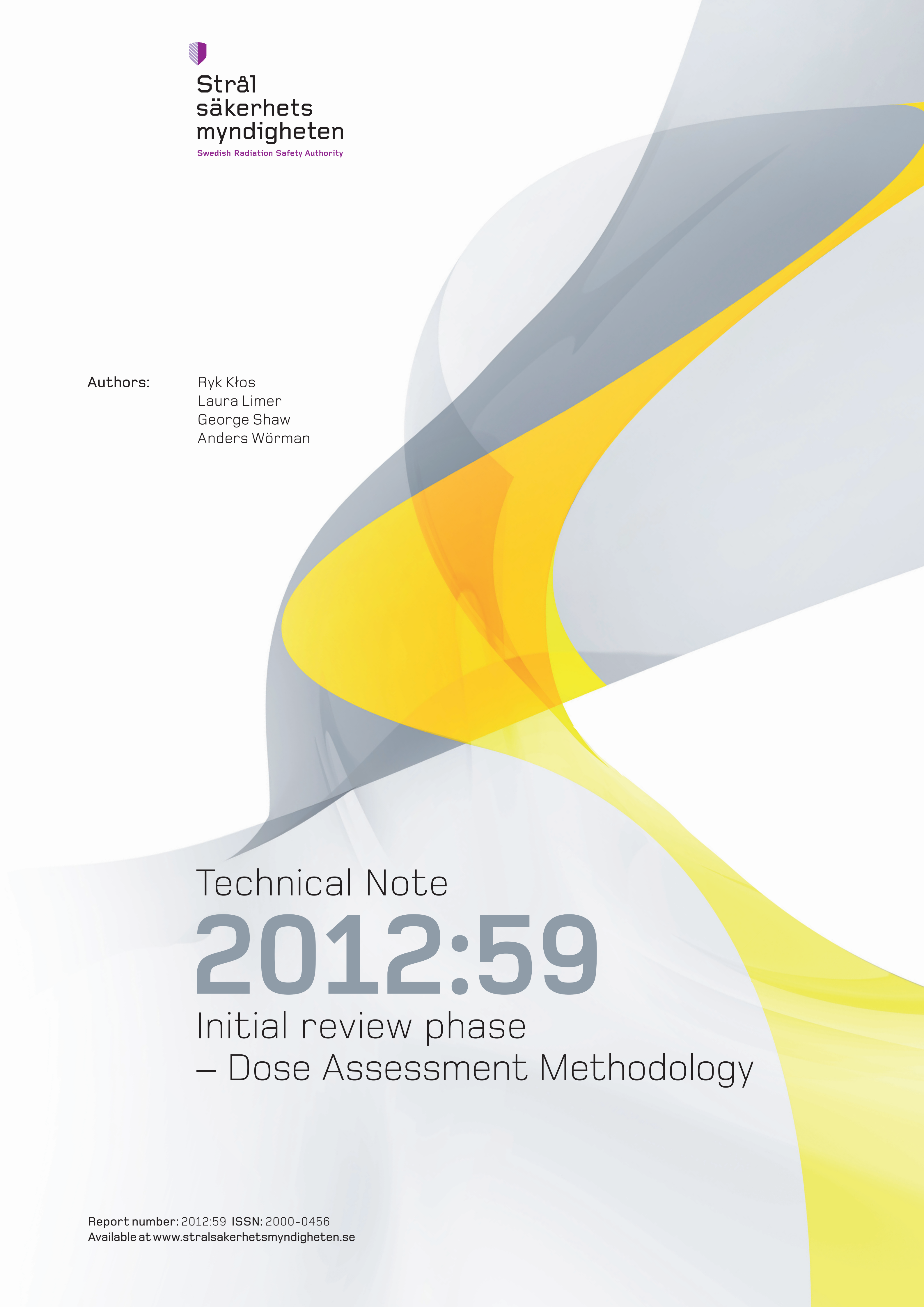

Strål
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myndigheten
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Technical Note

2012:59

Initial review phase – Dose Assessment Methodology

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SSM perspektiv

Bakgrund

Strålsäkerhetsmyndigheten (SSM) granskar Svensk Kärnbränslehantering AB:s (SKB) ansökningar enligt lagen (1984:3) om kärnteknisk verksamhet om uppförande, innehav och drift av ett slutförvar för använt kärnbränsle och av en inkapslingsanläggning. Som en del i granskningen ger SSM konsulter uppdrag för att inhämta information i avgränsade frågor. I SSM:s Technical note-serie rapporteras resultaten från dessa konsultuppdrag.

Projektets syfte

Syftet med detta uppdrag är att undersöka om SKB: s metod för att sammanfatta FEP (egenskaper, händelser, processer) samt plats- och andra data i säkerhetsanalys för biosfären och dosmodellering är lämplig och tillräcklig för sitt ändamål. I synnerhet skall det analyseras om SKB har visat transparenta och trovärdiga dosberäkningar inklusive val av data för att härleda LDFs (landskap dos faktorer).

Författarnas sammanfattning

Denna rapport har upprättats som en del av den inledande granskningsfasen av SKB:s säkerhetsanalys av den långsiktiga säkerheten, SR-Site, för KBS-3 geologisk slutförvaringsanläggning (GDF) som föreslås för byggnation i Forsmark. Granskningen behandlar de metoder som använts i dosberäkningarna inom SR-Site. I detta avseende har granskningen en naturlig fokus på biosfärsmodelleringsaspekter av SR-Site:s dokumentation. Inom SR-Site behandlas dosberäkningar för biosfären som en extern enhet vilken skiljer sig från andra aspekter av den övergripande säkerhetsanalysen såsom inneslutning och säkerhetsfunktioner för GDF. På detta sätt är biosfärsmodelleringen väsentligen oberoende av representationen av tekniska barriärer och berggrund.

Denna granskning handlar därför om behandling och rapportering av vad som händer med radionuklider som inträder i regolit (jord ovanför berggrund), ytvatten och andra komponenter av ekosystem i det framtida landskapet i Forsmark, samt hur hälsoeffekter på potentiella invånare i den framtida biosfären (både mänskliga och icke-mänskliga) bedöms efter exponering för radionuklider i miljön. Begreppet Landskap Dos Factor (LDF) används för att skala utsläpp från berggrunden för att ge ett mått på den radiologiska effekten av slutförvaring.

I den inledande fasen har granskningen utgått från SR-Site:s huvudrapport (SKB 2011) fram till biosfär syntes rapporten (2010a) och ett antal relaterade underrapporter. Sex huvudområden av betydelse har behandlats:

- Fullständigheten i SKB:s känslighetsanalys som används för att bestämma de numeriska intervallen för beräknade LDFs.
- Den vetenskapliga grunden för införandet av nya funktioner, händelser och processer (FEP) i den nya radionuklidtransportmodellen som utvecklats av SKB inom SR-Site.
- Grunden för modellering av gränssnittet mellan geosfär-biosfär i den nya modellen. SKB använder sig av en uttalad geosfär-biosfär-gränssnittszon som ett nytt inslag i biosfärmodellen.

- Tolkning av spridning av radionuklider i den omgivande ytan hos varje biosfärsobjekt identifierade av SKB i sin landskapsmodell.
- Tidpunkten och varaktigheten för ackumulation av radionuklider som sker i regolit och den efterföljande övergången från naturliga ekosystem till jordbrukets ekosystem.
- Databasen för biosfärmodellering och särskilt hur de nya inkluderade FEP tilldelas parametervärden och giltighetsintervall.

Exempel där den publicerade SKB-dokumentationen kan kompletteras med ytterligare uppgifter identifieras och alternativ för den följande huvudsakliga granskningsfasen diskuteras.

Resultaten av granskningen visar att det finns ett antal områden med en varierande detaljeringsnivå i dokumentationen. Härledningen av LDFs bygger på en hierarki av modeller. Medan den vetenskapliga kvaliteten i mycket av arbetet som ligger till grund för härledning av LDFs är av hög standard, är sambandet mellan modellerade FEP och konceptuella och matematiska modeller inte väl etablerade med hänvisning till biosfärens interaktionsmatris. Några av de nyligen införda FEP saknar tillräcklig motivering och intervallen i LDFs uttrycker inte hela skalan av osäkerhet i modellerna.

Projektinformation
Kontaktperson på SSM: Shulan Xu
Diarienummer ramavtal: SSM2011-4268
Diarienummer avrop: SSM2011-4544
Aktivitetsnummer: 3030007-4033

SSM perspective

Background

The Swedish Radiation Safety Authority (SSM) reviews the Swedish Nuclear Fuel Company's (SKB) applications under the Act on Nuclear Activities (SFS 1984:3) for the construction and operation of a repository for spent nuclear fuel and for an encapsulation facility. As part of the review, SSM commissions consultants to carry out work in order to obtain information on specific issues. The results from the consultants' tasks are reported in SSM's Technical Note series.

Objectives of the project

The objective of this assignment is to consider whether SKB's methodology to abstract FEPs (features, events, processes) as well as site information and other data into assessment models for biosphere and dose modelling is appropriate and sufficient for its purpose. In particular, it shall be analysed if SKB has demonstrated a transparent and credible dose assessment including selection of data to derive the LDFs (landscape dose factors).

Summary by the authors

This report has been prepared as part of the Initial Review Phase of SKB's SR-Site performance assessment of the long-term safety of the KBS-3 geological disposal facility (GDF) proposed for construction at Forsmark. The review addresses the methodology employed in the dose assessment calculations of SR-Site. In this respect the review has a natural focus upon biosphere modelling aspects of the SR-Site documentation.

Within SR-Site the biosphere dose assessment is treated as an external element, distinct from those aspects of the overall assessment that scrutinise containment and safety functions of the GDF. In this way biosphere modelling is essentially independent of any of the representation of the engineered barriers and bedrock. The scope of this review is therefore the treatment and reporting of the fate of radionuclides entering the regolith, surface water and other ecosystem components of the future landscape at the Forsmark site and how the health effects on potential inhabitants of the future bio-sphere (both human and non-human) are assessed following exposure to environmental concentrations of radionuclides.

The Landscape Dose Factor (LDF) concept is used to scale releases from the bedrock to give a measure of the radiological impact of the disposal. In this initial phase the review has traced a path from the main SR-Site report (SKB 2011) through to the Biosphere Synthesis Report (2010a) and a number of subsidiary, supporting documents. Six principle areas of concern have been addressed:

- The completeness of SKBs sensitivity analysis used to determine the numeric ranges of the calculated LDFs.
- The scientific basis for the inclusion of new features, events and processes in the new radionuclide transport model developed by SKB for this assessment.

- The basis for the modelling of the geosphere-biosphere interface in the new model. An explicit geosphere-biosphere interface zone is a new feature of the biosphere model.
- Interpretation of the dispersal of radionuclides in the surface environment of each of the biosphere objects characterised by SKB in their landscape model.
- The timing and duration of accumulations in the regolith and the subsequent transition from natural ecosystems to agricultural ecosystems.
- The database for biosphere assessment models and particularly how the newly included FEPs are assigned parameter values and ranges.

Instances where the published SKB documentation could be supplemented by additional information are identified and options for the main review phase are discussed.

The findings of the review indicate that there are a number of areas where there is an inconsistent level of detail in the documentation. The derivation of the LDFs relies on a hierarchy of models. While the scientific quality of much of the work underpinning the derivation of the LDFs is of a high standard the link between the modelled FEPs and the conceptual and mathematical models is not well established by reference to the biosphere system interaction matrix. Some of the newly introduced FEPs lack sufficient justification and the ranges in LDFs do not express the full range of uncertainty in the models.

Project information
Contact person at SSM: Shulan Xu
Framework agreement number: SSM2011-4248
Call-off request number: SSM2011-4544
Activity number: 3030007-4033

Strål
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Content

1. Introduction

In 2011 the Swedish Nuclear Fuel and Waste Management Company (SKB) submitted an assessment of the long-term safety of a KBS-3 geological disposal facility (GDF) for the disposal of spent nuclear fuel and high level radioactive waste in Forsmark, Sweden. This assessment, the SR-Site project, supports the licence application of SKB to build such a final disposal facility. The SKB documents which comprise and support the licence application will be reviewed by SSM in a stepwise and iterative fashion. The first step is called the Initial Review Phase, with the overall goal to achieve a broad coverage of SR-Site and supporting references and in particular to identify the need for complementary information and clarifications to be delivered by SKB. Detailed analysis of specific issues are postponed to the Main Review phase.

This report has been prepared as part of the Initial Review Phase, and has a particular focus on the methodology employed for performing dose assessment calculations. In that respect, the review presented in this report has a natural focus upon biosphere aspects of the SR-Site documentation.

Within SR-Site the biosphere dose assessment is treated as a separate part of the assessment, distinct from those aspects of the overall assessment that scrutinise containment and safety functions of the GDF. In this way biosphere modelling is essentially independent of any of the representation of the engineered barriers, and the bedrock. Interaction of the safety systems (repository and geosphere) is purely via releases of radionuclides from the disposal system, through the geosphere and ultimately to the “biosphere”. The biosphere is represented by objects in an interconnected landscape. The scope of this review is therefore the treatment and reporting of the fate of radionuclides entering the regolith, surface water and other ecosystem components of the future landscape at the Forsmark site and how the potential radiological impact of releases of radionuclides to inhabitants of the future biosphere (both human and non-human) are assessed.

1.1. Key questions to address in Initial Phase of the SR-Site review

SSM have issued general guidelines to reviewers regarding the requirements for this initial phase of the review. In particular, the following items require consideration:

- Completeness of the safety assessment
- Scientific soundness and quality of the SR-Site
- Adequacy of relevant models, data and safety functions
- Handling of uncertainties
- Safety significance (although this will be more elaborately dealt with during the Main Review Phase)
- Quality in terms of transparency and traceability of information in SR-Site and in the associated references.

1.2. Approach to the review

This initial review of the dose assessment methodology has been prepared by a consortium of four independent reviewers, each with many years experience of radiological dose assessments. Each reviewer has their particular area(s) of technical expertise, including large hydrological transport modelling, chemical behaviour of radionuclides in soil and plants, and assessment model development.

Rather than concentrating on an in depth review of the SR-Site documentation and methods at this stage, the focus is on identifying areas for SKB's immediate consideration and the themes for deeper review in the main phase.

