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Comments on SKB's SFL 3-5 Preliminary Performance Assessment

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Summary

The Swedish Nuclear Fuel and Waste Management Company (SKB) has recently published a preliminary performance assessment (PA) for a disposal concept for long-lived low-level and intermediate-level radioactive waste (L/ILW). No decision has yet been made about the siting of the SFL 3-5 repository. For the purposes of the PA, SKB has assumed that the repository would be co-located with a repository for spent fuel (KBS-3 concept), and has therefore based the site characterisation data for the SFL 3-5 assessment on that used for the SR-97 assessment of the KBS-3 repository. Three hypothetical sites, known as Aberg, Beberg and Ceberg, have been used in both assessments.

This report presents a review of the SFL 3-5 PA undertaken by Galson Sciences Ltd on behalf of the Swedish Nuclear Power Inspectorate (SKI). The review examined all aspects of the PA, although particular emphasis was placed on the treatment of uncertainty, the use of probability, and the use of expert judgements. Limitations in the resources available for the review meant that it was restricted to the main PA report; the supporting documents were not reviewed.

Recently introduced regulations in Sweden have established an individual risk criterion for the long-term performance of repositories. The SFL 3-5 PA has not focussed on this criterion, but has been restricted to determinations of individual dose. Because the calculated doses are below the regulatory limit when the probability of significant events is effectively one, SKB has assumed that this approach is conservative and that event probabilities do not need to be determined. There is insufficient information available on the uncertainties in the PA to determine whether this approach is reasonable. The limited treatment of uncertainty also means that key sensitivities in system performance cannot be identified from the assessment results.

The SFL 3-5 PA is strongly reliant on the use of expert judgement. Judgements have been used to determine how the assessment should be conducted, and also to parameterise models in the absence of site characterisation data. The preliminary nature of the assessment means that the use of judgements is justified for both of these purposes. However, the PA documentation does not identify where judgements have been made or provide traceable links to the description, justification or review of individual judgements.

SKB defined four scenarios in the SFL 3-5 PA, but only used two of these as the basis for performance calculations – a Reference Scenario and a Future Human Actions Scenario. These scenarios are appropriate for a preliminary examination of the effects of hydrological and biosphere properties on individual doses, but the lack of a clear scenario development process limits the usefulness of the results in terms of overall system understanding. Also, the use of different biospheres at each site makes it difficult to assess the impact of different hydrological conditions on radionuclide transport in the far-field. The Future Human Actions Scenario does not consider intrusion or by-passing of system barriers, but is based solely on a change in dose conversion factors in the biosphere.

Overall, the SFL 3-5 PA is appropriate as a top-level document that summarises the assessment context, disposal system characteristics, key assumptions and results. A clearer treatment of uncertainties would help in developing an understanding of sensitivities, and the use of a Reference Biosphere at each site would help to clarify the significant differences between the sites in terms of long-term system performance.

1 Introduction

This report has been prepared by Galson Sciences Ltd (GSL) on behalf of the Swedish Nuclear Power Inspectorate (SKI) as part of SKI's overall review of the recently published SFL 3-5 performance assessment (PA) from the Swedish Nuclear Fuel and Waste Management Company (SKB) (SKB, 1999a). The SFL 3-5 PA is a preliminary assessment of a disposal concept for long-lived low-level and intermediate-level waste (L/ILW).

The SFL 3-5 PA is linked to the safety assessment of the KBS-3 disposal concept for spent nuclear fuel, also published recently by SKB (SR 97; SKB, 1999b). SR 97 compared long-term performance at three hypothetical sites (Aberg, Beberg and Ceberg), and the SFL 3-5 PA assumes that the L/ILW repository would be co-located with the spent fuel repository at one of these sites. Site characterisation and hydrogeological data derived for SR 97 are used as the basis for the SFL 3-5 assessment. GSL recently undertook a review of SR 97 on behalf of SKI (Wilmot and Crawford, 2000), and examined the use of probabilistic risk calculations and how expert judgements had been applied by SKB in the SR 97 assessment.

This report includes the same review objectives as GSL's review of SR 97, but the scope of the review has been extended to include a broader assessment of the overall approach to PA for SFL 3-5. The review addresses four principal issues:

- The methodology and scientific rationale that underlie SKB's approach to risk calculations.
- SKB's approach to defining calculation cases, including the role of conservative and realistic modelling.
- SKB's approach to the combination of distribution functions for PA input parameters, and SKB's approach to combining scenarios for overall safety assessment.
- SKB's approach to presentation and interpretation of risk results.

