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Joint SKI and SSI review of SKB preliminary safety assessment of repository for long-lived low- and intermediate-level waste

Review report

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Foreword

This report presents the SKI (Swedish Nuclear Power Inspectorate) and SSI (National Swedish Institute of Radiation Protection) review of the SKB (Svensk kärnbränslehantering AB /*Swedish Nuclear Fuel and Waste Management Company*/) preliminary safety assessment of a final repository for long-lived low- and intermediate-level waste (Swedish version: SKB R-99-59; English version: SKB TR-99-28). In addition to the evaluations from these authorities, the report also includes a summary of the SKB report and viewpoints from outside experts engaged by SKI and SSI. The main target group for this report includes SKB and other organisations and experts active in the nuclear waste field.

The review by the authorities has been conducted with close co-operation between the departments for nuclear waste safety (SKI) and waste and the environment (SSI). The opinions expressed have been formulated by a working group with representatives from both SKI/SSI. The preparation of the text has been supervised by Bo Strömberg from SKI (safety assessment methodology and radionuclide transport), Anders Wiebert from SSI (waste and radionuclide inventory and Rodolfo Avila (biosphere calculations). The following persons have also contributed their views: Björn Dverstorp (SKI), Fritz Kautsky (SKI), Mikael Jensen (SSI), Benny Sundström (SKI), Öivind Toverud (SKI) and Stig Wingefors (SKI).

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Chapter 1 Introduction

An important part of the Swedish nuclear waste program that so far has played a somewhat obscured role is the final repository for long-lived low- and intermediate-level waste. Such waste includes, for example, core components from the Swedish nuclear plants, certain waste derived from the repair and maintenance of nuclear power plants, demolition waste from the planned encapsulation facility for spent nuclear fuel and CLAB /*central interim storage facility*/, as well as nuclear waste generated in connection with research and development work at the Studsvik facilities. SKB (Svensk Kärnbränslehantering AB) plans to finally store this waste in a cement repository, located at the approximate depth of 300 m in the Swedish bedrock, known as SFL 3-5. This structure, is highly reminiscent of the structure that SKB selected for the so-called SFR repository for operational waste (mainly an underground cavern for intermediate-level waste) which is already in operation, and is located outside of the nuclear power plant at Forsmark.

The previous SKB report gave no reason to question whether the development of a final repository for long-lived low- and intermediate-level waste, SFL 3-5, should differ notably from the development of a final repository for spent fuel, SFL 2 (with respect to location, dates for building permit applications, etc.). However, according to the current SKB timetable, the building of SFL 3-5 will not commence for about 35 years (2035), i.e., some 20 years after the construction of SFL 2 begins, according to the same timetable. With respect to sites, the current SKB perception is that co-siting of the two repository types represents only one of a number of possible alternatives. It has also been proposed that co-siting with SFR should be studied, as well as a totally separate site. SKB has not at present specified any date when these studies should be conducted, but has indicated that the preparation of an environmental impact assessment report for SFL 3-5 should take roughly three years, and the detailed studies and plant work about four years.

The SKB preliminary safety assessment is the first coherent safety report for SFL 3-5. According to SKB, ”preliminary” in this context means that the safety report is limited in comparison with, e.g., the corresponding report for SFL 2 (the fuel repository), and that all the assumptions used have not been evaluated. The safety assessment is based on an earlier formulated design and a study of, primarily, the importance of the technical barrier systems (SKB TR-95-03). The most comprehensive documentary basis prepared for this safety assessment consists of a list of the estimated inventory of radionuclides in the waste (Lindgren et al., 1998). There are also documentation reports concerning radionuclide transport (SKB R-99-14), data (SKB R-99-13), geochemical conditions (SKB R-99-15) and the impact of gas generation and transport (SKB R-99-16). The specific goals of the preliminary safety assessment are, as stated by SKB, to assess the proposed repository types and to study the impact of the site choice.

Chapter 2 Aim and basis

2.1 Background

In its resolution (Dec. 19, 1996) concerning the SKB research, development and demonstration program that was presented in 1995 (FUD Program 95), the Swedish government required that SKB presents a safety assessment for the long-term safety of a repository for long-lived low and intermediate-level waste. At the end of 1999, SKB presented SR 97 (Safety assessment of a repository for spent fuel) and their preliminary safety assessment for SFL 3-5. SKI and SSI reported on their review of SR 97 during year 2000 (SKI Report 00:39, SSI Report 2000:17).

The authorities consider it to be SKB's responsibility to have well developed plans for handling the waste from nuclear power plants and SKB's own facilities. Such plans entail that there should be a well developed final storage concept for all waste, and one that is fully capable of meeting the requirements imposed by the authorities (SKI and SSI). As a result, the authorities believe that the safety report for SFL 3-5 must, in the long run, be expanded to the same scope and depth as the report for SFL 2. This position is also set forth in the Swedish government resolution (Jan. 24, 2000) concerning FUD Program 98:

”The government assumes that the company will take into account relevant issues *[concerning SFL 3-5]* in connection with its program for site studies.”

In order to perform this assessment, SKB has prepared a reference inventory for the waste that is intended to be deposited in the various parts of the repository. The inventory must include waste amounts, radionuclide contents and chemical compositions. Large portions of this waste, mainly those intended to be deposited in SFL 4 and 5, do not yet exist, except as components used in the nuclear power plants and in CLAB. The existing waste was generated mainly during the development of the Swedish nuclear energy program from the 1950s through the 1970s. The authorities believe that one of the most important pieces of preliminary research for the SFL 3-5 safety assessment was to formulate as accurate a reference inventory as possible, since it is a guiding factor in designing the repository and dimensioning the barriers. It will be necessary to gradually refine and improve this reference inventory before the continued work on developing SFL 3-5 is done.

2.2 Conduct of the review

SKI and SSI embarked upon a joint review of the safety report for SFL 3-5 (SKB TR-99-28) in late 1999/early 2000. The results of this review are presented in this report. In addition to SKI/SSI's own perceptions, brief summaries of some of SKB's most important assumptions are offered, along with a number of outside opinions.

A large number of organisations have been given an opportunity to offer their viewpoints on the SKB safety assessments for the planned fuel repository (SR 97) and SFL 3-5; these viewpoints should have been submitted to SKI by no later than April 15, 2000. In addition, the Swedish National Council on Nuclear Waste Issues (*Statens råd för kärnavfallsfrågor* or KASAM) was asked to offer its views by no later than May 15, 2000. The reviewing bodies of the safety assessment were also given an opportunity to offer their views on the safety report in connection with the review of the SKB supplemental report on the FUD Program 98, published in December 2000. However, the SKB supplemental report on FUD Program 98 contains no additional accounts of issues pertaining to SFL 3-5.

Of the bodies that responded, only one commented specifically on the safety assessment for SFL 3-5, namely the National Swedish Council on Nuclear Waste Issues KASAM (SKI Report 00:34). This may be attributable to the, in general, limited knowledge about technical issues related to the planned SFL 3-5 repository among the organisations that showed an interest in the nuclear waste issue. SKI and SSI feel that efforts to furnish information about these less familiar aspects of the SKB program are urgent.

The authorities have also appointed an outside committee of international experts to review the SKB safety report on SFL 3-5. The committee were asked to review the SKB assessment methodology and its application, SKB's overall safety strategy and, from an international perspective, the potential feasibility of the final storage concept proposed by SKB. The international committee submitted a number of questions to SKB prior to a meeting held between the group and SKB in Stockholm on March 22, 2000. These questions were answered in writing by SKB. At the meeting, SKB were given another opportunity to field further questions from the review committee, and to offer clarification from the SKB point of view. A final presentation of the review committee's results took place in Stockholm on May 31, 2000. The committee's final report was published as an SKI report (SKI Report 00:41). The original English version is also available in Swedish translation (SKI Report 00:54).

SKI and SSI have also approached experts on certain technical matters in order to get more in-depth opinions on how SKB have, it their safety assessment, handled certain aspects of long-term safety (such as the use of expert opinions, definition of calculation cases, geochemistry, and the importance of colloids). These opinions have been published in various parts of the SKI reports 00:47 and 00:33.

This report includes a summary of the most important outside viewpoints on the SKB safety report for SFL 3-5 (KASAM, the expert committee appointed by SKI and SSI, and SKI consultants). These observations are compiled below under the headings ”Viewpoints from outside experts”.

2.3 The basis of SSI and SKI review

The requirement on the present safety assessment derives from the Swedish government resolution of Dec. 19, 1996. According to the resolution, a safety assessment must be submitted to SKI and SSI before site investigations of two or more sites begin. The site investigations do not constitute a nuclear engineering activity, and thus do not require a permit under the Swedish Nuclear Technology Act /*kärntekniklagen*/. Consequently, the review that has now been conducted by the authorities does not constitute a review of a permit application.

The authorities have nevertheless chosen to conduct this review based on the regulations set forth by SSI and the proposed regulations set forth by SKI. However, we account for the fact that these regulations were not available when SKB began their work on the safety assessment, and that the SKB assessment is only preliminary.

The radiation protection requirements which are of primary relevance to the review of SKB's safety assessment are described in the SSI regulations on the protection of human health and the environment in connection with the final handling of spent nuclear fuel and nuclear waste (SSI FS 1998:1). The fundamental requirement with respect to the protection of human health is that the annual risk of harmful effects after closure must be less than 10^{-6} for a representative individual in the group exposed to the highest risk. The SSI environmental protection regulations are formulated in a more general terms.

SSI require in their regulations that a final repository must be designed based on the ”best available technique” principle. This means, for example, that the barrier system for the chosen concept must be executed in such a way that it can be considered to be the best feasible technique that is currently available at reasonable cost. Another requirement of the SSI regulations is that reports on the long-term evolution and development of the repository are to be prepared for two separate time periods (the first thousand years and long time periods). The report on the first thousand years is subject to stricter requirements with respect to, e.g. quantitative calculations.

The SKI safety regulations for nuclear facilities (SKI FS 1998:1) are applicable to the construction, operation and closure of a repository. On the other hand, they include no provisions concerning long-term safety after closure. As a result, a proposal for supplemental regulations pertaining to final storage has been prepared and disseminated for consideration and review. The proposed supplemental SKI regulations are intended to meet the requirement for full containment of the radioactive substances for as long a time as is necessary, given the hazard posed by the waste. This is to be accomplished by a system of barriers. A defect in a basic safety function of any of these barriers may not perceptibly degrade the safety of the final repository. Another requirement is that the site chosen for a final repository must offer sufficiently stable and favourable conditions so that the barriers will function as intended for a sufficiently long period of time.

The proposed SKI regulations require that conditions, events and processes of significance to safety must be analysed and documented. The general guidelines for these regulations offer recommendations describing, e.g., how scenarios should be selected and reported, how probabilities for scenarios and calculation cases should be taken into account, how uncertainties can be assessed, and how the validity of calculating models can be judged. The proposal points out that the safety assessment must cover the entire period of time during which safety functions are necessary (although not less than 10,000 years and not more than 1,000,000 years).