In this stage of the review, two particular reports, the main SR-Site report (SKB 2011) and the Biosphere Synthesis Report (2010a), were of primary interest. In addition to these two reports, and to support review of the two main reports, the members of the consortium considered additional documentation which fell under their area of technical expertise. Details are given in Appendix 1, together with an indication of the coverage of the reports achieved in this initial review phase.

Section 2 of this report contains comments and observations arising from this initial review. The review has focussed upon the documentation of thematic issues and assessment assumptions which underpin the assessment.

- The scope of potential exposures employed to generate the *Landscape Dose Factors* (LDFs) used by SKB to scale releases to the biosphere to assess the potential radiological consequences of the planned repository. This includes the set of sensitivity and uncertainty analyses used to assess uncertainty in the LDFs.
- For SR-Site SKB have introduced a new dose assessment model and methodology. The dose assessment model comprises a number of components, central to which is a new model for radionuclides transport and accumulation in the landscape, hereinafter referred to as the *Radionuclide Model*[1]. Of interest are the methods used by SKB to identify, justify and validate/verify the new dose assessment model.
- Treatment of the geosphere biosphere interface: New to the SR-Site assessment is the lower regolith which functions as the interface between the release from the geosphere and the upper regolith / surface water systems where exposures occur. The dimensions, structure and spatial resolution of the lower regolith are at issue.
- Application and interpretation of the landscape modelling approach as used in the assessment of dose: The "surface footprint" of the releases to the biosphere is of concern. SKB use a discrete fracture network to identify flow paths for radionuclides from repository to surface – describing releases in terms of "release points" within identified landscape objects. In parallel, and feeding into the assessment modelling alongside the release points, is the use of MIKE-SHE to evaluate water fluxes in the bedrock and regolith. Water fluxes determined for "landscape objects" identified by the maximum spatial extent of lakes within the watersheds and catchment areas in the landscape. Of concern is whether the footprint of the release in the surface environment can reasonably be expected

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[1] The name "Radionuclide Model" follows the convention adopted by SKB and is used here as a shorthand label. We also use the term *LDF Model* to refer to the dose assessment model used to derive the Landscape Dose Factors in SR-Site. SKB also appear to use the terms "landscape object" and "biosphere object" interchangeably.

to fit the entire landscape object or whether the footprint could be smaller. This issue impacts the way in which exposed groups in the human population are identified.

- The timing and duration of accumulation in natural and agricultural ecosystems and the potential impact of emplaced drainage systems for agricultural production.
- Data requirements of the new model – the methodology used to translate the detailed site descriptive database for the Forsmark and Laxemar sites into suitable data for the LDF Model. One interesting new method in the Radionuclide Model is the derivation of uptake rates for flora in natural ecosystems.

In addition to these technical aspects of the assessment, consideration is also given to the overall consistency and integration of the documentation which comprises SR-Site. Although this was not required for this initial phase review it is considered necessary to raise these issues as adequate document integration and consistent reporting would serve to build confidence in the assessment.

The conclusions of the initial phase review are then given in Section 3. Here the SR-Site documentation is evaluated against the key items listed in Section 1.1. Aspects of the initial review which are suitable for numerical evaluation using scoping calculations as part of this initial review phase are identified. Final reporting of these issues will be provided in mid August, 2012.

The key questions and themes identified in this initial phase review are further detailed in Appendices 2 and 3. Appendix 2 provides a list of suggested essential questions to SKB requiring clarifications, complementary information, complementary data and so forth (including references to specific sections of SKB reports). In Appendix 3, the reviewers give a list of suggested topics requiring substantial additional work on the part of SSM and SSM’s external experts during the Main Review Phase.

2. Initial review phase – comments and observations

As part of the initial review the following reports, as outlined in Table 1, have been considered. This table contains a shortened version of the report title. The extent of the coverage of these reports in the initial review is given in Appendix 1.

The purpose of this section is to summarise the principal findings of this initial review phase of the dose assessment methodology. Section 2.1 contains observations and comments relating to specific themes within the SR-Site documentation. Section 2.2 outlines a series of issues relating to assessment assumptions. Section 2.3 contains a series of observations and comments which relate to presentational issues affecting the SR-Site documentation. The questions which arise from this initial review phase are then listed in Section 2.4.

Comments relating to specific aspects of some of these reports are contained in Appendix 2.

2.1. Thematic areas

Within the SR-Site documentation there are a number of themes which run through many of the reports. In this section review comments have been attributed to the following themes:

- Hydrological modelling (Section 2.1.1)
- Ecosystem understanding (Section 2.1.2)
- Landscape modelling (Section 2.1.3)
- “Accumulation” and “exposure” ecosystems, and the representation of transitions between them (Section 2.1.4)
- The Radionuclide Model (Section 2.1.5)
- The dose assessment models for potential impacts on humans and non-human biota (Section 2.1.6)
- Assessment of potential impacts associated with ^{14}C (Section 2.1.7)

2.1.1. Hydrological modelling

It is clear from the number of reports presented as part of SR-Site that SKB has undertaken a significant body of work in their endeavour to understand the current hydrological situation at the site and its past and potential future evolution. This is to be expected given one of the primary assumptions of the assessment is that radionuclides will migrate from the GDF to, and move through, the surface environment, with the water fluxes, either in a dissolved form or attached to particulates.

The analysis of discharge areas identifies the distribution of discharge points in the landscape using either Darcy Tools (Svensson & Follin, 2010) or ConnectFlow (R-09-20 and R-09-21) depending on climate scenario and system component subject to the analysis. The waterborne transport is represented using results from MIKE-SHE (Avila et al., 2010, p.19; Bosson et al., 2010) and results are transferred to the LDF model in the data values used to generate landscape object specific transfer coefficients.

Table 1: List of reports considered in the initial phase review

Reviewed report	Shortened title	Reference
TR-11-01, Vol. I-III	Main SR-Site report	SKB (2011)
TR-10-09	Biosphere synthesis report	SKB (2010a)
TR-10-01	Terrestrial ecosystem report	Löfgren (2010)
TR-10-02	Limnic ecosystem report	Andersson (2010)
TR-10-03	Marine ecosystem report	Aquilonius (2010)
TR-10-05	Biosphere data report	Lindborg (2010)
TR-10-06	LDF report	Avila et al. (2010)
TR-10-07	Element specific and constant parameter report	Nordén et al. (2010)
TR-10-08	Non-human biota report	Torudd (2010)
TR-10-50	Radionuclide transport report	SKB (2010b)
R-10-02	Hydrology and solute transport report	Bosson et al. (2010)
R-08-09	Numerical modelling of near surface hydrology and hydrogeology	Bosson et al. (2008)
R-08-11	Surface systems Forsmark: SDM report	Lindborg (2008)
R-08-16	^{14}C model	Avila and Pröhl (2008)
R-09-20	Temperate groundwater flow modelling report	Joyce et al. (2010)
R-09-19	Groundwater flow in excavation and operation phases report	Svensson & Follin (2010)
R-10-09	High resolution hydrodynamic marine model report	Karlsson et al. (2010)
R-10-28	Chemistry data	Tröjbom and Nordén (2010)
R-10-30	Radionuclide transport modelling report	Piqué et al. (2010)
R-10-37	Biosphere FEP report	SKB (2010c)
R-04-10	Human population and activities	Miliander et al. (2004)
R-04-67	Landscape and historical geography	Jansson et al. (2004)
R-06-37	Historical landuse report	Berg et al. (2006)

Those hydrological issues relating to specific assessment assumptions are discussed further in Sections 2.2.1, 2.2.4 and 2.2.5. Suggested topics related to the hydrological modelling for the main review phase are given in Appendix 3.

2.1.2. Ecosystem understanding

Understanding of the various ecosystems present at the Forsmark, and Laxemar-Simpevarp, location(s) is well summarised in a series of ecosystem reports within the SR-Site documentation (Andersson, 2010; Aquilonius, 2010; Löfgren, 2010).

The understanding of current ecosystems at Forsmark, and an evaluation of their potential evolution, is based upon a combination of site investigation data and results from numerical models of the evolution of these ecosystems. The aforementioned three reports would benefit from some form of table or figure to clarify the connectivity between data and models in the understanding of each ecosystem, including a summary of the spatial and temporal scale of the data and models. This relates directly to the presentational issues raised in Section 2.3.

The ecosystem understanding developed for these reports is used to characterise the processes of relevance to the radionuclide model in an interaction matrix (IM). Concerns relating to the justification of the radionuclide model are discussed further in Section 2.1.5. However, one issue that needs to be raised here is that of assumptions relating to irrigation of agricultural crops. Within the LDF report (Avila et al., 2010) it is stated that radionuclides can enter agricultural land via irrigation with surface water. The transfer of surface water to crops occurs via “Water supply” within the IM (SKB, 2010c). It is therefore not clear why this process is disregarded in the IM used to represent the terrestrial radionuclide model (Löfgren, 2010).

2.1.3. Role of the Landscape Model

The landscape model and its evolution is the centrepiece of SKB’s LDF modelling. The rapid evolution of the site over the next ten millennia due to the emergence of large areas of land from the Baltic is the dominating driver of system change. In SR-Site, SKB use their detailed landscape model to determine the spatial extent of biosphere objects that can become contaminated by releases from the fracture network in the bedrock. Water fluxes in and through the regolith are interpreted from detailed MIKE-SHE modelling of the surface system. However there is concern that the spatial scale of the objects in the landscape model does not match the spatial distribution of the release locations estimated using MIKE-SHE and that, in common with the earlier SR-Can assessment, the volumes of the biosphere into which the activity accumulates are significantly overestimated, with lower overall activity concentrations from which agricultural foodstuffs can be derived. The result would be an underestimation of the LDF for key nuclides (eg, ^{79}Se, ^{129}I) due to dilution throughout the whole object..

This choice of object area affects the size of the population group potentially affected by the release. The population may be relatively large (some hundreds in some of the objects discussed by Avila et al., 2010). From an radiological protection perspective it is legitimate to consider release to a more restricted area - say the size of a single farmstead of four adults. Such an interpretation can be consistent with known farming practices and associated drainage systems for small holdings (Biebighauser, 2007). However the collective dose may be the same in each case.

The above applies to agricultural systems. A larger area is required if food intake is assumed from naturals ecosystems. However, Kłos (2011) showed that only agriculture can be practiced on a small enough scale to be affected by small scale surface footprints. Hydrology and particularly surface drainage patterns (including emplaced drainage) are therefore key to a robust understanding of modes of exposure.

While the landscape model is well justified in the documentation it is possible to argue that it is not sufficient as the basis for a dose assessment model and that alternative interpretations of the contaminant footprint are possible and should be investigated in order to scope the effect on the distribution of the calculated LDFs.

Lindborg (2010) suggests that the footprint could be as little as 10^4 m^2 and this corresponds to the spatial scale of surface drainage system used to manage wetlands for agricultural purposes (Biebighauser, 2007; Smedema et al., 2004). A review of the potential for radionuclide accumulation in small but potentially crucial sub-areas of the overall catchment areas and basins in the landscape model is recommended.

Development of the landscape model only considers the role of farming practices insofar as there is a transition to agriculture from natural ecosystems. The impact on the natural system is not otherwise addressed. There are likely to be profound influences on the surface drainage pattern due to anthropogenic activity and these should be investigated with the tools available (see below).

2.1.4. “Accumulation” and “exposure” ecosystems - the transition to agricultural land

Kłos (2011), Kłos, Limer & Shaw (2011) have distinguished between a) ecosystems in which radionuclides can accumulate to significant concentrations but which, for reasons of biomass productivity, cannot support high levels of human consumption and b) ecosystems with high productivity of contaminated foodstuffs. The former “accumulation” ecosystems are typified by natural systems (forests, wetlands, lakes) and the latter are agricultural systems. Natural ecosystems are, radiologically speaking, insignificant, but agricultural systems reach high accumulations of radionuclides only after extended periods, often beyond the practical lifetime of agricultural soils.

In the evolving landscape of central Sweden anthropogenic transformation of natural ecosystems to agricultural areas is a real possibility. The LDF report acknowledges this and the evolving system assumes that agriculture is practised as soon as environmental conditions will allow, namely as soon as the lake-wetland transition has reached 2 m above current sea level (see Table 7.2 of SKB, 2010a).

Transitions “as soon as possible” do not necessarily allow for the highest possible accumulations in the undisturbed “natural” system. Climate options for future system suggest that accumulations for 10 – 20 ka might be possible. Transition to agriculture after only 1 or 2 ka can be expected to lead to a potentially significant underestimation of the concentrations in the reclaimed agricultural land. The sensitivity analyses carried out in SKB (2010a) have not discussed timing of changes in land use in this way and alternative accumulation periods are therefore suggested as an important contribution to uncertainty in the LDF values.

2.1.5. Justifiability of the radionuclide model

SKB (2010c) describes the components, features and processes of the biosphere considered in the biosphere for SR-Site. From this an interaction matrix (IM) containing 15 components and 51 interactions is identified. This list of interactions is subsequently reduced to 34 “relevant processes” within the biosphere synthesis report (SKB, 2010a); more detailed justifications for this are given in the ecosystem specific reports (Andersson, 2010; Aquilonius, 2010, Löfgren, 2010). From this reduced IM ‘The radionuclide model for the biosphere’ (Chapter 8 of SKB, 2010a) is presented. However, a clearly demonstrated link between the processes identified from the matrix and the radionuclide model is not presented. SKB should describe a clearly traceable procedure by which a collection of agreed relevant processes is transformed into a conceptual then a mathematical model. This procedure should discuss whether the radionuclide model for the biosphere is conceptually the same for all radionuclides (eg. selenium, iodine, carbon) and, if it is not, the justification and description of modelling approaches for individual radionuclides should be given in a clear and traceable form.

A major concern is the apparent lack of ‘validation’ of the radionuclide model against the abundant site database compiled for SR-Site – note the italicised text:

> TR-10-09, p101: “…site investigations of the two candidate sites Forsmark and Laxemar-Simpevarp were coordinated, which gives *valuable possibilities* to validate data and build confidence. The radionuclide model for the biosphere has, *as far as possible*, utilised the site specific data both for describing parameters and populating parameter values.