Section 2 of this report provides specific comments on the SFL 3-5 PA, presented according to the structure of the assessment report. Section 3 summarises these comments, and presents overall conclusions on the issues listed above. The review is focused on the main SFL 3-5 PA report (SKB Technical Report TR-99-28; SKB, 1999a). Supporting references (most notably Karlsson *et al.*, 1999; Pettersson *et al., 1999*; Skagius *et al.*, 1999a, 1999b) have been checked where cross-reference is made from the main report, but these references have not been reviewed in detail.

2 Specific Comments

In this Section of our review, we provide a commentary that follows the structure of the SFL 3-5 report. We have focused our review on the broad issues of assessment structure, justification and clarity set out as review criteria in Section 1. We illustrate our general comments with more detailed comments where appropriate. Further detailed comments by GSL relating to the treatment of colloids in the SFL 3-5 PA can be found in Wickham *et al.* (2000).

Section 1 Introduction

This section sets out the background, purpose and outline of the SFL 3-5 report. It summarises the role of the SFL 3-5 PA and the links between the reported assessment and that undertaken for three hypothetical sites for the disposal of spent fuel (SR 97). The intended role of the SFL 3-5 report in any regulatory decision-making process is not explained, although the purpose of the report is stated to be a preliminary safety assessment. Safety is not an absolute concept, and an assessment of safety must be made against some criteria or target. SR 97 acknowledges the recent introduction of a risk criterion in Swedish regulations on radioactive waste disposal (SSI, 1999), and takes some steps towards undertaking a risk analysis to demonstrate compliance with this criterion. The SFL 3-5 assessment, however, has only a passing reference to the applicable regulations (in Section 8.6.2), and there is no indication that an assessment of overall uncertainties has been undertaken as required by a risk analysis.

Section 2 Inventory

There are extensive discussions and tabulations of the waste forms, radionuclides and radiotoxicity of the inventory that form the basis of the SFL 3-5 assessment (Sections 2.2, 2.3 and 2.4). Section 2.5, however, reveals that there are considerable uncertainties in the inventory. These stem from uncertainties in the components and materials to be consigned to the SFL 3-5 repository and from uncertainties in the radionuclide content of these components. Some uncertainties are acknowledged to be ±70%, but there is no structured assessment of the uncertainties that would indicate the overall uncertainty in the disposed inventory. Further, many of the expert judgements made to establish parameter values for the PA are only discussed at a generic level, e.g., use of correlation factors where data are lacking, use of data for a single reactor to estimate waste volumes from all similar reactors, and estimation of neutron-induced activity. It is not clear if or where these judgements are analysed in detail to estimate the resulting uncertainty. Without this information, it is difficult to assess the effect of the assumptions made on the overall assessment results.

The lack of quantified justification of the treatment of uncertainty is exemplified by the needless use of two sets of radionuclide half-lives for different parts of the assessment (p. 2-14). The reason for using two sets is not provided; instead a statement is made that the effect of the differences is negligible in comparison to other uncertainties. The statement seems to be based on expert judgement only, and is not supported by any quantitative evaluation.

Section 3 Repository Design

Section 3 presents a design for the SFL 3-5 repository that is quite detailed in terms of the development stage of the concept. SKB acknowledges this, and notes that the reason is to allow more detailed modelling of the near-field environment. The conceptual models of the near-field environment (Section 8) are, however, simplified representations that do not appear to account for potentially significant aspects of the detailed design. For example, there will be voids at the top of the gravel backfill that could have an effect on both fluid flow (groundwater and gases from waste degradation) and the mechanical stability and hydrogeological properties of the host rock.

A further reason for developing a detailed design is to assess the amount of constructional materials and backfill that will be present in the repository. Several design changes from the preceding 1993 design (PLAN 93; SKB, 1993) are presented (p. 3-1), but these are neither fully explained nor justified in Section 3. Some of the changes are discussed in Section 10 and in supporting references (e.g., Appendix D of Karlsson *et al.*, 1999; Section 11 of Pettersson *et al.*, 1999), but the reader is not directed to this supporting material. Two of the key changes with respect to the behaviour of the near-field are that the rock chambers will be backfilled with crushed rock, rather than a mixture of crushed rock and bentonite, and that the waste packages in SFL 3 and SFL 5 will be grouted with porous concrete. As a reference for the safety assessment, SKB assumes that Standard Portland Cement will be used throughout the repository. The reasons for this choice and the variation or uncertainty that might be caused by using other types of cement are mentioned (p. 3-10), but not evaluated in any detail.

