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Project SAFE

Scenario and system analysis

Svensk Kärnbränslehantering AB

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Foreword

This report describes the methodology for and results of developing a qualitative system description of the SFR disposal system. The main authors of the report are Johan Andersson, JA Streamflow AB, and Kristina Skagius, Kemakta Konsult AB, but many persons have been involved in the work and contributed to the results. These are listed in Appendix A.

Abstract

This report describes the scenario analysis conducted within the SAFE project, which has resulted in a qualitative description of the SFR disposal system. The scenario report generally documents and justifies the selected system description model, selected scenario initiating events and conditions, the general selection of the type of quantitative evaluation models to be used and the information flow between models. The development of a system description model is done by groups of experts through a series of documented meetings, utilising the Interaction Matrix methodology. This methodology involves a systematic identification of processes and interactions between these processes occurring in the system and documented expert judgements of the relevance of these processes and interactions for the evolution of the system. The SFR disposal system is described by three coupled matrices: one for the repository vaults, one for the geosphere and one for the biosphere. The contents of the matrices have been audited against different international lists of FEPs (Features, Events Processes) in order to ensure that all FEPs that are relevant are considered in the matrices. These lists of FEPs as well as experiences from past and recent SKB assessments have also been used in the selection of scenario initiating events and conditions. The system description in terms of interaction matrices cannot directly be used in the quantitative assessment. However, the system description can be used to point out the important interactions and how they should be treated in the quantitative analyses and to check that this is done. For this purpose an information flow diagram has been used. This diagram graphically displays the information exchange between the different analyses selected for the quantitative assessment of the evolution of the disposal system.

Sammanfattning

I denna rapport beskrivs det scenarioarbete som bedrivits inom projekt SAFE och som resulterat i en kvalitativ beskrivning av SFR:s förvarssystem. Den systembeskrivnings-modell som tagits fram är dokumenterad och motiverad i föreliggande scenariorapport tillsammans med valet av scenarioinitierande händelser. Dessutom redovisas den typ av modeller och analyser som valts för den kvantitativa utvärderingen samt det utbyte av informations som behöver ske mellan de olika kvantitativa modellerna och analyserna. Den kvalitativa systembeskrivningen har arbetats fram via en serie expertgruppmöten enligt en metodik baserad på interaktionsmatriser. I denna metodik ingår en systematisk identifiering av processer och interaktioner mellan processer som verkar i systemet samt dokumenterade expertbedömningar av betydelsen av dessa processer och interaktioner för systemets utveckling. Tre kopplade matriser används för att beskriva förvars-systemet i SFR, en för själva förvaret, en för geosfären och en för biosfären. Innehållet i matriserna har granskats mot internationella listor med FEPs (Features, Events, Processes) för att så långt som möjligt säkerställa att alla relevanta FEPs är omhändertagna i matriserna. Dessa listor med FEPs har också använts tillsammans med erfarenheter från säkerhetsanalyser genomförda av SKB under senare tid för att välja scenarioinitierande händelser. Systembeskrivningen i form av interaktionsmatriser kan inte direkt användas för att göra kvantitativa analyser. Däremot kan den användas för att visa vilka interaktioner i systemet som är viktiga och hur dessa bör tas om hand i den kvantitativa analysen samt för att kontrollera att detta genomförs. För detta ändamål har ett informationsflödesdiagram använts. Detta diagram beskriver grafiskt det informationsutbyte som sker mellan olika modeller och analyser i den kvantitativa bedömningen av förvarets utveckling.

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Appendices:

1 Introduction

This report describes the scenario analysis conducted within the SAFE project and is thus one of the supporting documents (“key references”) to the SAFE safety assessment report. The report generally documents and justifies the selected system description model, selected scenario initiating events and conditions, the general selection of the type of quantitative evaluation models to be used and the information flow between models. Data selection, definitions of calculation cases as well as assessment results when evaluating the different scenarios are provided in other reports.

1.1 Aim and background

The SFR-1 repository for final disposal of low-level radioactive waste produced at the Swedish nuclear power plants and low level waste from industry, medicine and research obtained operational license in March 1988. The aim of the project SAFE (Safety Assessment of Final Disposal of Operational Radioactive Waste), /SKB, 1998/, is to update the 1987 Safety Report /SKB, 1987/ and the 1991 Deepened Safety Analysis /SKB, 1991/ of SFR-1 and to prepare a safety report by the year of 2001.

A crucial element of any safety assessment is to describe the assessed facility (*system model description*) in a way such that its future evolution can be analysed and to identify which future events and conditions (*scenario selection*) that may affect this evolution. The future evolution is analysed with models. *Models* and *information exchange* between models need to be selected such that they represent the general system model and such that they are able to assess the impact of selected future events. Over the years, SKB has developed a structured approach for handling these matters.

As a part of the deepened safety analysis of SFR-1 /SKB, 1991/, a methodology to systemise and visualise all Features, Events and Processes (FEPs) that can influence the performance of the repository in the future was applied /Skagius and Höglund, 1991/. Influenced by the methodology outlined in a joint SKI/SKB scenario development project /Andersson *et al*., 1989/ an initial list of FEPs was compiled, containing phenomena that potentially could influence the long-term performance of the repository. From this list, FEPs judged to belong to the Process System (i.e. FEPs required for description of the performance of the system components and radionuclide behaviour in the repository system) were selected. The Process System was graphically displayed in a reversed event-tree structure, showing how FEPs are linked according to cause and effects. The graphical description of the Process System was used as a base for a written description of the system in terms of transport pathways for radionuclides and initial state and evolutionary processes in the different barriers. In addition, a screening out of phenomena was made and motivations for judging the out-screened phenomena to have negligible consequences for the performance of the system were given in text. The graphical and written description of the components of the Process System and their interrelations were used as a base for describing the radionuclide release from the repository for different scenarios.

In the 1992 review /SKI/SSI, 1992/ SKI and SSI found the scenario work to be satisfactorily carried out in that the most important scenarios from a safety point of view were identified and described. However, some criticisms were given to the coupling between the scenario work and the selection of calculation cases. The reviewers also wished a more realistic approach (see further discussion in SKB /1998/).

Since 1992 there has been significant advances in scenario methodology. For example SKI developed the Process Influence Diagram approach /Chapman et al., 1995/ for the SKI safety assessment project SKI SITE-94 /SKI, 1996/. In parallel, SKB developed the Interaction Matrix Methodology, which is the basic device in the Rock Engineering Systems (RES) approach /Hudson, 1992/, for identification and structuring FEPs in the Process System. A comparison of the PID and the RES methodologies revealed that the methodologies in general are very similar /Eng *et al*., 1994/, but that a combination of parts of the PID and RES methodologies was likely to be a promising approach. As a result of this comparison of methodologies a combination of these methods was tested by SKB as a part of the preparation for the forthcoming performance and safety analyses /Skagius *et al*., 1995/. Common to all these methodologies is the structured use of expert judgement, the focus on interaction between processes and the systematic documentation procedures.

There has also been rather much international development in the field of scenario development. Notably, the OECD Nuclear Energy Agency has assembled and maintains an International FEPs Database /NEA, 1997 and NEA, 1999/. The International FEPs database is a collection of FEP lists and databases, with references, compiled during repository safety assessment and scenario development studies within several performance assessment projects. The International FEPs database is particularly important as a means for testing the completeness of a System Model and selected future events.

The scenario methodology used in the SAFE project was presented in the SAFE project report from the first stage /SKB, 1998/. The methodology builds on the previous advances of the methodology. Its main components are a systematic identification of interactions/processes by the use of Interaction Matrices, auditing against International Databases, mapping the content of the interaction matrices on a Model Information Flow Diagram and exploring how to assess the impact of future events and conditions.

1.2 Objectives and scope

The overall objective of the present report is to:

- develop and motivate a system description model of SFR-1,
- select and motivate scenarios to be analysed,
- select and motivate models and information flow needed between models to represent the selected scenarios.

A more precise definition of what is meant with these terms (like scenario) is given in the next chapter.

There are also some limits in scope of the work described in this report. In particular the report:

- does not discuss data selection,
- does not suggest how to combine the suggested data into combined calculation cases,
- does not present the result of the numerical evaluation of selected scenarios.

These aspects are covered in other reports, in particular the "data report" /SKB, 2001b/, the "calculation report" /Lindgren *et al.*, 2001/ and the "main safety assessment report" /SKB, 2001a/.

1.3 Structure of report

The scenario methodology applied in the SAFE project is described in Chapter 2 and the identification and definition of scenarios analysed within the SAFE project in Chapter 3. Chapter 4 describes a system description model of the SFR-1 in terms of three, coupled interaction matrices, developed within the project. The system model covers the repository vaults, the geosphere and the biosphere and is valid for all the identified scenarios. The system description is valid for all scenarios identified. Chapter 5 covers the treatment of processes and interactions in the quantitative analysis. The conclusions are found in Chapter 6.

2 Outline of the approach for scenario and system analysis

In order to evaluate the performance of the SFR-1 it is necessary to develop a system description model, to identify scenario initiating events and conditions, to select quantitative evaluation models, to identify the information flow between models and to select quantitative calculation cases. This chapter outlines the approach used to perform these tasks. The selection of quantitative calculation cases is further described in the report compiling the data for the quantitative analysis /SKB, 2001b/.

2.1 Development of a system description model

An important starting point in a safety assessment is to identify processes and interaction between processes that has to be considered in the quantitative analyses of the system. This need is here addressed by developing an interaction matrix of the SFR process system.

2.1.1 Interaction matrices

The basic principle of an interaction matrix is to list the parameters defining the properties and conditions in the physical components of the system studied along the leading diagonal elements of a square matrix. Events and processes that are influenced by and affects the properties and conditions defined in the leading diagonal elements of the matrix occur in the off-diagonal elements of the matrix.

An interaction matrix for the SFR-1 repository should cover the Silo and the repository rock vaults, the rock around and above the repository and the surface environment. Instead of compiling all information into one matrix, three sub-matrices are constructed, one repository/near-field matrix, one geosphere matrix and one biosphere matrix.

The development of the interaction matrices is generally made by different *expert groups* through a series of documented meetings. In the SAFE project the members of the SAFE-project team have usually made the development, but other experts have been invited to specific meetings.

The development consists of the following steps:

Definition of the sub-systems to be included in each matrix in terms of physical components, the initial state of these components and boundaries between the subsystem as well as the external boundary and boundary conditions of the whole system.

Selection of parameters required to describe the properties and conditions in the physical components of the sub-systems and listing them in the leading diagonal elements of the matrices (see *Figure 2-1*).

Identification of binary interactions between diagonal elements, by going through all off-diagonal elements in the matrices, using a clock-wise convention for the direction of the interaction (see *Figure 2-1*), and judging whether the interaction is relevant and, if so, give a short description of its relevance.

Auditing the contents of the matrices against different international lists of FEPs (Features, Events Processes) in order to ensure that all FEPs that are relevant are considered in the matrices.

Selection of scenario initiating events and conditions.

Judging the importance of all identified interactions in the matrices using a pre-defined priority scale, both for the initial and boundary conditions selected as a base/reference scenario and for other scenario initiating events and conditions.

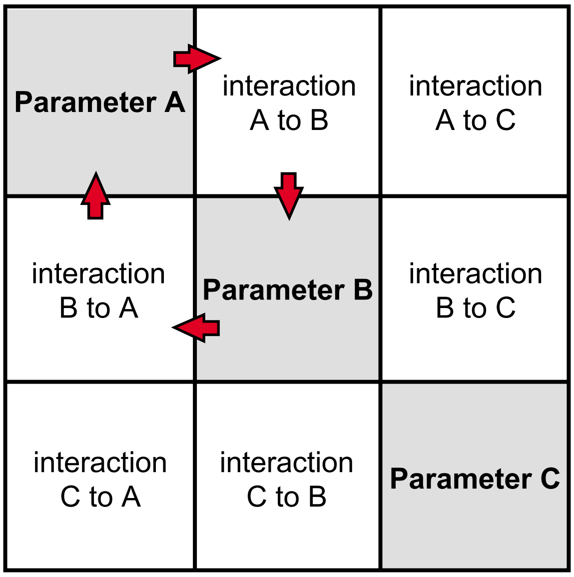

Figure 2-1 *The principles of the interaction matrix*

The matrices and the decisions made in developing the matrices are carefully documented in an Interaction Matrix Database. For each matrix element the database contain a short description of the process/or condition, its relevance (with a justification) and a record on date of entry/revision and which experts were involved.

2.1.2 Identification of diagonal elements

The first step of the procedure is to define the diagonal elements of the matrix. This is done by exploring how the state of the system can be described in terms of physical components, spatial and temporal extension of the system and initial and boundary conditions of the system. It has been found practical to let the diagonal elements represent *system state* variables (such as chemical composition of water, or rock stress) and to let the off-diagonal elements represent *processes* affecting the state.

In order to save space, it has been found practical to allow a diagonal element to represent a “heading” rather than a single variable. For example, a typical diagonal element could be “groundwater composition”, which in turn can be divided into concentrations of various constituents, colloid content etc.

2.1.3 Identification of interactions

When the leading diagonal elements of the matrix are specified and documented, the interactions between the main variables of the system are identified and introduced into the appropriate off-diagonal elements (interaction boxes) in the matrix. All interactions should be binary, i.e. they should be direct interactions between variables in two diagonal elements and not a path via a variable in a third diagonal element.

Each interaction is documented by defining the process or event involved in the interaction as well as the variables in the two interacting diagonal elements that are influencing the process or event and affected by the process or event. Every off-diagonal element of the matrix is checked for interactions, and the reason for leaving empty off-diagonal elements in the matrix is documented.

In a first step, all possible interacting mechanisms are considered without making any evaluation of the probability of occurrence or the significance of the effect. Only fully irrelevant or totally unreasonable interactions have been discarded. The reason for this is that the outcome of such an evaluation may be scenario dependent and must therefore be done for the selected scenarios (see Section 2.2).

The identification process works systematically with all off-diagonal elements. For each such element the question is asked whether there are any potential events or processes that are affecting any of the variables assigned to the target diagonal element and at the same time are affected by any of the variables in the source diagonal element. If the answer is yes, a short description of the interaction is documented together with the variables in the two leading diagonal elements that are involved in the interaction. If the answer is no, this is also documented and if possible also the reason for not finding any interacting event or process. For example, if the physical components defined by the variables in two diagonal elements are physically isolated, there is no direct dependence between the variables in these diagonal elements. This does not preclude that the variables may be indirectly dependent via a path involving additional diagonal elements.

As there is a need to introduce more than one variable in each diagonal element, it is not possible to display all interacting events and processes in the off-diagonal elements of the matrices. Therefore also the diagonal elements have to be checked for events and processes that are affected by and affect the variables within the element. When such processes are identified they are introduced as 'internal' interactions in the diagonal elements and documented in the same way as the interactions in the off-diagonal elements.

