is a special section devoted the "spatial and temporal" variability. Indeed much of the uncertainty in the Site Description is due to spatial variability – which always makes extrapolation outside well know measurement points uncertain. Much of the spatial variability is also directly represented by e.g. DFN-model realisations resulting in an ensemble of migration paths. This spatial variability is actually not seen as uncertainty – but reflects the site property – whereas differences between realisations are seen as uncertainty. However, in other cases the difference between "true" uncertainty and spatial variability is less clear - and it is doubtful if a clear and reliable quantitative distinction can be made regarding e.g. all the important rock properties that enter the assessment. The relatively simple treatment in section 10.5.10 does, however, yield at least one use-

	ful result: Both types of uncertainty are important and it is certainly worthwhile to increase understanding through further R&D efforts since the impact of epistemic uncertainty is not "drowned" by that of aleatory uncertainty which is maybe difficult to reduce e.g. through further site characterisation.
70.	**Does SKB plan to test the realism of the three alternate hydrologic models (CPM, fully correlated DFN and partially correlated DFN)? Or would the quantitative demonstration of compliance be based on the most pessimistic model?** We should not necessarily expect to identify a single conceptual model or hydrogeological parameterisation since we need to remain objective and acknowledge the level of uncertainty in data and its interpretation. We can expect to obtain better support for our conceptual models in the CSI studies, but we still need to demonstrate the robustness of our conclusions to alternative interpretations. Thus, also in SR-Site the same approach of choosing the most conservative case as in SR-Can may have to be utilized.
71.	**It is stated on p.465 of the Main Report that (i) "*more extreme glacial loads than those in the reference evolution are not considered*" and (ii) "*... those uncertainties regarding manufacturing flaws and deficiencies that are not covered by the reference initial state are not included in the main scenario*". Are these included in other scenarios? Could these not be considered as stochastic variables in the main scenario? Similarly, on the same page, it is stated that "*... biosphere models are discussed in ... but not fully considered in this framework*". What is the implication of this statement? Is it intended to imply that these are not important or that they will be considered in the future?** More extreme glacial loads and manufacturing flaws are indeed included in other scenarios in accordance with the methodology outlined in section 11.4 and also in the discussion of the handling of uncertainties in additional scenarios in section 11.5.2. The implementation for these particular uncertainties is found in section 12.8. The occurrence of manufacturing flaws can possibly be included stochastically in the main scenario, whereas the extent, order of succession, longevity etc of glacial loads are not seen as suitable for stochastic treatment. Regarding uncertainties relating to the biosphere, they were not fully considered in SR-Can due to time constraints. They will be considered in SR-Site.
72.	**The FHA report discusses drilling up to several hundreds of metres into the overlying rock for use in heat pumps. It asserts that the hydraulic impacts of this would be small and of no importance to repository function. No evidence is provided and, since the scale of this practice could be large if the area was to become urbanised, SKB should present the basis for their conclusion. Have any calculations been carried out?** The FHA scenarios are based on current practise. The current practise for heat pump facilities in the Swedish crystalline rock is to circulate a heat transfer fluid in a closed system in a drill hole which is 100-200 metres deep. This has several explanations; it allows temperatures below zero; the facilities are not dependent on water supply or water quality; the facilities will have minor or no impact on the groundwater. The latter is especially important in urbanised areas where alteration of the groundwater surface may impact other wells, foundation of houses, cables, piping etc. It is the impact of this kind of facilities which is considered limited, even if several holes were to be drilled.