The effects of the repository operational period on the engineered barriers and the host rock are reviewed and, subsequently, dismissed in Section 3.5. The main supporting work for the review is presented in Karlsson *et al.* (1999), but this report is not referenced. The issues associated with closure and resaturation are discussed qualitatively, but there is little or no quantitative evaluation, for example, of the implications and time it will take for the repository to resaturate (see also Section 6.4.1) and return to its steady-state redox conditions (see also Section 6.6), and of the implications of the initially very high pH (13.5) environment in the cement-filled parts of the repository (see also Section 6.6). In any event, all of these issues are circumvented by simplifying assumptions in the assessment calculations.

Sections 4 and 5 Site Location and Biosphere Description

The SFL 3-5 assessment assumes that the L/ILW repository is located at the same site as the repository for spent fuel. In order to avoid thermal and chemical interactions between the two repositories, they would, in practice, be some distance apart, even if they shared common access shafts and surface facilities. This separation is shown on the maps of the "hypothetical" sites in Section 4, and discharge points for groundwater passing through the SFL 3-5 repository are shown on representations of the biosphere at each of the three sites. The separation is set at 1 km, but this is apparently arbitrary and based on expert judgement, and is not justified on a site-specific basis by consideration of chemical and thermal transport.

This approach is appropriate, as it allows hydrogeological models developed as part of SR 97 to be used. The "realism" imposed by this approach may, however, detract to some extent from the assessment as it leads to differences between the sites that may have a strong influence on the calculated results and obscure the effects of other assumptions. This most obviously applies in the treatment of the surface environment. Different biospheres are used in the calculations of dose at the three sites, and these have at least as much influence on the calculated doses as differences in water chemistry and hydrogeological setting. It would be more appropriate to use a reference biosphere to explore differences between the three sites, and to investigate the effects of different biospheres on doses from a given release at a site.

Section 6 Reference Scenario

This section presents a Reference Scenario for the SFL 3-5 PA. This scenario is intended to include the features, events and processes (FEPs) that would occur during the "expected" evolution of the near-field but with the premise of uniform conditions in the far-field. It is not, therefore, a scenario that represents the expected evolution of the disposal system as a whole, because changes in the far-field are not included. This is an appropriate approach for developing an understanding of near-field behaviour, but it is not an appropriate basis for regulatory decision-making because it does not examine all sources of uncertainty. As noted above, the use of different biospheres seems inappropriate in an assessment that assumes uniform far-field conditions and is clearly not intended to explore the whole range of uncertainties.

Section 6 includes brief discussions of a number of processes that are expected to take place within the near-field. Few if any of these processes are, however, carried through to the conceptual model of repository evolution. The reasons for omitting processes from the near-field model are not, in general, made explicit. There are references to other documents in support of statements about the rates of some of the omitted processes, but no references to supporting calculations to show that they can be omitted on the basis of low consequence to the overall performance of the SFL 3-5 disposal system. Similarly, there are no references in the main report to support the use of parameter values that are stated by SKB to be conservative estimates.

There is no formal documentation in the report of a FEP list to demonstrate comprehensiveness, and the THMC (Thermal, Hydrological, Mechanical, Chemical) diagram, which supposedly show processes, events, and their interactions, is not actually presented. The reference scenario used in an earlier assessment of the SFL 3-5 concept (Wiborgh, 1995) was developed using the Process Influence Diagram (PID) methodology. SKB states that the material supporting the development of this scenario has been re-examined and that the results are "summarized" in Section 6. However, the lack of supporting references and formalisation makes the ownership and review/signoff of the expert decisions involved in scenario development for the SFL 3-5 PA difficult to trace.