2.1.4 Prioritisation of interactions

The next step is to set priorities to the importance of identified interactions (FEPs) in the interaction matrix. This requires a well-defined priority scale. It should be noted that the priorities set are valid only for the previously defined initial states and boundary conditions. The output from this exercise is a ranked system, in which the most important issues to be focused on in subsequent parts of the performance assessment are highlighted. A colour coding is used to display the priorities in the interaction matrices. In cases where one interaction box contains more than one interaction, the interaction with the highest priority determines the colour of the interaction box. The definition of the priorities used in the evaluation of the matrices is given in Table 2-1.

Table 2-1. Definition of priorities used in the matrices

Priority No	Colour	Description
4	Pink	**Important interaction only in the water saturation phase – part of the Performance Assessment.** It can influence other parts of the process system included in this matrix, or other parts of the repository system not included in this matrix.
3	Red	**Important interaction - part of the Performance Assessment.** Could also influence other parts of the process system, (defined in this matrix), or other parts of the repository system. The interaction can be either a prerequisite for the PA or handled by assumptions or modelling efforts in the PA.
2	Yellow	**Interaction present – probably part of the Performance Assessment.** Limited or uncertain influence directly or via this interaction on other parts of the process system, or other parts of the repository system. However, this interaction can be in main focus in other matrices.
1	Green	**Interaction present - do not have to be considered in the Performance Assessment.** Negligible influence on other parts of the process system, (defined in this matrix) and other parts of the repository system.
0	White	**No identified interactions**

2.1.5 Modes of operations, experts involved and documentation

In order to save space, the description has been divided into three interconnected matrices: repository, geosphere and biosphere. The work has mainly been conducted through a series of meetings with the SAFE-project team and invited experts to cover certain special areas. There has been a strive for involving people with relevant expertise. The group working with the repository matrix and geosphere matrix contained members with expertise in hydrology and chemistry and general knowledge of rock mechanics and microbiology. The group working with the biosphere matrix contained members with experience in the fields of oceanography, systems ecology, terrestrial ecology, limnology, botany, radioecology and radiochemistry. The persons involved in the construction of matrices and in the assignment of priorities are given in the Interaction Matrix Database, and summarised in Appendix A.

The completeness of the Matrices are checked by auditing their contents against the project databases included in the NEA International FEP database (Version 1.0) /NEA, 1997/. The audit is further described in Section 3.1.2.

Decisions made on the content, including priorities, of the interaction matrices are recorded in the Interaction Matrix Database. In addition, all identified interactions were introduced into graphical versions of the matrices, using a short name or a key word for the interacting event or process, see Appendix F. The main contents of the matrices are described in Chapter 4.

2.2 Selection of scenario initiating events and conditions

The evolution of the SFR-1 will be influenced by future events (such as re-saturation, land rise, climate change, human actions etc.) and by the initial state of the repository at closure. Such events and conditions are called scenario initiators. Evidently, it is necessary to identify the scenario initiating events and conditions that would have a significant impact on the system behaviour as well as to motivate why others not need to be analysed.

The selection process is one of a broad identification of different scenario initiators that is followed by a screening process where only those initiators with some potential relevance are retained. The remaining list is assessed and a few initiators are selected and developed to encompass the future evolution of the SFR-1.

There are several sources for the first step of identifying potential scenario initiators. The scenarios considered in past SFR assessments (e.g. SKB /1993/) are reassessed. Also the scenarios considered in the preliminary safety assessment of a repository for long-lived low and intermediate level waste /SKB, 1999b/ and the SR 97 safety assessment of a spent fuel repository /SKB, 1999a/ are considered. Another, important source of external FEPs are existing FEP-lists, where the NEA International FEP database /NEA, 1997/ is one such source.

The screening process essentially builds on the following criteria:

- is the initiator relevant for the considered type of waste (i.e. LLW/ILW reactor waste),
- is the initiator relevant for type of geology and geographic setting of the SFR,
- is the initiator relevant within the selected time cut-off at 10 000 years after repository closure.

Application of these criteria only leaves a relatively minor subset for further consideration. This subset is sorted into a few classes, where similar scenario initiators are brought together under a common heading. These remaining groups of scenario initiators are assessed qualitatively, and decisions are made to what extent additional analyses are warranted.

The results of the selection process, the NEA FEPs audit, grouping and qualitative analyses are provided in Chapter 3.

2.3 Model selection and identification of information flow needs

The interaction matrix and the list of scenario initiating events and conditions do not provide quantitative information on the repository performance. There is a need to select models and to identify the information flow between the models selected. To facilitate this procedure a flow chart of the models and information flow, a model information flow diagram, between models is developed.

A model information flow diagram is a graphical illustration of the models and the information flow selected for quantitative analyses in the assessment. It is used for:

- motivating the model selection by checking the consistency between models as well as information flow actually selected and the important interactions identified in the interaction matrices,
- providing a framework for assuring consistency in data transfer between different analyses and as a tool for planning of a logical order of analyses.

The information model flow diagram has been developed by:

- linking together the various quantitative analyses already identified as being necessary to conduct within the project according to the Phase-1 planning document /SKB, 1998/,

- revising the diagram by checking to what extent the already selected analyses reflect the prioritised interactions in the interaction matrices.

Chapter 5 presents the resulting model information flow diagram and also discusses to what extent it actually covers the prioritised interactions.

3 Scenarios

The interaction matrices cover a wide range of processes, which may affect the future state of the SFR-1 repository system. However, there may be several conditions or events, not considered in the matrix, which may also effect the evolution. Generally, a FEP not (yet) considered in the matrix, but judged to be potentially important could be:

- considered to be included in the system description (i.e. the interaction matrix is updated), or,
- considered as a boundary condition affecting the system.

FEPs in the latter group are called scenario initiating events and conditions.

The current chapter describes the procedures undertaken to check the completeness of the matrices and the lists of potentially important boundary conditions. The chapter also discusses the rationale for selecting a Base Scenario and other scenarios and finally defines the scenarios selected for the analysis. The content of the interaction matrices (i.e. the system description) and judgements of the importance of the interactions under different scenarios are presented in the next chapter.

3.1 Selection of scenario initiating events and conditions

There are several sources for the first step of identifying potential scenario initiators. Existing FEP-lists, including the NEA International FEP database /NEA, 1997/, is one such source. Scenarios considered in past SFR-1 assessments is another. Also the scenarios considered in the SR 97 safety assessment of a spent fuel repository /SKB, 1999a/ and the preliminary assessment of a deep repository for long-lived intermediate level waste /SKB, 1999b/ are considered. The suggested scenario initiators (EFEPs) are screened. The screening process essentially builds on the following criteria:

- is the EFEP relevant for the considered type of waste and waste containers (i.e. LLW/ILW in concrete and steel containers),
- is the EFEP relevant for type of geology and geographic setting of the SFR-1,
- is the EFEP relevant within the selected time cut-off at 12 000 AD.

Application of these criteria only leaves a relatively minor subset for further consideration. Furthermore, the selected subset of scenario initiating EFEPs is categorised into a limited number of scenarios, selected for further evaluation.

3.1.1 EFEPs considered in past and recent SKB assessments

The scenario identification is based on experiences in past safety assessments. Even if methods of scenario identification have developed significantly since the last safety assessment of SFR, it seems evident that most of the relevant external conditions worth studying have already been identified in past assessments.

Previous SFR assessment

The past SFR safety assessment /SKB, 1993/ essentially considered two different types of scenarios; a reference scenario and some extreme scenarios. The extreme scenarios considered phenomena that were assessed to be very unlikely, but could have large impact on dose to man if occurring.

- The reference scenario was intended to describe the most realistic evolution of the Process System with *land uplift* as the scenario initiating FEP.
- The scenario initiating FEPs for the extreme scenarios were *fracturing of the concrete Silo* and *blocking of the gas release paths* in the Silo and a combination of these, and these were applied on the reference scenario.
- The extreme scenarios for the vaults concerned the *drilling of wells* directly into the vaults.

Of these different EFEPs the SAFE project have decided that *a priori* assumptions of potential fracturing and blocking of gas in the Silo could not be motivated. Such events, if they occur needs to have a credible cause, essentially resulting from the ongoing degradation of the repository barriers. Given the more careful analysis of the system evolution envisaged in the SAFE project, these EFEPs are thus included in the system description. However, there may also be reason to explore consequences of initial failures, i.e. the “what-if” situation occurring if the Silo or the vaults contain some undetected construction defects. The different types of intruding wells need to be considered as EFEPs also in the SAFE assessment.

It may also be noted that the regulatory review of the deepened safety assessment /SKI/SSI, 1992/ did not consider any fundamentally different scenario initiating events, compared to the SKB selection. Some parameter values and parameter combinations were selected differently, but the potential validity of these selections should be made clear after a more careful analysis of the repository evolution.

Assessment of a deep repository for long-lived low- and intermediate level waste

In the preliminary safety assessment of a deep repository for long-lived low- and intermediate level waste /SKB, 1999b/, the following scenarios and EFEPs were considered:

- Reference scenario assuming stable thermal, hydrological, mechanical and chemical conditions in the rock surrounding the repository.
- Climatic change.
- Seismic/tectonics.
- Future human action, including wells.
- Design and operation (stray materials etc.).

These EFEPs/scenarios should also be considered for the SFR assessment. The conclusions regarding the applicability may, however, differ due the differences between the repository concepts and relevant time frames.

SKB SR 97

The SKB SR 97 safety assessment /SKB, 1999a/ of a deep repository for spent nuclear fuel considered the following scenarios and EFEPs:

- A Base Scenario where the repository is imagined to be built according to specification and where present-day conditions are assumed to exist outside the system.
- A canister defect scenario, which differs from the Base Scenario in that it is assumed that a few canisters have initial defects.
- A climate scenario that deals with future climate induced changes.
- A tectonics/earthquake scenario.
- A collective scenario that deals with future human actions that could conceivably affect the deep repository.

These EFEPs/scenarios should also be considered for the SFR assessment. The conclusions regarding the applicability may, however, differ due to the marked differences between the repository concepts and relevant time frames. In particular, one should note that the SFR safety concept does not include an initially tight canister, but it may still be motivated to explore a scenario postulating some initial (undetected) deficiencies in the repository structures.

In reviewing SR 97, the regulatory authorities /SKI/SSI, 2001/ suggested that the tectonics/earthquake scenario rather should be seen as a variant of the climatic change scenario. The authorities also questioned whether the climatic change scenario should not have been a part of the Base Scenario. In general, more discussion was asked for as regards combination of different scenario initiators. When relevant, these concerns should be addressed within SAFE.

3.1.2 Auditing against the NEA FEP Database

Building on past experience there are several external conditions like potential initial defects, climatic change, land rise or human activities that should be considered. In order to get a more structured approach the SAFE project have consulted the OECD/NEA International FEPs database /NEA, 1997/ and conducted a FEPs audit. The FEPs audit is both a check that as many as possible of the relevant interaction mechanisms are included in the three interaction matrices, and means to arrive at a list of FEPs to be considered as scenario initiators.

The procedure for the audit was to make a first screening and classification of the NEA project FEPs to obtain reduced lists of FEPs. These lists were then used to perform an audit of the contents of the matrices.

NEA FEP database

The international NEA FEP database consists of two parts, an International FEP list and a Project database /NEA, 1997/. The International FEP list is a list of factors relevant to the assessment of long-term safety of repositories for radioactive waste. The list forms a master keyword list by which to examine the various project specific database entries. Name, number, definition and comment describe each FEP. The International FEP list is given in Appendix B. The Project database is a collection of FEP lists and databases, with references, compiled during repository safety assessment and scenario development studies. The Project database comprise contributions from the following seven performance assessment projects /NEA 1997/:

- the joint SKI/SKB database of FEPs related to the Swedish KBS-3 spent fuel disposal concept /Andersson (ed.), 1989/

- NEA example compilation of FEPs (names only) relevant to deep geological repository that appears in the NEA Scenario Working Group report /NEA 1992/
- the AECL database of FEPs (termed factors) related to the Canadian fuel waste disposal concept /Goodwin *et al*., 1994/
- the HMIP database of FEPs related to the assessment of disposal of low and intermediate-level waste in fractured hard rock /Miller and Chapman, 1993/
- the NAGRA database of FEPs related to the Kristallin-I assessment of disposal of high-level waste in crystalline basement rock of Northern Switzerland /NAGRA 1994/
- the US DOE database of FEPs related to the assessment of disposal of transuranic waste in bedded salt at the WIPP site /US DOE 1996/
- the SKI database of FEPs related to the KBS-3 spent fuel disposal concept /Stenhouse *et al*., 1993; Chapman *et al*., 1995/

The Project FEP database (version 1.0) /NEA, 1997/ includes a total of 1261 project FEPs. Name, number, description and comment describe each project FEP. In addition, each project FEP is mapped to one or more of the FEPs in the International FEP list.

In a later version of the NEA international FEP database (version 1.1) /NEA, 1999/, that not was available at the time of the audit, the project FEP database has been complemented with about 150 FEPs. The project FEPs are from the AECL database of FEPs, termed issues, related to the preliminary safety assessment of the near-surface Intrusion Resistant Underground Structure (IRUS) at the Chalk River site /Stephens *et al.*, 1997/.

Screening and classification of the NEA project FEPs

All Project FEPs in the international database are not relevant for SFR. One reason for this is that the FEPs in the database mainly are for deep underground repositories for spent fuel whereas SFR is an underground repository for LLW/ILW. Therefore, the content of the NEA Project database was screened based on the description of each FEP in the database. FEPs that were found to be *irrelevant* for SFR at any circumstances were screened out. Examples of screened out FEPs are those describing processes, events or features connected to spent fuel, glass, copper canisters etc. Other FEPs that were screened out are the NEA example compilation of FEPs /NEA, 1992/, which is a list of FEP names only without any descriptions. These FEPs and other FEPs with unclear descriptions or definitions were screened out since the interpretation of the name or description in all cases lead to the conclusion that these FEPs are duplicates of, or covered by, other more well described FEPs in the database.

After screening the FEPs in the Project database, a first classification of the remaining FEPs was made. The FEPs were classified as being either an External FEP (EFEP) to the SFR system covered by the three interaction matrices or to belong to one or several of the systems covered by the three interaction matrices. For this purpose the NEA International FEPs list was used. NEA project FEPs mapped exclusively to "*Assessment Basis*" and "*External Factors*" in the International FEPs list was classified as potential External FEPs, i.e. potential scenario initiating events, in the SFR analysis (Table 3-1). The other items in the International FEPs list were classified according to where in the system the FEP is expected to occur (Table 3-2).

To ensure that all FEPs relevant to the SFR system were included in the FEPs lists that were to be used in the audit, the list with FEPs classified as External FEPs were examined. Each FEP was checked and if a FEP was assessed to belong to the SFR system, the earlier classification was changed and the FEP transferred to the new category of FEPs (Repository, Geosphere, and Biosphere).