The authorities confirm in their preamble that the preliminary safety assessment does not expressly state how these official requirements have been met.

Chapter 3 Waste inventory

3.1 The SKB report

3.1.1 General

The SKB report on the source term in SFL 3-5, presented in Chapter 2, is mainly based on the report ”Low- and Intermediate-Level Waste in SFL 3-5; Reference Inventory” (hereafter referred to as “the inventory report”). In Chapter 2 of the main report (R-99-59), SKB have summarised the results of this document, and present in Chapter 8 (Table 8-1) the source term that is used as the basis of the calculation chain. The source term comprises a smaller number of radionuclides than the inventory. The radionuclides not included in the source term have been eliminated either because of their low incidence or based on their low immediate-vicinity release levels relative to other radionuclides.

The inventory report describes the different types of waste that are intended to be deposited in the various parts of the repository, SFL 3, 4 and 5. A portion of this waste has already been produced and conditioned, mainly waste at the Studsvik plants. Certain waste derived from maintenance and repairs of nuclear power plants is also intended to be deposited in SFL 3-5. The remaining waste, which essentially consists of demolition waste from CLAB, the encapsulation facility and the nuclear power plants has, for obvious reasons, not yet been produced, since these facilities are either in operation or have not yet been built.

SKB indicates that the aim of the inventory report is to provide a reference inventory for SFL 3-5 to be used in the preliminary safety assessment. The inventory report describes the waste and its conditioning and radionuclide content, based on current information about the waste. In Chapters 2, 3 and 4, SKB provides a summary description of the waste intended for the three different parts of the repository, and a summary of the results for SFL 3-5 as a whole is provided in Chapter 5. As it pertains to the radionuclide content of in the waste, this summary is based on the correlation factors derived from Appendix A and the more detailed description of the waste furnished in Appendices B-E. SKB discuss uncertainties related to both volumes and activity contents in Chapter 6.

3.1.2 The waste in SFL 3

The waste in SFL 3 consists of operational waste from CLAB and the encapsulation facility (similar to the waste currently deposited in SFR 1), waste from Studsvik’s own research operations, and waste from the former FOA (the Swedish Defence Research Institute /*Försvarets Forskningsanstalt*/), industry, healthcare, universities and colleges. The waste is intended to be placed in 200 litre drums or concrete moulds.

3.1.3 The waste in SFL 4

The waste in SFL 4 consists of demolition waste from CLAB, the encapsulation facility, storage containers for spent fuel from CLAB and shipping containers. The waste is intended to be disposed either without additional conditioning or placed in 2.4m cubic sheet metal boxes. It is somewhat unclear as to whether the waste in the sheet metal boxes will be cast, as indicated in the preliminary safety assessment, or not cast, as indicated in the inventory report.

3.1.4 The waste in SFL 5

The waste in SFL 5 consists of internals from the nuclear power plants and certain waste from Studsvik. The waste is intended to be placed in long concrete moulds with a steel insert. SKB indicate that the waste will be cast in moulds.

3.1.5 Inventory in SFL 3-5

Correlation factors between so-called ”key nuclides” (Co-60, Cs-137 and Pu-239/240) and other nuclides have been presented in the inventory report.

These correlation coefficients have been determined by either calculation or measurement. SKB indicate in their report that the emphasis has been placed on measured correlation factors and, in particular, on measurements made at Swedish plants. However, in the case of correlations between Pu-239/240 and other actinides, the correlation factors were chosen exclusively on the basis of calculations of the radionuclide inventory for a spent fuel bundle from a boiling-water reactor (BWR). The report does however also contain measurements of correlations between Pu-239/240 and other actinides.

In their report, SKB review a number of radionuclides and present both previously measured as well as calculated correlation factors for each nuclide that was considered relevant. Radionuclides are sorted out in two steps, one based on the source term for the calculations in the inventory report, the other for the source term for the calculations in the safety assessment report. Nuclides which are eliminated are thus those with a half-life of less than two years, radionuclides whose half-lives are so long that the nuclide can be considered stable, and those which are not expected to be present in the waste. The levels of key nuclides in the waste, which then yield the levels of correlated nuclides, are described in Appendices B-E of the inventory report for the different types of waste.

SKB indicate that the activation of the trace quantities of uranium and thorium present in metal components near the cores of the reactors has not been analysed.

3.2 Viewpoints from outside experts

The international expert committee indicate in their review report that the inventory report provides an excellent basis for a continuously refined and upgraded inventory. The committee advanced a number of views on the use of correlation factors to estimate the inventory, and point out that such use must be seen in relation to how large a part of the inventory should be considered as completely erroneous. The committee also identify a number of issues that would benefit from greater clarity. Among other things, the committee asks for descriptions of the uncertainties involved in the studies that served as the basis for the correlation factors, and that SKB document the expert assessments underlying their correlation factor choices. With regard to the matter of inventory in SFL 5, the committee point out the underestimation of the neutron activation of components outside the core to which use of the ORIGEN-2 program gives rise. This underestimation can, according to the committee, result in an error of two orders of magnitude in calculated Pu-, Am- and Cm activity in the waste in SFL 5.

3.3 SKI/SSI evaluation

3.3.1 Conservatism and feedback for continued work

The use of correlation factors for determining the radionuclide inventory entails varying degrees of uncertainty, and according to SKB, the uncertainties in the nuclide inventory for certain types of waste could be as high as a factor of 100. SKB also indicate that the documentation that has now been presented could, together with the results from the safety assessment, provide guidance in determining which radionuclides must be prioritised in order to reduce the uncertainties surrounding the inventory. The authorities agree that this approach is applicable, but believe that if conclusions are to be drawn at this stage regarding the prioritisation or, more accurately, the elimination of certain nuclides, SKB need to ensure that the inventory (i.e., the basis for the safety assessment) at least not underestimate the presence of these radionuclides and that the safety assessment is sufficiently comprehensive with respect to analysed scenarios and exposure routes. The obvious risk otherwise is that potentially important radionuclides will be eliminated far too early in the process. The authorities have provided their comments on the comprehensiveness of selected scenarios and exposure pathways in Chapters 5 and 7.

3.3.2 Correlation factors

With respect to the chosen correlation factors, SKI and SSI agree with the international review committee in that SKB should have paid greater attention to the existing uncertainties, and to documenting the expert assessments performed. The SKB choices in terms of correlation factors should have been better justified for many radionuclides, and particularly in those cases where *measurements* indicate higher values for the correlation factors than those SKB chose for their assessment. For instance, SKB should have justified their choice of correlation factors for certain transuraniums (such as Np-237, Pu-238, Am-241 and Am-243), and for certain important fission products (I-129 and Sr-90) which, despite SKB's expressed intention to base their choices on measurements, are based in large part on calculations. The measurements presented in Appendix A indicate that the selected correlation factor values may not be conservative ones.

The selected correlation factors for all the transuraniums, which are correlated to Pu-239/240, and for certain fission factors, which are correlated to Cs-137, are based on calculations found in Kjellbert 1990 (SKB Work Report 90-41). These calculations agree well with the calculations performed by SSI (SSI Report 96-03). However, these calculations pertain mainly to the fuel inventory and fuel cladding, and do not necessarily provide an accurate representation of conditions in the reactor water, and even less so with respect to conditions in the contaminating or induced activity on surfaces that are not directly connected to the core. The international review committee concur. Measurements can thus provide important supplemental information concerning prevailing conditions outside the core.

To be able to assess the generation of activation products, all assumptions need to be stated. Important assumptions include the material composition, the assumed neutron flux/neutron spectrum, the irradiation time, the calculation method, the computer code used, etc. Given that the Co-59 content in the original material comprises the source for the presence of the key nuclide Co-60, and that this original content is often known only as a ”less than” value, the calculated correlation factors are highly uncertain. In contrast to other radiation protection efforts, a high assumed content of Co-59 in the material yields a non-conservative result.

SKB have chosen to present the range and median values for the measurement results. The median value has served as the basis for the correlation factor in many cases. Given the large range of measured correlation factors, the authorities believe that the mean value may be more representative. SKB should have justified their decision to use the median value in the vast majority of cases.

The reason why SKB have correlated the content of Cl-36 in crud to Cs-137 is unclear. Cl-36 is an activation product, while Cs-137 is a fission product; they thus have different sources and are consequently mutually independent. Their relationship is affected by the incidence and types of fuel damage the reactor has sustained. The important factors in estimating Cl-36 in crud are the content of chlorine in the reactor water and how that chlorine is distributed between cleanup filters and system surfaces. There is, in principle, no direct correlation to Cs-137; Cl-36 should rather be correlated to Co-60. Based on the data presented by SKB, the contaminated content of Cl-36 will be 10 to 20 times greater if Cl-36 is correlated to Co-60 rather than Cs-137.

3.3.3 Radionuclide inventory in SFL 3-5

An overall description of the different types of waste that are intended to be deposited in SFL 3-5 is provided in Chapter 2 of the safety assessment. A much more detailed description of the various types of waste intended to be deposited in SFL 3-5 is found in Appendices B-F of the inventory report. Naturally, a review of a report as comprehensive as the inventory report gives rise to a large number of questions and comments of varying degrees of detail. It has not been the intention of the authorities to account for all these viewpoints in this review report. Only the most important evaluations and a number of more general observations are presented below.

General comments
In Table 8-1 in the safety report, SKB presents the radionuclide inventory which was used in the consequence calculations performed. The inventory determination is based largely on calculations and measurements combined with the application of correlation factors. The authorities find, as do the international expert committee, that this compilation is of great value, and may constitute the basis for refinements and successive updating of the inventory.

The authorities believe, as do the international expert committee, that correlation factors should be used with caution, and that their use must be considered in relation to the magnitude of the expected uncertainty. For example, SSI consultant Ingemansson points out that it is inappropriate to use correlation factors calculated for waste from nuclear power plants, for large parts of the waste that is being or has been generated at Studsvik (Ingemansson, 2000).

The use of correlation factors and other similar calculations can, in some cases, result in unreasonable estimated activity values. There are a number of examples in Tables 2-3 and 8-1 of radionuclides that appear to be given values that are far too low; for instance, the total incidence of plutonium in SFL 5 is only about 40 mg. This value can be compared to the permissible plutonium inventory in SFR-1, which is roughly 400 g. Because the contamination of system surfaces comprises a significant sink for radionuclides released in the reactor system, SKI and SSI consider SKB’s estimated plutonium level to be unreasonable. Another similar example is the inventory of U-238 in SFL 4, which is estimated to barely 10 Bq. The authorities believe, as do the international expert committee, that the activation of Th/U contaminants in steel can give rise to transuranium activity in the waste in addition to the activity spread through contaminated reactor water.

SKI and SSI further believe that the radionuclide Pu-239, which is also one of SKB's key nuclides, should have been included among the radionuclides (Table 8-1) involved in the consequence calculations in the safety assessment.