The discussion of the thermal evolution in Section 6.3 is brief, and is supported by reference to Skagius *et al.* (1999b). In the main SFL 3-5 report, SKB states that "... after closure, radioactive decay in the waste is the only process that generates heat", and radioactive decay is the only heat-generating process that is considered in Skagius *et al.* (1999b, Section 5). This presumably relies on the assumption that any contribution to heat generation from exothermic reactions in the concrete backfill and grout is negligible. This assumption should be justified with discussion of the potential for, and impacts of, higher temperatures due to concrete hydration both before and after closure.

Sections 6.6 and 6.7 discuss hydrochemical conditions and barrier properties and how these may change over time. However, the complexity of these discussions is not reflected by the simplicity of the assessment calculations in Section 8. For example, the near-field porewaters are assumed to have either a pH of 12.5 in cement-filled areas or that of the *in situ* groundwater elsewhere. However, higher pH values of 13.5 can be expected at early times in cement-filled areas, the pH will drop in these areas beyond around 100 000 years, and the *in situ* groundwater composition is also likely to change over a timescale of thousands to tens of thousands of years. No evaluation is presented of the effects of uncertainty in hydrochemical conditions and barrier properties or near-field performance. SKB states (in Section 9) that the changing groundwater composition is covered by the range of results from the sites with a fresh and a saline groundwater. This is a rather simplistic view and does not consider holistically the effect of repeated changes in groundwater conditions coupled with other climatic and hydrogeological changes (see review of Section 9 below).

Mineralogical and porosity changes related to the use of large amounts of cement in the disposal concept, and the consequences of a plume of alkaline groundwater are dismissed rather summarily in Section 6, and a constant high porosity (30%) is assumed for the gravel fill (the main hydraulic pathway) in Section 8. There is no quantitative evaluation of the significance of porosity changes and of the possible creation of flow heterogeneity and preferential pathways.

As a further example of the issue of inadequate documentation of FEPs and the basis for their omission, the following comments on how colloids have been treated have been summarised from GSL's recent evaluation of colloid treatment in assessments (Wickham *et al.*, 2000):

- SKB assumes that only low concentrations of colloids will be produced from the cementitious materials in the SFL 3-5 repository, based on studies of the Maqarin natural analogue site, where only low colloid concentrations have been observed in high-pH groundwaters that are similar to those expected in the SFL 3-5 repository. There are, however, a number of colloid types and colloid formation processes that should be discussed before a general conclusion is drawn on the role of colloids. Colloid types include actinide intrinsic colloids (e.g., polymeric plutonium), inorganic colloids (e.g., mineral fragments), organic colloids (e.g., humic and fulvic acids), and microbes (e.g., bacteria), and colloids may be formed by several processes, including waste degradation and chemical precipitation at steep chemical gradients within the repository system (e.g., at the boundary between the high-pH near-field and the near-neutral far-field).

- SKB argues that the transport of colloids from the waste may be limited by anion exclusion. This argument is supported by reference to studies of colloids in a system with a bentonite backfill, rather than with crushed rock as is proposed for the SFL 3-5 repository. Also, although anion exclusion may restrict the transport of certain anionic species by excluding them from small pore spaces, these same species may be concentrated at the centre of larger pore spaces and flow paths such as fractures. As flow velocities are relatively greater in the centre of such preferential pathways, the effect of anion exclusion may be to enhance the transport of anionic species including colloids.

Section 7 Hydrology Calculations

Section 7 presents hydrological calculations for the near-field (Sections 7.2 and 7.3) and far-field (Section 7.4) at each of the three "hypothetical" sites. Section 7.3 is one of the few examples where the effect of uncertainty is discussed, with an evaluation of the effects of changes in repository design and barrier properties on flow rates in the near-field. However, it is unclear how the results of these evaluations have influenced the assumptions made in the assessment calculations. For example, despite there being site-specific data available concerning hydraulic conditions at all three sites, flow through SFL 4 is treated by applying results for Beberg to all three sites. It would appear that uncertainties or unrealistic assumptions have been introduced, and it is not clear why.

The discussion of the far-field in this section presents results from detailed hydrological models for each of the sites, including particle tracking calculations to determine discharge areas. However, the results of these detailed calculations are not used in the remainder of the assessment. Instead, simplified assumptions about travel times from the repository to the surface have been made (with about two orders of magnitude between the fastest and slowest times). This approach could be appropriate for calculations intended to develop an initial understanding of near-field behaviour. A more integrated approach that accounts for uncertainties in each part of the disposal system would, however, be required to support regulatory decision-making.