This first classification of the NEA project FEPs produced the FEPs lists that were used to perform the audit of the content of the Repository, Geosphere and Biosphere matrix for the SFR disposal system as well as a first version of a list of potential EFEPs for the SFR system.

Table 3-1. NEA Project FEPs mapped to the following FEPs in the International list were classified as potential EFEPs in the SFR study.

Name in International FEP list	Number in International FEP list
Assessment basis	0 (0.01-0.10)
External factors	1
Repository issues	1.1 (1.1.01-1.1.13)
Geological processes and effects	1.2 (1.2.01-1.2.10)
Climatic processes and effects	1.3 (1.3.01-1.3.09)
Future human actions (active)	1.4 (1.4.01-1.4.11)
Other	1.5 (1.5.01-1.5.03)

Table 3-2. NEA Project FEPs mapped to the following FEPs in the International list were classified as belonging to the SFR disposal system.

Name in International FEP list	Number in International FEP list	SFR system
DISPOSAL SYSTEM DOMAIN: ENVIRONMENTAL FACTORS	2	
• Wastes and engineered features	2.1 (2.1.01-2.1.14)	Repository
• Geological environment	2.2 (2.2.01-2.2.13)	Geosphere
• Surface environment	2.3 (2.3.01-2.3.13)	Biosphere
• Human behaviour	2.4 (2.4.01-2.4.11)	Biosphere
RADIONUCLIDE/CONTAMINANT FACTORS	3	
• Contaminant characteristics	3.1 (3.1.01-3.1.06)	Repository/Geosphere/ Biosphere
• Contaminant release/migration factors	3.2 (3.2.01-3.2.13)	
• Exposure factors	3.3 (3.3.01-3.3.08)	Biosphere

The FEP audit

The lists with NEA project FEPs that were classified as being relevant for the SFR system were used to perform an audit of the content of the interaction matrices developed for the SFR system. One or two of the persons that participated in the development of the interaction matrices carried out this audit.

During the audit, each FEP in the three lists was examined and it was first concluded whether the FEP belongs to the SFR system or is a potential External FEP (EFEP). If a

FEP was assessed as a potential EFEP, the earlier classification was changed and the FEP was transferred to the list of potential EFEPs. For FEPs belonging to the SFR system, the earlier classification was first checked and then the interaction matrix where the FEP should occur was checked. If the FEP was included in the matrix, a note was made of where in the matrix the FEP appears. If the FEP could not be found in the matrix, the FEP was tabulated in a separate list for missing FEPs.

When all FEP lists had been examined, the list with missing FEPs was worked through. The appropriate interaction element or diagonal element in the matrix for the FEP was identified and the FEP was added to the matrix and the associated database containing the descriptions of the interactions. For some of the missing FEPs it was already at this stage judged that the FEP would be of negligible importance for the evolution of the system. It was therefore decided to not include them in the matrix, but the reason for leaving them out was documented.

Figure 3-1 shows a flowchart of the screening of the NEA project FEPs and the linking of the remaining FEPs to the interaction matrices and the list of EFEPs.

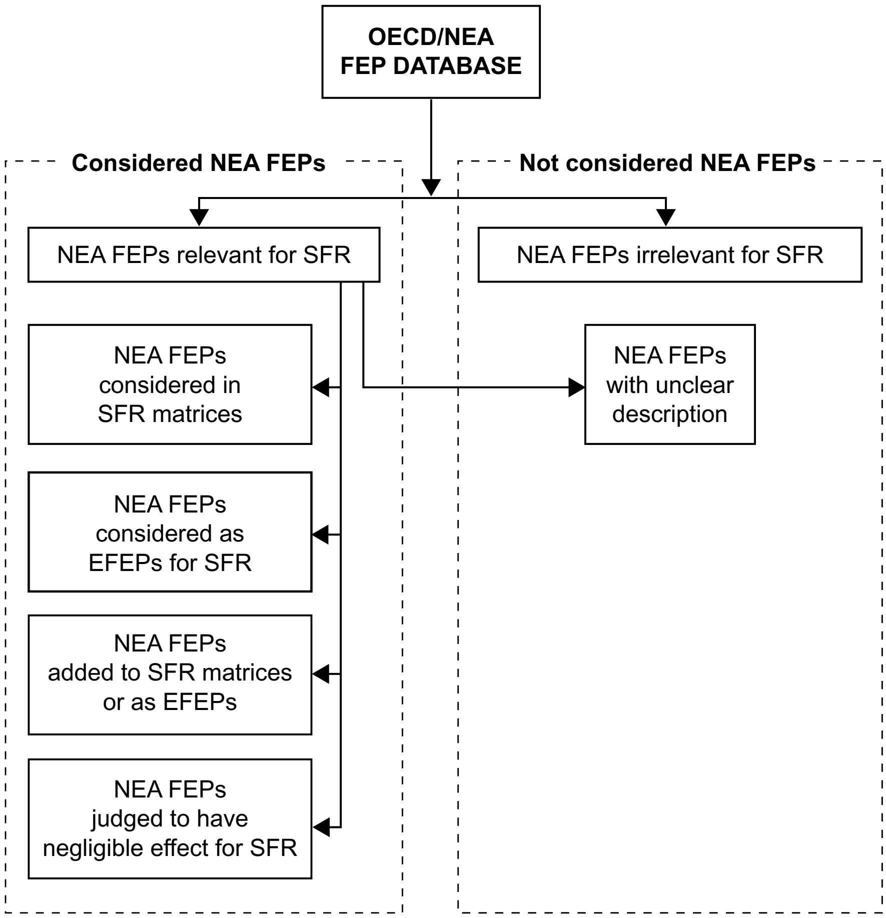

Figure 3-1. *Screening of the NEA project FEPs and the linking of remaining FEPs to the SFR interaction matrices and list of EFEPs.*

Results

The scenario identification is based on experiences in past safety assessments. Even if methods of scenario identification have developed significantly since the last SFR safety assessment, it seems evident that most of the relevant external conditions worth studying have already been identified in past assessments.

The NEA FEP database (version 1.0) contains a total of 1261 project FEPs. The outcome of the audit is presented in Appendix C. In summary it was found that:

- More than 900 project FEPs were assessed to be relevant for SFR. About 700 of these FEPs were found in the matrices and more than 200 FEPs were assessed as potential EFEPs and have been considered in the selection of scenarios in the SFR analyses.
- The remaining 300 FEPs were judged to be irrelevant for SFR or identified to have unclear definitions (most likely covered by more specific FEPs).
- Only 9 FEPs were added to the matrices as a result of the auditing.

It can also be noted that all FEPs included in the SFR matrices are not covered by the international project database. However, no formal check of which FEPs are included in the SFR interaction matrices and not in the NEA database has been performed.

Quality check of the interaction matrices

Apart from being a source of input for EFEPs, the FEPs audit is primarily a quality check of the content of the Interaction Matrices, i.e. of the system description. This point will be further addressed in Chapter 4.

3.1.3 Classification of EFEPs into scenario categories

The basis for selecting scenario initiating event for the SAFE analysis are the scenarios considered in the past safety assessments and the FEPs in NEA database that are classified as being EFEP to the SFR system. These EFEPs have been sorted into one of the following categories, see Appendix D:

- Part of the Base Scenario boundary conditions
- Climate change – natural
- Climate change – human induced
- Initial defects in technical barriers
- Human activities
- Tectonics
- Others

The SAFE project team has selected scenario-initiating conditions judged to be relevant to SFR from these categories and from the different individual FEPs sorted into these categories. The team also made a qualitative assessment of the scenarios identified in order to decide if the scenario warranted any other treatment than already considered for the analysis of the Base Scenario. The results of these considerations are presented in the remaining sections of this chapter.

3.2 Base Scenario

The starting point for the scenario analysis within SAFE is the selection of a Base Scenario. The Base Scenario should be highly plausible and be a good reference point for superposition with other scenarios. In essence the Base Scenario assumes that the repository at closure is constructed according to specification and that the external environment will stay the same, although well known trends, such as land rise will be included in the scenario.

3.2.1 General assumptions

The general assumptions that defines the Base Scenario are:

- The state of barriers and plugs at repository closure is in accordance with design criteria.
- Present day climate maintains for 10 000 years after repository closure.
- The best estimate of the future land rise /Påsse, 1997/ is considered.
- The types of ecosystems in the biosphere system are the same as those present today, but succession due to land rise is considered.
- Present day wells and future wells that do not penetrate the repository barriers are considered.
- The time considered for the evolution of the system is restricted to 10 000 years.

It needs to be emphasised that this definition does not exclude the possibilities for changes of the state of the repository after closure. On the contrary, the system definition with the processes interactions as described in the interaction matrices potentially imply significant alteration of the repository, including release of radionuclides, also if the system boundary conditions do not change more than assumed in the Base Scenario.

3.2.2 Likelihood of scenario

The following factors may be considered when addressing the likelihood of the Base Scenario:

- The expected initial state of the components at repository closure can be defined based on the selection of barrier materials and the design of the repository as well as on results of studies aimed at characterising the waste and the repository site “on site”.
- The boundary conditions to the system, e.g. climatic factors and predicted land rise, at the time of repository closure are also rather well known.
- The development of the ecosystems will change from present day conditions, but reasonable future developments, based on the succession of the land rise, are included in the Base Scenario.
- The trend in future climate evolution for the coming several 1000 years is, in a way, less clear than over longer time periods, where there is a rather well established consensus for the development of glacial conditions etc. For the nearest 1000 years, in particular, where there are different competing short term trends (including global warming) the assumption of remaining present day climate may in fact be the best assumption, see also subsection 3.4.1 and SR 97 /SKB 1999a, Chapter 10/, at least up to 7 000 AD.

These arguments suggest that the Base Scenario is quite plausible and should be a corner stone in the safety assessment of the SFR.

3.2.3 Suggested means of analysis

The system evolution and the potentially resulting radiologic consequences of this evolution should be carefully analysed for the Base Scenario. It is expected that the analysis of the Base Scenario, will to a large extent be relevant also for other scenarios, or that other scenarios often can be handled as parameter variations in the models used to assess the Base Scenario.

3.3 Initial defects in technical barriers

Some initial defects in the technical barriers cannot be excluded, and should anyway be analysed as “what-if” cases. As the SFR to a less extent builds on total isolation of the nuclear waste, the essential barrier functions (sorption and low groundwater flow) are not that sensitive to defects. There are potentially some exceptions, which may be detrimental to the barrier functions. These are:

- Defects in the engineered structures, which may enhance radionuclide migration through some barriers.
- Undetected or improperly sealed investigation bore holes, which may imply increased groundwater flow and reduced transport resistance in the rock.
- Materials left in the repository with improper chemical properties, thus jeopardising the sorption barrier function.

These different conditions are further discussed in the following subsections.

3.3.1 Defects in engineered structures

General assumptions

Regarding the engineered structures the following conditions may be detrimental:

- Fractures in the concrete structures allowing higher groundwater flows closer to the waste forms emplaced in concrete structures (i.e. Silo, BMA and part of BTF).
- Improper plugging of the vaults (all vaults including the Silo), which may allow higher groundwater flow in the vaults.

Regarding the Silo, the worst location of a fracture would be in the bottom of the Silo. For the BMA the worst position of a fracture would be in a compartment that is close to a fracture zone and has no concrete backfill around the waste packages.

Likelihood of scenario

The likelihood of undetected defects is not really possible to determine. The scenario is rather of a “what-if” character.

Suggested means of analysis

The impact of the listed defects is not obvious and needs to be evaluated. However, the defects consider conditions that may occur in the course of events also of the Base Scenario. This means that modelling tools developed for the Base Scenario should in principle be applicable (or be sure to be made applicable) also to an initial defect scenario of this type.

The scenario calls both for specific hydrogeological analyses of the flow within the repository, and subsequent adoption of the radionuclide release and transport analyses.

Evidently, different calculation cases need to be developed, while considering the different uncertainties within the Base Scenario.

3.3.2 Open undetected boreholes

There are several observation holes drilled from the tunnel system. Most of them were drilled for exploring the geological and hydrogeological structures before waste emplacement commenced. Some are still used for groundwater pressure measurements or for groundwater sampling. The location and present use of the boreholes are discussed by Axelsson /1997/. There are no holes drilled directly from the disposal vaults (BMA, BTF, BLA or the Silo), all holes are drilled from the access tunnels. Several of the holes cross the local fracture zones close to the repository tunnels, see Axelsson and Hansen /1997/. It is intended to plug and seal all boreholes before repository closure.

General assumptions

A potential scenario would be to assume that some, or all of the observation boreholes are improperly sealed.

Likelihood of scenario

The likelihood of undetected boreholes is not really possible to determine. The scenario is rather of a "what-if" character.

Qualitative assessment of scenario

After closure the groundwater flow inside the repository will follow a rather complex geometrical pattern. Unsealed boreholes imply highly permeable flow routes from the tunnels out into the rock. These routes will have comparatively high flow and little transport resistance.

However, it should pointed out that there are no observation holes drilled from the tunnels directly to the ground surface. Given this fact, and the fact that some fracture zones already intersects the disposal vaults, it seems quite unlikely that bore holes connecting the tunnels outside the vaults with the fracture zones would have any significant impact on the flow or migration characteristics from the vaults. The situation would possibly change if the scenario is combined with a failure of the plugs, but as the tunnel system already is well connected to the fracture zones (especially, zone H2 and zone 6), the additional problem of unsealed observation boreholes seems to be minor. A qualitative assessment of the flow pattern resulting from the Base Scenario /Holmén and Stigsson, 2001/ strongly supports such a conclusion.

Suggested means of analysis

Unsealed boreholes do not imply any features or processes in addition to those needed to be considered within the Base Scenario. This means that modelling tools developed for the Base Scenario should in principle be applicable (or be sure to be made applicable) also for analysing the impact of unsealed boreholes.

It could also be argued that non-sealed boreholes imply small changes to the groundwater flow and transport resistance. Its impact is likely to be covered by the conditions that needs to be considered in the Base Scenario and in a Defect Plug Scenario. Consequently no specific analysis of unsealed boreholes will be undertaken.

3.3.3 Undesirable materials left in the repository

General assumptions

Undesirable materials left in the repository after closure may affect the chemical barrier functions. Examples of such potentially unfavourable materials are oil or organic fluid spill, decontamination materials, organic materials/contaminants in bentonite (see e.g. Jones *et al.* /1999/ or Karlsson *et al*. /1999/).

Likelihood of scenario

The likelihood of undetected undesirable materials is not easy to estimate, but is probably very low. Anyhow, the scenario should be assessed.

Suggested means of analysis

Assuming undesired materials left in the repository does not imply any features or processes other than those needed to be considered within the Base Scenario. This means that modelling tools developed for the Base Scenario should in principle be applicable (or be sure to be made applicable) also for analysing the effect of undesired materials. The consequence of the scenario may be assessed as a special calculation case, with sorption values adjusted to reflect the change in chemistry.