Nuclide inventory in core components for SFL 5

The nuclide inventory list for core components is generally good, and contains traceable references to all essential information and data. According to the present safety assessment, the waste in SFL 5 significantly impacts the calculated doses of the dominant radionuclides Mo-93, Cl-36, C-14, Ni-59, Zr-93 and, from a short-term perspective, H-3 and Sr-90. Because many of these radionuclides are relatively difficult to measure from a purely technical standpoint, it is important for SKB to continue with their development of measuring technology currently underway to measure these nuclides in the waste. SKB should also consider calculating the level of activation products in the material based on integrated neutron flux and spectrum data, reactor cross-sections and known (or estimated) contents of, e.g. stable nickel, chlorine and molybdenum in irradiated components. These activation products are currently estimated using the coefficients in Appendix A, which can lead to both unnecessary conservatism and underestimation of the inventory.

Nuclide inventory in neutron detectors for SFL 5

The activity inventory in neutron detectors should be updated intermittently, and the introduction of new types should then be taken into account; the material in the detectors should be afforded special consideration. An evaluation should be made as to whether estimates of hard-to-measure nuclides for these materials can be based on the use of the correlation factors in Appendix A.

Handling of references for historic waste at Studsvik

As SSI pointed out in connection with their review of FUD Program 98, the handling of references is poor in those sections which deal with the historic waste from Studsvik. In general, the source given for many quantitative data is undocumented ”Personal communications”. The authorities consider it important to furnish optimally documented information about this waste, and request that the information that has been, and continues to be, retrieved be documented in a thoroughgoing fashion.

Correlation between Cs-137, Pu-239/240 and Am-241 in historic waste at Studsvik

SKI and SSI find it doubtful that the so-called ”1 and 4% rule” should apply to the Studsvik material. This rule states that the activity of Pu-239+240 and Am-241 corresponds respectively to 1% and 4 % of the activity of Cs-137. This correlation is based on *measurements of ash* from the incinerating facility, HA, at Studsvik. The regulations concerning materials for incineration have always required that no waste containing known transuranium activity may be incinerated. It is essentially to waste that *may not be incinerated* that these correlation factors are now being applied. As a result, SKI and SSI consider as dubious the validity of the SKB conclusion that the application of the 1 and 4% rule is likely to overestimate the Pu- and Am content in the waste.

Historic waste at Studsvik not included in the inventory report

SKB indicates that it is unclear whether the ca. 2.5 kg of plutonium that is present in portions of the waste (mainly irradiated fuel residue) stored at AT (a storage facility for irradiated material) will undergo final storage in SFL 3 or SFL 2. This material is however not included in the inventory for SFL 3.

Ash drums containing uranium waste
The amount of uranium present in the 147 drums of ash contains on the order of 73 kg U-235 and 2.73 metric tonnes of U-238. This is equivalent to 15.5 fresh fuel assemblies with a mean enrichment of 2.5%. The authorities believe that SKB should investigate the long-term risk of criticality (after resaturation of SFL 3).

Drums containing garbage and scrap
There are currently some 5,500 older waste drums containing garbage and scrap at Studsvik, which are being stored in a sheet metal shed. The bulk of these drums is intended to be deposited in SFL 3. The contents of some 30% of these 5,500 drum are documented either incompletely or not at all. In addition to these, there are about 700 drums originally derived from plutonium research performed by the Swedish Defence Research Institute (FOA). Information concerning the composition and content of the waste in these drums is also extremely sketchy. The documented plutonium content of these drums is given as just over 1 kg in the inventory report. According to SKI and SSI, these estimates serve only as a lower limit for the plutonium content in the drums.

Decontamination of storage magazines for SFL 4
One strategy offered by SKB is that the storage magazines for fuel used at CLAB be decontaminated before they are deposited in SFL 4. SKB assumes in the calculations performed that *all* surface contamination has been removed, which leads to a decrease in the estimated total inventory in SFL by a factor of on the order of 700. SKI and SSI believe that SKB should have based the safety assessment on the inventory that exists. Based on the results and apparent need, the *possibility* of decontamination should have been discussed, rather than proceeding from the assumption that all the surface contamination can be removed. In the view of SKI and SSI, this assumption is encumbered by great uncertainty.

Chapter 4 Design and siting of SFL 3-5

4.1 The SKB report

Prior to this safety assessment, SKB proposed substantial modifications in the design and layout of SFL 3-5 in comparison with previous reports (PLAN 93, preliminary study of final repository for long-lived low- and intermediate-level waste, SKB TR 95-03). Important modifications include the fact that crushed rock is now to be used as filling material in all parts of the repository (bentonite has been dropped as the filling material), and that SFL 3 and SFL 5 have been made more like one another for greater flexibility. SKB stress in their report that the design proposal for SFL 3-5, in large part, is based upon experience gained from the design and operation of the BMA repository in SFR.

SKB assume in their preliminary safety assessment that the SFL 3-5 repository will be co-sited with the repository for spent fuel (although it is pointed out that other sites are also possible). Three hypothetical sites have been proposed for Aberg, Beberg and Ceberg at a distance of about 1 km from the fuel repository (SFL 2) and a storage depth of 300 – 375 m. With regard to siting, the fact that the currently dominant flow direction must not cause high-pH groundwater from SFL 3-5 to pass across repository has been accounted for. SKB point out that the studied areas, Aberg, Beberg and Ceberg, are too small to accommodate both SFL 2 and SFL 3-5, but they believe that the information that is known is sufficient for assessing how site-specific factors would impact SFL 3-5. The most important factors, also discussed in most detail, are the prevailing hydrological and geochemical conditions at each site.

In the concluding discussion in the safety assessment, SKB point to the possibility of improving the barrier systems, particularly in cases where the siting could entail that relatively high groundwater flow rates might occur. The proposals they discuss involve increasing the thickness of the cement barriers, using clay instead of crushed rock as the filling material, and coating the rock caverns with a diffusion-proof material.

4.2 Viewpoints from outside experts

The Swedish National Council on Nuclear Waste Issues (KASAM) find that it is unclear whether the ongoing (or recently concluded) preliminary studies are part of the siting of SFL 3-5, or whether they pertain solely to SFL 2, particularly given that SKB have indicated that future site investigations will shed light on the possible siting of SFL 3-5. KASAM further find that SKB have not justified with sufficient clarity their decision to locate the repository at a depth of roughly 300 m and a distance of about 1 km from SFL 2.

The international expert committee find that the justification of the proposed design and siting of SFL 3-5 in the SKB safety assessment is insufficient. First and foremost, there is no clear and coherent justification for the storage concept, which should include a description of the design principles, the repository layout and dimensions, and a description of how each component is expected to contribute to the safety of the repository. With respect to the hypothetical siting of SFL 3-5 in the safety assessment, the expert committee are critical of the fact that the outer areas of Aberg, Beberg and Ceberg are to be used for SFL 3-5, since the available information about the properties of the rock in these areas is extremely limited. The committee feel that it would be more reasonable to hypothetically site SFL 3-5 at each repository location wherever the most information is available (i.e. in the same place as SFL 2 in SR 97).

The international expert committee also point out that various safety-related aspects that could be impacted by the proposed design modifications have not been adequately evaluated prior to the present safety assessment. This means that certain opinions and results from earlier research, used in the report may not be relevant to the current design.

SKI consultants Wilmot and Crawford (SKI Report 00:47) find that the reasons why the proposed design should be modified in comparison with previous reports (e.g., the use of crushed rock as filling material and the use of porous concrete in the storage spaces), are not fully justified.

SKI consultant Glynn considers that the choice of 1 km as the distance separating SFL 3-5 and SFL 2 needs to be justified. Glynn further doubts whether 300 m is sufficiently deep for SFL 3-5.

4.3 SKI/SSI evaluation

4.3.1 Choice of repository design and site

The authorities agree with SKB that the experience from SFR will be valuable in the work on SFL 3-5, and that optimum advantage should be taken of this experience. This is especially true with respect to issues that bear upon the design and operation of the repository, but not to such a great extent to issues that bear upon its long-term safety. Since the safety assessment for SFR never addressed the long-term time scales that are relevant to SFL 3-5 in detail, the authorities find that the conceptual similarity with SFR (the BMA repository) does not constitute viable grounds in support of SFL 3-5's long-term safety. The relatively short time scales during which SFR's barrier properties are assumed to be intact in the SKB safety assessment are inadequate for an assessment of SFL 3-5.

In this context, the authorities agree with the international expert committee that SKB need to prepare a highly coherent report that justifies their choice of design from a long-term safety perspective. Issues that require a more detailed discussion include the choice of repository depth, the distance separating SFL 3-5 and SFL 2, the filling material, the hydraulic cage principle, the repository dimensions, the amount of cement, the chemical composition of the cement, etc. (see also Chapter 8). The repository design that is finally proposed should be shown to be reasonable in terms of its optimisation of a number of factors (in order to meet the requirements imposed with respect to ”best available technique”). To summarise, SKB should demonstrate that the design that is finally proposed can be justified convincingly both with regard to its long-term safety as well as from a design and operations perspective.

One important issue associated with a final choice of design concerns an explicit description of the requirements that must be imposed on a potential candidate site so that it will meet the requirements established for the proposed design of SFL 3-5. It is important to point out that these requirements are not necessarily identical with those recently presented for SFL 2 (see SKB TR-00-12). The current study indicates that site-specific factors are of decisive importance to the long-term safety of the repository, and that the restrictions with respect to, e.g., site-specific groundwater flow and chemistry may be more restrictive than for the fuel repository. The authorities do not believe that SKB should proceed on the assumption that an adaptation of the repository design based on the conditions that are relevant for a specific site is possible (as is indicated in the preliminary safety assessment), but that SKB should instead formulate a sufficiently robust design that is acceptable for all the sites that could potentially be considered for SFL 3-5. As SKB themselves point out, it is not clear that the conceivable modifications in the repository design that have been proposed would actually improve the long-term safety of the repository.

It would obviously be beneficial to the future siting of SFL 3-5 if it should prove possible to create a repository concept that is less sensitive to site-specific conditions than that described in the present safety assessment. SKB should make use of the opportunities afforded by future site studies to investigate what impact acquired data and site-specific knowledge might have in terms of siting SFL 3-5.

Even though the construction of SFL 3-5 lies some 30 years ahead according to the current SKB timetable, the authorities still believe that it would be meaningful to study potential siting alternatives for SFL 3-5; this will be possible during the planned site investigation phase (for alternative co-siting). This would increase SKB's freedom of action prior to the future work of siting SFL 3-5, and would also mean that the work on SFL 3-5 would not stagnate. Two issues that need to be addressed in greater detail than in the present study are the distance separating SFL 2 and SFL 3-5 and the repository depth.