Section 8 Radionuclide Transport

This section presents the results of radionuclide transport calculations for the near-field and far-field and calculations of dose. Releases of chemotoxic pollutants and gas-phase radionuclides are also briefly summarised.

Radionuclide transport

Flow rates through the far-field and overall flow through the repository are derived from hydrological modelling. Compartment models of the near-field, in which different components (concrete, gravel backfill, etc.) are assigned different permeabilities, are used to determine rates of advection and diffusion within the near-field. Radionuclides released from the near-field are transported within the far-field by advection, with retardation occurring through sorption on fracture surfaces and diffusion into the rock matrix.

There is a clear statement in Section 8 of the assumptions (premises) used to define the calculational cases. However, there is little, if any, discussion of the basis for these assumptions or of the impact of these on the calculated results. References are given for selected parameter values, but there is no indication of why a particular set of values has been used (e.g., reasonable, pessimistic), nor is there any discussion of parameter uncertainty.

The assumptions that underlie the calculations of dose are less clearly presented. Doses are determined on the basis of mean dose conversion factors for each ecosystem. There is an outline in Section 5 of the assumptions underlying these factors in terms of the transport pathways involved (ingestion, inhalation, surface exposure) and the habits assumed (e.g., fishing, agricultural practices, food consumption patterns). There is an indication of variability of some biosphere parameters in Section 5, but this has not been translated into parameter uncertainty for the dose conversion factors.

The discussion of the dose results acknowledges the applicable regulations, but elects to convert the risk criterion (individual risk to representative member of the most exposed group $< 10^{-6}$ per year) to a dose target (annual dose of 14 ìSv) with the assumption that the probability of exposure is one. There is no discussion of this approach, which has presumably been adopted on the basis that satisfying this dose target would automatically satisfy the risk criterion. All of the dose calculations presented do satisfy this dose target, although some calculated doses are within 50% of the target (note that in Figure 8-10 the target or comparison level has been mis-labelled as the background level). A proper accounting for uncertainties would probably lead to some calculated doses exceeding the dose target. In these circumstances, it would be appropriate for SKB to use a risk-based approach for demonstrating compliance with the risk criterion.

Results of dose calculations are only presented for one ecosystem for each of the three sites. For sites where potential discharges to two different ecosystems are identified, doses arising within the alternative ecosystem are mentioned in terms of dominant radionuclides, but combined dose results have not been presented. As noted above, it would be easier to interpret the influence of different parts of the disposal system if the assessment had used the same reference biosphere for each site. However, since different biospheres and a range of ecosystems have been used, an understanding of the influence of various aspects of the system would be helped if all of the available results were presented.

SKB acknowledges that there are uncertainties in ecosystem evolution. However, despite noting that three glacial periods are expected within the next 100 000 years, the only treatment of uncertainty that has been made is to shade the region representing times *beyond* 100 000 years on the dose-time plots. A more considered approach to the treatment of uncertainty is required if the results are to be used for regulatory decision-making.

Chemotoxic Pollutants

Transport of chemotoxic pollutants from the repository has been calculated in the same manner as transport of radionuclides, although the results of these calculations are not presented. Instead, concentrations have been derived by assuming that the entire inventory of chemotoxic pollutants is transported to the ecosystem. Concentrations are derived by dividing the quantity of material by the volume of the ecosystem. SKB regards this as a conservative assumption, although there is no justification provided for assuming a uniform distribution throughout the ecosystem. It would seem more reasonable to assume that accumulation would be concentrated in smaller regions. The concentrations determined by SKB are stated to be orders of magnitude below comparison levels. These comparison levels are based on mean concentrations measured in different areas. There is no comparison with any regulatory constraints, nor are there any statements regarding the risks posed by either the calculated or the comparison levels.

Gaseous Releases

Consideration of radioactive gas release is restricted to ^{14}C from degradation of organic waste forming a component of methane released from the repository. Comparing the estimated inventory ($<10^5$ Bq) with the corresponding ^{14}C inventory in a spent fuel repository (SR 95; SKB, 1995), and making the same conservative assumption about pulse release, yields a calculated collective dose of 0.04 ìmanSv. Annual individual doses will be still lower. This appears to be a reasonable approach, although additional detail regarding the calculational approach and the assumptions made would be required for a final safety case.