3.4 Climate change

The NEA FEPs audit resulted in a large group of FEPs, like permafrost conditions, arctic desert, tundra, erosion, denudation, drought, accumulation of gas, changes in sea level due to glaciation, greenhouse effect, flooding due to increased precipitation and acid rain. These FEPs may all be sorted under the headings natural and human induced climate evolution.

3.4.1 Potential climate evolution in the area

The future climate evolution at the SFR site will be driven both by natural and human induced alterations. Possible evolutions are briefly discussed in the following.

Natural evolution

The SKB SR 97 project /SKB, 1999a, Chapter 10/ provides a suggested reasonable climate evolution in Sweden for the next 150 000 years. According to the prediction in SR 97 the climate will essentially resemble present day climate for about 5000 years into the future (i.e. up to 7000 AD). The period between 7000 year to 22 000 year AD (i.e. from 7000 AD and the rest of the period of interest) will be colder and the temperature will gradually decrease. A permanent ice cover (glaciation) will start to grow in the Scandinavian Mountain range and permafrost may occur in front of the ice cover. However, the ice cover will not reach anywhere near the Forsmark area, i.e. close to the present Baltic Sea shoreline and the south of the region of Dalarna, before 22 000 AD. The position of the shoreline will change, starting with continued regression (due to general sea water level decline), but will then start to rise when the ice cover is thick enough to cause significant downwarping in the area. This latter process will, however, not occur within the time frame of 10 000 years considered for the SFR assessment.

For the Finnsjön area (called “Beberg” in SR 97), which is close, but inland, to the Forsmark area, the effect of the shoreline rise will be noticeable first around 15 000 years from now. Furthermore, as Finnsjön is close to the sea it is not very likely that a continuous permafrost layer develops there. Forsmark lies even closer to the sea than Finnsjön, indicating that permafrost there would be even less likely.

Forsmark lies in a tectonically stable area. If larger tectonic events occur they are probable connected to the melting period of glacial ice. Such melting is not expected during the time period of interest, which may be used as an argument for not considering tectonic events. However, the reasons for "neo-tectonic" events are not fully understood, and there may in fact be non-climatic related factors involved. At least a qualitative discussion of a tectonic scenario may thus be warranted.

The following conclusions can be made:

- The most likely evolution up to 5000 years from now (7000 AD) is that the climate remains essentially unchanged, i.e. the Base Scenario assumptions.
- There is no reason to explore the impact of a glacial ice cover in the area.
- The shoreline may start to vary (further decline followed by a rise) in the later parts of the assessment period.
- Formation of permafrost is highly unlikely, but may not be totally excluded after 7000 AD, but if it occurs it will most likely be discontinuous.
- Climate driven tectonic events are unlikely since there will not be any ice cover during the assessment period, but it is still worthwhile to discuss a tectonic scenario.

Scenarios for permafrost, tectonic evolution and sea-level change are thus to be developed.

Human induced climatic change

There are also human activities that can affect future climate. Due to the release of gases, mainly carbon dioxide, through e.g. burning of fossil fuels and industrial processes the climate may become warmer and the rainwater may become more acidic. For the present analysis the following anthropogenic climate factors are defined:

- Acid rain
- Global warming ("greenhouse effects") including warmer climate and arid, equable humid or seasonal humid surface environment.

These potentially important scenario initiators need at least be qualitatively discussed before they can be discarded for further analysis.

3.4.2 Changes in sea-level – shoreline displacement

The Base Scenario implies a shoreline displacement due to land rise /Påsse, 1997/. However, the rate and direction of the shoreline displacement could be affected by climatic changes. The cold period expected from 7000 AD (see Section 3.4.1) implies at first a continued shoreline displacement (regression) followed by a rise in relative shoreline (transgression) caused by downwarping. Global warming may imply a rise in relative shoreline at earlier times.

General assumptions

It appears warranted to discuss two different cases:

- consequences of a further shoreline displacement than already considered in the Base Scenario, and
- consequences of a constant or rising relative shoreline.

Qualitative assessment

There is hardly any reason to make a special analysis of a faster shoreline displacement than what is considered in the Base Scenario. The primary reason for this is that there are no indications of such a development (i.e. low likelihood). Furthermore, if this unlikely situation still occurs, the consequence would be conditions comparable to the conditions predicted to exist in the Base Scenario, but the time scale for the development would be faster.

If the sea-level decreases beyond the levels assumed in the Base Scenario (could e.g. happen after about 7000 AD as a consequence of the cold climate period), the impact on the groundwater circulation would be minimal. The hydraulic analysis of the Base Scenario /Holmén and Stigsson, 2001/ clearly demonstrate that once the shoreline has passed the immediate repository area (between 3000 and 4000 AD) the groundwater flow passing the repository is controlled by the permeability distribution in rock and fracture zones and by local topography. The Base Scenario then covers the effect of a larger lowering of the relative shoreline.

If the sea level increases before the repository is closed and sealed, there may be a risk for flooding. However, this has already been analysed as a part of the assessment of the operational phase of SFR (see e.g. SKB /1993/ Section 6.6).

If no shoreline displacement occurs, or if the displacement is slower than expected, it would only delay the consequences already considered in the Base Scenario. Without continued shoreline displacement, the groundwater flow will eventually stop completely since its present movements is caused by the land rise /Holmén and Stigsson, 2001/. In general, the situation would imply slower release and much more dilution than in the Base Scenario. The consequences are thus well covered (i.e. overestimated) by the Base Scenario.

Suggested analyses

In conclusion, there is little reason for pursuing a sea-level change scenario other than the sea-level change and shoreline displacement already considered in the Base Scenario. The consequences will be smaller (less groundwater flow, more dilution) or identical to the Base Scenario conditions.

3.4.3 Permafrost

The expected climate evolution, see Section 3.4.1, suggests a colder period starting from about 7000 AD. This may imply periods of permafrost after this time.

General assumptions and likelihood

Development of permafrost in the Forsmark area within the coming 10 000 years is considered quite unlikely (see Section 3.4.1). If it at all occurs it will most likely be discontinuous, i.e. with patches of frozen ground surrounded by unfrozen ground. Permafrost may occur at the earliest after 7000 AD.

Qualitative assessment

According to SR 97 /SKB, 1999a, Section 10.3.5/ vegetation and fauna for permafrost conditions are not too unlike the present day situation. Thus, there is no reason to develop a specific “permafrost” ecosystem model for the marine ecosystem, considering the uncertainties about this future ecosystem.

If the permafrost is discontinuous it could hardly reach the depths of the vaults and affect conditions there. The likely consequence of the unlikely permafrost scenario is thus that there would be no impact on the vaults that are different from the assumptions made in the Base Scenario. Still, the more extreme case of continuous permafrost may also be considered. Calculations made within SKI SITE-94 /SKI, 1996, Section 10.2.2.4/ implies a possible permafrost depth of about 100 m after 20 000 years. Even if it is very unlikely, it may thus not be totally excluded that some or all of the vaults would freeze. The consequences of freezing may be a significant disruption of existing concrete structures and plugs between the vaults and the tunnels. However, disruption of the barriers would only have effect after thawing. This would not really be realistic within the assessment period.

Discontinuous permafrost would decrease groundwater recharge and redistribute recharge and discharge areas. It is hard to see any reason for a significant increase in groundwater flow, though. Continuous permafrost implies that recharge/discharge would stop, and so would the groundwater movement, until thawing would make the permafrost discontinuous.

Suggested means of analysis

Effects of discontinuous permafrost, which is the more likely event of the unlikely permafrost scenario, are well covered by the assumptions already made within the Base Scenario. No additional analysis is warranted.

The extremely unlikely event of continuous permafrost may warrant some special analysis. The effect of disrupted concrete structures, packaging and plugs can be considered by simplified assumptions in the analysis. The scenario could only start at the end of the assessment period, otherwise the time for freezing and thawing would be far too short.

3.4.4 Tectonics

The earthquake scenario of SR 97 /SKB, 1999a, Chapter 11/ elaborates quite extensively on the likelihood of larger tectonic events (earthquakes) in Sweden and what the consequences may be. The analysis within the SAFE project would essentially build on these previous analyses.

General assumptions and likelihood

In SR 97 the likelihood of seismic events is assessed by extrapolation from existing statistics of such events. According to the analysis the probability of an earthquake larger than 7 M in a region of 100 km radius and within the next 100 000 years is about 0.2 (Table 4-5 in LaPointe *et al.* /1999/). The probability of such an event in the SFR region within the next 10 000 years would thus be about 0.02 or less depending on what size of the region that is necessary to consider. The probability estimates are certainly criticised in the SKI/SSI review of SR 97 /SKI/SSI, 2001/.

Still, for illustration, the consequences of a 7 M earthquake occurring in the midterm of the assessment period, or at about 7000 AD, will at least be qualitatively assessed within SAFE.

Qualitative assessment

La Pointe *et al.* /1997/ and La Pointe *et al.* /1999/ estimate the extent of fracture movements resulting from a specific magnitude of an earthquake. In a generic example LaPointe *et al*. /1997/ suggest that a M 7.5 event occurring within 100 m from a KBS-3 type repository would at most give a fracture displacement in the order of 0.1 m. If the earthquake is larger than magnitude 8 such displacements may occur if the tectonic event is initiated within 1 km from the repository.

SR 97 concludes that the fracture displacement analysis builds on several assumptions that exaggerate the resulting displacement. In particular the analysis neglects the impact of friction in the fractures. When considering friction, SR 97 judged it most unlikely to obtain significant fracture displacement unless the earthquakes is larger than magnitude 8.2 and occurs within 100 m from the repository. Such a large earthquake could only occur in fracture zones longer than 100 km. Only the Singö-zone is large enough according to this criterion. In conclusion, it seams quite unlikely that reasonable seismic events would imply fracture displacements in the SFR, but they cannot be totally excluded.

A mechanical analysis of the impacts on the engineered structures in SFR resulting from fracture displacements has not been undertaken in the past. However, a judgement of the impact of fracture displacement on the concrete structures in the SFL 3 and SFL 5 repository vaults, which are of similar design as the BMA vault in SFR, was made in the preliminary safety assessment of the SFL 3-5 repository /SKB, 1999b/. The conclusion was that local minor displacements in the bedrock is absorbed in the foundation material by concrete deformations and that an isolated and instantaneous local displacement in the order of 0.01 m or less will not lead to harmful cracking in the concrete structures. From this it may be assumed that displacements in the bedrock at the most would imply fracturing of the concrete structures. In addition, it could be noted that adverse fracturing of the concrete structures is considered for the Initial Barrier Defect Scenario (see Section 3.3.1).

Fracture displacement would also affect the rock. A very pessimistic assumption would be to assume that the resulting transport resistance of the rock would be negligible after a large seismic event.

Suggested means of analysis

The likelihood for a major tectonic event is low, but cannot be totally excluded. The consequences, if the event occurred, would at most be similar to the consequences of the Initial Barrier Defect Scenario, combined with a rock with no transport resistance. This means that there is no need for a special analysis of a tectonic scenario within SAFE. Its consequences can be assessed based on the consequences resulting from the Initial Barrier Defect Scenario.

3.4.5 Acid rain

Assumptions and likelihood

The chemical composition of the rainwater has changed the last couple of decades. The changes in rainwater chemistry are expected to prevail for a rather considerable time.

Qualitative assessment

Acid rain implies a change of the composition of the recharging groundwater. However, the infiltrating water will be buffered by surface soils. In the Forsmark area the surface soils consists of calcium-rich till and clay and the surface waters are well buffered /Brunberg and Blomqvist, 1999/. Furthermore, the abundance of cement in the SFR implies a significant buffering of the groundwater in the repository regions. It could thus be extensively questioned whether acid rain would have any effect at all on the chemical conditions in the repository.

Suggested means of analysis

The argumentation, as given above, needs to be strengthened. Some quantitative considerations are warranted before it is fully possible to conclude that the impact on the SFR safety functions would be minimal. There is no need to plan for specific radionuclide release and transport calculations. It is expected that the Base Scenario cover the consequences.

3.4.6 Global warming

The greenhouse effect may imply significant global warming for the coming 1 000 years. For Forsmark area the most marked impact of global warming would be a sea-level increase.

General assumptions

If the repository were sealed, the Sea-level change and shoreline displacement Scenario (see Section 3.4.2 above) would cover the increase in sea level. Furthermore, it is expected that global warming is a transient phenomenon, which means that it would not need to be considered for the biosphere analysis for the periods after some 1000 years when there may be an on-shore biosphere receiving radionuclides released from the SFR.

A significant sea-level increase before the repository is closed, i.e. in the 20 to 50 years time frame, would potentially threaten to flood the repository. However, flooding is part of the analyses already considered for the operational phase /SKB, 1993, Section 6.6/.

Suggested means of analysis

For the post-closure assessment the effects of global warming may be subsumed (i.e. included) in the Sea-level change and shoreline displacement Scenario. No specific analysis is warranted.

Global warming affects the likelihood of flooding of the repository during the operational phase. This is considered when exploring flooding events.

3.5 Human activities

Human activities primarily affect the biosphere, but these activities may also indirectly influence the conditions deeper down in the rock by changing the boundary conditions for e.g. groundwater flow and groundwater composition. There are a large number of human activities that could be relevant for the SFR repository area. Some are already included as processes in the biosphere matrix, e.g. digging and dumping, but others are not since it is very difficult to predict human behaviour in the future. In line with the safety assessment of a deep repository for spent fuel, SR 97 /SKB, 1999a/ it is therefore decided to restrict the analysis to human activities that takes place without knowledge of the existence of the repository, e.g. unintentional activities. Previous safety assessment of SFR /SKB, 1993 and SKB, 1991/ analysed the consequence of a well drilled into the repository. This type of intrusion scenario will be chosen also here as a representative scenario for human activities.

3.5.1 Wells

Drinking water wells have to be considered as a part of the Base Scenario. Hydrogeological analyses /Holmén and Stigsson, 2001/ are used to explore realistic well discharge rates and to what extent wells may contain water contaminated by the repository.

Another situation occurs if a well is drilled directly into one of the vaults. When in use, such a well may change the groundwater turnover in the affected vault, and thus also influence the total radionuclide release. The well may also create a direct release path from the repository to the biosphere.

Suggested means of analysis

Consequences of a well intruding the different vaults should be analysed. The analysis needs to consider effects on both groundwater flow and radionuclide transport. The analysis should also explore the likelihood of placing a well in any of the vaults.

3.5.2 Direct intrusion – excavation of the repository

The likelihood of an inadvertent excavation of the repository is judged to be quite low. There seems to be little reason for such an intrusion. For example, there are no known important ore-potential mineralogical deposits in the area /SKB, 2000/. Consequences of direct intrusion will not be studied with in the SAFE project.