Are there any explicit examples of how or where this has been done? SKB describes (TR-10-09, Section 9.1.2) the manner in which concentration ratios (CRs) and distribution coefficients (K_ds) have been estimated from site and/or literature data. It would ‘build confidence’ in the model and the SR-Site data if a demonstration calculation were provided to show how, when parameterised with site specific data for stable elements, the radionuclide model could reproduce the distribution of those elements in the ecosystem(s) as they are observed at Forsmark today.

As part of the same calculation the time to steady state of radionuclides concentrations in the ecosystems should also be demonstrated. Concerning the calculation of LDFs following continuous, has the time taken to reach steady state in different parts of the landscape been investigated? It is stated (TR-10-09, p. 114) that “*most radionuclides have approached steady state at 9400 AD*”. This would suggest steady state has been reached but, as described in the previous paragraph, it would be useful to demonstrate that the behaviour of individual elements in the ecosystems at Forsmark is understood with demonstrable confidence. Alternative models to address the dynamics in conjunction with a selective sensitivity/uncertainty analysis are recommended to verify that the range of LDFs calculated in SR-Site is appropriate.

A further concern is the patchiness of the site-specific database. ^{79}Se has the highest LDF of all the radionuclides evaluated in TR-10-06 yet the source data for soil to plant concentration ratio is taken from Coughtrey et al. (1985) via Karlsson & Bergström (2002). For all the sophistication of the Bayesian updating approach outlined in TR-10-07 (Nordén et al., 2010) it seems remarkable that this key radionuclide is so little understood at the local level, particularly as the CRs employed are comparatively high in relation to those of the other radionuclides considered in the assessment. It is not clear to what extent site specific data published subsequent to the SR-Site submission (e.g. Sheppard et al., 2011) have been used in SR-Site.

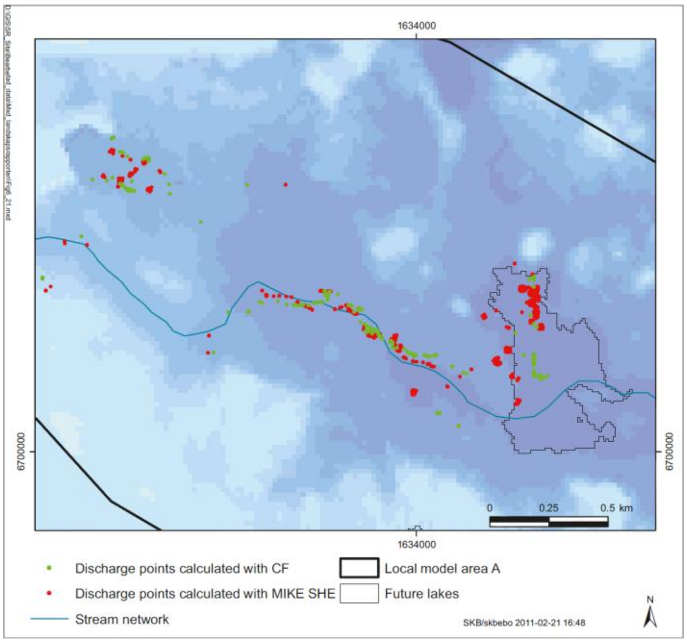

Figure 1: Comparison of discharge point locations in terrestrialised lakes and along a stream, calculated with MIKE SHE (red dots) and ConnectFlow (CF, green dots). The spatial context is that of Landscape Object 121, and the "lake" is the contour of the lake at isolation. (Reproduced from TR-10-05.)

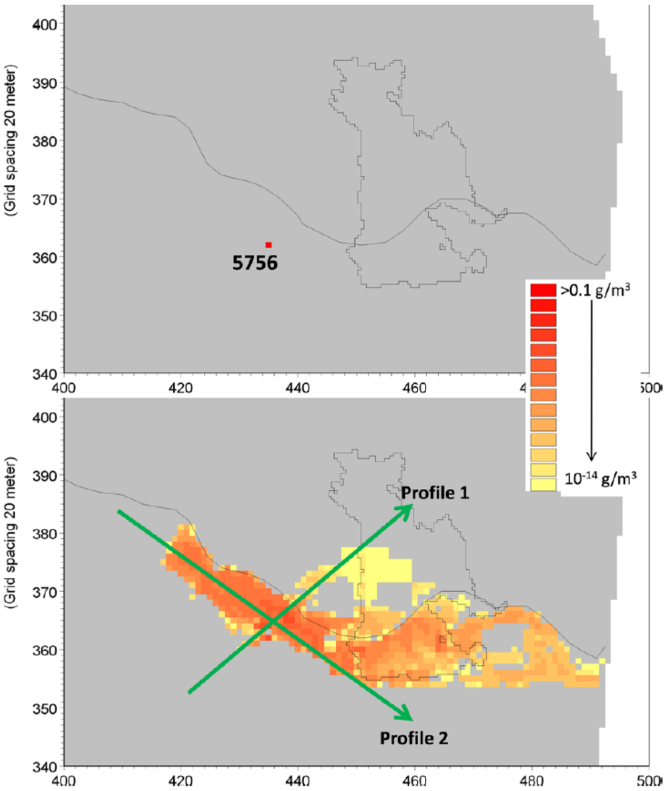

Figure 2: Surface plot for object 121_01. The upper figure shows the location of source 5756 and the lower figure shows the extent of the concentration plume in the uppermost layer. The lower figure also shows the locations and directions of the profiles illustrated in Figure 7-89 and 7-90. The simulation is based on the 10000AD_10000QD model. (Reproduced from R-10-02.)

There are two modelling descriptions of the interaction of the deeper groundwater with near surface circulation. One is the model of the discrete fracture network (DFN) which is combined with particle tracking to determine the release point in the future landscape where contaminants released from distinct canisters in the repository structure would reach the surface. The other element is the MIKE-SHE modelling which discusses interactions of surface and groundwaters in the modelled region using a continuum representation. The combination of the two approaches is discussed in TR-10-05, in which the landscape model is described and the biosphere modelling objects are defined.

There is reasonably good agreement between the two approaches in terms of the spatial distribution of contaminants in the biosphere. The release locations are at low points in the local topography, coincident with the expression of the fractures at the surface of the bedrock and the release points are closely grouped in the surface environment. This is illustrated by Figure 6-21 of TR-10-05, reproduced here as Figure 1. Further in TR-10-05 the distribution of the contaminant footprint in the surface system is analysed in some detail for each of the canister locations. Figure 2, illustrates the dispersion at the surface for canister location 5756. The plume does not occupy the whole of the lake object.

When determining the size of the biosphere object SKB use the contour of the lake at isolation from the bay. This they take as the size of the object into the future, with the size of the terrestrial and aquatic components changing as the object evolves with the combined area remaining constant. The role played by agricultural practices in determining the exploited area is not addressed. This is not surprising as the description of the societal components of the system (Miliander et al., 2004; Jansson et al., 2004; Berg et al., 2006) deal in a broad description of habits, customs and practices in the area. As with the discussion of the hydrology, the spatial resolution is too coarse to be able to describe the system at the spatial scale of individual farms.

In the LDF modelling report (Avila et al., 2010), the results of the deeper groundwater interactions are interpreted in a straightforward and simple way for all landscape objects. The vertical flux in the object, through the lower regolith and into the mid-layer regolith is defined as either 0.008 m y^{-1} (object classified as “marine”) or 0.048 m y^{-1} (lake/wetland). The MIKE-SHE representation assumes a continuum in the flow properties and this discharge rate is applicable to the whole object.

However from Figures 1 and 2 above, the discharges are clearly spatially constrained to the domain around the topographic minima (associated with the surface expression of the fracture network) and the spread of the contamination (the footprint) can be significantly less than the whole landscape object. It is questionable as to whether it is supportable to assume dispersion of the contamination over the whole area of the object as is the case in the LDF calculations. Clearly there is scope for alternative interpretations. As noted above, the impact of anthropogenic influences on the surface drainage system needs to be addressed using MIKE-SHE.

2.1.6. Identification, justification and verification of the LDF Model

The model used for the dose assessment calculations is at the pinnacle of a pyramid of supporting models. The data requirements are generally suitably addressed in the marine, limnic and terrestrial reports (TR-10-01, TR-10-02 and TR-10-03). However, the LDF Model has been introduced here for the first time and there is insufficient discussion of the behaviour of the new spatial structures and the dynamics of the compartmental accumulations.

There are some obvious inconsistencies; for example the terrestrial model features a dynamic interaction between plants and soil, characterised by an uptake rate derived from the more traditional soil-plant concentration ratio. The same method has been applied to the Posiva biosphere modelling (Hjerpe & Broed, 2009). It is not clear that this method is valid as its justification has neither been illustrated nor discussed in the SR-Site documentation. In the evaluation of the LDFs the new method of estimating the activity content of plants is discarded in favour of the simple concentration ratio method. This interpretation is examined further in the initial numerical review carried out by this consortium.

The new model features a spatial domain not included in dose assessment models up to and including SR-Can, namely the lower regolith. Essentially this functions as the geosphere-biosphere interface in the model, comprising the link between the bedrock and the traditional “biosphere” models. Motivation for this feature of the models is not clear and this represents an important deficit in the model identification and justification.

Analysis of biosphere FEPs have, for a long time, been conspicuous by their absence. A biosphere FEP report was anticipated at the time of SR-Can but it is only now that the report R-10-37 has appeared. Ideally this report would provide a clear link to the new model on the basis of a reasoned and justified discussion of the contents of the interaction matrices that appear in the LDF report (Avila et al., 2010) and biosphere process report (SKB, 2010c). Unfortunately the interaction matrices give the strong impression that they have been fitted to the new model rather than the model being derived from the system understanding expressed by the IMs. An alternative, and less charitable, interpretation of the biosphere process report is that the interactions so codified are so generic as to be practically meaningless for model definition. These and several other similar features of the model should be investigated in detail in the main review phase.

The non-human biota aspect of the safety assessment is based upon the output of recent international projects, in some of which SKB has been an active participant. It is considered that this aspect of the assessment is both clearly documented in the higher level reports (SKB, 2011, 2010a) and is well supported by the underlying SKB report (Torudd, 2010) as well as international reports. The assessment of potential exposure of non-human biota is therefore not considered an area of concern for the main review phase. However, if analyses of the estimation of the concentration of radionuclides in the environmental media increase significantly then the assessment of impacts to non-human biota will need to be re-evaluated.

2.1.7. Assessment of impacts associated with ^{14}C

The potential impacts to humans associated with ^{14}C are assessed within SR-Site using specific activity models developed for SFR1 SAR-08 (Avila and Pröhl, 2008). For the non-human biota assessment, the same approach as used for the other radionuclides is used for ^{14}C (i.e. ^{14}C is treated as a trace element). There is no discussion within the SR-Site documentation of the implications of any uncertainties associated with the models, although such material is found in Avila and Pröhl (2008).

With respect to the terrestrial ecosystems, it is unexpected that the SR-Site documentation gives no consideration to potential uncertainties in the conceptual model and its parameterisation given SKB's involvement in the BIOPROTA forum's ^{14}C working group (Limer et al., 2011). For example, some of the participants in the BIOPROTA working group assumed that only 10% of any methane released was oxidised and thus available for plant uptake to give any appreciable impact to humans (beyond inhalation). Some quantification of the ratio of CH_4 to CO_2 released from the soil (as a result of contaminated gas or groundwater reaching the soil from below, or contaminated water being used for irrigation in agricultural land) could enable a more realistic assumption with respect to the amount of plant available ^{14}C entering the terrestrial biosphere. In the assessment of the potential impacts of ^{14}C -labelled gas in the Low Level Waste Repository Ltd (LLWR) 2011 Environmental Safety Case (Limer, Thorne & Towler, 2011) it was shown that placing an upper limit on CH_4 oxidation from a realistic gas composition could, independent of other uncertainties in the model, lead to considerable reductions in the assessed potential impacts to humans arising from ^{14}C. Another aspect noted in Avila and Pröhl (2008) is the sensitivity of the calculated doses to the wind speed. Within the SR-Site documentation there is neither discussion of this issue, nor is the wind velocity (*vel_vind*, Section 13.4.3, p361, TR-10-01) stated as being given with respect to a particular height. This latter issue is of importance with respect to the definition of the wind speed used in the calculation of ^{14}C transport of the contaminated area.

It is understood that during the preparation of the SR-Site documentation SKB were developing a new terrestrial ^{14}C model, and that a report on this model is currently in preparation (Tagesson, in preparation[2]). Some comparison study of the two models would be expected at a later stage.

With respect to the assessment of ^{14}C in aquatic environments, an alternative approach to that of Avila and Pröhl is, in principle, presented for marine ecosystems in Section 9.4 of TR-10-03. However, although the radionuclide model in TR-10-03 has been used to simulate ^{14}C dynamics in the marine system, these results are not presented. It is suggested that SKB present the results from their SR-Site calculations, and that some comparison between those results and the results which might be obtained using the Avila and Pröhl (2008)model be undertaken.

2.2. Assessment assumptions

A number of issues relating to assumptions made for the assessment have been identified in the documentation. The following issues listed below are discussed further in this section.

- Justification of the transfer coefficients within the Radionuclide Model of the LDF Model (Section 2.2.1)
- Spatial delimitation of biosphere objects (Section 2.2.2)
- Representation of the lower regolith (Section 2.2.3)
- Runoff rate for the Forsmark area (Section 2.2.4)
- Hydrological time-series for surface water (Section 2.2.5)
- Behaviour of redox sensitive radionuclides in soil (Section 2.2.6)

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[2] It is understood this will be published as TR-12-05.

2.2.1. Justification of inter-compartment transfer coefficients in the LDF Model

It appears that SKB is using area-averaged water fluxes over biosphere objects in the determination of the transfer coefficients used in the LDF Model. Such an area-average is probably not representative of the radionuclides migrating from the repository for which the water flow is generally much slower. Discharging deep groundwater is physically separated in stream tubes from the more intense mixing that occurs in Quaternary deposits. SKB should more specifically describe how the transfer coefficients are estimated specifically (tabulate values) and justify the spatial averaging with respect to a conservative risk approach. [A more detailed problem background is given in Appendix 3, issue 1.]