Section 9 Other Scenarios

This section discusses alternative scenarios to the reference case for the evolution of the SFL 3-5 repository. There is discussion of the potential effects of climate change and earthquakes, and of unintentional operational activities. Additional calculations have only been performed, however, for the human intrusion scenario.

Climate Change

The discussion of climate change assumes that the principal effect, in terms of repository performance, will be the periodic growth and retreat of continental-scale ice sheets. The report identifies three domains within the cycle and discusses the effects of these domains on groundwater flow and salinity. The results in terms of radionuclide transport are assumed to be directly related to these changes, and reference is made to results presented in Section 8. The Reference Case results are, however, insufficient to account for all of the changes arising from climate change. For example, there are no results for flow rates greater than those assumed at Aberg, and there is only a direct comparison of the effects of saline and non-saline waters at Beberg. There is also no consideration given to other changes (e.g., length of transport pathways, changes in ecosystem characteristics) arising from climate change.

An assessment to be used for regulatory decision-making will require a clear identification of the FEPs that have an influence on radionuclide transport and dose rates, and documented justification for excluding FEPs from assessment calculations on the basis of low consequence or low probability of occurrence. The material presented in Section 9 for climate change is inadequate on this basis, as it neither incorporates climate change into the analysis of dose rates, nor presents a sufficiently clear argument for excluding climate change from assessment calculations.

Earthquakes

Section 9 also discusses the potential effects of earthquakes on the performance of the SFL 3-5 repository. There are no calculations reported to assess the effects on disposal system performance of possible displacements, and it is therefore unclear as to whether the repository design measures outlined by SKB for reducing these effects are indeed required.

Future Human Actions

The Swedish Radiation Protection Institute (SSI) highlight in their regulation [SSI FS 1998:1] that an assessment of the effects of human activities is required separate from the assessment of the natural evolution of the repository. SKB's decision to consider future human actions as a separate scenario therefore appears appropriate. However, the guidance that accompanies SSI's regulation (SSI, 1999) makes it clear that SSI expects an assessment of the ability of the repository to contain wastes following an intrusion. The future human actions that SKB has considered in Section 9.4 are not intrusive events, and the results presented do not illustrate the long-term behaviour of the repository.

The report presents the results of a review of possible future human actions undertaken for SR 97. These actions are classified according to whether they would have a thermal, hydrological, mechanical or chemical impact on the repository, and include activities such as the building of a heat store or hydroelectric scheme. From this set of human actions, SKB has selected wells drilled in the vicinity of the repository as the activity that defines the Future Human Actions Scenario. However, the assumptions made about these wells are such that they do not have a hydrological or other impact on the repository. The only difference, therefore, between the Future Human Actions Scenario and the Reference Scenario is that different dose conversion factors have been used. This means that the relative contributions of different radionuclides differ between these two scenarios, but there are no changes in the times of peak doses from different radionuclides.

As with the dose conversion factors used in the Reference Case, there is insufficient discussion to understand the assumptions that have been made in deciding how wells are used. The dose conversion factors are described as eco-system dependent, but there is only a limited description of the processes that are assumed to affect radionuclides released via wells. As is the case for the Reference Scenario, comparison of the results between sites for the Future Human Actions Scenario (e.g., Figures 9-9 to 9-11) would be easier if a consistent set of biosphere assumptions was used.

In plots of dose against time for releases from wells, SKB has shaded the region up to 100 years on the basis that institutional controls and societal memory of the repository site would prevent use of wells in the vicinity of the repository during this period. This is a very simplistic approach, and a more detailed consideration should be given to the fate of radionuclides that were not released to the biosphere during a period of institutional controls. For example, the accumulation of radionuclides within an aquifer while controls were in place could lead to higher doses once knowledge of the site was lost and controls became ineffective.

Releases of chemotoxic pollutants to a well are calculated, but are presented only as concentrations in well water. The principal assumption behind this calculation is that the annual release of each pollutant is diluted within the annual capacity of a well. Within the context of the calculation (no bypassing of the near-field), this appears to be a worst case assumption. In this case, regulatory limits for these pollutants are also given for comparison (cf. releases in the Reference Scenario). These show that the calculated releases are several orders of magnitude below the regulatory target.