3.6 Other scenarios

Based on the FEPs audit also the following scenario initiators may be potentially important to consider:

- Deviation in radionuclide inventory
- Gas explosions – hydrogen, methane, air – early after repository closure.

However, neither of these scenarios will be further considered in SAFE. The radionuclide inventory will be estimated by a conservative method and analysing consequences of additional deviations from the Base Scenario would not be warranted. The consequence of fire etc is considered in the assessment of the operational phase, and was also discussed in past assessments /SKB, 1993, Section 6.6/, but there are no indications that gas explosions after repository closure should be possible. The heat generation from the waste is very low already during the operational phase and the repository will be saturated with water in a short time after repository closure. Gas explosions after repository closure is therefore assessed as a highly unlikely event.

4 System description

4.1 General

The current chapter presents the resulting prioritised repository, geosphere and biosphere matrices. The diagonal elements and the more important (“pink”, “red” and “yellow”) interactions are described. In addition, an indication is given on how the processes are considered in the quantitative analysis. The complete content of the matrices is recorded in the interaction matrix database. The system description is mainly developed for the Base Scenario. But, it is expected that the analysis of the Base Scenario to a large extent will be relevant also for other scenarios, or that other scenarios often can be handled as parameter variations in the models used to assess the Base Scenario. This is already described in Sections 3.3 to 3.6.

4.2 Repository

The system included in the repository matrix contains the Silo and the repository vaults BMA, 1BTF, 2BTF and BLA. The repository matrix is graphically displayed in Appendix F. The geometrical boundary of the system is defined as the interface between the Silo or repository vaults and the surrounding rock or access tunnels, including the plugs. Thus, the repository matrix should display interactions (processes) between the different physical components within each repository part and interactions with the surrounding rock and access tunnels.

Interactions between the different repository parts occur via the surrounding rock or the access tunnels that are included in the geosphere matrix. These types of interactions are then primarily displayed in the geosphere matrix, but the propagation of such interactions into the different physical components of the repository is taken care of via the boundary elements of the repository matrix.

4.2.1 Diagonal elements -– system variables

The definition of diagonal elements are based on the different types of physical components in the repository as a whole and not on different types of physical components within each repository part. This reduces the number of diagonal elements since only one diagonal element is required for physical components that are similar in the different repository parts.

The physical components of the repository that are considered in the repository matrix are (see Table 4-1):

- Non-solidified waste and waste matrices of cement and bitumen
- Waste packaging of concrete and steel
- Concrete backfill between waste packages
- Concrete structures (walls, roof, floor)
- Bentonite and sand/bentonite barriers in the Silo
- Gravel/sand fill in vaults and Silo
- Rock reinforcements in terms of shotcrete and rock bolts
- Water
- Gas

These physical components of the repository are characterised by different variables. Ideally, there should be one leading diagonal element in the matrix defined for each of these variables in order to be able to fully use the off-diagonal elements for interacting processes in the system. However, this would lead to an unrealistically large matrix with many empty off-diagonal elements and therefore some variables are lumped together in one diagonal element. This lumping of variables is made in such a way that it should be possible to display as many as possible of the processes in the system in the off-diagonal elements.

The definition of the diagonal elements in the repository matrix is given in Table 4-1 in terms of a short description and the variables that are assigned to the diagonal elements.

Variables that define the properties of the *solid components* of the repository system are assigned to the first nine diagonal elements (1.1 to 9.9). These variables are those defining the geometry, physical and chemical characteristics of the solid materials as a function of time and space within each component. Also the type and amount of trace components in the materials are included here, such as different chemicals and additives in waste and barriers and impurities in barrier materials.

Variables needed to describe the *water* in all parts of the repository as a function of time and space are assigned to diagonal elements *10.10 Water composition* and *11.11 Hydrology*, and variables describing gas in gas phase in all parts of the repository are assigned to diagonal element *12.12 Gas*. However, gas dissolved in water is included in diagonal element 10.10 *Water composition*.

The variables that define the *thermal, mechanical and biological state* of the physical components of the system as a function of time and space are assigned to diagonal elements *13.13 Temperature*, *14.14 Stress conditions* and *15.15 Biological state*, respectively.

Diagonal element *16.16 Radionuclides and toxicants* contains variables that describe the *physical and chemical state of radionuclides and toxicants* in all physical components of the repository as a function of time and space. These variables could have been included in diagonal elements 1.1 to 10.10 and 12.12, but using a separate diagonal element for these variables more clearly displays how different properties and conditions of the system and the evolution of these are affecting radionuclides and toxicants in the system.

Boundary conditions, i.e. impacts from the access tunnels and the rock surrounding the Silo and repository vaults, are introduced via the diagonal elements *17.17 Tunnels* and *18.18 Repository rock*. These diagonal elements are the link between the repository matrix and the geosphere matrix.

Table 4-1. Definition of the diagonal elements in the repository matrix

Element name	Short description	Variables
1.1 Waste/cement	Waste and cement matrix of all waste types that are stabilised in cement, i.e. ion-exchange resin, sludge, scrap and trash allocated to the Silo, BMA and 1BTF	Volume, dimensions, voids Porosity, pore characteristics Amount, characteristics of fractures Amount, composition, surface characteristics of materials Type, amount of chemicals Type, amount of organic materials and components that can be utilised by microbes as nutrients and energy sources Extent of cement hydration in cement/concrete components Amount and composition of surface coating on steel packaging
2.2 Waste/bitumen	Waste and bitumen matrix of all waste types that are stabilised in bitumen, i.e. ion-exchange resins and evaporator concentrates allocated to the Silo, BMA and BLA	
3.3 Waste/non-solidified	All non-solidified waste in the different repository parts, i.e. ion-exchange resins in 1BTF and 2BTF, ashes in 1BTF, trash and scrap in BLA.	
4.4 Concrete packaging	Concrete packaging with reinforcement and expansion cassettes, when present, in concrete moulds in the Silo and BMA. Concrete packaging, reinforcement and rubber liners in concrete tanks in BTF. The two steel drums and the concrete in between the steel drums that are used as packaging for ashes in 1BTF	
5.5 Steel packaging	All types of steel packaging that are used in the different repository parts, i.e. drums, boxes and containers, except the ash drums in 1BTF (included in element 4.4). .It also includes surface coating on the drums when present, e.g. paint.	
6.6 Concrete backfill	Concrete backfill surrounding the waste packages in the Silo and in BMA. Concrete that will be filled in the void between the concrete tanks and the vault walls in 2BTF, and the concrete that will be filled in between the drums in 1BTF.	
7.7 Concrete structures	Concrete structures in the different repository parts in terms of bottom, lid and outer as well as inner walls in the Silo and BMA and concrete floor in BTF and BLA. It also includes shotcrete and rock bolts in the rock walls in all repository parts.	
8.8 Bentonite barriers	Sand/bentonite in the bottom and top of the Silo and the bentonite surrounding the cylindrical concrete walls	
9.9 Vaults and backfill	Voids and backfill in the Silo cupola, outside the concrete structures in BMA and outside the waste packages in 1BTF, 2BTF and BLA. It also includes the sand layer above the concrete lid and the gas release devices in the Silo	
10.10 Water composition	Water composition, including colloids/ particles and dissolved gas, in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA	Redox, pH, ionic strength, concentration of dissolved species, type and amount of colloids/particles, amount and composition of dissolved gas, density and viscosity
11.11 Hydrology	Water and water movement in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA	Magnitude, direction and distribution of water flow, Degree of saturation, Amount of water, Water pressure, Aggregation state (water/ice)
12.12 Gas	Gas and gas movement in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA	Amount, composition, volume, pressure, degree of saturation Magnitude, direction and distribution of gas flow
13.13 Temperature	Temperature in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA	Temperature
14.14 Stress conditions	Stress and strain in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA	Stress and strain, Swelling pressure in bentonite barriers
15.15 Biological state	The biological state of waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA	Type, amount, mobility of microbes and bacteria (and other types of biomass)
16.16 Radio-nuclides and toxicants	Radionuclides and toxicants in solid, aqueous and gas phase in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA	Amount, type, chemical and physical form, concentration
17.17 Tunnels (Boundary condition)	*The geometry of access tunnels and all physical components in tunnels, i.e. backfill, plugs and rock reinforcements (e.g. shotcrete, rock bolts etc). The definition also includes water and gas in the tunnels.*	*Those variables assigned to diagonal elements 5.5, 6.6, 7.7, 8.8, 10.10, 11.11, 12.12, 13.13, 14.14, 15.15 and 16.16 in the geosphere matrix (see Table 4-2)*
18.18 Repository rock (Boundary condition)	*Rock and fracture system in between as well as around the vaults and the Silo to a distance of about 20 to 30 m from the repository. The definition includes all solid phases as well as water and gas.*	

With the selected definition of the diagonal elements in the repository matrix most of the thermal, hydrological, gas, mechanical, chemical and biological processes that affect the properties and conditions in the system should occur in the off-diagonal elements of the matrix. This is also the case for processes that affect radionuclides and toxicants and are affected by the properties and conditions of the system. However, there are a few exceptions. Processes that can change the physical or chemical properties of the solid materials in the repository without being dependent on the thermal, mechanical or biological state of the material or the characteristics of water and gas are not displayed in the off-diagonal elements. Neither is chemical processes occurring in the water phase that only are dependent on the chemical state of the water. When this type of 'internal' interactions have been identified these are introduced in the diagonal element containing the affecting and affected variables.

4.2.2 Waste forms

The waste forms allocated to SFR are here divided into three categories. These are wastes solidified in cement, waste solidified in bitumen and non-solidified waste.

Cement solidified waste refer to the properties (see Table 4-1) of cement conditioned ion-exchange resins, sludge, trash and scrap in the Silo, BMA and 1BTF and also include internal parts of the waste containers such as the steel stirrer.

Bitumen type waste forms refers to the properties (see Table 4-1) of both waste and bitumen for all waste types that are solidified in bitumen, i.e. ion-exchange resins and evaporator concentrates allocated to the Silo, BMA and BLA.

Non-solidified waste forms refer to the properties (see Table 4-1) of all non-solidified waste in the different repository parts, i.e. ion-exchange resins in BTF, ashes in 1BTF, and trash and scrap in BLA.

The following interactions (processes) are judged to be potentially important for the different waste forms. The interactions that are judged to be of negligible importance are listed in Appendix E.

Recrystallisation

Recrystallisation/mineralisation of the hydration products in cement in the waste matrix may change the internal physical structure of the cement. The impact of recrystallisation on the barrier function of the cement waste matrix could then be that the surface area available for sorption as well as the diffusion coefficient in the cement waste matrix is affected. However, the rate of transformation is probably low due to the low solubility of the hydrated calcium silicate gels /Höglund and Bengtsson, 1991/. These effects are not specifically addressed in the quantitative analysis, but should be covered by the pessimistic selection of sorption and diffusion data for the quantitative analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

Expansion/contraction of the waste

For non-conditioned wastes with a concrete packaging, changes in volume and dimensions of the concrete packaging may cause expansion/contraction of the waste and by that change the volume and dimensions of the waste and the void inside the waste package. Volume expanding reaction products in the concrete will probably primarily affect the stress situation in the concrete packaging, but the internal void inside the packages with non-solidified waste may also be utilised for this expansion in volume. Similarly, for wastes with a steel packaging changes in volume and dimensions of the steel packaging may cause expansion/contraction of the waste thereby affecting the volume and dimensions of the materials and voids inside the waste package. Corrosion of the steel packaging will result in the formation of volume expanding corrosion products. The internal void inside the packages with non-solidified waste may be utilised for this expansion in volume.

It is uncertain whether any of the above effects are significant. However, within SAFE there is no credit taken for the transport resistance in the non-solidified waste and the potential change in internal void is probably difficult to quantify considering the variability in the initial internal void in the waste packages and thus the uncertainties in the quantification of this entity. The process is therefore at this stage discarded for further analysis.

Water uptake

Uptake of water may change the geometry, structure and volume of the waste/cement and waste/bitumen matrix due to the hygroscopic character of the waste (ion-exchange resin and evaporator concentrate). The gradient in ionic strength in the waste matrix as well as the amount of water (degree of saturation) and water pressure in the waste matrix and in surrounding components of the system affects the uptake of water.

Volume expansion of ion-exchange resin in cement could cause cracking of the cement waste matrix and surrounding containers. These effects have not been studied in detail within SAFE, but swelling of ion-exchange resins is deemed to be minor since water is used in the preparation of the waste matrix and the resins are therefore expected to be fully swelled already at repository closure.

Water uptake in bitumen was described in the previous safety assessment. Within SAFE, the process is assessed /Pettersson and Elert, 2001/ and the results are considered when choosing the release mode in the quantitative analysis of radionuclide release /Lindgren *et al.*, 2001/ (see also Section 5.3.6).

Chemical and microbial degradation

Chemical and microbial degradation of organic materials in the waste and matrix may change the amount, composition, dimensions and porosity of the waste and cement matrix. These processes are primarily dependent on the water composition in the waste and cement matrix. Changes in material composition may affect the sorption properties of the waste matrix and changes in porosity may affect the diffusion coefficient in the matrix. In the SAFE analysis, the waste material itself is not considered as a sorption barrier and the quantity of organic additives in the cement matrix is too small for having any impact on the sorption properties of the cement. The impact of changes in material composition on the sorption properties of the cement waste matrix may then be discarded. The potential change in porosity of the waste matrix due to degradation of organic materials is not explicitly addressed in the assessment, but should be covered by the pessimistic selection of sorption and diffusion data for the quantitative analysis of radionuclide release /SKB, 2001b/.

Microbes can degrade organic waste and the bitumen matrix, but it is assessed that the effect on properties of the waste matrix is small compared to the effect of water uptake.

Degradation of organic materials may also generate gas and complexing agents. Gas can via pressure build-up cause cracking of the waste matrix (see Cracking below). Complexing agents can affect the sorptivity of certain elements, but this impact on sorption goes via water composition and is therefore treated in Section 4.2.7.

Corrosion of metals

The mode and rate of corrosion of metals in the waste will affect the amount, composition, dimensions and porosity of the waste and cement matrix. This process is influenced by the water composition in contact with the waste. The formation of corrosion products induces a volume increase of the waste that primarily affects the porosity, but can also lead to cracking of a cement matrix (see Cracking below). Iron corrosion products can also be a good sorbent for many elements (see e.g. Savage *et al.* /2000/), but this potential extra sorption barrier is not considered in the quantitative analysis of radionuclide release in the SAFE project.

The initial void in the packages with unconditioned waste is probably large enough to take care of the volume expansion that will take place. The size of the void inside the package will be affected, allowing smaller and smaller volume of water in contact with the waste. Within SAFE the non-solidified waste is not considered as a physical or chemical barrier for radionuclides and the potential change in internal void is probably difficult to quantify considering the variability in the initial internal void in the waste packages. This effect of the process is therefore at this stage discarded for further analysis.