With respect to the separation distance, SKI and SSI believe that there is a possibility that SKB have significantly overestimated the capacity of the filling material to neutralise the high-pH plume from the repository (SKB R-99-15). An analysis of the separation distance must take into account the possibility that the dominant groundwater flow direction may change under the influence of climate changes. In the view of SKI and SSI, the possibility cannot at present be ruled out that the pH plume might temporarily extend far beyond the SFL 3-5 repository. A surrounding bentonite layer might possibly be able to prevent or limit the propagation of a pH plume, but the use of bentonite has been entirely eliminated in the current repository design. The SKB analysis of pH buffering (SKB R-99-15) must be considered as potentially non-conservative, since it does not take into account, e.g. the fact that the reaction products generated by the weathering of silicate minerals may limit additional dissolution. Furthermore, SKB need to bear in mind that the relatively rapid dissolution of minerals, that can be measured in laboratory tests involving prepared mineral samples, is not representative of large systems and long time scales. This is attributable to a number of factors having well documented effects on the dissolution of minerals, namely: particle size, which is included in the SKB model size and structure of mineral grains, presence of surface coatings, depletion of reactive surfaces and variably efficient contact surfaces between minerals and the mobile water phase. The analysis of pH buffering would have been more reliable if these factors had been taken into account. Furthermore, some type of long-term testing needs to be cited. The issue of pH effects on groundwater conditions is also relevant with respect to the use of cement as a construction material in SFL 2.

With respect to an evaluation of the repository depth, considerations regarding future climate changes should be of decisive interest. New efforts in this area are called for, as the SKB assessment contains no in-depth analysis of the effects of climate changes .

4.3.2 Consideration of unfavourable events

SKB should identify and study factors that could undermine the functions assumed in the present safety assessment (such as a sufficient amount of cement to maintain high pH, hydraulic cages with sufficient contrast in terms of hydraulic conductivity between the cement matrix/bed and the filling material). Examples of unfavourable effects and events that cannot be ruled out include concrete disintegration (due to leaching, reactions with ballast materials, reinforcement corrosion, etc.) and the formation of large penetrating cracks in the concrete structure (thus producing a less effective barrier to limit leaching of radionuclides).

The significance of assessing unfavourable events and circumstances when selecting a repository design is that it is possible to demonstrate a certain degree of redundancy among the safety functions. SKI and SSI find that SKB must show that unfavourable events or circumstances, that may be considered as reasonably likely, will not lead to unacceptable consequences for the design selected. This is linked to the question of whether the design proposed in the SKB report can be considered to offer multiple barrier functions. A report on this matter is also one of the requirements in the preliminary regulations drawn up by SKI. For example, SR 97 contains a number of calculation cases to demonstrate that the proposed repository design offers multiple barrier functions and is not dependent on just one safety function. Similar calculation cases should also be included in the assessment of the SFL 3-5 repository.

The fact that future climatic variations will occur cannot be viewed as either particularly unfavourable or unlikely, but rather as the most likely case. As a result, the probable climatic evolution should be included as an integral part of a main scenario (i.e. a scenario that may be considered to have a relatively high likelihood of occurrence). However, certain climatic changes involving long periods of permafrost could be especially unfavourable if the possibility of the permafrost reaching the storage depth cannot be ruled out. Permafrost at storage depth could result in relatively rapid and substantial mechanical degradation of the barrier system. This brings up the question of whether 300 m is sufficiently deep for SFL 3-5. For instance, one SKB documentary report states that a number of researchers believe that permafrost will be widespread, and that it will extend to a depth of at least 300 m below the surface of the ground (SKB R-99-41).

To answer the question of the optimum storage depth for SFL 3-5, other factors must be taken into consideration, such as aspects related to bedrock mechanics and probable changes in groundwater composition during the period of time comprehended by the safety assessment. In the present safety assessment, it is shown that the groundwater composition (and especially its salt content) could have a major impact on the migration of certain nuclides (such as Ni-59). However, the variations proposed in the study are in all likelihood too small to adequately represent the variations that may be expected during, e.g. a glacial cycle, as has been pointed out by SKI consultant Glynn, among others (SKI Report 00:47).

Chapter 5 System and scenario analyses

5.1 The SKB report

The preliminary safety assessment for SFL 3-5 is based on earlier system studies of SFL 3-5, including an earlier version of a PID (Process Influence Diagram) of SFL 3-5 prepared in connection with a preliminary study (Wiborgh, 1995). Based on previous experience, SKB have updated the system analysis and structured the information in the form of a THMC (Thermal, Hydrological, Mechanical and Chemical) diagram. This type of diagram divides processes and events based on the types of effects they have on the system.

A reference scenario has been prepared which serves as the basis for the consequence calculations presented. The starting point for this scenario is that the technical barrier systems have evolved as expected, and that no major changes in the properties of the barrier systems occurs. Ambient factors such as hydrological, geochemical and biospheric conditions are assumed to remain unchanged throughout the entire period of time comprehended by the assessment. In other words, anticipated climate changes are not included in the reference scenario. SKB recount how the various expected processes in the repository must be accounted for in developing the quantitative models used in the consequence analysis (such as cement leaching, corrosion, gas generation, decomposition of organic materials, mineralogical transformations, release of radionuclides, diffusion and sorption.)

In addition to the reference scenario, the following alternative scenarios are discussed in overview:

- Climate changes
- Seismic and tectonic activity
- Design and operation
- Future human activities

With respect to the scenario for climate changes, the discussion proceeds from qualitative considerations of several potential effects on an SFL 3-5 repository, such as hydrological and geochemical changes, as well as mechanical effects in the case involving permafrost at storage depth. Concerning the scenario for seismic and tectonic activity, SKB indicate that displacements of up to 10 mm would not affect the repository. However, a number of measures are proposed that could be undertaken to improve the safety margin for the effects of earthquakes. The design and operation scenario includes a discussion of the types and amounts of unintentionally deposited materials that may conceivably be left in the repository after closure.

The scenario regarding human activities is distinguished from the other scenarios in that it is the only scenario (other than the reference scenario), that includes quantitative dose estimates. These estimates are based on a case in which a well is sunk near the repository and then gives rise to dose exposure when the well water is consumed as drinking water. A number of other types of human activity are mentioned, but not discussed further.

5.2 Viewpoints from outside experts

The National Swedish Council on Nuclear Waste Issues (KASAM) point out the absence of an analysis of the significance of various uncertainties, which limits the value of the consequence calculations. KASAM also note that the safety assessment for SFL 3-5 actually concerns a more complex system than SR 97 (for the fuel repository), since SFL 3-5 contains substantial amounts of organic material and has a potential for gas generation inside the repository.

The international expert committee find it remarkable that SKB have not documented a system analysis of SFL 3-5 to demonstrate that their assessment can be viewed as comprehensive and that the most critical issues have been addressed properly. The committee point out that formal system analyses based on identification of all relevant FEP (Features, Events and Processes) have gained widespread favour in connection with national programs for the final storage of radioactive waste. The committee also point out the lack of a formal systematic sensitivity analysis to elucidate uncertainty in parameters and conceptual models. Finally, the group are critical of the fact that the alternative scenarios are based solely on qualitative considerations, which are regarded as insufficient and, in some cases, questionable. The committee find it particularly remarkable that glacial and periglacial conditions are scarcely touched upon here.

SKI consultants Wilmot and Crawford find that the SKB reference scenario does provide a starting point for developing an understanding of the characteristics of the near-field. It is however insufficient to serve as a basis for decision taking, since uncertainties associated with environmental changes are not included. It further seems skewed to Wilmot and Crawford to include a number of different types of biospheres, since the assessment obviously does not yet cover all types of uncertainties. The use of a reference biosphere would be an acceptable approach if the sole aim was an understanding of the characteristics of the immediate vicinity. Wilmot and Crawford also point out the lack of formal documentation for the FEP and the absence of a THMC diagram showing how the relevant FEP interact.

SKI consultants Wickham, Bennett and Higgo (SKI Report 00:33) point out that the SKB conclusions concerning the importance of colloids are insufficiently substantiated, since all the different types of colloids that could be formed must be considered, including those produced by precipitation within the pH gradient (which produces major changes in geochemical conditions) expected to occur in the vicinity of the repository. This is not discussed in the SKB report, nor are possible relationships with other processes, such as gas generation. The SKI consultants would also point out that anion exclusion could scarcely have the major impact in crushed rock that it is expected to have in bentonite clay.

SKI consultant Glynn (SKI Report 00:47) considers the treatment of the ice ages, which are expected within a period of 100,000 years, to be insufficient.

5.3 SKI/SSI evaluation

5.3.1 System analysis

SKI and SSI find, along with the international expert committee and SKI consultants Wilmot and Crawford, that a systematic review and documentation of FEP relevant to SFL 3-5, would have increased the reliability of the safety assessment and provided a better basis for evaluating its completeness. It is important that the documented knowledge that serves as the basis for formulating scenarios, developing calculating models and designing calculation cases to be reported in a transparent manner. The SKB report (SKB TR-99-28 with supporting references) certainly describes a major portion of his underlying knowledge in a good way, but the traceability could be improved. More systematic documentation of the underlying knowledge would also furnish an opportunity to incorporate the international experience that is relevant to SFL 3-5. SKI and SSI agree with the international expert committee that all the available experience and knowledge have probably not been utilised to the fullest possible extent.

In connection with their review of SR 97, the authorities expressed positive opinions on the THMC method and its application in SR 97. They found the method to be a valuable contribution to the methodology of safety assessments (SKI Report 00:39). It is evident in the SKB preliminary safety assessment of SFL 3-5 that the THMC method was also used in this case, and it must be viewed as remarkable that this was not reported. The preparation of THMC diagrams, the closely related PIDs and the interaction matrices is certainly difficult and resource-intensive, given the complexity of the studied systems. Since the aim is to facilitate an understanding of how different FEP affect one another, a documented system analysis would contribute to improved clarity. This would provide a basis for evaluating the prioritisation and selection of the processes included in the conceptual models.

Given the impossibility of thoroughly characterising a candidate site or acquiring complete knowledge of the large number of processes or events that can affect the storage system, the handling of uncertainties represents a key aspect in evaluating the reliability of the safety assessment. The present analysis lacks a systematic approach to handling uncertainties, although it is pointed out in a number of sections that uncertainties have been handled using conservative approaches with respect to both conceptual simplifications and data selection. The authorities consider such an approach to be acceptable, but in such cases the justification for the conceptual approach used must be clearly set forth, so that it is possible to determine the degree of conservatism present. Such a determination often requires more realistic and complex models to supplement the simplified models used in consequence calculations. The choice of parameters must also be evaluated consequently (e.g. on what basis have the realistic or conservative data been chosen). In general, SKI and SSI would like to see a systematic approach with better traceability in uncertainty reports for future safety assessments.

The issue of conceptual uncertainties and heterogeneities in the near-field and far-field must, in particular, be elucidated more thoroughly. The processes identified in the system analysis can also be expected to have different importance in different scenarios, and this needs to be described. Evaluations as to how certain processes may be expected to evolve over long periods of time also require supplementation.

A system analysis is based largely on expert judgements. It is desirable that these judgements represent a range of expertise in various fields, and that they be reviewed by independent experts and documented. The SKB safety report exhibits deficiencies in this respect, as was also pointed out in the authorities' review of SR 97 (SKI Report 00:39).