2.2.2. Spatial delimitation of biosphere objects

The boundaries of biosphere objects are generally taken as the contour curves of sub-watersheds or surface water bodies like lakes and wetlands. However, SKB's model exercise shows that the expected discharge area for the main scenario, in which one canister fails, is much smaller than the biosphere object and approximately of the same size as the typical area used by a small family for farming (see TR-10-05, page 125). This relatively small area is consistent with the farming practices assumed for potentially exposed groups in the UK, Limer, Thorne & Towler (2011). SKB should more clearly motivate the relatively large biosphere objects with respect to a conservative risk approach. [A more detailed problem background is given in Appendix 3, issue 2.]

Another issue relating to the delimitation of biosphere objects relates to a specific object, object 121. In TR-10-09 it is noted (p141) that the

> "*… basin of one of the original biosphere objects (121) was partitioned into three separate biosphere objects in order to represent discharge directly into a stream or a wetland without going through a lake stage. One of these objects, 121_03, turned out to be small with respect to both area of the sub-catchment and watershed*."

The reporting of this object, and its sub-objects, is not consistent through the SR-Site documentation. In particular, the parameterisation of object 121 typically relates to the whole object rather than to its sub-divisions. Given object 121 is identified as presently being a marine ecosystem, it is of particular note that only one parameter is defined for a sub-object (121_01) in the marine ecosystem report (Aquilonius, 2010).

Within the LDF report (Avila et al., 2010), many of the highest calculated LDF values are attributed to object 121_03 (Table 4-1, p38). Section 12.3.1 of the biosphere synthesis report (SKB, 2010a) notes that the effect of subdividing object 121 was evaluated by determining the LDF's associated with the undivided object, but that

> "*as several other small biosphere objects were included in the assessment and the contribution from the well is independent of the size of the objects, the effect on the maximum LDF was small.*".

Unless peak LDF values associated with object 121_03 were dominated by the consumption of water, this statement does not sufficiently justify the variation in calculated LDF's for the whole and sub-divided object. Therefore, further justification for the effect on LDF values being minimal is requested. For example, both ^{129}I and ^{79}Se have their maximum calculated LDF values associated with object 121_03, yet Table 4-1 of Avila et al. (2010) states that the primary source of exposure is the ingestion of food. According to Table 10-1 of Lindborg (2010), these high LDF values are associated with vegetation consumed (which is not irrigated with well water) and, in the case of ^{129}I, consumption of milk (cows are assumed to consume some well water).

2.2.3. Representation of the lower regolith

The lower regolith is a new concept in the biosphere modelling performed by SKB. It is the spatial domain in the surface deposits between the biologically active parts (soils and bed sediments) and the bedrock and as such constitutes the geosphere-biosphere interface into which discharges from underlying rock fractures take place. The spatial scale varies from less than a metre to tens of metres in places. There is still considerable discussion about flow paths within this volume and the role of diffusion should be taken into account. The treatment of the domain as a single compartment in the Radionuclide Model is potentially problematic and could lead to higher activity fluxes into the upper regolith as a result of numerical dispersion or retention of the more strongly sorbing radionuclides could lead to a buffer between the bedrock and the soils and sediments. The investigation of the discretisation and transport properties of the lower regolith in the LDF report (Avila et al., 2010) does not provide sufficient discussion of these issues.

2.2.4. Runoff rate for the Forsmark area

SKB shows both for present and future states of the Forsmark site that the runoff is extremely small in a regional perspective. The runoff coefficient varies between 20% to 30% (percentage of precipitation that runs off), which is much smaller than for any other of 1001 other Swedish watersheds according to evaluations performed by the Swedish Meteorological and Hydrological Institute. Which particular hydrological conditions explain this unusual behaviour in comparison to neighbouring and similar watersheds in Sweden?

The low turnover of surface water is a potentially significant factor in determining accumulation of radionuclides that migrate into surface water (see also Sections 2.2.1 and 2.2.5). A low flow rate could mean high retention in the upper regolith but a low input from the rock fractures could also mean high accumulation in the lower regolith with a low rate of transfer to surface soils. [A more detailed problem background is given in Appendix 3, issue A3.5.]

2.2.5. Hydrological time-series for surface water and the potential impact on uncertainty in of the safety assessment

The surface hydrological time-series are very short (generally less than 10 years). This has implications for the uncertainty in estimation of the local hydrological behaviour of the site, such as the mean runoff. Estimates of the uncertainty due to the short time-series in the runoff as well as parameters used in the Radionuclide Model would have great value in building confidence in the safety assessment. [A more detailed problem background is given in Appendix 3, issue A3.6.]

2.2.6. Behaviour of redox sensitive radionuclides in soils

Table 10-1 of the Biosphere Synthesis Report (SKB, 2010a) lists the six radionuclides contributing most to dose in the central corrosion case: ^{226}Ra, ^{79}Se, ^{129}I, ^{237}Np, ^{135}Cs and ^{36}Cl. With the exception of ^{237}Np, the key pathway for exposure is the ingestion of crops and, in many cases, milk. The agricultural land upon which crops are grown and livestock graze is a potential end-state of a wetland (Section 3.1.1, Avila et al., 2010). It is hypothesized that the accumulation of radionuclides in the soil will occur only prior to its transformation to agricultural use, with a loss of radionuclides subsequently (Section 3.1.1, Avila et al., 2010). Two of the radionuclides identified as being key contributors to dose, ^{129}I and ^{79}Se, are known to be redox sensitive elements, meaning that their behaviour in waterlogged and well-drained soils might reasonably be expected to differ (e.g. Wheater et al., 2007). This issue was highlighted in the specification of the dose assessment review supply agreement as an area of concern due to the potential for enhanced accumulation in the biosphere of such radionuclides.

Whilst the chemistry report (Tröjbom and Nordén, 2010) describes the methodology employed in deriving the soil partition coefficients (K_d) for the assessment, the values themselves are contained in the element specific parameter report (Nordén et al., 2010). From this is it apparent that SKB have made some account of the potential for radionuclide behaviour to differ between organic and inorganic sediments (Tables 3-1 and 3-2 in Nordén et al., 2010). However, the K_d values attributed to any given layer in the soil profile do not appear to be altered following the drainage of the site.

Further consideration of the representation of the behaviour of redox sensitive radionuclides in the assessment model, accounting for changes in hydrological conditions of an ecosystem, might be anticipated to support statements relating to the potential impacts of redox sensitive radionuclides (e.g. Kłos et al., 2011; Pérez-Sánchez et al., 2012; Smith et al., 2012).

Further numerical review of this issue will follow, employing suitable models from the GEMA family, developed for Swedish biosphere conditions during the SSI/SSM CLIMB project (Kłos, 2011; Kłos, Shaw & Limer, 2011). In addition to the redox issue, the use of alternative model interpretations for ^{79}Se, ^{99}Tc and ^{129}I will be addressed in the context of the dynamic modelling of plant-soil pore water interactions and the dynamics of accumulation in natural and agricultural systems.

2.3. Presentational issues within SR-Site documentation

It is acknowledged that the SR-Site documentation is fairly extensive. It is therefore important to have made clear the connections between the various documents, such as the SR-Site Biosphere project report hierarchy schematic as shown in Figure 3 (reproduced from SKB, 2010a). Such a schematic aids and directs the reader in working down the report hierarchy when looking for supporting evidence for particular statements or assumptions.

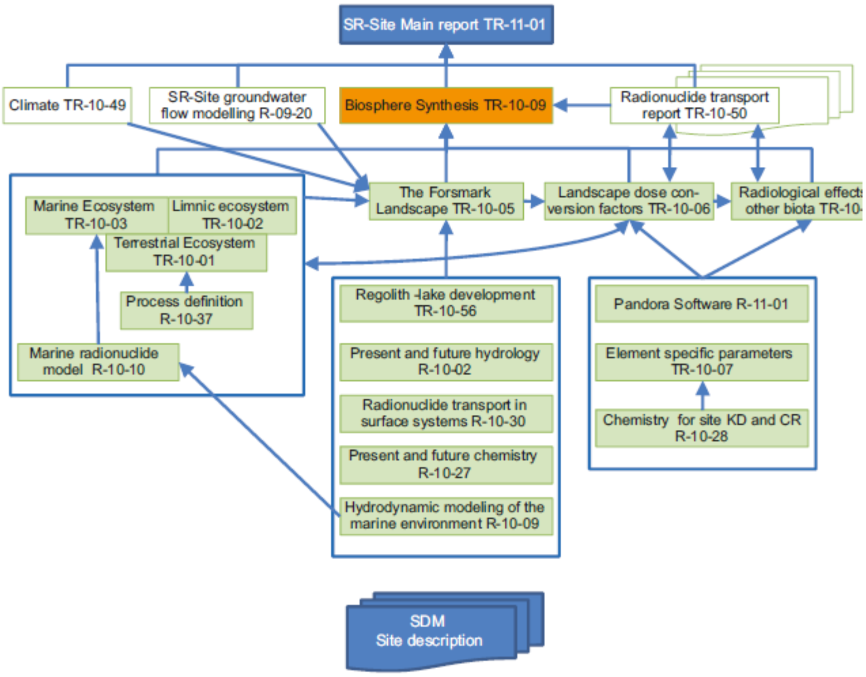

Figure 3: SR-Site Biosphere project report hierarchy (reproduced from SKB 2010a)

It is not the purpose for this current review to make general comments about the SR-Site documentation. However, there are some aspects of the presentation of these documents which may require further work on the part of SKB in preparation for the main part of SSM's review.

Firstly, numerous calculation scenarios have been considered within the assessment. A more comprehensive table than Table 11-1 of TR-11-01 (SKB, 2011) would facilitate a clearer understanding of the scenarios considered in this assessment. Suggestions for the content of such a table are given in Appendix 2.

Secondly, the risk assessment is based on synthesizing a network of assessment level models in which the most essential are near field model (comp23), far-field transport model (FRAF31 and MARFA) and LDF-values (Fig. 3-4 of TR-10-09 / Fig. 13-12 TR-11-01, vol. III). The biosphere modelling (e.g. COUP model, LPJ-GUESS, both discussed in Löfgren, 2010) and hydrological analysis (ConnectFlow, MIKE-SHE and Darcy Tools) are used to support parameter values of the Radionuclide and LDF Models. Whilst the essential features of many of the models used in SR-Site are presented in the model summary report (TR-10-51, SKB, 2010d), it does not cover every model used to underpin the assessment (e.g. LPJ-GUESS). SKB (2010d) contains figures representing the assessment model flow charts, which provide an indication as to how the models support the assessment hierarchy. However, as those figures relate to the whole SR-Site assessment they are not able to provide sufficient detail with respect to the models used in the biosphere to support the dose assessment in the biosphere. A table highlighting the key properties of the models used in the biosphere aspect of the assessment (spatial and temporal scales and time steps, time domain) and a figure demonstrating the relationships between these models would further aid the reader’s understanding of the basis of the dose assessment.

Finally, the very large number of reports which comprise SR-Site often fragments the traceability and logic in the analysis. Most information goes primarily into the analyses of different safety functions (canister, buffer, tunnels, geosphere), i.e. to support the isolation design. This should be essential to improve the design and for confidence building. However, very limited information is actually passed on to evaluate *risk* and the vast literature is not clearly organised to show which pieces of information are used and integrated in the risk assessment. Identification of specific parameter values, and the justification for the numerical value chosen, is generally a non-trivial matter.

It is noted that the primary data are stored in SKB’s internal databases (Lindborg, 2010). As part of the main review phase, access to specific elements in these databases, on an on-request basis, would allow the reviewers to evaluate aspects of model parameterisation within SR-Site and also facilitate the parameterisation of any model calculations performed as part of any numerical review of SR-Site.

2.4. Questions arising from this initial review phase

Following this initial review phase a number of questions to be addressed either by SKB directly, or which can form part of the main review phase, have arisen.

Questions that might be addressed by SKB directly:

1. Can SKB produce a summarizing table of the characteristic properties of risk scenarios?
2. Can SKB produce a summary of the models and their inter-connectedness, as well as the model parameters used in the biosphere aspect of the assessment, to supplement the information provided in TR-10-51?
3. Can SKB provide a clear description of the procedure by which the 34 biosphere processes identified in the interaction matrix as relevant, are transformed into a conceptual then a mathematical model of radionuclide transport and accumulation in the biosphere?
4. Can SKB demonstrate the ‘validation’ of the biosphere model against the abundant site data which has been obtained in SR-Site? As verification of the new model, and its representation of biosphere FEPs, can SKB discuss how the new model compares with the previous biosphere models? This verification would build confidence that the new Radionuclide Model has captured the essential FEPs in the Forsmark system
5. Can SKB clarify the basic assumptions of the assessment?

Questions that might be addressed by supporting calculations in the main phase of the review, in addition to responses from SKB:

1. What is the basis for the transfer coefficients in the Radionuclide Model, based on an independent numerical modelling review?
2. Will the selected size of biosphere objects underestimate doses?
3. Is the extremely low runoff of the Forsmark area accurately determined and will it have implications for the values determined for the LDFs?
4. What is the implication of the short hydrological time-series for surface water on the uncertainty of the safety assessment?

5. What is the potential impact of extended periods of accumulation in natural ecosystems prior to their conversion to agricultural land? How high can initial concentrations in agricultural soils practically become and what is the timescale for this process?

The initial phase of the review of SR-Site's dose assessment modelling has not been carried out in depth. There is a need to revisit specific areas of the documentation. Primary amongst these is the need for a forensic review of the new LDF Model (with particular attention to the new Radionuclide Model) described in detail in the LDF report (Avila et al. 2010). The basis for the derivation of the transfer coefficients used in the assessment unclear and the relation to the biosphere FEP report needs to be addressed in some detail in conjunction with the models developed in parallel to SKB's models over the past few years in the SSI/SSM CLIMB project.

Review of the motivation for the new radionuclide model can be expected to address such issues as

- Alternative conceptual models consistent with the system defining FEPs.
- Additional FEPs involved in the upwards migration of activity concentrations in the deeper regolith, particularly in alternate climate conditions which could lead to higher surface concentrations on the resumption of agriculture, including a review of the justification for the simplistic treatment of the geosphere-biosphere interface.
- Alternative interpretation of data requirements and the quantification of process in the biosphere model. Bioturbation, for example, needs to be better understood as a mechanism for the upward migration of radionuclides sorbed on to particulates.