Anaerobic corrosion of iron/steel and aluminium will generate hydrogen gas. A gas pressure build-up can indirectly cause cracking of a cement waste matrix (see Cracking below)

Dissolution/precipitation

Dissolution/precipitation of waste and matrix components may affect the amount, composition, dimensions and porosity of the waste and cement matrix. The types of reactions that take place are dependent on the water composition in the waste and cement matrix. Dissolution of alkali hydroxides (sodium and potassium), portlandite and calcium silicate hydrate (CSH) in the cement will affect the composition and porosity of the matrix. Calcium aluminate minerals in the cement can react with sulphate in the water to form the minerals ettringite and monosulphate hydrate or with chloride in the water to form Friedel's salt (calcium chloroaluminate hydrates). Formation of ettringite and Friedel's salt is associated with a volume increase since significant amounts of crystal water are bound to the solid phase. This will primarily reduce the porosity of the matrix, but can also lead to cracking of the cement matrix (see Cracking below). Other minerals that can be formed and thus influence the porosity of the cement waste matrix are calcite and brucite. These type of chemical reactions and their impact on the chemical conditions and properties of the concrete structures has been studied within the SAFE project /Höglund, 2001/. The cement waste matrix has not been specifically addressed, but the results reported in Höglund /2001/ as well as results from earlier analyses /Höglund, 1989/ are considered in the selection of data and calculation cases for the quantitative analysis of radionuclide release in SAFE /SKB, 2001b/ (see also 5.3.5).

The composition of water inside the bitumen matrix will affect the dissolution of the waste. However, the effect on the properties of the waste and waste matrix is most likely much less important than the effect of the preceding water uptake.

Cracking

Formation of volume expanding reaction products in the cement waste matrix, e.g. ettringite and corrosion products and creation of gas overpressure, e.g. due to hydrogen evolving corrosion, changes the stress conditions in the waste/cement matrix and surrounding barriers. This may cause cracking of the materials thereby affecting the geometry and porosity and amount and aperture of fractures in the materials. These processes have not been analysed in detail within SAFE, but it is believed that cracking primarily will affect the hydraulic properties of the waste matrix. This is indirectly accounted for in the selection of data and calculation cases for the quantitative analysis /SKB, 2001b/ (see also 5.3.5).

Changes in stress conditions in the waste/bitumen matrix and surrounding barriers may cause cracking of the materials thereby affecting the geometry and porosity and amount and aperture of fractures in the materials. Such stress changes may result from volume expansion due to water uptake and is thus one aspect that should be considered when analysing water uptake. In the study of water uptake the influence on the physical properties is included /Pettersson and Elert, 2001/ and these effects are considered when choosing the release mode in the quantitative analysis of radionuclide release /Lindgren *et al.,* 2001/ (see also Section 5.3.6).

Microbial activity/growth

Microbes that utilise components in the waste matrix as a source for energy and/or nutrients can by this process affect the composition and porosity of the waste matrix. Microbes may also grow as biofilms on the surfaces and thereby affect the amount of surfaces of the materials that are accessible to chemical reactions and also affect the porosity by clogging.

Microbial activity and growth requires a continuous supply of oxidants and/or removal of degradation products /Pedersen, 2001/. Since the hydraulic conditions inside a cement waste matrix is expected to be fairly stagnant the conditions will be unfavourable for microbial growth and the impact of microbial activity on the composition and porosity of the cement waste matrix is therefore neglected.

Similarly, the expected low water content in a bitumen matrix and slow exchange of oxidants and degradation products is expected to limit the microbial activity in a bitumen matrix. In addition, bitumen will be degraded at a slow rate if conditions are anaerobic /Pedersen, 2001/. The effects on the properties of a bitumen matrix are therefore of negligible importance and not further considered in the analysis.

Irradiation

Irradiation by decaying radionuclides may affect the chemical and physical properties of the waste and waste matrix. No influence on composition or structures of the waste and waste matrix is expected because of small amounts of radionuclides, other than possibly radiolytic decomposition of water and organic materials in the waste. Radiolytic degradation of e.g. cellulose may make the material more accessible to chemical degradation by splitting the carbon chain. However, a check of radiation levels in the bitumenised waste has showed that radiation levels are insignificant /Pettersson and Elert, 2001/ and the process may thus be discarded. Furthermore, the impact of this process on the properties of a bitumen matrix is negligible in relation to the effects of degradation by water uptake.

4.2.3 Concrete and steel packaging

Concrete packaging refers to the properties (see Table 4-1) of the concrete packaging with its reinforcement and also expansion cassettes, when present, in concrete moulds in the Silo and BMA. It also includes the concrete packaging, reinforcement and rubber liners in concrete tanks in BTF and the ash drums in 1BTF.

Steel packaging refer to the properties (see Table 4-1) of all types of steel packaging used in the different repository parts, i.e. drums, boxes and containers, except the ash drums in 1BTF. It also includes surface coating on the drums when present, e.g. paint.

The following interactions (processes) are judged to be potentially important for the properties of the packaging.

Recrystallisation

Recrystallisation/mineralisation of the hydration products in cement in the concrete packaging may change the composition and internal physical structure of the concrete (see Recrystallisation in 4.2.2). These effects are not specifically addressed in the quantitative analysis, but should be covered by the pessimistic selection of sorption and diffusion data for the quantitative analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

Corrosion

Corrosion of metal (reinforcement bars) in the concrete will affect the amount, composition, dimensions and porosity of the concrete. Corrosion induces volume changes due to formation of corrosion products, which in turn may fracture the concrete, at least in the vicinity of the reinforcement bars.

It is primarily the amount and surface area of metal, its chemical form and the water composition, which affects the mode and rate of corrosion. Corrosion of metals was considered and analysed in the past safety assessment /SKB, 1993/. Within SAFE, corrosion of reinforcement bars is considered as one mechanism that with time can change the hydraulic properties of the concrete packaging /SKB, 2001b/ (see also Section 5.3.5).

Corrosion also affects the composition, dimensions and porosity of the steel packaging. It induces volume changes due to formation of corrosion products and localised corrosion of containers open access paths for radionuclide migration. The impact of corrosion on steel packaging is not specifically considered within SAFE since there is no credit taken for any transport resistance from the steel packaging.

Dissolution/precipitation

Dissolution/precipitation in the concrete packaging affects the composition, dimensions and porosity of the concrete packaging. The water composition in the concrete packaging controls the process and the potential reactions are the same as for the cement waste matrix (see Dissolution/precipitation in 4.2.2). The evolution of concrete properties for SFR conditions has been studied /Höglund, 2001/. The results of this study as well as results from earlier analyses /Höglund, 1989/ are considered in the selection of data and calculation cases for the quantitative analysis of radionuclide release in SAFE /SKB, 2001b/ (see also Section 5.3.5).

Cracking/deformation

Changes in stress conditions in the concrete packaging and/or in adjacent barriers may cause cracking of the materials thereby affecting the geometry and porosity and amount and aperture of fractures in the materials. The main cause for stress changes would be the volume changes resulting from metal corrosion and other chemical reactions in the concrete forming volume expanding reaction products, see above, as well as gas generation and pressure build-up inside the waste package. In SAFE this process is not directly analysed, but it is indirectly considered in the selection of data and calculation cases for the quantitative analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

Changes in stress conditions in the steel packaging and adjacent barriers may cause a deformation or even cracking of the packaging thereby affecting the dimension and geometry of the steel packaging. However, in general it is difficult to take any credit in the steel packaging as a barrier since it is difficult to prove that the packaging initially is watertight. This will also be the assumption made in SAFE in the analysis of radionuclide release /Lindgren *et al*., 2001/.

Microbial growth

Microbes that utilise components in the concrete and steel packaging as a source for energy and/or nutrients can by this process affect the composition and porosity of the packaging. Microbes may also affect the amount of surfaces of the materials that are available for corrosion and sorption by creating biofilms on the surfaces. According to Pedersen /2001/, microbial activity is low under stagnant hydraulic conditions due to the slow supply of oxidants and slow removal of reaction products. Because of the slow water turnover in and around waste packages in the Silo, BMA and BTF vaults the process is therefore discarded for further analysis. In BLA, the water turnover is faster, but this repository part contains steel containers only and steel containers are not considered as a barrier for radionuclides in the analysis.

4.2.4 Concrete backfill and concrete structures

Concrete backfill refer to the properties (see Table 4-1) of the concrete backfill surrounding the waste packages in the Silo and optionally also in BMA. It also refers to the concrete that will be filled in the void between the concrete tanks and the vault walls in the BTF vaults and in between the ash drums in 1BTF.

Concrete structures refer to the properties (see Table 4-1) of the concrete structures in the different repository parts in terms of bottom, lid and outer as well as inner walls in the Silo and BMA and concrete floor and lid in the BTF vaults and concrete floor in BLA. It also includes shotcrete and rock bolts in the rock walls in all repository parts.

The following interactions (processes) are judged to be potentially important for the properties of concrete backfill and concrete structures. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Recrystallisation

Recrystallisation/mineralisation of the hydration products in cement in the concrete backfill and concrete structures may change the composition and internal physical structure of the concrete backfill and structures (see Recrystallisation in Section 4.2.2). These effects should be covered by the pessimistic selection of sorption and diffusion data for the quantitative analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

Corrosion

Corrosion of metal reinforcements in the structures affects the composition, dimensions and porosity of the structures. Corrosion induces volume changes due to formation of corrosion products, which in turn may lead to fracturing of the concrete at least in the neighbourhood of the reinforcements. The amounts and surfaces of metal and the water composition affect the mode and rate of corrosion. Within SAFE, corrosion of reinforcement bars is considered as one mechanism that with time can change the hydraulic properties of the concrete structures /SKB, 2001b/ (see also Section 5.3.5).

Dissolution/precipitation

A number of dissolution/precipitation reactions can take place that affects the composition, dimensions and porosity of concrete backfill, concrete structures and shotcrete (see Dissolution/precipitation in Section 4.2.2). The water composition controls this process. The evolution of concrete properties for SFR conditions has been studied /Höglund, 2001/ and the results are considered in the selection of data for the quantitative analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5). The potential effects on shotcrete are disregarded since shotcrete not is considered in the migration analysis.

Cracking

Changes in stress conditions in the concrete backfill and concrete structures and in adjacent barriers may cause cracking of the backfill and structures thereby affecting the geometry and porosity and amount and aperture of fractures in these materials. The cause for stress changes can be the formation of volume expanding reaction products and gas pressure build-up. This process is considered in the selection of data and calculation cases for the quantitative analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5)

Rock fallout/redistribution

Rock stress or strength changes may result in rock block fallout if there is no proper backfill in the vault. Such rock fallout would affect the dimensions, geometry and properties of the concrete structures in such a vault. A scoping analysis of the potential for rock fallout is undertaken within SAFE /Fredriksson, 2000/, but the potential impact on the concrete structures in not explicitly considered since the vaults that contain concrete structures also have a rock fill. Rock deformation may also cause fall out of shotcrete thereby affecting the amount of shotcrete left in place and the physical properties of the shotcrete. This effect is not directly considered in the quantitative analyses.

Microbial growth

Microbes utilising components in the concrete backfill or concrete structures as a source for energy and/or nutrients can by this process affect the composition and porosity of these materials. Microbes may also affect the amount of surfaces of the materials that are accessible to reactions with components in the water. The process is probably of negligible importance because the slow water turnover will limit the supply of reactants needed and the removal of reaction products. Under such circumstances the microbial activity is low /Pedersen, 2001/.

4.2.5 Bentonite barriers

Bentonite barriers refer to the properties (see Table 4-1) of the sand/bentonite in the bottom and top of the Silo and of the bentonite surrounding the cylindrical concrete walls. The following interactions (processes) are judged to be potentially important. The processes/interactions that are judged to be of negligible importance are listed in Appendix E.

Bentonite expansion and contraction

Changes in volume and dimensions of the concrete structures in the Silo may affect the dimensions and volume of the bentonite barriers in the Silo and thereby also the density and swelling pressure of the bentonite barriers. The importance of the effect depends on the extent of volume change of the concrete. The chemical degradation of the concrete and subsequent volume changes will be small /Höglund, 2001/.

Bentonite may expand into fractures in the concrete structures and into fractures in the surrounding rock. The extent of swelling will depend on the amount and apertures of these fractures and the expansion may affect the density and homogeneity of the bentonite. The process could be important for the buffer properties locally close to fractures. A fracture characterisation of the rock around the Silo indicates that the amount of fractures is small and thus the effect on the overall properties should be small. The amount of fractures in the concrete structures is probably also small and thus the effect on the overall properties should be small.

Bentonite may also expand into the sand layers and backfill at the top of the Silo. The extent of swelling will depend on the porosity of the sand layers and backfill and the expansion may affect the density and homogeneity of the bentonite. The process could maybe affect the properties of the sand/bentonite layer above the concrete lid in the Silo.

Bentonite expansion is generally discussed in the SKB SR 97 process report /SKB 1999c/. Based on this and the expected small “extra” volume accessible for bentonite expansion the effects on the properties of the bentonite should also be small. However, this impact is indirectly considered since a situation with a less effective (i.e. more pervious) bentonite around the Silo is included as a calculation case in the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

Water uptake

Water uptake in the bentonite barriers is a complicated process that depends on the gradient in ionic strength, the amount of water (degree of saturation) and the water pressure in the bentonite barriers and in adjacent components of the system. The process affects the geometry, structure, volume, swelling pressure, expandability and self-healing ability of the bentonite barriers as well as the time of saturation and the homogeneity of the swelling. The process is generally described in SKB SR 97 process report /SKB, 1999c/. Uneven water uptake and swelling could mechanically affect the concrete structures and adjacent rock.

The process of water uptake in the bentonite barriers is not analysed in detail within SAFE. However, a simplified treatment of the process is included in an estimate of the time required to saturate the whole Silo after repository closure /Holmén and Stigsson, 2001/. Furthermore, it is judged that the network of tubes that is located on the rock walls outside the bentonite barriers, and today are used to drain the Silo from inflowing water, should favour an even wetting of the outer surfaces of the bentonite barriers when pumping is terminated. In addition, the concrete structures of the Silo are designed to withstand a certain amount of uneven swelling pressure in the bentonite /SKB, 1991/.