5.3.2 Scenario analysis

The authorities agree with SKI consultants Wilmot and Crawford that the SKB reference scenario in the assessment of SFL 3-5, provides a valuable starting point for, e.g. studies of different barrier functions and repository geometries. However, it does not provide an adequate basis for assessing long-term safety, since environmental changes are not analysed. A main scenario should be formulated that includes probable climate changes. To elucidate the major uncertainty that is always present in assessments of climatic evolution over periods on the order of 100,000 of years, a number of climatic variants different variants of climatic changes should be studied and compared. Uncertainties in assessing the evolution of the technical barriers can be elucidated by defining variants based on different types of internal disturbances and their impact on the barriers (such as different degrees of degradation or cracking of and chemical changes in the barriers).

According to SKI and SSI, the alternative scenarios offered by SKB in TR-99-28 are inadequate to enable assessment of the impact of external forces such as glaciation and earthquakes. The SKB account of these scenarios leads to the perception that these forces are of minor significance without providing sufficient grounds for such an assumption. A number of qualitative judgements need to be justified or explained, such as those concerning the impact of altered groundwater conditions and the stresses imposed on the repository by earthquakes and permafrost. It is apparent that SKB have sought to limit the scope of the SFL 3-5 assessment, and have consequently chosen not to address all the types of events and processes that could affect the repository. SKI and SSI believe that, instead of dealing with, e.g. climate changes in a superficial manner, SKB should have refrained entirely from considering the impact of such factors if the purpose of the assessment was solely to foster an understanding of the basic concept. However, an assessment that was limited in such a way could not serve as a complete basis for evaluating the impact of site-specific factors or the choice of design.

The authorities consider that the occurrence of normal wells for drinking water should constitute one of a number of normal exposure pathways that should be evaluated for different types of scenarios (see also Chapter 7). The use of a well for drinking water must be viewed as an unavoidable part of human activity. Such use should therefore be integrated as part of, e.g. both a main scenario and a reference scenario. Because the case involving a well entails the highest doses from among the cases presented, the way in which it is handled in the scenario analysis must be viewed as being of particular importance. According to SKI and SSI, cases that should especially be included in scenarios for human activities include, e.g. a deep bore hole that runs to the absolute immediate area of the repository. SKB have cited a number of such scenarios that were formulated as part of SR 97. SKB should, prior to future assessments, determine whether any of those scenarios might be relevant to SFL 3-5.

A future safety assessment of SFL 3-5 will presumably need to include multiple scenarios that are handled with a similar level of ambition. In this context it would be worthwhile for SKB to justify their scenario choices by describing how the various FEP selected in the system analysis are represented in the scenarios chosen.

Chapter 6 Geospheric conditions

6.1 The SKB report

In their report, SKB describe the geological, hydrogeological and geochemical conditions at the three selected sites, Aberg, Beberg and Ceberg (Äspö, Finnsjön and Gideå). These three sites exhibit a certain range of variation in terms of basic factors, thereby making it possible to study the impact of various factors on the repository when the sites are compared. On the other hand, the conceivable parametric variations within a single site have not been studied (with the exception of groundwater chemistry at Beberg). Since the assessment of SFL 3-5 is focused primarily on the near field, and on the characteristics of the technical barriers, information and data regarding the geospheric conditions have not been studied in detail, but have instead been derived mostly from the more comprehensive safety assessment for the fuel repository (SR 97).

SKB have, in their assessment of SFL 3-5, used many simplifying assumptions with regard to the geospheric conditions, such as that the rock surrounding SFL 3-5 is homogenous, that the flow situation corresponds to a steady-state situation, and that the direction of flow is mainly horizontal and oriented along the SFL 3 and SFL 5 tunnels.

The groundwater flow rates assumed in the calculations span three orders of magnitude, with the highest flow at Aberg and the lowest at Ceberg. The groundwater flows close to the repository are of major importance to the outward diffusion of radionuclides through the technical barriers (since they affect the boundary conditions for diffusive transport from the near-field). The assumed groundwater composition is based on analysis data from water samples collected at depths of 300 – 600 m. The biggest differences among the sites pertain to alkalinity, sulphate and salt contents. Beberg is represented by two groundwater compositions, one with a relatively high salt content, the other with a relatively low salt content. Geospheric retardation is impacted heavily by the length of the transport routes, the flow-wetted surface and the advective travel times. Because the proposed site of SFL 3-5 at Aberg is near a fracture zone, the advective travel times are relatively short, on the average of 13 years. The average figure for Beberg is 40 years, while the average for Ceberg is 906 years.

6.2 Viewpoints from outside experts

The international expert committee consider the groundwater flow rates used by SKB for the Aberg, Beberg and Ceberg sites not to be comparable, since they were derived based on different types of groundwater models that were in turn based on underlying data of varying degrees of relevance and detail for the different sites. As a result, the committee find that the conservatism in the choice of flow rates cannot be evaluated, nor are the variations that were included sufficient.

SKI consultants Wilmot and Crawford find that the numerous simplifying assumptions regarding hydrological conditions are certainly defensible, given the limited aims of the assessment, but also that they need to be developed further prior to future decision taking. The consultants mention in particular the use of simplified assumptions for transport times, and the application of the analysis results from Beberg to the other sites (SFL 4).

SKI consultant Glynn stresses the importance of studying how the effects of varying groundwater composition would impact the repository, and in particular the effects of groundwater with a high salt content. Glynn also feels that the regional groundwater flow model covers too small an area to provide sufficient insight into the regional conditions.

6.3 SKI/SSI evaluation

Because the SKB analysis of site-specific conditions at Aberg, Beberg and Ceberg is derived largely from the SR 97 study, the views expressed by the authorities in connection with their review of SR 97 (SKI Report 00:39) are also relevant to the SFL 3-5 assessment. With regard to the siting of SFL 3-5, SKI and SSI recommend that SKB describe in greater depth the specific relevance of geological conditions, as well as which conditions need to be evaluated differently than in the case of SFL 2 (separation distance from fracture zones, direction of flow, rock stresses, acceptable groundwater chemistry, etc.)

The authorities agree with the international expert committee that one major deficiency is the fact that, within the framework of their radionuclide transport calculations, SKB locally assume homogenous hydrological conditions without more closely analysing the importance of spatial and temporal variability. Spatial variability may be viewed as one of the most distinguishing properties of the flow in fissured rock. The groundwater flow variations among the currently studied sites indicate that hydrology can have a strong influence on radionuclide transport within the barriers. This makes it necessary to analyse the effects of spatial and temporal variations in the groundwater flow at each of the three sites.

According to the authorities, the hydrocalculations based on a regional model were too simplified to identify specific ecosystems (36 particle routes were used for Beberg and Ceberg in SFL 3-5 as compared with several thousand in SR 97). For instance, in SR 97, wells and peat bogs were analysed for all cases, but were excluded for Aberg in the safety report for SFL 3-5. SKI and SSI believe that this imparts the misleading impression that Aberg is the best site, despite the fact that the geological conditions there would appear to be the worst.

Chapter 7 Biospheric conditions

7.1 The SKB report

The potential radiation doses from releases of radionuclides to the biosphere have been calculated in the same way as in SR 97 (the safety assessment for a deep repository for spent fuel). Various ecosystem types have been selected for the dominant ecosystems at the outflow points: lake, running water, coastal areas (open coast and archipelago), cultivated fields, a peat bog and a well (SKB TR-99-15). An ecospecific dose-conversion factor (EDF) has been calculated for each ecosystem type and for each radionuclide. The same EDF is used for forest land as for peat bogs, which is claimed to be a conservative assumption. Each EDF indicates the ratio between activity in Bq supplied to the ecosystem type and the dose in Sieverts (Sv) to humans, taking into account all exposure pathways. A continuous yearly supply to the system of 1 Bq of each radionuclide has been assumed in calculating the EDF values. The course of events over 10,000 years has been simulated using, among other things, the BIOPATH software package (SKB TR-99-14).

An overview description of the biosphere at Aberg, Beberg and Ceberg is provided in the main report (Section 5.4), and in a supporting report (SKB TR-99-15). A more thorough description of the biosphere at the three sites is provided by Lindborg and Schüldt (SKB TR-98-20). The three areas are divided into subsectors (250 x 250 m), and each subsector is associated with an ecosystem type based on the existing ecosystem. The areas on the ground surface that constitute areas where radionuclides are released from the repository are determined based on the hydrology calculations. From this information a determination is made as to which ecosystems dominate in the release areas, and thus which EDF is to be used in the dose calculations. The EDF values used for Aberg, Beberg and Ceberg are presented in Table 8-16 in Section 8.6, and in Table 9-2 in Section 9.4. At Aberg the outflow areas are classed as archipelago and open coast; at Beberg the outflow areas are classed as cultivated fields, while at Ceberg the outflow areas are classed as peat bogs. The calculations for Beberg were also performed for a case in which release occurs to a peat bog.

The well is viewed as an example of future human activity that could impact the function and, in turn, the safety of the final repository. Site-specific wells are defined as wells with the same capacity as the average capacity of the wells currently present within each release area. It is assumed that radionuclides will reach the well at the rate (Bq/year) that applies to the release from the remote zone, and that the nuclides will reach the well with no time delay. The EDF values obtained for the three average wells are presented in Table 9-2, Section 9.4.1. The underlying model is described in Chapter 5.

7.2 Viewpoints from outside experts

The international committee consider the range of possible EDF values used in the existing SFL 3-5 assessment to be sufficiently comprehensive. They point out that SKB need to furnish evidence that the EDF for the forest ecosystem would fall within the range of EDF values given. They also note that the EDF values would decrease if the conservatism with respect to the coastal area ecosystem type were eliminated. However, it is impossible to determine how great this decrease would be based on the information presented. The international committee feel that SKB must provide additional support for their assumptions about the biosphere and exposure routes, and about how these assumptions could affect the choice of site and repository design.

The experts further find that the division of the biosphere into subsectors (250 x 250 m) is not sufficiently substantiated. They believe that SKB should perform sensitivity analyses to determine how the size of the subsectors can impact the EDF values. Correlations between the size of the radionuclide plume in the geosphere and the size of the subsectors should also be studied. It is similarly important to determine the land area necessary to take the included exposure pathways into account in a reasonable fashion.

The international committee find that SKB must be clearer in their description of the ”Well” ecosystem type. For example, it is unclear what SKB mean by the term ”water capacity.” The conservatism inherent in the assumption that the EDF value for the well is inversely proportional to its water capacity must be better justified. The experts believe that the level of conservatism is affected by the magnitude of the water flow in the plume (”plume flux”) in comparison with the amount of water extracted from the well. This would mean that the EDF values could be both overestimated and underestimated.

The experts consider that SKB should specify the mechanism of radionuclide transport in the final 20 m of the geosphere, i.e. the uppermost portion of the geosphere before release to the biosphere (cultivated fields). The level of conservatism inherent in the assumption of instantaneous radionuclide transport through the final 20 m of the geosphere is unknown. The international committee advise SKB to study different ways of improving their biosphere model, such as describing processes that occur in the final 20 m of the geosphere.

The international committee believe that SKB have not presented a sufficiently thorough analysis of uncertainties. While parametric uncertainties are discussed, no analysis of the conceptual uncertainties is offered. One way of handling the conceptual uncertainties proposed by the experts would be to use more than one model to calculate the EDF values.