Design and Operation

The final scenario considered in Section 9 is termed Design and Operation. The only additional FEP considered in this scenario is the presence of stray materials within the repository. SKB has made estimates of the amount of stray organic material and metals/metal oxides that may be left behind in the SFL 3-5 repository. These amounts are likely to be small in comparison to the amounts of organic materials and metals/metal oxides in the overall SFL 3-5 inventory, but will contribute organic material to SFL 4 and SFL 5 where there is normally none in the inventory. SKB has calculated the effects of the organic inventory in SFL 3 on radionuclide transport, and has shown that there are no significant effects during the first million years. The small amounts of stray organic material in SFL 4 and SFL 5 are therefore considered not to be significant. Similarly the effects of stray metals/metal oxides are not considered significant in comparison to the overall effects of metals/metal oxides in the inventory. These comparisons are an appropriate basis for eliminating stray materials from the scenario.

Section 10 Discussion and Conclusions

This final section summarises the conclusions of the preliminary assessment, discusses differences between this assessment and earlier studies of the SFL 3-5 concept, and makes recommendations for future work.

In analysing the results of the assessment, the mixture of realism (i.e., use of site-specific data), conservative assumptions, and simplifying assumptions for the sake of a preliminary assessment creates confusion. The calculated doses cannot easily be related to a coherent set of assumptions, although there is material in this section that uses these results as a basis for decision analysis, design evaluation, and the identification of key issues and uncertainties. The discussion of these issues is, however, somewhat cursory, and a much more detailed and precise set of lessons and proposed future actions might be expected from an assessment at the current stage of SKB's programme.

3 Overall Comments

In this Section, we summarise our comments on the SFL 3-5 assessment, and express them in accordance with the review criteria set out in Section 1.

Overall Approach to PA

Recently introduced regulations in Sweden have established an individual risk criterion ($<10^{-6}$ per year) for the long-term performance of repositories for the disposal of radioactive wastes. SKB has not focused its assessment of SFL 3-5 on demonstrating compliance with this regulation. Instead, SKB has calculated individual dose and provided a comparison with an annual individual dose of 14 iSv (derived from the risk criteria using the ICRP's dose-risk conversion factor of 0.073 per Sv). The justification of this approach is that probabilities do not need to be determined if doses are less than the dose equivalent to the risk criterion. However, there is insufficient information regarding uncertainty provided in the documentation of the SFL 3-5 assessment to determine whether this approach is reasonable.

SKB's parallel assessment of a repository for spent fuel using the KBS-3 concept (SR 97) accounts for uncertainty by specifying a "reasonable" and a "pessimistic" value for uncertain parameters in the assessment calculations. Although there are problems with the way probabilities have been assigned to these values (Wilmot and Crawford, 2000), this approach does indicate where there are significant uncertainties. The SFL 3-5 PA does not include a structured approach to defining uncertainty, although a number of assumptions and parameter values are stated to be conservative. As a preliminary assessment, there is insufficient information to identify key uncertainties or sensitivities, or to determine where further work should be focused.

Approach to Expert Judgement

Any assessment requires the use of expert judgement to determine how the assessment is conducted, what modelling approach to use, what features, events and processes (FEPs) could potentially affect the disposal system, which FEPs should be included in the conceptual models, and which scenarios should be assessed. Judgements are also required in determining how to parameterise the models, and this may extend to formal expert elicitation for particular parameter values. These uses of expert judgement in assessments are discussed more extensively in a recent study for SKI (Wilmot and Galson, 2000).

The key point to be made about the use of judgements is that they must be documented in such a way that not only can the judgements themselves be examined but so too can the basis for them. Only in this way can judgements be properly reviewed and confidence developed in the results of an assessment based on them.

Very similar comments apply to SFL 3-5 as were made in our review of SR 97 (Wilmot and Crawford, 2000) regarding the use of expert judgement. There is no formal documentation of the expert judgements made at the various stages of the development of the SFL 3-5 assessment, although the use of expert judgement is recognised by SKB. Therefore, the ownership of the judgements (i.e., who made them, how they were made, and why) cannot be determined, and the review and approval process applied to these judgements cannot be assessed. The assessment is at a preliminary stage, and this may preclude the extensive use of expert elicitation as a judgement tool. However, dialogue and peer review could both be applied beneficially to build confidence in the assessment.