	If the water supply is sufficient to cover the need and the water quality acceptable the groundwater can be used as a heat source. This kind of facilities also requires some system to manage the return water. Based on current practise this kind of facilities is very uncommon. Further the operation time of any kind facility can be expected to be tens to hundreds of years at the most, so in a longer time perspective the impact on hydrology would be similar as for a closed system, i.e. some conductive features added to the bedrock. No calculations have been carried out for this case specifically. However, if the boreholes do not penetrate the repository, the impact should be small since these boreholes are not pumped but rather circulated with liquid in a closed system. A general dilemma in the analysis of FHA scenarios is that there are no limitations for the situations that can be imagined, and in order to analyse the consequences a fairly detailed description of the performed action/impact is required. For example for the heat pump case a situation with many deep boreholes using water as a heat resource can be imagined, even if no such facilities occur today. For this reason the calculations performed in SR-can are limited to the FHA generally occurring today or actions that could occur and that have the most severe impact on the safety functions and doses.
Analyses of selected scenarios	
73.	**In presenting the conclusions for the corrosion failure scenario, it is stated: "*Thus, case B in Figure 12-14, with unit probability, is propagated to the risk summation from the canister corrosion scenario*". Is it reasonable to assume that case B from Figure 12-15 was similarly propagated?** Yes, this is correct.
Conclusions	
74.	**It is difficult to trace the assumptions that underlie calculations of the main risk versus time curve. In Section 10.4.3, it is noted that "an appropriate" dose conversion factor is used, but it seems likely that only temperate LDFs were used, which is presumably why the curve shows no detailed time-dependent structure. Has SKB produced a 'best estimate' risk versus time estimation that does incorporate some temporal structure relating to landscape evolution? It is hard to track the climate variants of the reference case through to the conclusions.** No such 'best estimate' risk versus time has been produced. Such an example could be produced by alternating LDF-values for temperate, permafrost and glacial conditions (Figure 10-11) in accordance with the successions of climate states during the Weichselian glacial cycle, Figures 9-67 and 9-68. Such a graph would, though, exhibit such an intense temporal variation due to the changing climate that other causes for temporal variations, relating to the repository components, would be difficult to distinguish. Furthermore, the LDF-values for permafrost and glacial conditions are yet not very mature. The essence of the greenhouse variants of the main scenario (or reference case) is described in section 13.2.2, the last sub-heading. If the question refers to more extreme climate conditions than those analysed in either of the variants of the main scenario, then

	• more extreme permafrost evolutions are analysed in section 12.4, underpinning the conclusion regarding buffer freezing (the first sub-heading in section 13.2.2) • more extreme ice thicknesses are analysed in section 12.8, underpinning the conclusion regarding canister failure due to isostatic load (the second sub-heading in section 13.2.2)
75.	**In Figure 13-2 on p.535 of the Main Report, the Laxemar total dose intersects the regulatory limit at exactly 100 000 years. Is this a pure coincidence or is it driven by some underlying assumption?** This is a pure coincidence.
76.	**The truncation of the risk versus time curve at one million years, while it is still rising, may meet the explicit requirements of the regulatory guidance but it does not provide the contextual confidence in the overall safety of the disposal system that both SKB and the authorities will need to be able to state to the public. An identical approach was followed by AECL in the 1980s when presenting their safety results, and for the same reason. They were criticised in the subsequent review for leaving open such an obvious question. The statement on p.537 of the Main Report that "*... it may be stated that there is no reason to suppose that the trends analysed for the one million year assessment period would not continue*" invites the addition of "i.e., upwards".** **Has SKB carried out any evaluation of the ultimate 'fate of the repository' and is it prepared to say anything about long-term, bounding exposures from natural pathways? For example, can the canister lifetime distribution shown in Fig. 9-103 be used to bound the risks after 1 Ma? Simply referring us back to the decay in radiotoxicity curve without some discussion of potential exposure paths and health effects does not answer the question satisfactorily.** Yes, the canister lifetime distribution in Fig 9-103 is an indication of the evolution beyond one million years. Other factors would however also affect the resulting dose curve. For example, an increasing fraction of the fuel would be altered in the canisters failed before one million years. The increase in dose would, however, be reduced due to the fact that the deposition holes contributing to canister failures beyond one million years are associated with increasingly favourable retention properties. The calculation cases could readily be extended to longer times, but a careful discussion of the reasonableness of the results would need to accompany such a case. See also response to EBS question 17, subheading "Peak Mean-Annual Dose Rate".
77.	**The project has evidently begun to think about issues of optimisation and BAT (Section 13.3.4), albeit reserving SKB's position for the time being. One of the aspects of this issue is consideration of whether reasonably practicable means might be available to improve the protective capacity of the repository. This matter is mentioned but not convincingly discussed and the implication of SR-Can seems to be that SKB does not think it can be (or needs to be, or ought to be?) improved. Is this the case?** No, this is not the case. Rather, the knowledge base and data available does not allow an