7.3 SKI/SSI evaluation

SKB used largely the same models and assumptions as in SR 97 to calculate doses to humans. The bulk of the comments offered by the authorities in connection with their review of SR 97 is thus applicable to the SFL 3-5 safety assessment as well (see Chapter 2 of SKI Report 00:39). These comments are summarised below:

- The processes in the biosphere are described very generally, and the descriptions are not formulated in the same systematic way as the processes for other parts of the repository system.
- There is no description of which processes and interactions could affect the transport of radioactive substances from the geosphere to the biosphere. SKI and SSI feel that there needs to be better justification for the assumption at that radionuclides undergo transfer from the geosphere directly to the ecosystem type being studied. Furthermore, there is no discussion as to how this approach could affect the uncertainty in the final results.
- The description pertains essentially to the biosphere as it looks today. The safety report must certainly include a case involving the present-day biosphere, but this does not mean that changes in the biosphere can be ruled out entirely, particularly if such changes may be deemed likely.

- The assumption that peat bog can be used as a pessimistic descriptor of forest land is not self-evident, and requires justification. Forest land may be expected to be a dominant ecosystem, and should consequently be included as a separate ecosystem type.
- The conservatism inherent in the EDF values used must be better elucidated. The informational value of the EDF values is affected by the safety margins that exist, and by how these safety margins can differ for different radionuclides and ecosystems. A safety assessment must similarly include an account of which flows and concentrations comprise intermediate results in the EDF value calculations, since these values serve as starting points for assessing the relevance of alternative exposure routes and protection objectives.
- The well alternative should be viewed as an exposure pathway rather than as a separate ecosystem type. This exposure pathway could instead be included as a part of different ecosystem types, particularly cultivated fields and the peat ecosystem. The degree of conservatism in the calculations of radionuclide concentrations in the water requires better elucidation.
- The way in which ecosystem types combine at a site can be artificial to some extent; it is not necessarily true that the calculated release points from the geosphere (30 meters below the ground surface) will coincide geographically with the outflow points in the biosphere. One possible alternative is to identify the affected areas from geosphere transport calculations, so that different ecosystem types can be assumed to cover these surfaces.

See Appendix 2 of SKI Report 00:39 for more specific comments on the models used in calculating the EDF values.

The SKB hydrological calculations were performed using a regional model based on regional hydrological data. This means that uncertainties in the release areas for radionuclides from the repository may be significant, even from a short time perspective. SKI and SSI therefore feel that the choice of ecosystem type for the various sites may be called into question. Future environmental changes constitute another source of uncertainty in the release areas that was not taken into account in the analyses presented by SKB.

The authorities find that the calculated doses are near to or in excess of applicable dose criteria. At the same time, calculations were performed for only three deterministic cases from a huge range of possible combinations of geospheric and biospheric conditions. At this point in the research process SFL 3-5 could in theory be sited almost anywhere in Sweden, and the number of possible combinations of different conditions could thus be expected to be very large. Consequently, the authorities are of the opinion that SKB should have used sensitivity analyses and uncertainty analyses to a far greater extent to study how conditions in the geosphere and biosphere could impact the calculated doses. The relatively high dose values motivate more in-depth study of the degree of conservatism inherent in the assumptions used. Realistic analyses would also be necessary to enable reasonable comparisons among different sites, and to determine which radionuclides are most important in various contexts.

SKI and SSI find it very hard to understand why SKB has opted to view the well as an example of future human actions (in the form of a separate scenario, ”future human actions”). The well that SKB has chosen to study may be considered to be commonly occurring, insofar as it does not extend near the technical barriers of the final repository. The use of groundwater for consumption as drinking water or irrigation must be viewed as constituting an extremely likely exposure route in the various ecosystem types studied. Doses deriving from the use of well water should be added to the doses from other exposure routes in an appropriate manner.

Chapter 8 The technical barriers and their long-term properties

8.1 The SKB report

According to the SKB report, the resaturation of SFL 3-5 could take tens to several hundred years. Thereafter, stationary conditions with regard to pressure and groundwater flow are expected to develop.. The main part of the groundwater flow will cross SFL 4, since this tunnel forms a ring around the others. Long-term changes in the groundwater flow through the barriers can be expected as a result of, e.g. deposition, iron corrosion, precipitation and cracking. However, the hydrological calculations performed are based solely on stationary conditions in which the barriers were assumed to possess the properties that could be expected in the longer term.

SKB believe that fissures will form in the waste containers within tens of years after resaturation as a result of the build-up of gas pressure. The concrete structures will also probably crack, although somewhat more slowly (within several hundred/thousand years). Gas would be generated mainly as a result of the anaerobic corrosion of iron, but also to some extent because of the decomposition of organic materials and the corrosion of aluminium. However, according to SKB, only a few gas-conducting passages (cracks) are necessary in order for the gas to be carried efficiently out into the filling material with no notable increase in pressure. As a result, the effects of gas need not be accorded special consideration in the safety assessment (except for the release of ^{14}C in gas form).

SKB have studied the groundwater flow through the barriers and the function of the hydraulic cage by varying the conductivity of the filling material in relation to the surrounding rock (SKB TR-97-10). This is to reflect the choice of either crushed rock or bentonite as the filling material. Certain calculations were also performed to study the effects of plugs and heterogenicities in the rock. The results show that the flow in a filling consisting of crushed rock is about 6,000 times higher than in the surrounding rock. On the other hand, the flow in the intact cement structure is instead roughly 1000 times lower than in the case without a hydraulic cage. SFL 4 functions in some cases as a hydraulic cage for SFL 3 and SFL 5, but only if the groundwater flow is horizontal or near horizontal. The absence of plugs and heterogeneous flow generally leads to an increase in the groundwater flow in all repository spaces.

8.2 Viewpoints from outside experts

The international expert committee feel that chemical buffering is a key issue in connection with resaturation that requires more thorough elucidation, and the committee question in particular the SKB results indicating that the pH front would be neutralised entirely by the filling material. Moreover, the committee are of the opinion that SKB have probably underestimated the porosity increases due to cement leaching, and that SKB have not given sufficient consideration to the effects of saltwater.

With respect to the analysis of the impact of gas generation, the committee find that the SKB scenario in which gas is generated relatively rapidly may need to be supplemented with variants involving both slower and more pulse-like gas formation. The committee also point out the risk of more comprehensive cracking, which would serve as a transport route not only for gas, but for groundwater as well.

The international expert committee find that the SKB focus on the concept of a hydraulic cage needs to be better substantiated. Among other things, the committee feel that the importance of the long-term integrity of the concrete structures may be greater than the SKB report indicates. The committee believe that SKB should analyse the bentonite-based filling material more thoroughly before casting it aside, since this material would create, at least theoretically, the conditions necessary for lower release rates.

SKI consultants Wilmot and Crawford note the absence of a quantitative evaluation of the resaturation process.

8.3 SKI/SSI evaluation

SKI and SSI find the SKB investigations regarding the hydraulic cage to be quite convincing and feel that they have been presented well. Certain disadvantages were, however, not sufficiently elucidated, such as the fact that the channelisation of the groundwater flow from the surrounding rock would substantially accelerate the degradation of the cement barriers. Given that the choice of crushed rock as filling material (with its high hydraulic conductivity) must be viewed as a key component in the safety concept that SKB are currently applying to SFL 3-5, the report needs to be more exhaustive. For example, the supporting documentary basis is not sufficient to enable an assessment as to whether the chosen repository design offers better conditions for meeting applicable radiation protection criteria than do other comparable alternatives, particularly in scenarios involving substantial mechanical or chemical effects on the barriers. A more comprehensive analysis of the long-term barrier transformations may be considered of particular interest. Such an analysis should then be used as the basis when choosing the design. With regard to the chosen concept, which is based on extremely large differences in hydraulic conductivity between the repository structures and the filling material, the risk that these differences might decrease as a result of either mechanical effects or gradual chemical effects must be taken into account. This conclusion is based on the perception that there may be cases that could entirely endanger the current safety concept for SFL 3-5.

SKB have previously evaluated the hydraulic cage concept in an entirely different context (SKB TR-89-20). It was then concluded that an analysis of the hydraulic cage based on a continuum of assumptions indicated highly advantageous properties. If, on the other hand, the discrete network of fractures that arises in connection with the cage (fractured rock) and the cage’s long-term integrity are accounted for, the concept becomes considerably more difficult to assess according to SKB. SKI and SSI find that these conclusions are consistent with those drawn by the international expert committee regarding
the current design for SFL 3-5. As a result, these conclusions should provide the basis for prioritising further research efforts in this area.

The SKB analysis of gas formation and transport offers, according to SKI and SSI, a good starting point for further studies. What is mainly missing is a systematic analysis and discussion of the uncertainties and time-dependent variations that could occur. For instance, it seems unrealistic to assume that the gas formation will remain constant until all metal of a given category has been entirely consumed. Additional efforts in this area should take into account gradual changes in the metal surfaces, as well as the potential effects of the corrosion products generated. It is reasonable to assume that uncertainties with respect to the extent of the original metal surfaces and the amounts of metals present must also be significant. The gas analysis must also be modified so that it is consistent with the SFL 3-5 design studied in this instance (choice of filling material, repository depth, etc.)

In summary, the authorities recommend (as was also pointed out in Chapter 4) that SKB formulate and study a number of alternative designs for SFL 3-5, e.g. barriers of different dimensions, with different filling materials or possibly combinations of various filling materials (such as crushed rock, bentonite, sand). If SKB ultimately chose to base the safety concept for SFL 3-5 on the hydraulic cage, SKB should look into the possibility of supplementing with additional tunnels or bore holes at a greater distance from the SFL 3-5 waste in order to shield it more efficiently and minimise the effects on the barriers closest to the waste. The authorities believe that the SKB rationale for choosing to eliminate bentonite is far too limited. In view of the major, well-documented advantages of this material, the authorities feel that there are many good reasons to further analyse the use of bentonite in SFL 3-5.

Comparisons of alternatives should preferably be based on quantitative analyses that encompass various conceivable long-term transformations in the barrier system (such as changes in permeability conditions and the presence of large, through-passing fissures). Gradual changes in groundwater chemistry and the scope and direction of the groundwater flow due to climate changes could also affect an assessment of how the barrier system should be designed, and these changes should thus also be elucidated. The purpose of these comparisons is not to produce the SFL 3-5 design that entails the lowest dose burden for a reference case, but rather to produce a design robust enough for the repository structure to provide acceptable protection in all of the scenarios considered to be reasonably likely. The design must also be formulated in such a way that the conditions for finding a suitable site for SFL 3-5 will be sound. The existing safety assessment gives the impression that SKB are not convinced that such is the case, based on the results presented heretofore.