A broader and deeper understanding of the representation of water fluxes in the near surface hydrogeology is required. Justification of the size of the contaminated areas assumed in the landscape model is necessary.

Additionally, the supply agreement specifically identified the redox sensitivity of some radionuclides as an issue potentially leading to enhanced accumulation in the biosphere system. This has been identified here but further numerical review will follow employing suitable models from the GEMA family, developed for Swedish biosphere conditions during the SSI/SSM CLIMB project (Kłos, 2010; Kłos, Shaw & Limer, 2011). In addition to the redox issue, the use of alternative model interpretations for ^{79}Se, ^{99}Tc and ^{129}I will be addressed in the context of the dynamic modelling of plant-soil pore water interactions and the dynamics of accumulation in natural and agricultural systems

With expertise built up during CLIMB and Oversite it is clear that there are significant areas of uncertainty – both conceptual and parametric – that have not been addressed by SKB. Indeed, it could be argued that he sensitivity/uncertainty analyses carried out in the LDF report (Avila et al., 2010) is designed to justify the modelling assumptions on which SKB have based the new LDF Model, rather than to explore alternative interpretations. The suite of modelling tools developed in CLIMB should be used to extend the range of the uncertainty envelope.

Suggestions for topics to be addressed in the main review phase are set out in Appendix 3.

3. Conclusions of initial review phase

3.1. Overview

In this initial review phase the four reviewers have covered a wide range of the SR-Site documentation ranging from the main report, first level TR-series reports and supporting TR- and R-level documents. Details are presented in Appendix 1.

In this initial phase the reviewers have identified where additional information could be provided by SKB to simplify the main review tasks. These requirements are set out in Appendix 2.

This initial phase was not intended to be an in-depth review but to determine the suitability of the SR-Site documentation and identify options for the main review phase. Despite misgivings about the standard and quality of the documentation of SR-Site, there is sufficient information to perform the main review phase. In SR-Site there is a substantial quantity of newly published material related to the derivation of LDFs. A prime requirement of the main phase is a detailed forensic review of the new LDF Model and its performance. This is required because there is a lack of detailed model performance description in the SR-Site documentation. In particular the interpretation and model representation of biosphere FEPs should be tested against an independent modelling approach where alternative conceptualisations of the system can be implemented.

Suggestions for a deeper and broader documentary and numerical review of key points are set out in Appendix 3. A number of these issues will be given preliminary consideration in this phase of the review via scoping calculations. In addition, calculations pertaining to the behaviour of redox sensitive radionuclides will also be undertaken, as specified in the supply agreement.

3.2. Initial review phase findings

In this section the key questions posed at the outset of this initial review phase are addressed.

3.2.1. Completeness of the safety assessment

A large number of reports have been published in support of the dose assessment aspect of the SR-Site licence application. These documents can be viewed as giving complete coverage of the assessment in that each feature and process that forms part of the biosphere system and the dose assessment calculations is discussed somewhere within the documentation. However, some aspects of the system have been reported in greater detail than others. More importantly, it is considered that not all of the uncertainties associated with assumptions made for the safety assessment have been adequately addressed within the reporting. The implications of this finding are discussed in more detail below.

3.2.2. Scientific soundness and quality of SR-Site

The derivation of the LDFs is based on a hierarchy of models. At the base there is the site description furnished by many detailed site investigations with attendant supporting models. At the apex is the LDF Model. In between there is a succession of intermediate models and methods for the interpretation of site information used to generate the database for the LDF Model. The requirement for a concise flowchart, or something similar, showing the model hierarchy and information/data flows used to generate the LDF Model has been identified. At each stage there is interpretation and filtering of the information passed forwards. In the definition of the conceptual model for the dose assessment (dealt with in SKB, 2010c) the link between the modelled FEPs and the conceptual and mathematical models is not well established on the basis of the biosphere interaction matrix.

So, while the scientific quality of much of the work underpinning the derivation of the LDFs is of a high standard, there are serious reservations concerning the use to which the information is put in the evaluation of the LDFs themselves.

3.2.3. Adequacy of relevant models, data and safety functions

At the base of the hierarchy, the models are generally of good quality. The adequacy of the LDF Model itself is more open to question. It is a new interpretation of the surface system and has not been subjected to adequate verification/validation.

Further examples of data issues include the selection of the run-off for the Forsmark area, and the selection of the biosphere objects and the derivation of the soil-plant transfer rate in the model for natural (forest/wetland) ecosystems described by Avila et al. (2010). The approach to estimating dynamic uptake in plants is not based on justified or published material. The method for determining key nuclide specific parameters in the Radionuclide Model employs Bayesian updating methods to extract information from the literature where no site specifc material is available. This is a useful approach but there are gaps in the database. For example the database for ^{79}Se – the radionuclide with the highest LDF – is apparently[3] based on a limited reinterpretation of material taken from Coughtrey et al. (1985). It is surprising that site specific data for this potentially important element is not part of the SR-Site database.

Finally, it is surprising that the extensive data base for the Forsmark biosphere system has not been used by SKB to validate the behaviour of the Radionuclide Model and the Carbon model. Abundant data are available for the present-day distributions of stable elements such as C and I and these should be used to check the adequacy of model predictions of long-term radionuclide accumulation in key parts of the biosphere. Once such validation has been carried out the models could then be used with much greater confidence to address questions of accumulation times and radionuclide distributions within biosphere objects at steady state. Given the emphasis on collection of data for carbon within SR-Site it is particularly surprising that this process has not been carried out for this element.

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[3] The values used in the LDF model are quoted as being based on data from Karlsson & Bergström (2002). However, Sheppard et al. (2011) have derived site specific data for a wide variety of radionuclides. The reason for the use of older data in the LDF calculations should be clarified by SKB.

3.2.4. Handling of uncertainties

The uncertainty analysis carried out in respect of the LDFs is well fitted to the conceptual model described and implemented mathematically by Avila et al. (2010). However there are concerns that conceptual model uncertainty has not been adequately addressed. Recommendations for the main review phase set out in Appendix 3 are intended to address these issues.

3.2.5. Safety significance

It is not the role of the biosphere to offer any safety function with respect to the potential impact to humans and non-human biota resulting from any releases of radionuclides from the geological disposal facility. That role is performed by the engineered barrier systems which form the disposal facility and the geological setting for the facility. The biosphere is a receptor for any radionuclides reaching the surface environment and the calculated LDFs are used as a scaling factor for the assessment of the adequacy of the barrier function of the repository. It is therefore essential that the basis for the LDF calculations and the range of values calculated in the uncertainty analysis should be representative of the full range of possible values.

The assessed risks to non-human biota lie well below any internationally recognised guidance levels. However, the SR-Site assessment presents potential annual risks to humans which are within a few orders of magnitude of the risk guidance level identified by SSM as being a cause for concern with respect to human safety (SSMFS 2008:37; SSM, 2009). In light of the issues relating to the handling of uncertainties within the SR-Site assessment it is possible that a further independent evaluation of particular assumptions within the SR-Site assessment would lead to estimates of potential risk to humans in excess of the guidance levels.

Quality in terms of transparency and traceability of information in SR-Site and in the associated references
As noted in Section 2.3, there are a number of presentational issues within the SR-Site documentation which affect the transparency and traceability of logic within the assessment. This has a negative impact upon the readers understanding of the manner in which primary data and the various models have been used to support the assessment. It is also often a non-trivial manner to trace the value attributed to a particular parameter and the justification for that value or uncertainty range.

Access to SKB’s parameter database, Sicada, in the main review phase should better enable the reviewers to evaluate some aspects of the parameterisation of the models used within SR-Site and also facilitate the parameterisation of any model calculations performed in calculations to support the review itself.

3.3. Recommendations to SSM

All necessary information to carry out the main review phase is probably present in the SR-Site documentation. The word *probably* is used advisedly because the traceability and transparency of the SR-site documentation is not as good as it could be. Equally, there is a wealth of information within SR-Site which clearly is presented but which has apparently not been used to any significant degree in the development and justification of models for the biosphere. Both of these issues will be addressed in the forthcoming detailed review phase. The remainder of this report contains two major appendices (appendices 2 and 3) which set out the following:

a) requests for further information and clarification intended to facilitate the broader and deeper review (Appendix 2)

b) the outcome of this preliminary review in the form of a set of topics for further investigation in the main review phase (Appendix 3).

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APPENDIX 1: Coverage of SKB reports

In this appendix the coverage of the SR-Site reports in this initial review phase is detailed in Table A1.1. This table includes an indication as to which member(s) of the team performed the review of that document, and their particular focus in the report.

Table A1.1: Summary of report coverage in initial phase review

Reviewed report	Reviewed sections
Main reports	
TR-11-01, Vol. I-III	(All) Whole report; overview + more detailed on synthesis and use of hydrological analysis in dose assessments
TR-10-09	(All) Whole report; Focus on hydrological transport for landscape model, data assessment and LDF estimation
Supporting TR-series reports	
TR-10-01	(LL) Whole report (RK) Selected data values
TR-10-02	(AW) Selective review with focus on hydrological aspects of relevance for transmitting information to LDF estimations RK) Selected data values
TR-10-03	(AW) Selective review with focus on hydrological aspects of relevance for transmitting information to LDF estimations (LL) Whole report RK) Selected data values
TR-10-05	(AW) Whole report; Focus on hydrological transport for landscape model, data assessment and LDF estimation (RK) Selective for spatial extent of surface footprint
TR-10-06	(AW) Whole report; Focus on hydrological transport for landscape model, data assessment and LDF estimation (LL + RK) Whole report
TR-10-07	(GS) Whole report (RK) Selective
TR-10-08	(LL) Whole report
TR-10-50	(AW) Selective; Transport characteristics with importance to pathways and discharge pattern transmitted to MIKE-SHE (LL + RK) Selective;

Table A1.1: Summary of report coverage in initial phase review

Reviewed report	Reviewed sections
Supporting R-series reports	
R-10-02	(AW) Whole report (RK) Selective
R-08-09	(AW + RK) Selective; Issues related to MIKE-SHE and water flux calculations
R-08-11	(AW + RK) Selective; Issues related to MIKE-SHE and water flux calculations
R-08-16	(LL) Whole report
R-09-20	(AW + RK) Selective; Groundwater flow pattern and implication for discharge pattern in biosphere and definition of biosphere objects
R-09-19	(AW) Selective; Groundwater flow pattern and implication for discharge pattern in biosphere
R-10-09	(AW) Selective; Brief review of information of importance for definition of biosphere objects and transfer coefficients in the LDF Model (RK) Selective
R-10-28	(GS) Selective
R-10-30	(AW) Brief review
R-10-37	(AW) Brief review (LL + RK) Whole report
R-04-10	(RK) Selective
R-04-67	(RK) Selective
R-06-37	(RK) Selective

APPENDIX 2: Suggested needs for complementary information from SKB

This appendix contains suggested requests for complementary information from SKB. The first part of this appendix details needs that relate to no specific report. The second part of this appendix outlines some report specific queries.

A2.1. Open areas for further information

1. **Can SKB produce a summarizing table of the important characterizing properties of risk scenarios?**
   The risk assessment is based on synthesizing a chain of models in which the most essential are near field model (comp23), far-field transport model (FRAF31 and MARFA) and LDF-values (Fig. 3-4 of TR-10-09 / Fig. 13-12 TR-11-01, vol. III). The biosphere modelling and hydrological analysis (ConnectFlow, MIKE-SHE and Darcy Tools) are used to support parameter values of the transport-dose assessment. Further, there are considerations of both continuous and instantaneous release fractions (CRF and IRF) and correspondingly there are two LDF's translating environmental concentrations to dose.

   There is a summary of essential scenario properties in Table 13-6 (TR-11-01, vol. III) for the central corrosion case and dose diagrams associated only with the IRF are given in Figures 13-17 – 13-19. It would be useful in communication on different scenarios that a more complete table with key factors characterising the sequence of sub-scenarios, i.e. based on the scenarios identified in Table 11-1 in TR-11-01 vol III (p. 570). It would be clarifying to have a collection of typical properties linking these scenarios to the dose diagrams on p. 36 TR-11-01 vol I.. Especially since there are a few key parameters determining the dose, such summarizing table would aid analyses of possible flaws and critical issues for the KBS-3 approach. Critical properties should include: a) scenario (cause and number of affected canisters), b) probabilities (e.g. like in Table 13-6), c) released inventory (IRF + CRF), d) period of release (for CRF) or flux vs. time relationships, e) mean transfer time in subsurface flows (e.g. like in Table 13-4), f) mean residence time in surface water body, g) dose transfer coefficients (IRF + CRF), h) sum of dose (maximum value or time variable).

2. **Can SKB provide results for the "LDF" time histories for each of the objects considered?**
   The time history of the LDFs (Figure A2.1) shows a good deal of structure with many sharp edges and spikes. In order to understand the objects and processes contributing to the overall LDF, it would be useful if the time series for the LDFs calculated for releases to each object in turn were available to the reviewers so as to be able to determine which of the objects is contributing most to the overall LDF values at different times in the landscape's future.

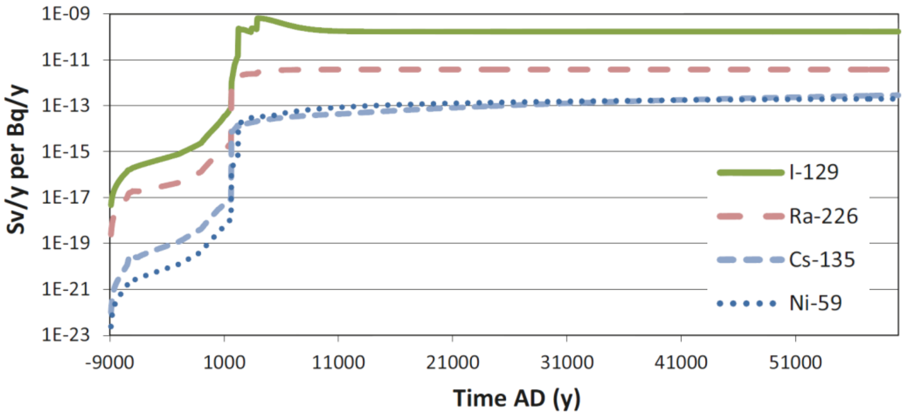

Figure A2.1: Time series of LDF values for a selection of radionuclides, showing maximum values across all biosphere objects are (Taken from the LDF report, Avila et al. 2010).