Montmorillonite transformation

The presence of different species in the water may lead to transformation of the montmorillonite in the bentonite barriers. For example, the presence of potassium may lead to formation of illite and high pH may lead to alkaline hydrolysis of montmorillonite. The bentonite around the Silo will be exposed to concrete water with both high pH and high concentration of potassium so these transformation mechanisms are potentially important for the long-term properties of the bentonite (see also Dissolution/precipitation below). However, there are large uncertainties regarding the impact of alkaline concrete water on bentonite, both in terms of reaction mechanisms and rates and the consequences on bentonite properties. Transformation to illite is discussed in the SR 97 process report /SKB, 1999c/ and the present knowledge indicates that the low temperature in the bentonite around the Silo will prevent extensive transformation to illite in a time perspective of 10 000 years. A high pH will probably cause a dissolution of accessory minerals in the bentonite buffer (see Dissolution/precipitation below) rather than alkaline hydrolysis of the montmorillonite. This is supported by results from experiments where sodium bentonite was percolated with calcium hydroxide (pH = 13.8) during 16 months /Karnland, 1997/. Only small changes in the bentonite was observed in terms of dissolution of cristobalite and silica and formation of CSH phases and minor formation of illite, but no clear evidence of montmorillonite alteration was found.

In order to increase the understanding of the impact of concrete pore water on bentonite, SKB is presently participating in the ongoing ECOCLAY project within the European Community. Within SAFE, the potential impact of concrete pore water on the bentonite barriers around the Silo is indirectly treated by analysing the consequences of deteriorated hydraulic properties of these barriers /SKB, 2001b/ (see also Section 5.3.5).

Dissolution/precipitation

The water composition in the bentonite barriers in the Silo affects the dissolution/precipitation of non-clay minerals and other impurities in the bentonite barriers and thus the composition, porosity, homogeneity and expandability of the bentonite barrier. The bentonite around the Silo will be exposed to concrete water with high pH and high concentration of alkali metals. This could result in the dissolution of cristobalite (an accessory mineral in bentonite) and in alkaline hydrolysis of the clay mineral montmorillonite (see Montmorillonite transformation above). A reaction between hydroxide and cristobalite is expected to result in the formation of calcium silicate hydrate (CSH) /Höglund, 2001/. This is supported by the results from tests with percolation of calcium hydroxide (pH = 13.8) during 16 months /Karnland, 1997/. Only small changes in the bentonite were observed in terms of dissolution of cristobalite and silica and formation of CSH phases and minor formation of illite.

Because of the uncertainties associated with the impact of concrete pore water on bentonite, the process of dissolution/precipitation is indirectly considered within SAFE by analysing the consequences of deteriorated hydraulic properties of these barriers /SKB, 2001b/ (see also Section 5.3.5).

Ion exchange

The composition of the water in the bentonite barriers in the Silo can change the type of adsorbed cation through ion exchange (sorption) by which the physical properties of the adsorbed (interlamellar) water and the ability to form an intergranular clay gel are altered. The bentonite in the barriers is originally a calcium bentonite that by treatment with sodium carbonate are converted to sodium bentonite. This sodium can be replaced by potassium, calcium and magnesium supplied by the concrete and dissolved in the groundwater. The process is generally discussed in the SR 97 process report /SKB, 1999c/ and also considered within SAFE in the analysis of the chemical degradation of concrete /Höglund, 2001/. The consequence of this would mainly be an increase in hydraulic conductivity of the bentonite barriers. This is indirectly considered in the selection of calculation cases and data for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

Dispersion of clay particles

Clay particles in the bentonite may be dispersed through swelling, i.e. uptake of water in between the particles. Bentonite expansion and dispersion of clay particles requires a low ionic strength of the water and a free expansion volume such as fractures. The process is generally described in the SKB SR 97 Process Report /SKB, 1999c, Section 4.7.7/. The process could possibly be of importance, but not in a short-term perspective when the groundwater is saline and the concrete supplies cations. Furthermore, the fracture density around the Silo is small. Anyhow, the potential impact of the process should be covered by the selected calculation case with deteriorated hydraulic properties of the bentonite barriers /SKB, 2001b/ (see also Section 5.3.5).

Microbial growth

Microbes utilising components in the bentonite barriers in the Silo as a source for energy and/or nutrients can affect the composition and porosity of the bentonite barriers. Microbes may also affect the amount of surfaces of the materials that is available to chemical reactions.

Compacted bentonite with a density of > 1800 kg/m^3 is unfavourable for the growth of microbes due to low water availability, low porosity and stagnant transport conditions, allowing only diffusive transport of nutrients, energy sources and degradation products /Pedersen, 2001/. The bentonite barriers in the Silo will have a lower density, around 1000 kg/m^3, and the top and bottom barriers contain large amounts of sand. The criteria of low water availability is thus not fulfilled, but stagnant transport conditions with only diffusive transport of nutrients, energy sources and degradation products are expected and the microbial growth should then be limited. This process is therefore not further considered within SAFE.

4.2.6 Vaults and backfill

Vaults and backfill refer to the properties (see Table 4-1) of the voids and backfill in the Silo cupola, outside the concrete structures in BMA and outside the waste packages in 1BTF, 2BTF and BLA. It also includes the sand layer above the concrete lid and the gas release devices in the Silo. The following interactions (processes) are judged to be potentially important. The processes/interactions that are judged to be of negligible importance are listed in Appendix E.

Expansion/contraction

Changes in volume and dimensions of the materials and voids in the concrete packaging, in the steel packaging or in the concrete backfill and structures may affect the dimension and volume of the repository vaults and the backfill in the vaults. The volume changes are probably too small to have any significant effect on volumes and dimensions (voids and porosity) of the backfill in the vaults. Leaching of cement components from concrete backfill and structures is slow and will mainly affect the porosity of the backfill and structures /Höglund, 2001/. Leaching of concrete packaging will be insignificant within a time period of 10 000 years. Formation of volume expanding corrosion products may possibly slightly decrease the porosity in the backfill close to steel packaging. This is only relevant if backfill is present around the waste packages in the BLA vault. This process is therefore judged to be of negligible importance for the overall properties of the backfill that affects radionuclide release and is therefore discarded.

Redistribution of backfill

Inflow of water during the saturation phase may cause redistribution/settling of the rock backfill and create a permeable zone beneath the tunnel roof. This will affect the distribution of water flow in the tunnel, but not the total inflow of water to the tunnel. The water will mainly flow in the permeable zone. A smaller fraction of the water flowing in the rock fill should not increase the release of radionuclides. On the contrary, this will probably reduce the release and this interaction is therefore not considered in the analysis of radionuclide release.

Bentonite intrusion

Bentonite expansion may result in intrusion of bentonite into the sand layer between the concrete roof and bentonite top in Silo and into the rock fill above bentonite top. There may also be sedimentation of released bentonite particles in the voids. Bentonite intrusion may affect the sand layer in the Silo, but the sand layer is very thin and this will probably not be significant for the overall properties of the sand layer or the bentonite top fill. This effect is therefore discarded. The process is generally described in the SR 97 Process Report /SKB, 1999c, p 147/.

Dissolution/precipitation

The water composition in the backfill in the vaults (including sand backfill in the Silo) affects the dissolution/precipitation of components in the backfill in the vaults and thus the composition and porosity of the backfill in the vaults. The process is important since concrete pore water may react with the rock fill thereby possibly changing the properties of the fill, e.g. porosity and sorption capacities. Calcite and brucite may precipitate in the void and secondary calcium silicate hydrate (CSH) phases that form on the surface of the solid material may lead to some volume increase in the solid phase and thereby reduced porosity. The transformation to CSH phases may also lead to changes in sorption properties of the rock fill /SKB, 1999b/. This process is not analysed within SAFE, but the potential effects on the properties of the rock fill are considered in the selection of data for the analysis of radionuclide migration /SKB, 2001b/ (see also Section 5.3.5).

Microbial growth

Microbes utilising components in the rock backfill in the vaults (including sand filling in the Silo) as a source for energy and/or nutrients can affect the composition and porosity of the rock fill in the vaults. In the sand fill between the concrete lid and bentonite top fill in the Silo the stagnant hydraulic conditions should prevent substantial microbial growth. Microbial growth in the rock fill in the Silo cupola and in the vaults may alter the hydraulic conditions, provided that the growth is large. Biofilms may form and clog the preferential flow pathways. This would probably only be possible in parts of the fill that contain dissolved organic materials from the waste packages /Pedersen, 2001/. Clogging of the fill by microbes would then be most likely to occur close to the waste storage area and thus reduce the water flow in the vicinity of the waste. This would be beneficial in terms of radionuclide release from the waste storage area and this process is therefore not further considered.

4.2.7 Water composition

Water composition refers to the water composition, including colloids/particles and dissolved gas (see Table 4-1), in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA. The following interactions (processes) are judged to be potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Dissolution/precipitation

Dissolution and precipitation affect the water composition and potential colloid formation in all repository parts. The process depends on the water composition and the type and amount of material in the different parts. Some aspects of the process is described in the preliminary safety assessment of the deep repository for long-lived low-and intermediate level waste (SFL 3-5) /SKB, 1999b, Section 6.8.1/. For SFR the following aspects may be particularly interesting to explore:

- Dissolution and leaching of cementitious components from cement and concrete in the repository are important for the pH and ionic strength of the water. These effects are analysed within SAFE /Höglund, 2001/ and the results are considered in the selection of data for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.4).

- Dissolution of chemicals in the waste may generate complexing agents that affect the sorptivity of radionuclides. An inventory of the possible quantities of chemicals with complexing properties in the wastes to SFR is made within SAFE and the concentration of these complexing agents in the water in the waste packages is estimated /Fanger *et al.*, 2001/. The results of this study are considered in the selection of data and calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.4).

- Bitumenised waste contains evaporator concentrates that are composed of soluble salts. Dissolution of the salts will affect at least the ionic strength of the water in the bitumen matrix. This could be of importance for the diffusion of anionic radionuclides. The salt also contains sulphate that could react with concrete in the barriers. A study of the long term behaviour of bitumenised waste in SFR indicates that the rate determining step for the release of radionuclide from a bitumen waste matrix rather is the water uptake and establishment of a connected porosity than the diffusion of radionuclides /Pettersson and Elert, 2001/. The effect on ionic strength and diffusion in the bitumen matrix is therefore not considered. The impact of dissolved salt on water composition and degradation of surrounding concrete barriers is not specifically addressed within SAFE. However, this mode of concrete degradation is indirectly considered together with other degradation mechanisms in the selection of data and calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

- The amount and composition of the bentonite barriers in the Silo affects the dissolution/precipitation of non-clay minerals and other impurities in the bentonite barriers as well as the transformation of montmorillonite in the barriers. This is important at least for the dispersion of high pH from the concrete interior of the Silo and for the rate of alteration of the bentonite barriers in the Silo. The dispersion of high pH is not specifically addressed within SAFE (see Dissolution/precipitation and Montmorillonite transformation in Section 4.2.5), but indirectly considered in the selection of data and calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

Degradation of organics

Chemical and microbial degradation of organic materials, e.g. degradation of cellulose will affect the water composition and the formation of colloids. The process depends on the type and amount of organic matter and on the water composition. Particular consideration should be given to the alkaline hydrolysis of cellulose that can generate isosaccharinic acid (ISA), which can form strong complexes with radionuclides. In the absence of oxygen, the products of microbial degradation of organic materials are usually carboxylic acids, which are not particularly strong complexing agents. The process is generally described in the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.6.1/. Degradation of cellulose in SFR and the potential effects of ISA is studied within SAFE /Fanger *et al.*, 2001/ and the results are considered in the selection of data and calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.4).

Corrosion

Metal corrosion affects the water composition. The corrosion process as well as the presence of corrosion products is important in maintaining reducing conditions in the system. The process generally depends on the type, amount and configuration (surfaces) of metals and on the water composition. Presence of different types of metal may give rise to galvanic corrosion. The process is generally described in the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.6.1/. The process should be considered in all repository components where there are metals, i.e. in the waste/cement matrix, the concrete packaging, steel packaging, reinforcements in the concrete structures and rock bolts and reinforcement in shotcrete. Within SAFE, it is assumed that corrosion is one of the processes that ensure anaerobic conditions in the different repository parts /SKB, 2001b/ (see also Section 5.3.4).

Sorption

The composition of the water in the waste/cement matrix will be affected by sorption. Sorption will also affect the composition, including colloids of the water in the concrete packaging, the concrete backfill and the concrete structures. The process is probably of negligible importance for the major constituents in the water, but could be of importance for complexing agents such as ISA /SKB, 1999b and Fanger *et al.*, 2001/. This is considered in the selection of data and calculation cases for the analysis of radionuclide release from SFR /SKB, 2001b/ (see also Section 5.3.4).

Sorption/ion-exchange in the bentonite barriers will affect the concentration of metal ions such as Ca^{2+} and Na^{+} in the water. Ion exchange could also be of importance for the water composition due to the ampholytic properties of montmorillonite and thereby its ability to buffer pH. This process is generally described in the SR 97 Process Report /SKB, 1999c, Section 4.7.4/. Within SAFE, the implications of ion exchange on the composition of the bentonite buffer is studied as a part of the chemical alteration of concrete barriers /Höglund, 2001/ (see Ion exchange in Section 4.2.5).

Diffusion

Diffusion affects the composition of the water in all repository parts (cement waste matrix, bitumen waste matrix, packaging, concrete backfill, concrete structures, bentonite barriers, backfill and voids etc.). The diffusion process depends on the physical properties of the medium and on the composition of the water. The diffusion process is generally described in the SR 97 Process Report /SKB, 1999c, Section 4.8.6/ and in the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.8.2/. Within SAFE, diffusion is considered when evaluating the future water composition and alteration of concrete barriers in SFR /Höglund, 2001/.

Advection and mixing

The advective and dispersive transport of species in the waters will cause mixing of different waters and affect the composition. The advection is determined by the magnitude, direction and distribution of the water flow in the different compartments, which in turn also depends on the boundary conditions to flow. The water flow rate in the near-field barriers is low and the transport of dissolved species is probably diffusion controlled, except in the gravel fill and in the BLA vault. Anyhow, the evolution of water composition in concrete barriers assuming advective controlled transport is studied within SAFE /Höglund, 2001/. The results of this study as well as the future change to a fresh groundwater flowing into the repository is discussed in the selection of data for the analysis of radionuclide release /SKB, 2001b/.

Erosion/colloid formation/colloid transport

Mechanical erosion, due to the flow of water, of the different repository components (such as concrete packaging, concrete backfill, concrete structures, bentonite barriers backfill etc.) is a potential source for colloids. The chemical and physical properties of the different components affect their ability to withstand mechanical erosion and thus the amount of colloids/particles in the water. Also the magnitude of water flow (velocity) in the different components of the repository system will affect the extent of mechanical erosion. Erosion of bentonite and dispersion of clay particles is generally described in the SR 97 Process Report /SKB, 1999c, Section 4.7.7/.

The formation and stability of colloids also depends on the composition of the water. High concentration of dissolved salt tends to destabilise colloids. The mineral particles are generally negatively charged so the positive ions in the water, e.g. Ca^{2+} and also K^+ and Na^+ are of greatest importance. The formation and stability of colloids in a cementitious environment is described in the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.6.1/.