	in-depth discussion on this. For example, the understanding of buffer erosion is not sufficient to allow a detailed analysis of several of the elements that would be required in such a discussion (copper thickness, buffer thickness, engineering measures to prevent or mitigate buffer erosion, etc). **Has SKB established a link between safety function indicators, optimisation and BAT? Can SKB explain whether or not the criteria for safety indicators are based on the best available technology considerations? That is to say, has there been a formal evaluation of possible alternatives in terms of effectiveness and cost? For example, if the depth of the repository were increased by, say, 10 metres, would safety improve and would the additional cost be reasonable? It should be worthwhile to discuss the alternate technologies available, for example in terms of the choice and design of the buffer, and to indicate why the chosen one is the best available technology (i.e. what alternatives were evaluated?).** The safety function indicators are not design criteria and are thus not directly related to the selected technology. It could, however, be possible to address at least some aspects of the issue of BAT more systematically by going through each function indicator and study how its "performance" could potentially be improved by a design modification and if this added performance is a reasonable benefit considering already existing margins (if there are such margins), potential negative influences the same modification could have on other safety functions and the costs involved in the design modification. The resolution of available rock data (or that of cost estimates) is far from sufficient to allow the type of optimisation mentioned above. Again regarding the buffer, the lack-of-knowledge regarding the erosion process does not allow a discussion of BAT of the buffer.
78.	**It seems that optimisation may play a role at two levels: (i) at a higher level to consider various options for waste management, the geological repository being one option among them, and (ii) at a lower level, once an option is selected, i.e., whether the risk (to workers and the public) is minimised with respect to say cost. In the second level, optimisation may play a role in site selection, location of an encapsulation plant, mechanisms for handling fuel at the power plant, its transportation, in the encapsulation plant, its loading in the disposal canister, and final deposition in deposition holes. Has SKB performed a formal optimization analysis?** No, this has not been done, either in SR-Can or elsewhere. These aspects are, to some extent, discussed but not analysed in a system's analysis report issued shortly after SR-Can (in Swedish).
79.	**In the discussion of confidence (Main Report, Section 13.3.5), which elements of the confidence statement that will need to be developed in the future for SR-Site are presently considered not yet sufficient or complete?** Most of the elements will be more developed in SR-Site, e.g. the level of demonstration of technology to obtain the initial state, the confidence in the SDMs (in particular for Laxemar), hopefully confidence in the understanding of buffer erosion and certainly a more developed QA in general.

80.	**An overall conclusion regarding the safety assessment methodology (Main Report Section 13.9.1) appears to be that the methodology is now mature. Hence, whilst the assessors recognise that detailed improvements are needed (e.g. with respect to up-dating databases, improving conceptual understanding etc.), they do not see any deficiencies or room for improvement concerning the (formal) methodology and they did not experience any serious methodological problems when performing the assessment. Is that a fair and correct interpretation of what is being said here?** In principle, this is correct in the sense that the methodology should be useful and essentially sufficient for the SR-Site analysis. There will, however, always be room for improvements in the methodology used for an analysis of this complexity.

Other Comments

No.	Comment
	A large number of acronyms are used in the reports, some only once (e.g., HCD, HRD, WLP, BC, FPC, LDF, RSMA, RSMM, RSMBA, RSMD, and many others). In order to improve communication and transparency, the use of acronyms should be minimized as far as possible. This will be considered when the SR-Site report is produced.
	Some figures (e.g. 4-39 on p.124 of the Main Report) need better explanation, including definition of the colour scheme. These also include the presentation of results Figure 10-4, Figure 10-19, Figure 10-36. This will be considered when the SR-Site report is produced.
	Some of the figures, especially those showing the geology of the site are too small and the writing is indistinct. This will be considered when the SR-Site report is produced.
	It would be helpful to readers if the assumed repository foot print were shown on various figures, such as Figure 9-12. This will be considered when the SR-Site report is produced.
	The main parts of a figure, such as defining paths Q1, Q2, and Q3 should be repeatedly defined in captions (e.g. Figures in chapter 10). It is not easy to remember these.