3. **Can SKB provide time series of radionuclide inventories in each of the compartments in each of the biosphere objects as a function of time?** For each radionuclide in the assessment, time series for inventories in each of the model's compartments would allow the reviewers to better understand the key spatial locations in the biosphere as a function of time. In this way the deeper review of the system can focus on the parts of the system where critical accumulations occur.

4. **Can SKB provide comparisons of the dynamics of the new Radionuclide Model and comparison with the SR-Can era models?** The new Radionuclide Model is significantly different to the models used in the earlier assessments (upto and including SR-Can). Although there is a great deal of documentation of the new model combined with the detailed interpretation of the site descriptive database there is no simple discussion of
    - i) Why the old approach was discarded,
    - ii) What advantages the new models bring,
    - iii) How results from the new model compare with those from the old approach (verification).

5. **Can SKB justify and/or validate their interpretation of the lower regolith as a single compartment?** The lower regolith is a new feature of the landscape models used for dose assessment. Essentially it represents the whole of the geosphere-biosphere interface (the spatial region between the bedrock and what was considered to be the "biosphere" in the SR-Can era models). In some biosphere objects this "compartment" is several metres in thickness whereas in many other objects it has a much smaller dimension. As the spatial domain into which radionuclides are released, and where they may accumulate, a more thorough justification of this modelling assumption is required.

6. **Can SKB provide access to the full time-dependent datasets used in the model calculations?**

This would be a great assistance to forensic and numerical reviews of the LDF Model.

7. **Can SKB clearly state the reasons for the sizes of the biosphere objects being what they are, given that the locations of the releases would be expected to be more localised within the confines of the biosphere object?**
   The biosphere objects as defined in SR-Site are taken as the contour line in a GIS system. As noted in SSI's review of SR-Can (Xu et al., 2008) release from the bedrock fractures are likely to contaminate a small area of the overall landscape object, leading to significant spatial dilution with doses to a larger potentially exposed "critical" group. SKB's own analyses have also shown that the contaminated area is generally much smaller than that of the biosphere object in which the discharge point is located. The minimum area suitable for farming coincides approximately with these smaller areas. The reason for ruling out a smaller spatial extent of the contaminant footprint is not adequately explained.

8. **Can SKB provide results for MIKE-SHE modelling for situations where emplaced drainage systems are superimposed on natural drainage patterns in the landscape?**
   Agricultural use in the landscape is dependent on good drainage because of the high water table. Areas of land have been reclaimed by ditching and the emplacement of drainage systems and this is likely to be similar to that found elsewhere (see Biebighauser, 2007; Smedema et al., 2004). The MIKE-SHE models used to define the hydrology of the landscape have not included these patterns of drainage systems, concentrating on the natural state of the system. The effects of emplaced drainage should be considered and presented.

9. **Can SKB provide access to databases for the maps of landscape objects?**
   In describing objects within the future landscape SKB have made extensive use of mapping tools, such as the ArcGIS system of ESRI. To aid understanding and to facilitate out own investigations it would be a considerable convenience if access to the datasets used in various situations were to be posiible. Example are the mapping of basins, watersheds and biosphere objects. At this stage, however, it is not practical to compile a list of requirements but if the datasets were to be accessible to reviewers a flexible response from SKB would be essential. The procedure in place upto and including SR-Can worked well (formal requests through SSM) and it is hoped that the practice might be maintained..

A2.2. Report specific queries

Below follow a series of report specific queries. This are noted for the following reports:

- TR-10-01
- TR-10-03
- TR-10-06
- TR-10-08
- TR-10-09

- R-10-37

TR-10-01

1. (Section 4.1.2, p57) Other assessments have assumed different carbon content for milk (e.g. 6.5% in the 2011 LLWR ESC assessment; Limer et al., 2011).
2. (Section 6.3.1, p144, “The oak forest (L1) in Laxemar-Simpevarp”) The text in the first paragraph seems to contradict itself. Could SKB please clarify?
3. (Section 6.3.2, p146, “Heterotrophic respiration”) It is suggested that SKB consider research performed by UK-based scientists (Dr A Heinemeyer, Dr I Hartley, Dr N McNamara) to consider the division of autotrophic and heterotrophic respiration in forest soils (and indeed other soils, such as peat, too). An example of papers to consider are:
    a. A. Heinemeyer , M. Wilkinson, R. Vargas, J.-A. Subke, E. Casella, J.I.L. Morison, P. Ineson (2011) Exploring the “overflow tap” theory: linking forest soil CO_2 fluxes and individual mycorrhizosphere components to photosynthesis. Biogeosciences, 9, 79–95, 2012.
    b. A. Heinemeyer , C. Di Bene, A.R. Lloyd, D. Tortorella, R. Baxter, B. Huntley, A. Gelsomino, P. Ineson (2011) Soil respiration: implications of the plant-soil continuum and respiration chamber collar-insertion depth on measurement and modelling of soil CO_2 efflux rates in three ecosystems. European Journal of Soil Science, 62: 82–94.
    c. A. Heinemeyer, I.P. Hartley, S.P. Evans, J.A. Carreira de la Fuente, P. Ineson (2007) Forest soil CO_2 flux: uncovering the contribution and environmental responses of ectomycorrhizas. Global Change Biology 13: 1786–1797.
    d. McNamara, N.P., Black, H.I.J., Piearce, T.G., Reay, D.S. and Ineson, P. (2008). The influence of afforestation and tree species on soil methane fluxes from shallow organic soils at the UK Gisburn Forest Experiment. *Soil Use and Management* 24, 1–7.
4. (Section 7.2.2, p152) The Beer-Lambert coefficient was not defined (in terms of its meaning).
5. (Section 7.2.2, p153, “Carbon dioxide”) How do the modelled CO_2 concentrations compare with that of the earlier Mauna Loa data (which extends to before 1999)?
6. (Section 7.2.3, p156) PAR in equation 7-3 is not defined. Is it meant to be the same are defined below equation 7-4?
7. (Section 7.2.5, p157) Although pasture is noted as an ecosystem in Table 7-2 (p155), there are no model results presented for this ecosystem, with results instead for forests and agricultural land, with crops grown on it, only. Were there no pasture results?
8. (Section 7.3.1, p163) Are these figures based upon LPJ-GUESS simulation outputs?
9. (Section 7.4,2, p170, 4th and 5th paragraphs) Given the discussion of uncertainties and model sensitivities in these paragraphs, and the note that the model was adapted to global not Nordic environments, it would be helpful to see some demonstration of a sensitivity study of some parameters upon the estimated NPP values and plant composition.
10. (Section 7.4.5, p174) If a forest stand reaches equilibrium with respect to carbon fluxes in 150-200 years, what is the implication of cutting at 100 years?
11. (Section 8.3.2, p182, last paragraph) This paragraph states that it is conservative to assume to exchange of radionuclides between wetlands and

lakes, under certain circumstances. It notes further that sometimes such an assumption is not valid. Clarification as to what has been assumed in this assessment is therefore required, given the potential implications with respect to the accumulation of radionuclides in environmental media.

12. (Section 8.5.4, p203, 1st paragraph) It is noted that using a single specific year to describe current conditions reduces variation in climate-driven fluxes. However, this does not then allow for wider variations to be accounted for, e.g. what if the year chosen was an “outlier” year?
13. (Section 10.2, p227) Interesting that the soils data presented in this Section relates to podzols, yet it is noted elsewhere (e.g. TR-10-05, Section 4.2.2, p48) that these soils have not yet developed at the Forsmark site.
14. (Section 10.4.2, p239, “The Forsmark area”) The last sentence of the first paragraph implies the existence of permanent residents, which directly contradicts TR-10-06 (Section 2.2.1, p13).
15. (Section 12.6, p309) Interaction 10:3 – “Water supply” is the means by which irrigation of surface water interacts with the primary producers in an agricultural ecosystem and is therefore the source term in such an ecosystem. It is therefore unclear as to why “Water supply” is disregarded in the radiological model. Could SKB please clarify?
16. (Section 13.3.2, p345, “Wind velocity”) If this parameter is used in the C-14 calculations then details as to the height for which this wind velocity relates to are required.
17. (Section 13.3.3, p348 and 349) Ter_z_mixlayer and Agri_z_mixlayer are values less than half of those used in Avila and Pröhl (2008). Justification for using alternative values?
18. (Section 13.3.5 , p355, "prod milk") It is stated that in the 'reference' calculations of the LDF the meat production per unit area of land was underestimated by a factor of five. It is claimed that this error is addressed and discussed in the sensitivity calculations in TR-10-06, but there is no evidence in TR-10-06 of any such analysis. The amount of meat produced would impact upon the number of people that could be supported by a given area, and as such will necessarily impact upon the LDF value. It is only by presenting the calculations that the implications of the error can be fully understood. Could SKB please provide evidence of such sensitivity calculations please?

TR-10-03

1. (Section 4.1.1, p86) In the first paragraph it is noted that the delimitation of the basins is not necessarily clear-cut, and that they have open borders to many other basins. Later in the report one of the more significant processes relating to radionuclide accumulation in a given basin is the flow through, which is dependent on the area of interaction between it and other basins (Section 9.2.4, 352). Thus, what sensitivity calculations have been performed to look at this issue? What if the basins had a different spatial configuration? (See also Section 2.2.2 of the main part of this report.)
2. (Section 4.2.1, p90, “Sediment...” paragraph) The radionuclide model has more than just the top 10cm of sediment. Care should be taken to ensure reader knows deeper sediments are considered elsewhere in the modelling.
3. In some instances the data collected, or model used, have a high spatial resolution (e.g. macrophyte data, with transect data converted to a data point every 1 m (§4.3.1, p94), with biotic ecosystem model on a 20 m x 20 m grid (§4.3.1, p94), and with the high resolution hydrodynamic model on a 2 nautical mile x 2 nautical mile grid (§9.2.2, p304). A clear demonstration as to how the data and models fit together would be helpful (see also Section 2.4 of the main part of this report).

4. (Section 4.4.7, p125) The results here need clarifying, as the current text is not clear.
5. (Section 4.4.7, p125, Figure 4-25) Basin 121 has the biggest discharge. Noting that this (or rather a sub-basin thereof) tends to have the highest LDF's associated with it, if and how does this high discharge rate effect that?
6. (Section 6.6, p241, first paragraph) Although small differences in the conversion factors may not greatly influence the mass balance, what are the potential implications for the radiological assessment?
7. (Section 6.6, p241, last paragraph) Do non-well balanced mass balances have any implications for the radiological assessment?
8. (Section 7.2.2, p250, paragraph below Table 7-2) What is the timescale of these climate effect induced changes versus the timescale / time –step of the (radiological) model?
9. (Section 8.1, p267, 4th paragraph) Do processes of ecological importance but not radiological include any which might affect non-human biota?
10. (Section 8.6, p281) IM elements 1:3, 1:4 and 1:5 are non-empty, and indeed highlighted dark yellow, yet are not discussed here.
11. (Section 9.1, p345) Here a large number of models are introduced. How do the ecosystem and radionuclide models implemented in MIKE relate to the LDF model? (See also Section 2.4 in the main part of this report for a wider discussion of the presentation of models in SR-Site.)
12. (Section 9.2.2, p348) How does the spatial scale of the hydrodynamic model compare with that the scale of features within the marine system? Is there a point within each of the 52 biosphere objects?
13. (Section 9.2.2, p349, first bullet) How does the resolution of the mesh compare with the 2 nautical mile grid?
14. (Section 9.2.3, p351) Where are the modified river run-off, salinity and temperature field data for the BC years presented?
15. (Section 9.2.3, p351, "Ice") Is the assumption to disregard ice cautious or does it reduce concentrations of radionuclides?
16. (Section 9.2.4, p352, "Basin flow") Has sensitivity to cross-sectional areas between basins been studied, or possibly effects of different delimitations for the basins? (See also comment above on Section 4.1.1, p86, and Section 2.2.2 of the main part of this report.)
17. (Section 9.2.4, p356) Why were the simulations presented in Sections 5 and 9 not based upon the same set of data?
18. (Section 9.2.5, p358) What is the 'Water Forecast Model'?
19. (Section 9.3.4, p365, "Spatial biomass distribution") Which two basins did not receive radionuclides via groundwater? Given two of these basins have high LDF's associated with them, this clarification would be helpful.
20. (Section 9.4.2, p369 and 370) Respiration is apparently not considered as a loss mechanism for radionuclides (p369) yet it is shown in Figure 9-16 (p370). Why?
21. (Section 9.4.4, 378) How fair an assumption is biomagnification? Note that this leads to particular conclusions about the BCF calculated in this section (see also Section 9.5, p383, 8th paragraph), and those which have been used in the assessment TR-10-07 (Nordén et al., 2010).
22. (Section 9.5, p383, 4th paragraph) Is it possible to validate a model with data from the future?
23. (Section 9.5, p383,7th paragraph) Where is the sensitivity analysis reported?
24. (Section 9.5, p383, 8th paragraph) The C-14 results are not reported. Why?
25. (Section 10.4.7, p389) Table 10-2 is the first and only place sub-basin 121_1 is mentioned. Why does this report (and indeed many of the others) not necessarily discuss the division of basin 121 into 3 sub-basins?
26. (Section 10.15.1, p425) More justification than "probably" would be appreciated.