Approach to Definition of Scenarios and Comprehensiveness of the PA

The stated purpose of the SFL 3-5 preliminary assessment is to examine the effects on calculated doses of different hydrological and biosphere conditions. In this sense, it would be appropriate for the assessment to be restricted to a limited set of scenarios, but only if such scenarios were clearly defined and allowed different aspects of the disposal system to be examined and sensitivities to be assessed. In the SFL 3-5 PA, SKB defines four scenarios, of which two have been used for performance calculations – a Reference Scenario and a Future Human Actions Scenario. However, neither of these scenarios adequately fulfil the requirements of clarity or usefulness. The principal issues of concern are:

- There is no structured reporting of a set of potentially important FEPs, or of the basis for omitting FEPs from the assessment calculations.
- The site descriptions used to develop a Reference Scenario for each of the three sites examined include differences in far-field conditions and in the biosphere. This prevents a clear understanding of the role of different groundwater flow rates, because of the significant differences in biosphere characteristics. Use of a reference biosphere at each of the three sites, in addition to more detailed biosphere calculations, would provide a better basis for comparison.
- The Reference Scenario is time-independent and excludes any changes in near-field, far-field or biosphere conditions for a period of 10^7 years.
- The Future Human Actions Scenario is based simply on a change in the dose conversion factors for the biosphere, and does not consider intrusion or bypassing of the near-field barriers.

Overall Clarity and Quality of Presentation of the PA

The overall structure of the main SFL 3-5 PA report is appropriate as a top-level document that summarises the assessment context, disposal system characteristics, key assumptions and results. In general, the report is well written and the material presented can be understood. There are places where there are insufficient cross-references within the document, particularly between the descriptions of the disposal system and the description of how it is modelled.

The key concern is that there are often insufficient references to other documents to fully explain and justify what has been done. A preliminary assessment requires this information just as much as a more detailed assessment. A more through and rigid cross-referencing to more detailed information in the supporting documents would allow reviewers to trace arguments and data to whatever level of detail is required, and would build confidence in the assessment process.

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Dr. Mark B. Crawford is a Senior Consultant at Galson Sciences Ltd. He has degrees in Geology and Geochemistry from Oxford University (BA) and Leicester University (PhD), and a Diploma in Environmental Impact Assessment. Over the last nine years he has been involved in consultancy and research work in the area of radioactive waste disposal for clients in Finland, France, the UK and the US. This work has included the development of geochemical models for organic complexation in natural systems, validation of sorption modelling within a European Community research initiative, and interpretation of hydrochemical data obtained as part of Nirex's site characterisation programme. He has performed reviews of geochemical techniques in relation to palaeo-hydrogeological studies and of the effects of alkaline plume migration from cementitious waste repositories. He made substantial contributions to the development and review of technical input for the Waste Isolation Pilot Plant (WIPP) Compliance Certification Application, and subsequently in responding to stakeholder comments. He has undertaken review and systems analysis of the WIPP near-field modelling, and helped in development of compliance monitoring strategies. He was involved in a review of scenario development methodologies on behalf of ANDRA in France, and was the lead author for a report describing the normal evolution of a spent fuel repository for the TILA-99 performance assessment study in Finland. He is currently managing a performance assessment for low-level waste disposal in the UK.

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Dr. Roger D. Wilmot is a Senior Consultant at Galson Sciences Ltd. He has degrees in Earth Sciences from Cambridge University (BA) and Imperial College, London (PhD). He is a geologist with over 20 years experience in providing a broad range of research, consultancy and management services to a range of clients. This involvement has included a review of validation in the context of radioactive waste disposal, and the development of guidance concerning the treatment of validation in safety cases. On behalf of Her Majesty's Inspectorate of Pollution and the Environment Agency, he has organised international seminars on "Validation," "Risk Perception and Communication," "Management of Safety Assessments" and "Use of the Expectation Value of Risk." He has recently completed a project on the use of the expectation value of risk, and contributed to a technical and policy review of the HMIP radioactive waste research programme. He has contributed to the development and use of computer codes for incorporating long-term environmental change into safety assessments. Recent work outside the UK has included descriptions of climatic and geomorphological evolution in Finland for POSIVA, a leading role in describing elements of a regulatory strategy for consideration of future human actions in assessments for SKI, and involvement in performance assessment and near-field systems analysis for the WIPP site in the US. He is currently managing an options appraisal for low-level waste management in the UK. Finally, he has experience of several QA programmes, and is the Company's Quality Assurance Manager.