	This will be considered when the SR-Site report is produced.
	The description of Step 1 in the Summary and Section 2.2 of the Main Report refers to FEPs that are "*related to assessment methodology in general*". It is not clear what exactly this means, although slightly different wording is used in Section 3.2, which refers to FEPs being characterised as "*general methodology issues*". In addition, Section 3.3 refers to FEPs from the NEA FEP database that are "*are of a very general nature*" and which relate "*to the factual basis of the assessment and to the methodology of the assessment.*" For clarity in the main report, it would be helpful to give examples of these and their implications for the overall assessment process followed by SKB. In the SR-Can FEP catalogue, these types of issues are compiled in two SR-Can FEPs – Meth01 Assessment basis and Meth02 Assessment methodology. Meth01 Assessment basis concerns issues that do not need much further evaluation, but for which a clear decision on handling in the assessment is required. These include decisions regarding handling of biological evolution and regarding potential progress in treating detrimental effects of radiation, e.g. cancer, and the handling of environmental impact issues. These types of issues are handled in SR-Can as documented in the FEP report (TR-06-20, Section 4.5) and in the digital SKB FEP database. Meth02 Assessment methodology is defined as the methodology in 10 steps applied in the SR-Can project. Many of the FEPs in the NEA FEP database sorted to this category are related to data and modelling issues such as correlations and uncertainties, design issues and implementation of various features in the modelling. A check of all these NEA FEP issues was carried out and the conclusion was that the issues relevant for SR-Can are captured by the methodology adopted in SR-Can and, thus, also handled in SR-Can. This is described in the FEP report (TR-06-20) and the result of the check is documented in the digital SKB FEP database, where also motives for discarding some of the FEPs are given.
	In discussion of the results of radionuclide transport and dose calculations (Main Report Section 10), it would be good to provide a clearly arranged (e.g. tabulated) compilation of the uncertainties that have been explored (10.5.7, 10.6.8, 10.7, 10.11) and the ways they are addressed (deterministic – probabilistic – irrelevant, analytical or numerical model etc.) for the various failure modes that were explored. This is provided in the response to OVERSITE's question 10.
	The "Contents" pages could be enhanced by including a list of figures and graphs. The Main Document is large and complex and the reader may like to be able to go back and forth and be able to easily find previous figures and tables.

	This will be considered when the SR-Site report is produced.
	On page 325 of the Main Report, the copper material is stated to have a ductility of at least 30% and the cast iron, at least 7%. The authors are likely referring to the maximum plastic strain presented in Tables 9-13A and 9-13B, rather than ductility. Generally, ductility is defined as the ratio of the maximum deformation (without significant strength degradation) and the yield deformation. The ratio is usually greater than 1. We shall clarify this in SR-Site by referring to "uniaxial strain to failure".

2008:01 Myndigheternas granskning av SKB:s preliminära säkerhetsbedömningar för Forsmark och Laxemar
Avdelningen för kärnteknik och avfall och SKI
Maria Nordén, Öivind Toverud, Petra Wallberg, Bo Strömberg, Anders Wiebert, Björn Dverstorp, Fritz Kautsky, Eva Simic och Shulan Xu — 90 SEK

2008:02 Patientstråldoser vid röntgendiagnostik i Sverige – 1999 och 2006
Avdelningen för personal- och patientstrålskydd
Wolfram Leitz och Anja Almén — 110 SEK

2008:03 Radiologiska undersökningar i Sverige under 2005
Avdelningen för personal- och patientstrålskydd
Anja Almén, Sven Richter och Wolfram Leitz — 110 SEK

2008:04 SKI:s och SSI:s gemensamma granskning av SKB:s Säkerhetsrapport SR-Can Granskningsrapport
Avdelningen för kärnteknik och avfall
Björn Dverstorp och Bo Strömberg — 110 SEK

2008:04 E SKI's and SSI's review of SKB's safety report SR-Can
Avdelningen för kärnteknik och avfall
Björn Dverstorp och Bo Strömberg — 110 SEK

2008:05 International Expert Review of Sr-Can: Safety Assessment Methodology; External review contribution in support of SSI's and SKI's review of SR-Can
Avdelningen för kärnteknik och avfall
Budhi Sagar, et al — 110 SEK

SSI report

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