TR-10-06

1. (Section 2.2.1, p13) Is Miliander et al. (2004) the most up-to-date reference for current land use practice and occupation of the area? A better discussion of historical agricultural practices would be useful in terms of the possibilities of the surface environment. (See also comment 14 on TR-10-10, which relates to Section 10.4.2, p239, “The Forsmark area” of TR-10-01.)
2. (Section 3.2, p27) The justification for all of the exposed groups food coming from the site is clearly a cautious one. However, there needs to be better justification for such a diet, as clearly it is not balanced to assume that, e.g. if an object was totally aquatic, that all the group ate was fish and other aquatic organisms.
3. (Section 3.2.3, paragraph 3, p28) Clarification of the last sentence is required. As written, the implication is that when agriculture is possible that 20% of the terrestrial area within an object is used for natural food stuffs, 20% for crops, 20% for root crops, 20% for vegetables and 20% for fodder.
4. (Section 3.3.1, p31, “Exchange with the atmosphere”) Are the potential impacts associated with the inhalation of other radionuclides not also considered? There are non-zero dose coefficients given for many in TR-10-07 (p59). For example, Ra-226 is reported as being a large contributor to exposure. What about the inhalation of Rn-222?
5. (Section 3.3.1, p31, “Exchange with the atmosphere”) The parameters for zero displacement height are not given in Nordén et al. (2010) as claimed. This potentially has implications for the C-14 aspect of the assessment if these data differ from that reported in R-08-16 (Avila and Pröhl, 2008), which is based on literature data only. It is therefore requested that this data be shown. (See also comment 16 on TR-10-01, which relates to Section 13.3.2, p345, “Wind velocity”, of TR-10-01.)
6. (Section 3.5, p33, first paragraph) The documentation needs to explain the duration over which a “unit pulse” is release to the biosphere object for the derivation of LDF pulse values. Is it a single instantaneous release? Or does it occur over a single year? In particular, later in the report (Section 5.1.1, p46) the effect of the duration of the pulse upon calculated potential impacts is studied. It is the interpretation of this reviewer that the sensitivity analysis considers the release to be 1Bq over 1y through to 1Bq over 1000 y, which implies a release of 1 Bq/y for 1 year to 1/1000 Bq/y for 1000 years. Even if this is not the case, further clarification would certainly be helpful.
7. (Section 4.1, p39, Table 4-2) Why does the LDF for C-14 not differ for the permafrost conditions as compared to the interglacial and global warming climate conditions?
8. (Section 5.1.1) What is the purpose of doing simulations of releases (continuous or pulse) occurring at 9000BC?
9. In Section 5 the captions associated with figures that show permafrost conditions imply that those lines show an averaging of parameters. Are they not in fact results associated with those conditions?
10. (Section 5.1.1, p54, “Global warming conditions”) – A clearer cross reference to Table 4-2 would be helpful.
11. (Section 5.3.1, p77) The baseline LDF’s for I-129 and Se-79 appear to be also outside of the 1st and 3rd quartiles.

TR-10-08

1. (Section 3.7.2, p28) The model/equation for implementing weighting factors (w_R) for alpha, beta and gamma radiation in the calculation of dose conversion coefficients for biota is not given. This report would benefit from inclusion of the equations used to derive DCC_{ing} and DCC_{ext}, which would show how w_R is used. If these equations are not included a reference to where these equations could be found should be given.

TR-10-09

1. (Section 2.1.2, p14) Is it made clear how the high resolution models have been used in the assessment? (See also Section 2.4 in the main part of this report.)
2. (Section 4.2, p37) Some data on what diet is assumed over time would be helpful, and to know what contributes most to a given LDF (may or may not be correlated with the most sensitive parameters as shown in Appendix C of TR-10-06).
3. (Section 5.1.2, p43) States regolith divided into seven layers, yet only 3 used in the biosphere model. Some further discussion on this would be appreciated.
4. (Section 6.2.3, p58) The third and fourth paragraphs seem to contradict. The third paragraphs states that the sea will not leave the area until 30,000 AD, yet in the fourth paragraph it is stated that the marine module of the model is run only until 11,500 AD. Could SKB please clarify?
5. (Section 6.2.4, p60) Is there any information presented on how the area of a talik might compare with that of a biosphere object? This has implications with respect to the assumption of a release to an object being automatically homogeneously spread through the lower regolith of that object. (See also Section 2.2.2 of the main part of this report.)
6. (Section 6.3.2, p67) Given boulder filled land is thought to be difficult to cultivate, how is it treated within the assessment with respect to land use? Is all land assumed to be suitable for some of vegetation to grow (i.e. boulders disregarded)?
7. (Section 7.1.1, p72) That the size of a discharge area receiving groundwater from the repository will shrink over time might be seen to go against the assumptions of homogeneous release within a biosphere object (presuming an object can and will at times contain aspects of more than one ecosystem type). Could SKB clarify? (See also Section 2.2.2 of the main part of this report.)
8. (Section 7.1.2, p72) Further justification for disregarding discharges that might reach their “discharge point” during a glacial climate domain period required. Are the radionuclides associated with any such discharge assumed to be lost from the system? Can they not accumulated at that location until such time as the glacier retreats and they can reach the surface?
9. (Section 7.2.4, p80) In the last paragraph it is stated that radionuclide decay is disregarded, but that it would most affect Ra-226 and Sr-90. Given Ra-226 is one of the more important radionuclides in this assessment, some discussion of the potential implications associated with considering radionuclide decay of Ra-226 (and parent and daughter radionuclides) might be expected.
10. (Section 7.3.1, p81, and Section 7.3.4, p85) The first paragraphs of these sections imply biosphere object area can change with time (see also comment associated with Section 7.1.1, p72). Clarification on this required. Would access to the SKB database aid the clarification on this matter?
11. (Section 8.6.3, p96) Further information of how food consumption rates vary over time would be useful. (See also comment 2 on TR-10-06.)

12. (Section 8.7.1, p97) It is not clear if actual fluxes of radionuclide to the surface were used in the evaluation of the importance (or not) of connectivity of groundwater between objects, or whether a flux of 1 Bq/year to each object was assumed.

R-10-37

1. (Section 1.1, p6) This report states that the IAEA FEP database has been used for the biosphere FEP's, yet the overarching SR-Site FEP report (TR-10-45) does not mention the IAEA FEP database at all, and instead refers to the NEA database only. This issue also arises in other SR-Site reports (e.g. TR-10-09). Some clarification therefore required in this area.
2. (Section 5.9, p23) Further justification for using a non-classical definition of groundwater required.
3. (Section 5.10, p23) It should be made clear whether, as is implied by the other aspects of this report, wells are included in the diagonal element "Surface water". This has implications with respect to drinking water sources for animals and humans.
4. (Table 6-1, p26) Under "Water supply" it should be made clear that irrigation is included here.
5. (Section 6.1.5, p30 and 6.2.4, p31) The use of "Uptake" rather than "Water use" for exposure as a result of drinking water is somewhat confusing. Drinking water might be better placed in the "Consumption" process, or listed in its own right.
6. (Section 6.3.9, p33) State irrigation explicitly.
7. (Section 6.4.2, p34) Does the grouping of advective and diffusive processes under one process within the IM make any difference to the definition of the conceptual model(s) used in this assessment?

APPENDIX 3: Suggested review topics for SSM

In the main report, a series of issues and related open questions that might be addressed in the main phase of the review were identified (Sections 2 and 3). These issues, and questions that could be asked to address these issues, are as follows:

1. Suitability of the new LDF Model
2. The dynamics of the new LDF Model (as expressed by the transfer coefficients in the new Radionuclide Model)
    a. How well do transfer coefficients comply with a physical representation of flow and transport?
    b. How important are certain, critical transfer coefficients in determining environmental concentrations?
    c. Is the low surface water circulation of the Forsmark site reflected in the LDF estimation?
3. Will the size of the biosphere objects lead to an underestimated dose?
4. Numerical review of the alternative interpretations of the biosphere model and their influence on uncertainties in the evaluation of the LDFs
    a. Can the extremely low runoff coefficient of the proposed Forsmark site be motivated from a regional hydrological perspective and selection of site? Is the low surface water circulation of the Forsmark site correct?
5. Are hydrological time series durations less than 10 years sufficient for the water balance (R-10-02), transport modelling (R-10-30) and LDF estimations (TR-10-06, TR-10-09)?

If further review studies relating to these issues indicate that they are of great importance SSM may be in a position to ask SKB for further research activities or clarifications.

A3.1. Suitability of the new LDF Model

A review of the derivation of FEPs and the conceptual models used in the new LDF Model is required. The new model structure is designed by SKB for all biosphere eventualities. The FEP basis for this should be understood by comparison with the structures in the GEMA suite of models (Kłos, 2011; Kłos, Shaw & Limer, 2011).

A3.2. Dynamics of the new Radionuclide Model

The information from the geosphere models (ConnectFlow, Darcy Flow) and surface hydrological models (MIKE-SHE) that is transferred to the model used for dose assessment is to a high degree limited to:

- Transfer coefficients between biosphere objects
- Size of biosphere objects

Further, the final scenario synthesis (TR-10-09 and TR-11-01, vol III, section 13.2 and 13.5.4) is based on these Landscape Dose Factors (LDF) that are derived for either a continuous 20,000 y release in biosphere objects or a pulse. This implies that the essential information from the basic modelling retained in the final dose assessment and safety assessment is limited and can be clearly accounted for. The parameter summary in Appendix B of TR-10-06 lacks most transfer coefficients related to surface water modelling in R-10-02, which prohibits an overview of the final model set-up used to estimate the LDFs.

On p. 25 in TR-10-06 it is described how transfer coefficients TC [y^{-1}] in the linear flux relationships (F = TC x A) is estimated from the modelling of primarily waterborne transport. Fluxes in the Radionuclide model are generally linked to water fluxes, gas fluxes and particle fluxes (p. 92 TR-10-09), but the waterborne transport should dominate the transport. The Waterborne transport is represented using results from MIKE-SHE (TR 10-06, p.19; R-10-02). However, there is no clear description in neither R-10-02 nor TR-10-06 how the transfer coefficients and associated model compartment sizes used in TR-10-06 are derived specifically from the release and transport conditions applicable to leaking radionuclides. Parameter summary in Appendix B of TR-10-06 seems to be missing most transfer coefficients related to surface water modelling in R-10-02. References for parameters other than transfer coefficients are: TR-10-01, TR-10-02, TR-10-03, TR-10-05 and TR-10-07.

In Table 5-2 of TR-10-06 there are transfer coefficients given in terms of different water fluxes in units [mm/y] which has been derived from Fig. 11-2 in TR-10-02. These fluxes are estimated using MIKE-SHE and it seems that Figure 6-7 in R-10-02 could be the reference that in more detail accounts for the water flux estimation. In this figure we can see that the deep groundwater flux is close to zero, whereas the shallow groundwater flux is estimated to be 48 mm/y. So it seems that the transfer coefficients are estimated as an areal average (for the biosphere object) and not for the trace particles that represent leakage from the repository.

The more intense mixing of water closer to the surface is demonstrated in the SKB regional groundwater modelling (R-09-19, Figure 5-15; R-06-64). About 90% of all groundwater exchange occurs in these soil strata in Sweden according to Lars Marklund’s doctoral thesis (2009). Only 10% of the water mixing goes into bedrock. Therefore, the estimated water flux averaged biosphere objects should generally lead to a significant overestimation of the transfer coefficients along the stream tube (in the surface environment) along which radionuclides are migrating. This faster migration would lead to less accumulation over time and lower environmental activities as well as doses to humans.

Review topics which might address this issue are listed below.

a) How well do transfer coefficients in the Radionuclide Model comply with a physical representation of flow and transport?

In order for the compartmental model used in the dose assessment modelling to be applicable to a combined transport problem through the geo- and biospheres including their interaction, the essential characteristics of transport need to be represented. For the main scenario with leakage from one canister, the transport in the geosphere and the discharge in surface water is found to be well confined to a few tens of meter in length scale (TR-10-05). The further transport follows the stream network, which means that the turnover of surface water is important for the development of radioactivity over time (TR-10-05).

A reasonable representation of the migration of radioactivity in the biosphere is schematically shown in Figure A3.1. Leakage can be defined in terms of a release flux over time, $q_L(t)$ [Bq/s], where t = time [s]. The spreading occurs primarily in a stream tube (blue object in Fig. A3.1), which is well confined because smaller groundwater circulation cells arise closer to the ground surface (Tóth, 1963; Marklund, 2009) and a converging flow for deep groundwater discharge (which is consistent with the findings of SKB, R-10-02 and TR-10-05). Further, one can represent the transport in the geosphere by a residence time probability density function $g_{Geo}(t)$ that is nuclide-specific (due to sorption properties). This $g(t)$-function can be estimated from information in the radionuclide transport analyses using COMP23, FARF31 and MARFA (TR-10-50). Hence, we can write the flux into surface water $q_{SW}(t)$ as convolution on the form;

$$q_{SW}(t) = q_L(t) * g_{Geo}(t)$$

where $*$ is the convolution operator. The flux out of the surface water could also be expressed as a similar convolution $q_{BS}(t) = q_{SW}(t) * g_{SW}(t)$, but it might be more useful to use mean residence time of the surface water τ [s]. The inventory in surface water at equilibrium (as analysed for the continuous release scenario in TR-10-09) can then be expressed as $I_{SW} = q_{SW}.\tau$ [Bq]. A comparison can be made for such estimation of the environmental activity in a stream tube representative to the leakage and for a compartmentalized analysis of spreading in the biosphere.

The steady-state activity flux in [Bq/s] in the stream tube between bedrock and Quaternary deposits requires that $q_{SW} = Q_{BR}C_{D,BR} = Q_{QD}C_{D,QD}$ where Q_{BR} [m^3/s] is the discharge in the stream tube in bedrock, Q_{QD} [m^3/s] is the discharge in the stream tube in Quaternary deposits, the dissolved phase activity concentration $C_D = C_T/(1+K_D)$ [Bq/m^3] and K_D is the partitioning factor for dissolved and adsorbed phases [-]. In order to obtain the physically representative activity concentration in the lower regolith compartment, the discharge has to be the same as that of the stream flow leading radionuclides from the bedrock to the overlying soil strata. The rate coefficient is obtained by dividing by the (arbitrarily or otherwise) selected volume of the receiving compartment $\alpha = q_C/I_{D,QD} = Q_{QD}/V_{QD}$, where $I_{D,QD}$ is the total accumulated inventory of activity under the steady-state conditions and V_{QD} is the selected volume.

b) How important are certain, critical transfer coefficients in the Radionuclide Model in determining environmental concentrations?

The influence of the transfer coefficients on the estimation of LDF-values can be evaluated from sensitivity analyses using compartmental models similar to the one implemented in SKB’s LDF Model. Especially, a purpose could be to use realistic values of the rate coefficient representing migration of radionuclides that comes with deep groundwater into the regolith low and further on along its transport pathway (stream tube).

c) Is the low surface water circulation of the Forsmark site reflected in the LDF estimation?