Chapter 9 Radionuclide transport and dose estimates

9.1 The SKB report

The SKB radionuclide transport calculations are based on the assumptions set forth in the defined reference scenario (see Section 5.1), as well as certain parts of the human activities scenario (exposure via drinking water from a well). The COMP-24 compartment model, which takes into account transport via diffusion or advection, was used for the nera-field of the repository (the waste, the technical barriers and portions of the surrounding rock). Some simplifications have been made concerning the repository geometries and dimensions; these simplifications are considered to be conservative with respect to the leaching of radionuclides. Parameters that govern the outward leakage of radionuclides are Kd values, diffusivity, density, porosity and, for some nuclides, solubility. The nuclides are assumed to be distributed homogeneously in the repository spaces and immediately available for leaching into the pore water.

The presence of certain organic substances or their decomposition products in the waste could disturb the retardation processes, primarily in the near-field. Additives in concrete represent another source of organic material with potentially unfavourable properties in this regard. In the present report, SKB have, in practical terms, limited themselves exclusively to one conceivable such effect: the effect of isosaccharinic acid (ISA), which is a by-product of the decomposition of cellulose in alkaline (cement) environments. In SFL 3, where the largest amounts of organic material are present in the waste, this process could lead to such dramatically increased solubility for certain metals, particularly Pu, that it is not possible to set any solubility limit; SKB have taken this into account in their calculations.

The chemistry of ISA in cement systems has been studied intensively over the last ten or so years, and it has been found that the effect of ISA on sorption is considerably less than its effect on solubility. ISA is also sorbed into the concrete, which lowers its effective content in solution. SKB have utilised such data, along with their assumption regarding the proportion of decomposable cellulose, and thence drawn the conclusion that the impact of ISA on sorption is negligible.

The calculations for the far-field include only those nuclides which did not result in negligible doses considering a hypothetical consumption of pore water directly from the repository spaces. The code FARF31 has been used, which is based on the assumption of one-dimensional transport along a stream tube with dispersion, sorption, matrix diffusion and chain decay of the nuclides. Parameters incorporated in the model include Kd values, diffusivity in the rock matrix, dispersivity, flow-wetted surface, advection and the length of the flow paths. Data were obtained mainly from the so-called ”realistic” estimates made within the framework of the SR 97 project. However, some supplementation has been done with respect to the nuclides of interest only in connection with SFL 3-5.

The dose estimates are based on the radionuclide transport calculations and dose conversion factors for the coast and archipelago biospheres for Aberg, peat and cultivated fields for Beberg, and for peat only in the case of Ceberg. A dose conversion factor for consumption of drinking water from a well was used in the human activities scenario. SKB have not presented a risk assessment but, to enable comparison with the SSI risk criterion (maximum risk of harmful effects equals 10^{-6} per year for a representative individual from the most highly exposed group), a probability coefficient equivalent to a probability of 1 has been used, which yields a maximum annual dose of 14 μSv. The dispersion of the heavy metals cadmium, lead and beryllium from SFL 3-5 has been estimated and its effects assessed based on comparisons with maximum permissible drinking water concentrations and mean concentrations in lakes and cultivated fields.

The results indicate that the groundwater flow, the length of the transport routes, the geochemistry and the dose conversion factors have a crucial impact on the estimated dose. The highest annual dose of roughly 25 μSv was obtained for the case involving a drinking water well at Aberg. Corresponding annual doses for Beberg and Ceberg were 2 μSv and 0.3 μSv, respectively. For the other cases, the maximum annual doses were 0.004 μSv for Aberg (archipelago), 3 μSv for Beberg (cultivated field) and 10 μSv for Ceberg (peat). These doses are dominated by the nuclides Ni-59, Mo-93, C-14 and Cl-36. Sr-90 and H-3 make significant contributions in some cases, which indicates early dose contribution (<100 years), as these nuclides are relatively short-lived.

9.2 Viewpoints from outside experts

The Swedish National Council on Nuclear Waste Issues (KASAM) point out that doses relatively close to the comparison level occur for SFL 3-5 even during the initial 100 years after closure. KASAM find unacceptable the argument that high doses are justified in that the repository will be under institutional supervision during its first 100 years. KASAM note that SKB handled the recipient situation differently in their safety assessments for SFL 3-5 and SR 97.

The international expert committee consider the most significant weakness of the safety assessment to be the decision by SKB to use only one set of parametric values for the calculation cases defined. In the committee's view, this provides insufficient grounds for assessing the impact of variability and the significant degree of uncertainty with which certain parameters are associated. SKB would probably have created a better understanding of the impact of, e.g. groundwater flow rates by using a range of rates for each site. Other parameters that could justifiably have been studied in greater detail include, e.g. the Kd and diffusivity values (D_e). The review committee suspect that the values used for the so-called F-factor and the penetration depth were non-conservative (i.e. they underestimate rather than overestimate the final calculated dose).

With respect to the near-field calculations, the review committee finds the application of the Kd values to be somewhat unclear (in terms of, e.g. assumed pH conditions and the impact of ballast). Furthermore, the account of how solubilities are used or how the decision was made as to what not to use was incomplete. Other issues that could require further elucidation include, in the view of the committee, colloid formation in the so-called pH gradient and the importance of heterogeneities in the source term (particularly if the direction of flow is perpendicular to the tunnels).

SKI consultants Wilmot and Crawford point to the absence of justification for the choice of parameters and a discussion of uncertainties. They further find that the mixture of realistic, conservative and simplified assumptions on which the assessment is based creates confusion as to what the calculated doses actually represent. It is likely that the dose limit used would be exceeded in certain cases if the importance of uncertainties were to be included in the assessment. Crawford and Wilmot feel that this necessitates a more thorough risk assessment. In the introduction to their review report, Crawford and Wilmot state that the SFL 3-5 assessment is not sufficiently oriented toward a set framework of requirements. Because safety is not an absolute concept, a safety assessment must be related and clearly oriented toward a framework of requirements.

SKI consultant Glynn finds the SKB calculations of sorption in crushed rock doubtful, since it is not made clear how the fact that the wet surface area of the relatively course particles is limited has been taken into account.

9.3 SKI/SSI evaluation

9.3.1 Near-field

SKI and SSI consider the SKB near-field model to be clearly described, and feel that it provides an accurate representation of the basic functions and properties of the final repository. However, the completeness of the assessment must be questioned, since justifications for and analyses of the assumptions underlying the choice of conceptual models are not provided (SKB however make no claim to completeness, given that the assessment is still a preliminary one). For example, it is not possible to assess the importance of certain assumptions based on the qualitative reasoning set forth, such as the assumptions of horizontal, homogenous and constant flow as a function of time. Other examples include the assumptions that the concrete structures will remain intact, that the nuclides are distributed uniformly throughout the repository space, and that all the concrete in the repository space is available for sorption.

The model structure based on such assumptions yields calculating examples that must be viewed as idealised. In order to be useful, they must consequently be supplemented with an analysis that assesses how probable and relatively favourable/unfavourable the results may be expected to be. Moreover, light should be shed on the consequences that a changed barrier function could be expected to have, i.e. including advection and heterogeneous conditions. The authorities feel that SKB should strive to produce more detailed models that enable investigation of realistic calculation cases to support the simplified assumptions used in existing models. These more detailed models could be used in sensitivity analyses to shed light on the effects of phenomena that were left out of the direct calculation chain, such as local variations, cement degradation, uplift, changed flow directions, etc. One possible worst case that should be elucidated is one in which a preferential flow path is created through the repository which passes through an area containing locally elevated nuclide concentrations.

Extremely simplified conceptual models could also be useful, e.g. to illustrate the relative importance of various barrier functions. The model based on a stirred tank reactor illustrates, e.g. the effect of a degraded physical barrier function combined with an intact chemical barrier function. However, this model does not describe the effects of heterogeneities, and thus needs not represent the most conservative case. However, comparisons between such a highly simplified representation of transport processes inside the repository and more detailed descriptions would illustrate the significance of various safety functions (”safety allocation”), and the importance of conceptual uncertainties.

With respect to the near-field sorption modelling, SKI and SSI concur with the international expert committee and Glynn that the justification for the choice of Kd values, which are key parameters in assessing this type of repository, needs to be clearer. Future safety assessments must more explicitly address issues concerning effective surfaces available for sorption (e.g.

in crushed rock and cracked concrete), as well as sorption in aged concrete. For example, lower Kd values have been used for aged concrete than for fresh in other safety assessments of comparable systems.

The authorities find that SKB have contributed to significant advances in both basic research on organic complex-formers and how these should be handled in the safety assessment. However, the authorities still feel that this issue has not yet been fully investigated, including with respect to both ISA and other complex-formers. The effects of increased solubilities for actinides are probably limited, since these effects appear after such long periods of time (millions of years) that the conditions required for ISA to be present may be questioned. However, the authorities feel that it is more difficult to assess the adequacy of the way in which SKB has handled the effect of complex formation on sorption (for ISA or other complex-formers).

SKB also concede that knowledge concerning the effects of organic additives in concrete is still insufficient, as has been pointed out by the international expert committee as well. The authorities state that the choice of sorption data in the presence of organic substances should always be made with caution; there are many more substances than just cellulose that can result in complex-formers. Sorption needs to be understood mechanically if it is to be possible to assess its long-term impact, not least in the case of ISA.

The authorities recommend that SKB develop and apply methods that can be used in a general manner to account for complex-formation in their safety assessment. Conversely, such methods can also be used to set limits on the content of certain materials in the waste, and to establish waste documentation requirements.

A few key nuclides have been shown to be particularly dependent on the sorption properties of cement environments (such as Mo-93, I-129 and Cl-36). The reason why the relatively weak sorption of these nuclides is especially significant is that it constitutes the only known chemical retardation mechanism. The absence of this retardation mechanism could entail a tenfold increase in the total anticipated doses. The formulation of a more thorough scientific basis regarding the sorption of these nuclides in cement environments should consequently provide an important topic of research.

The safety assessments recently presented by SKB contain no calculations concerning the transport of radionuclides with colloids. In SR 97 this lack is justified in that, among other things, the bentonite buffer around the capsules efficiently filters out colloids. Because, in its current design, SFL 3-5 has no bentonite, colloids would have greater opportunity to be disseminated from this type of repository than from SFL 2. Precipitation reactions in the pH gradient that would arise between the cement environment in the repository and the surrounding groundwater could create conditions favouring the formation of colloids. SKI and SSI believe that SKB need to study the importance of colloid transport to SFL 3-5 in greater detail, e.g. for cases where dilute groundwater could penetrate down to repository depth. The colloid issue may be one of a number of reasons for reconsidering the impact of using bentonite as a technical barrier in designing the repository.

9.3.2 Far-field

The authorities agree with the international expert committee that the SKB calculation cases for the far-field appear to be far too limited, insofar as they use only one set of parameters for each site and have included no representations of variability or uncertainty with respect to the geosphere. The authorities believe that there is a possibility that the doses would be higher than those reported if variability and uncertainty were accounted for. This is due to the fact that the use of realistic parameters for geospheric retardation leaves no room for taking uncertainties into account, and that certain parameters appear, in the view of the international expert committee, to be have been selected optimistically (such as the F-factor). If the consequence analysis is to be based solely on deterministic calculations, then the uncertainties must be factored into the input data for all parameters (i.e. it must be possible to show that the input data were chosen conservatively). Another possibility is, within the framework of a probabilistic approach, to illustrate parametric uncertainty by using probability distributions based on expert judgement.