The low surface runoff found in R-10-02 for the present state is somewhat larger for future states. However, generally the evaporation stands for a major part of water from the area, which leaves a large portion of the radioactivity accumulated in the area. More review is needed to clarify how the low surface water turnover is represented in terms of transfer coefficients of SKB’s Radionuclide model.

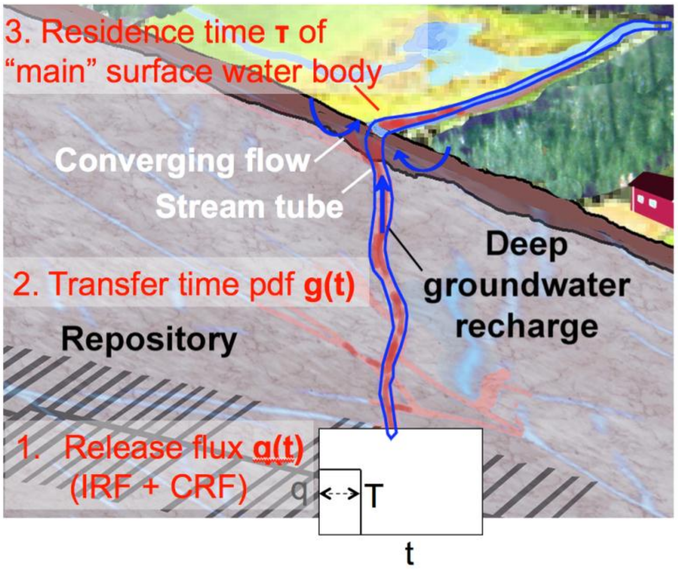

Figure A3.1 Schematic of transport of radionuclides along a stream tube (blue object) from the repository, through the geosphere and into the biosphere.

d) What are the possible dynamics of transport and accumulation of radionuclides in the near-surface hydrological system?

Accumulation in natural ecosystems is a key feature of the biosphere as represented in SR-Site. The conversion of "accumulation ecosystems" to agricultural land can occur at any stage of the landscape development in times after transition to the terrestrial phase. An important question to address in the main review phase is how long such systems need for the soil concentrations to reach a dynamic steady state and what the maximum soils concentration in agricultural soils can be. An alternative conceptual model should be implemented and these areas addressed, taking into account the role of redox variability in the system and details of anthropogenic factors such as drainage and soil conditioning.

A3.3. Will the size of biosphere objects lead to an underestimated dose?

In TR-10-05 p. 125 it is mentioned that the minimum area used for agriculture is 10^4 m^2 (1 ha), which is the smallest unit that can sustain a small agricultural family. The report further describes how landscape units suitable for agriculture (> 1 ha) are identified as function of (future) time together with the number of people that can live on farming the land. These studies indicate that the areas that potentially can be contaminated under different release scenarios are important for the safety assessment with respect to radiological risk.

The analysis of discharge areas in the same report (section 6.2) identifies the distribution of discharge points in the landscape using either Darcy Tools (R-09-19) or ConnectFlow (R-09-20 and R-09-21) depending on climate scenario and system component subject to the analysis. The distribution of discharge points was analyzed for multiple release points representing all canisters, whereas the actual spreading and contaminated surface area (and depth) was not addressed in this modelling phase. Advective-dispersive modelling is performed using flow paths from ConnectFlow as boundary source locations for MIKE-SHE modelling of the surface environment (top 200 m of the ground). Both multiple and single location release are analysed (section 6.3.2). An example of the (equilibrium?) concentration in a lake from a single source location is shown in Figure 6-25 (TR-10-05, p. 169). Here it is seen that the area that obtains more or less the same concentration/activity as the constant source at the lower boundary is less than 100 x 100 m^2 (ie, 1 ha). The total area of significant activity is 3 ha after 65 years of simulation. It is also concluded that the surface water turnover (stream network) is important for further spreading of the activity over time.

The transformation of radionuclide fluxes into the surface water and radiological dose was performed using landscape dose factors (LDF) (TR-10-06). The LDF's are estimated using the SKB's LDF Model and biosphere objects. The landscape is divided in three different geometric features or areas; watersheds, basins and sub-catchments (TR 10-05, p. 193). These areas do not necessarily reflect the areas of contamination analyzed using MIKE-SHE nor the minimum area usable for agriculture. There is statement for this procedure (TR-10-05, p. 202):

> The discharge points cluster in the landscape in typical areas such as lakes, wetlands, streams and by the sea shore. By using these clusters as evidence for a discharge area, the biosphere objects are identified.

Since the biosphere object is generally much larger than the actual discharge area as well as the minimum area suitable for farming, there is a possibility that the dose arising for a farming family is underestimated by using the biosphere object as a unit area.

Review topics which might address this issue are listed below.

a) Suggestion for review topic 1

The effect on LDF-values can be estimated from compartmental models similar to that used by SKB, eg the GEMA models (Kłos, 2010; Kłos, Limer & Shaw, 2011). A reduced area of discharge associates also with a smaller area over which the water flux is averaged (see topic 1). This smaller area associate with a lower rate coefficient will also increase accumulation.

b) *Suggestion for review topic2*

A similar process that can magnify the activity when radionuclide migrate from the bedrock to Quaternary deposits is sorption in soils. Further, review is needed how geochemical information is transmitted to the LDF Model for the LDF estimations. For steady-state radionuclide transport there is a certain relationship between the concentrations in bedrock and soil strata. Since the discharge along a stream tube is constant, the activity concentration magnifies according to $C_{D,QD} = \frac{1+K_{D,QD}}{1+K_{D,BR}} C_{D,BR}$. It is unclear how SKB's representation represents this magnification of radioactivity that is caused by sorption to soil (which is much higher than in bedrock).

A3.4. Numerical review of alternative biosphere conceptual/mathematical models and their influence on uncertainties in the evaluation of the LDFs

Modelling in SR-Site is carried out at the level of landscape objects. Following the preceding review topics the GEMA suite of modelling tools (Kłos, 2010, Kłos, Shaw & Limer, 2010) should be applied to reinterpret the site data with the aim of investigating:

a) The scope for smaller sub-areas within the biosphere landscape objects to accumulate activity with smaller associated critical groups
b) The potential for long-term accumulation in natural ecosystems, how high can activity concentrations in the natural soils be, depending on the approach to steady-state conditions in the biosphere system
c) The consequences for dose in natural and agricultural ecosystems of the alternative accumulation models
d) The need to include additional FEPs for selected radionuclides with significant redox properties and/or soil-plant interactions (for example ^{79}Se, ^{99}Tc, ^{129}I and, as a benchmark ^{135}Cs and the ^{238}U series including daughters, especially ^{226}Ra, ^{210}Pb and ^{210}Po).

A3.5. Can the extremely low runoff coefficient of the proposed Forsmark site be motivated from a regional hydrological perspective and selection of site?

The hydrological modelling of the site originally reported in R-08-08 and repeated in R-10-02 and TR-10-05 in both the present and future states suggests that the site investigation area has extreme water balance conditions. The reporting states that "the mean annual precipitation is 533 mm and the total annual evapotranspiration was 405 mm", which would imply a runoff coefficient of 0.24. Based on the numbers presented in the Figure 4-36 and including both Hortonian flow directly to the sea as well as stream runoff, the runoff coefficient is around 0.34. These extremely low values compared to the prevailing hydrological conditions of Sweden (cf. Figure A3.1) gives raise to questions on the uncertainty of data (see issue 3a), appropriateness of the site (see issues 2a and 1a) and how the site compare with other regional conditions (discussed here).

SKB discusses the effect of the drawdown of the groundwater surface caused by the SFR facility, which has a particular effect on creating a depression cone of the groundwater surface. According to the Forsmark SDM, Hortonian overland flow stands for 12% of the runoff (but depends on which calibration is referred to), which is an interesting result from a scientific point of view. The runoff coefficient seems to be mostly controlled by relatively large evapotranspiration even for future states.

Runoff in general increases with distance to the coast, overall slope of the watershed and increasing surfaces that sustain evaporation. For small watersheds close to the coast it is likely that Hortonian overland flow and groundwater flow can stand for a significant portion of the water export from the watershed directly to the sea. Figure A3.2 shows the runoff coefficient as the quota of annual runoff and annual precipitation for 1001 watersheds in sizes ranging from 14 to 9791 km^2 covering the entire surface of Sweden. The results are derived by SMHI by use of HBV-

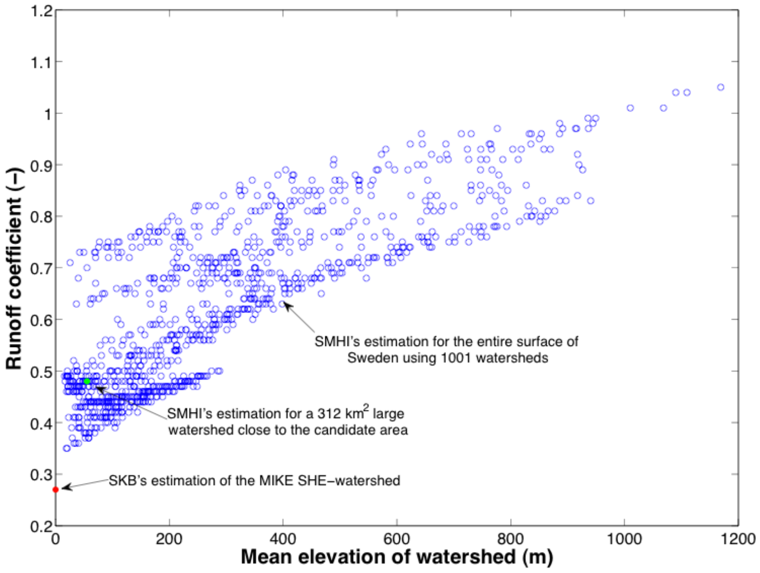

Figure A3.2 Runoff coefficients obtained from HBV interpretations of discharge and precipitation measurements applied to 1001 watersheds covering the entire surface of Sweden (results obtained from SMHI). In this diagram the average height of the site investigation area is assumed to be zero.

modelling of the water balance constrained by measured discharge in a large number of stream gauging stations and extrapolated precipitation for the watersheds. As can be seen in the figure the runoff coefficient range from 0.35 to somewhat more than unity for small watersheds in the Scandinavian mountain range. The reason for the runoff coefficients larger than unity is due to uncertain precipitation information in most minor watersheds with only a few rain-gauging stations. The green dot represents the result for a 312 km^2 watershed that contains the region subject to SKB's investigation. The red dot is the runoff coefficient found in the Forsmark site investigation, which is clearly much lower than found in previous investigations and is based on a MIKE SHE model supported by ConnectFlow (R-10-02).

SKB's own investigations (R-06-64, R-04-31) indicate a significant effect of the super-regional flow on the local dis- and recharge patterns. These investigations are consistent with the recently published PhD thesis of Lars Marklund (2009). A small surface water turnover implies accumulation of radioactivity that discharges from bedrock (see points 1a) and 2a) above).

Review topics which might address this issue are listed below.

a) Is the low surface water circulation of the Forsmark site correct?
It is warranted with a further analysis of the general importance of the surface water turnover on accumulation of radioactivity and especially to scrutinize in more detail why the Forsmark area deviates from the regional hydrological behaviour.

A3.6. Are hydrological time series durations less than ten years sufficient for water balance (R-10-02), transport modelling (R-10-30) and LDF estimations (TR-10-06, TR-10-09)?

The data sets used for the hydrological modelling includes meteorology, surface water levels, surface water discharge and groundwater levels (TR-10-05, p. 53) and these are mainly covered in previous reports of the Site Descriptive Model (R-08-08; R-08-10 ; R-08-11). Most of the hydrological time series that are based on automatic sampling, such as eg, flow adjusted sampling frequency in streams, were established in 2004. Groundwater level fluctuations in wells have been manually observed over a longer period. Meteorological data series as obtained from SMHI (two are inside the candidate area, section 2.2.1 in R-08-08) are also longer and, thus, of significantly better quality with respect to the temporal statistics.

However, the measurements of discharge and surface water level are relatively short without clear motivation or references to analyses that indicate that this leads to acceptable uncertainties in the data and in model predictions based on the data. Hydrological time-series commonly exhibit auto-correlations with great importance for estimating statistical properties such as the mean and variance (uncertainty) (Ballesta, 2005; Zhang, 2005). For instance, because of different frequencies in climatic conditions decadal long variations in discharge time-series can be identified (Wörman et al. 2010), which implies a slow decay of the uncertainty estimates (Wörman, 2011) as well as extremes that potentially could be decisive to water balance in an area such as that selected by SKB (see issue 2b). There is no analysis on the uncertainty of hydrological predictions based on the statistics in hydrological time-series such as auto- and cross-covariance (R-10-02; R-10-30).

The uncertainties discussed in TR-11-01 mainly concern scenario probabilities rather than uncertainties due to incomplete sampling of time-series. The estimations of LDF’s include analysis of parameter uncertainty (TR-10-09), but the relationship between time-series statistics and hydrological model estimates of transfer coefficients (R-10-02) is not clear (see issue 1a). In section 9.1 of TR-10-09 it is stated that all model parameters are described as a “best estimate” and a probability density function. References for the derivation of given to reports TR-10-01, TR-10-02, TR-10-03, TR-10-05 and TR-10-07. The water fluxes (for the inter–compartmental transfer coefficients) are discussed in section 9.2.5 of TR-10-09, but the references to R-10-02 and TR-10-02 do not lead the reader to a clear description of how uncertainty estimates were performed and how the short-time series were taken into consideration. On the section on parameter uncertainty in TR-10-09 (section 12.4) there is reference to report TR-10-06 concerning correlation structure of parameters. In TR-10-06 there is a discussion on correlation between parameters that would concern “time-independent” parameters (TR-10-06, p. 73), but it is not shown how these were estimated except that a “reviewer panel checked the reasonability of data” (TR-10-09, p. 99). Finally, “the Monte-Carlo sampling did not incorporate correlations between parameters” (TR-10-06, p. 87) implying that uncertainty estimates of LDF’s did not account for parameter correlations.

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The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 270 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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