Given that the studies concerning SFL 3-5 are in a highly preliminary stage, it is understandable that no detailed account of geospheric transport is provided. The emphasis at this stage should naturally be on the numerous options that exist for designing the repository spaces and handling the waste. Because the importance of site selection was identified as a specific theme, we could not expect any in-depth discussion concerning the differences among the sites from the standpoint of geosphere retardation. All the same, the assumed differences between the groundwater flows at the sites should have been justified more thoroughly based on the existing data.

9.3.3 Calculating dose and risk

The authorities agree with SKI consultants Crawford and Wilmot that SKB should have described the framework of requirements they considered relevant to the present safety assessment. This framework should have served as the starting point for the assessment, providing a perspective from which to evaluate the final results. SKB opted not to include a number of probabilistic calculations, but rather to convert the maximum annual risk of 10^{-6} into a dose of 14 μSv per year for the case in which the probability was assumed to equal one. The authorities find that this may be acceptable in a preliminary assessment, but point out that this method hardly provides a thorough basis for assessing the risk criterion. Future safety assessments must take the requirement framework set forth by the authorities into account to a greater degree. For example, risk contributions for more than one scenario must be able to be evaluated and weighed together, along with the quantitative effects of uncertainties within the various scenarios.

The authorities find that the SKB choices of biospheres for the various sites probably give a false idea of the relative suitability of the sites. Given that the EDF value chosen for Aberg is low and assumes a favourable biospheric situation, it probably gives the false impression that Aberg is the best site. The modelling underlying the choices of biospheres is not reliable to such an extent that less favourable biospheres can be brushed aside for any of the sites. SKI and SSI believe that, in this early safety assessment, SKB could have used a reference biosphere and applied it to all the sites. The aim in this case is to elucidate differences between the geological, hydrological and geochemical conditions at the sites. However, site-specific biospheric conditions must be taken into account in a subsequent phase, and in connection with the filing of an application.

In figures 10-1 and 10-2 (TR-99-28), SKB illustrate the relative importance of the near-field and far-field for the retardation of some key nuclides. These illustrations provide a clear, if somewhat limited, understanding of various barrier functions, and thus perform an important function in the assessment. The authorities propose that SKB should also describe selected hypothetical calculation cases to more clearly illustrate the individual safety significance of the various barriers/barrier functions, and include calculations to demonstrate the extent to which the repository has multiple barrier functions. Such calculation cases would provide a deeper and more complete basis for prioritising continued research efforts.

The relevance of descriptions of quantitative dose estimates for a given repository and a given scenario is unclear unless such descriptions are linked to an evaluation of the reliability of the results, the importance of uncertainties, the importance of simplifications in the models, etc. In other words, a discussion to put the results into perspective should provide feedback on the limits on which the assessment was based. Such reflections have not been given a prominent role in the SKB report. A reader of the safety report could easily come away with the impression that the reported dose estimates are much more reliable and definitive than is actually the case.

Chapter 10 SKI/SSI's general conclusions

SKI and SSI find that SKB's first proper safety assessment of the SFL 3-5 repositories (SKB TR-99-28) provides a valuable springboard for continued efforts in this field. Even though the safety assessment is relatively limited in scope, it has numerous merits. It is consistently clear and easy to read, and it provides a good illustration of the basic functions and properties of the final repository. The specific problems associated with the chosen repository concept for SFL 3-5 are discussed in a generally transparent manner. On the other hand, the authorities consider that SKB have only partly achieved the expressed goal of studying the significance of the current repository design and the choice of site. The greatest deficiency consists in that neither internal disturbances (such as considerable cracking or degradation of concrete structures) nor external disturbances (such as the effects of climate changes and glaciation) have been addressed in a thoroughgoing manner. Because consideration must be given to possible internal and external disturbances in choosing both the repository design and the desired properties of a specific site, the present assessment offers no clear guidance in the struggle to achieve these goals. Additional efforts to reduce these uncertainties are necessary.

One basic deficiency to which both SKI and SSI and the international expert committee would draw attention can be related to the basis for the SKB design choice. A coherent report justifying the design choice from a long-term safety perspective is, in large part, not found here. The rationale offered as the basis for the choice of the current design appears to be neither fully nor sufficiently worked out. It would be desirable for SKB to document the entire basis and considerations surrounding their choice of the current design in better fashion.

The authorities consider it likely that other attractive designs for an SFL 3-5 repository exist which have not yet been studied. For example, alternative barrier system designs could be more robust with respect to different types of external and internal disturbances than the currently proposed design, which is based on the ability to route the groundwater flow around the concrete structures throughout the entire necessary life of the repository (as per the hydraulic cage principle). Differences in the repository design (with respect to e.g. repository depth, choice of filling material, barrier dimensions) could, in some scenarios, entail considerable differences in future dose burdens. SKI and SSI recommend that SKB provide a comparison with other possible SFL 3-5 repository designs. Such a document could be useful in demonstrating conformity with the SKI and SSI requirement that the best available technique be used.

Depending upon, among other factors, what geospheric and biospheric conditions are assumed, SKB have shown that the calculated dose values could be relatively high for certain cases (in comparison with applicable dose criteria). The authorities feel that, in purely general terms, this should motivate SKB in the long run to conduct more comprehensive sensitivity and uncertainty assessment in order to study how the geospheric and biospheric conditions can impact the dose burden. More realistic assessments would be needed to draw reasonable comparisons between different sites, and to evaluate the importance of different nuclides in different contexts.

Our review of SKB's preliminary safety assessment indicates that a great deal of research and development work remains to be done before the level of knowledge in this field is comparable with that associated with the final repository for spent fuel. This is reflected with unanimity in the international expert committee's review (SKI Report 00:41), and in the consultants' reviews (SKI Report 00:47, 00:33). SKI and SSI wish to point out in particular the fact that comparison with SFR is of limited value, since the safety associated with SFL 3-5 must be assessed on a much longer time scale. This longer time scale poses increasing demands on our level of knowledge, if we are to produce reliable assessments of, e.g. technical barriers and site-specific conditions.

The preparation of the preliminary safety assessment should have given SKB a good idea of how future research efforts should be prioritised. Moreover, a main objective of such preliminary safety assessment should be to provide feedback, which is useful in the continued research and development (R & D) work. SKI and SSI consequently find it remarkable that SKB have included no discussion in the safety report as to which R & D activities they intend to prioritise (such a discussion is included in, e.g. SR 97). The authorities consider it important that SKB maintain a sufficient level and scope of activity in this area, and intend to follow up on this issue in future reviews of forthcoming R & D programs.

According to the current SKB timetable, siting and construction of SFL 3-5 will not begin for another 30 years. However, SKI and SSI do not consider this to be a reason to postpone essential R & D work. To plan the continued work, it is important to identify problems and special properties specific to the final storage of this waste category at an early stage, and to study them thoroughly. If a complete and thorough basis is not produced for assessing the long-term safety of an SFL 3-5 repository, the risk that these waste categories will have to undergo interim storage for an indefinite period of time increases. This applies both to the significant amount of waste which already exists (and which is currently stored at Studsvik), demolition waste, and waste stemming from the maintenance and repairs of our nuclear power plants. Improvement of our level of knowledge with respect to assessments of long-term safety issues would facilitate the process of formulating acceptance criteria for this type of waste. To summarise, SKI and SSI wish to point out the value and significance of having carefully thought-out plans for handling all waste stemming from our nuclear power plants and, of course, from SKB's own facilities.

A future siting of SFL 3-5 based on our current level of knowledge is problematic. The present safety assessment points toward a substantial site-specific effect on the repository's protective capacity that can be related primarily to the local groundwater flow rate, but also to relevant geochemical conditions. Calculated doses for cases involving consumption of drinking water give the impression that the margins are small vis-á-vis the existing requirement framework, at least based on the methods used heretofore,. In their main report, SKB discuss the possibility of improving the technical barriers to increase their impact on long-term safety (thereby mitigating the impact of site-specific factors). SKI and SSI feel that this approach is reasonable from the current preliminary perspective, but not for subsequent stages. SKB should in future formulate a proposed repository design that can be considered sufficiently robust with respect to the effects of the site-specific factors and their long-term evolution. The requirements and criteria that are relevant to the siting of SFL 3-5 must be addressed therein. These requirements and criteria are obviously related to the repository design chosen, but the requirements need not conform with those recently set forth for the fuel repository (SKB TR-00-12).

The authorities feel that the coming site investigations offer a good opportunity for advancing the SFL 3-5 issue. It was pointed out in the latest government resolution that, e.g. SKB are expected to include SFL 3-5 as part of their site investigation program. To avoid ruling out the possibility of future co-siting of SFL 2 and SFL 3-5, the selected site should be acceptable for both repository types. In addition, more in-depth studies regarding the optimum storage depth for SFL 3-5 and the importance of the interactions between SFL 2 and SFL 3-5 should be undertaken relatively soon. The importance of these issues needs to be well documented in order to provide a basis for identifying suitable rock volumes for potential siting of SFL 3-5. Once the site studies are completed, the time should be right to produce both a more comprehensive safety assessment of SFL 3-5 based on relevant site-specific data, and a more thoroughly developed repository design proposal.

SKB has made a comprehensive effort to map a large number of correlation factors in order to determine the contents of relevant nuclides in the waste. Their results will be very valuable in connection with any alternative inventory determinations of selected nuclides. However, SKI and SSI feel that the SKB choice of correlation factors could be better justified in a number of cases, particularly with respect to transuraniums and certain fission products. The authorities find that the SKB method of choosing conservative values for the present assessment was not followed for all radionuclides. Nor is the SKB safety assessment comprehensive enough to allow SKB, at this stage, to draw conclusions with the intention of refining their continued research to include only a limited selection of the relevant radionuclides. On the other hand, SKB's preliminary safety assessment has identified a number of radionuclides that definitely *cannot* be deprioritised from future evaluations.

SKB can be expected to improve the basis for making such determinations mainly via *measurements* of actual correlation factors, such as SKB intends to undertake for Ni-59, among others. SKB should similarly consider applying the measurements that are already available today, primarily involving reactor water, to a greater extent in determining reasonable but conservative correlation factors.

SKB have performed an extremely ambitious review of the waste that is intended to be deposited in SFL 3-5. The authorities consider the review of the waste to be deposited in SFL 5 to be particularly well-documented and highly traceable. At the same time, this waste should be easier to characterise than the historic waste present in large measure at Studsvik's plants, both because the SFL 5 waste is more homogenous and because it is relatively accessible for characterisation. The difficulties involved in accurate characterisation are greater in connection with the historic waste that is being stored at Studsvik and is intended for deposition in SFL 3. This waste is highly non-homogeneous and derives from many different sources. Moreover, a large part of this waste has already been conditioned, making any further characterisation difficult. The documentation furnished by SKB is also sparse. As a result, the authorities feel that it is of the utmost importance that whatever information does exist and can still be preserved, e.g. through interviews with personnel who worked with the material, be carefully and accurately documented.

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