The groundwater movement in the near-field barriers may transport colloids. However, filtering of colloids/particles can take place in the barriers depending on the amount and size of pores/fractures in the cement waste matrix, concrete packaging, concrete backfill, concrete structures, and the bentonite backfill in the Silo. If colloids can exist in the environment in the repository, such filtering can be an important mechanism, (see the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.8.2/ and the SR 97 Process Report /SKB, 1999c, Section 4.8.3/). In addition, transport of colloids attached to the surface of gas bubbles could affect the amount of colloids in the different components of the repository system. Based on the description of this mechanism in the SR 97 Process Report /SKB, 1999c, Sections 5.8.6/ and the filtering capacity of the near-field barriers this potential mechanism is only relevant for transport of bentonite particles through the surrounding rock.

Within SAFE, no specific analysis is made of the formation, stability and transport of colloids in the water in the near-field barriers. However, the low water flow rate in the barriers together with the cementitious environment with high calcium concentration and the saline groundwater with a high content of dissolved salts should be unfavourable for colloid formation. Adding also the potential filtering effects of the barriers, it should be possible to discard colloids in the near-field barriers in the Silo, BMA, 1BTF and 2BTF. In BLA, there are no barriers and a significant amount of colloids in the water in the BLA vault cannot be excluded. This is indirectly considered in the selection of calculation cases in the analysis of radionuclide release /SKB, 2001b/ and so is the transport of colloids with gas bubbles.

Microbial activity

The type and amount of microbes/bacteria will by their presence and growth affect the water composition in the different components of the repository system. Dissolved carbon dioxide and methane, acids, ferrous iron, sulphide, and organic complexing agents may form, while the amount of sulphate, nitrate, ferric iron, hydrogen and oxygen will decrease owing to microbial consumption /Pedersen, 2001/. Due to the stagnant hydraulic conditions in the waste packages and near-field barriers that limits the supply of energy and nutrients and the removal of reaction products, microbial activity in these parts is assessed to be low. In the sand/gravel fill and in the BLA vault the situation can be different, but no quantitative analysis of the effects of microbial activity on water composition is made within SAFE. However, no obvious detrimental effects of microbial activity in the sand/gravel fill or in BLA is identified, except possibly that the production of acids locally can increase the dissolution rate of concrete surfaces facing the sand/gravel fill. This is not considered in the quantitative analysis of radionuclide release. The microbial consumption of oxygen supports the assumption of reducing conditions in the water in the near-field barriers /SKB, 2001b/.

Gas dissolution/degassing

The water composition, e.g. concentration of dissolved species and amount and composition of dissolved gas, will be affected by the amount and composition of gas in gas phase in the different components of the repository system via gas dissolution or degassing. The amount of air and other gas entrapped at repository closure is important for the initial water composition and gas generated in the repository is important for water composition in the long term. No quantification of the process is made within SAFE, but the effects on water composition and barrier degradation is indirectly considered in the selection of data and calculation cases for the analysis of radionuclide release /SKB, 2001b/.

4.2.8 Hydrology

Hydrology refers to the water and water movement (see Table 4-1) in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA. The following interactions (processes) are judged to be potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Water flow and boundary conditions

The magnitude, direction and distribution of the water flow in the waste packages and near-field barriers depend upon the dimensions and permeability of these different parts as well as on the flow and pressure at the boundary to the rock. These interactions are considered in the modelling of the hydrology in the near-field barriers in SFR /Holmén and Stigsson, 2001/.

Two phase flow and saturation

The gas pressure, gas flow and saturation degree in the different components of the repository system will affect the magnitude, direction and distribution of water flow in the system components. In addition, the pore-size distribution of the various repository parts (cement waste matrix, bitumen waste matrix, concrete packaging, concrete backfill, concrete structures and backfill of the vaults) will affect the capillary suction of water of these parts, and thus the distribution and magnitude of any two-phase flow in the repository. The process of two-phase flow is described in e.g. a joint EC/NEA status report on gas migration and two-phase flow /Rodwell *et al.*, 1999/.

The process is potentially important for the saturation phase since gas in the interior of the repository parts may prolong the time period required for reaching water saturation. Gas escape through water saturated concrete and bentonite is only possible if the gas pressure exceeds a threshold value. Such build-up of gas pressure may expel water from the system. This mechanism was considered in past SFR assessments as a potential consequence of gas formation in the Silo /Moreno and Neretnieks, 1991/.

Within SAFE, the impact on saturation is neglected. However, the impact of gas pressure build-up on the expulsion of contaminated water from all repository parts except BLA is considered (see Section 5.3.3).

Osmosis

Gradients in concentration in the different components of the system may cause osmotic potentials that affect the magnitude, direction and distribution of water flow in the different repository system components. The process may affect the time for saturation of the bentonite barriers in the Silo and the water uptake in the bitumenised waste. The impact on saturation of the bentonite barriers in the Silo is not considered in SAFE. The uptake of water in bitumenised waste is studied within SAFE /Pettersson and Elert, 2001/ and the results are considered in the selection of the release mode from bitumenised waste in the analysis of radionuclide release /Lindgren *et al.*, 2001/.

4.2.9 Gas formation and movement of gas

Gas and gas movement in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA is treated in a single diagonal element of the matrix (see Table 4-1). The following interactions (processes) are judged to be potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Gas generation through degradation of organic material

The type and amount of organic materials in the various repository parts will affect the microbial and chemical degradation of these. The following should be particularly considered:

- In the cement conditioned waste there may be degradation of cellulose. Microbial degradation may still be important. Alkaline hydrolysis could be the first step, but it cannot be excluded that the products formed by chemical degradation are further decomposed to gas /Lessart *et al.*, 1996/.
- Microbial degradation of bitumen and ion-exchange resins can generate gas. However, the degradation rate of bitumen and ion-exchange resins is slow in comparison with the degradation rate of cellulose /SKB, 1991/.
- There are some organic materials present in the concrete packaging such as rubber liners and expansion cassettes. The amount is probably small enough to make degradation of these a negligible gas source compared to gas from corrosion of reinforcements and metals.

Also the water composition in the different components of the repository system will affect the microbial and chemical degradation of these, e.g. degradation of cellulose. High pH and reducing conditions may favour alkaline degradation without gas generation instead of microbial degradation with gas generation. The quantity and type of gas that is formed is also dependent on what type of microbes that are present and the extent of microbial activity.

In all repository parts except BLA, the microbial activity is expected to be low because the stagnant hydraulic conditions in and around the waste packages will limit the supply of nutrients and energy sources and/or the removal of degradation products. Nevertheless, the gas generation from microbial degradation of organic materials in all the repository parts is estimated within SAFE /Moreno *et al.*, 2001/.

Gas generation through metal corrosion

Corrosion of metals is one of the major gas sources in the repository. The presence of different type of metals may give rise to galvanic corrosion. The type, geometry (surfaces) and amount of metals affect the mechanism and rate of corrosion and thus the amount and composition of gas generated. The corrosion and thus the gas generation also depends on the water composition (redox, pH, and corrosive agents such as chloride). Metals exist in almost all repository parts and needs to be accounted for when assessing the gas generation.

The processes have been considered in past assessments of SFR /Moreno and Neretnieks, 1991/ and in the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.7.1/. Within SAFE, the gas formation due to metal corrosion is estimated as a basis for the analysis of pressure build-up and expulsion of contaminated water /Moreno *et al.*, 2001/ (see also Section 5.3.3).

Gas generation through radiolysis

Radiation may disintegrate chemical compounds and form gas. The rate depends on the type of radiation and its energy levels and thus on the radionuclide inventory and the material exposed to radiation. Radiolytic decomposition of water generates hydrogen and oxygen gas. This process is described in the SR 97 Process Report /SKB, 1999c, Section 2.7.3/ and radiolytic decomposition of water and different waste types are addressed in a joint EC/NEA status report on gas migration and two-phase flow /Rodwell *et al.*, 1999/.

Due to the limited inventory of strong radioactive sources, gas from radiolysis probably gives a totally negligible contribution to the total gas amount in the different repository parts compared to gas from corrosion. This is verified by calculations reported in Moreno *et al.* /2001/. However, gas from radiolysis of bitumen may give rise to a gas pressure build-up in the bitumen matrix. This may in turn via stress changes lead to cracking of the bitumen matrix. This problem is addressed in a study of the properties of bitumenised waste to SFR /Pettersson and Elert, 2001/.

Gas flow

The direction, magnitude and distribution of gas flow in the various repository parts (waste matrices, backfill, structures etc) is affected by the dimensions and physical properties (pore structure, permeability etc) of these parts. In particular the following may need to be considered in the different parts:

- Water inside the bitumen matrix is required for degradation of the matrix to take place. The uptake of water has created paths for water intrusion and gas escape. If gas generation is fast a build up of gas pressure may occur that may create new or wider transport paths for gas and water and dissolved radionuclides and toxicants. Within SAFE, this aspect of gas generation on the degradation of a bitumen waste matrix is addressed in the study of the properties of bitumenised waste to SFR /Pettersson and Elert, 2001/.

- Any gas generated inside the waste packages must be assumed to have access to the entire empty void in the waste packages. The size of the void in the packages will affect the gas pressure and thus the gas flow from the packages. This aspect is considered in the analysis of gas generation and escape from the Silo, BMA and BTF vaults /Moreno *et al.*, 2001/.

- The dimensions and physical properties (e.g. permeability, porosity, pore-size distribution, homogeneity) of cement and concrete barriers and of the bentonite barriers in the Silo will affect the gas pressure and gas flow in the barriers. This aspect of gas flow is described in the SR 97 Process Report /SKB, 1999c, Section 4.5.3/ for flow through bentonite and in a joint EC/NEA status report /Rodwell *et al*., 1999/ for flow through bentonite and cementitious materials.

Within SAFE, this interaction is considered in the study of gas generation and escape /Moreno *et al.*, 2001/.

The gas flow also depends on the degree of saturation, but the saturation of the system will be relatively fast /Holmén and Stigsson, 2001/ and this impact is not further considered in the analyses.

Expansion/contraction

The gas volume depends on the gas pressure. This, in turn, depends on the water pressure in the different components of the repository system. This aspect is considered in the analysis of gas generation and escape /Moreno *et al.*, 2001/.

4.2.10 Temperature

Temperature refers to the temperature (see Table 4-1) in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA. The following interactions (processes) are potentially important to consider when assessing the temperature. However, it should be pointed out that there are only a few processes relevant to the performance of the SFR that are sensitive to the temperature within the reasonable future temperature ranges. Consequently, there is no direct need to model the temperature distribution within the vaults. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Heat generating reactions

Exothermic chemical reactions generate heat and thus affect the temperature. Exothermic reactions may take place in the waste packages and engineered barriers, e.g. corrosion reactions, but the effect on temperature is also dependent on how fast the heat is distributed in the different components of the system. No such reactions can be identified that would generate heat in such extent that the temperature is significantly effected over longer time periods, except possibly corrosion of aluminium. To verify this, the heat generated by corrosion of aluminium and the potential effect on temperature is estimated /Moreno *et al.*, 2001/.

The uptake of water in the bentonite may generate some heat, but this is a transient effect and probably of negligible importance. In the identification of important processes for the repository evolution in SR 97 /Pers *et al.*, 1999/ this heat generating process is neglected for compacted bentonite around a copper canister since the heat generation is small and the heat is partly dissipated during the time of wetting.

Microbial activity can generate heat, but the effect on temperature is also dependent on how fast the heat is distributed in the different components of the system. However, the SFR environment is not so rich in easily degradable organic carbon and oxidants that the temperature will be affected /Pedersen, 2001/.

Decay of radionuclides may generate heat and affect the temperature in different components of the repository system. The heat generation is expected to be small because of low activity in the waste. To verify this, heat generation from decay and the potential affect on temperature is estimated /Moreno *et al.*, 2001/.

Heat conduction

The thermal properties, i.e. heat capacity and heat conductivity, and dimensions of the various repository parts will affect the heat conduction in the repository and thereby the temperature. The heat conducting properties also depend on the degree of water saturation. Heat transport in the waste matrix is important in order to keep the temperature increase in the waste low if there are heat-generating processes in the waste matrix. This is discussed in connection with the estimate of the impact on heat generation on the temperature in the different repository parts /Moreno *et al.*, 2001/.

Boundary conditions – heat transport

The temperature of the vaults is largely controlled by the heat exchange with the surrounding rock and groundwater flow. This implies that the repository temperature will stay essentially the same as the rock and water temperature at similar depths.

4.2.11 Mechanics – stress conditions

Mechanics refers to stress and strain (see Table 4-1) in waste and barrier materials in the Silo, BMA, 1BTF, 2BTF and BLA. The following interactions (processes) are potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Expansion/contraction

Changes in geometry and dimensions of various repository components (waste matrices, packaging, structures etc,) will affect the stress conditions in the components and its surrounding. The following should be considered in particular:

- changes in geometry and dimensions of the concrete structures, e.g. due to corrosion of reinforcement and metals in the waste, and ettringite formation in the cement waste matrix, concrete packaging, concrete backfill and concrete structures,
- water uptake leading to volume expansion in the bitumen waste matrix.

The stress changes may in turn lead to cracking of the materials. These aspects are considered within SAFE in the quantitative analysis of radionuclide release (see Cracking in Section 4.2.2, Cracking/deformation in Section 4.2.3 and Cracking in Section 4.2.4).

Changes in geometry and dimensions of the bentonite barriers will affect the swelling pressure of the bentonite barriers and the stress conditions in adjacent system components. This aspect has not been specifically addressed within SAFE, but it is believed that the most probable change of the bentonite barriers is a decrease in swelling pressure. This will probably not be of any importance for the stress conditions and mechanical stability of the concrete structures in the Silo. It might possibly increase the risk of some fallout of rock in the Silo, but the major impact is assessed to be on the hydraulic properties of the bentonite barriers itself. Such a situation is considered in the selection of data and calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.5).

Water pressure

The water pressure in the different components of the repository system affects the stress conditions in the components of the repository system. No phase changes are expected in the different components of the repository system. The changes in water pressure due to land rise are small compared to the present pressure. A fast increase in water pressure due to gas generation in the interior of the repository parts could lead to cracking of the barriers. This situation is analysed within SAFE in the study of gas generation and escape /Moreno *et al.*, 2001/.

Gas pressure

The gas pressure in the different components of the repository system affects the stress conditions in the components of the repository system. Gas pressure build-up will take place in the Silo interior. Build-up may also take place in concrete in the other repository parts if no fractures are present through which gas can escape. This was considered in the past assessments as a mechanism that may cause cracking of the Silo /Moreno and Neretnieks, 1991/. The consequence of cracks in the Silo and in the concrete barriers in the vaults is also addressed within SAFE /SKB, 2001b and Lindgren *et al.*, 2001/ (see also Section 5.3.5).

Boundary conditions

Deformation of the rock boundary will affect the mechanical state of the repository parts. This is assessed to be of no importance for the BLA vault as long as no backfill around the waste packages are present. For the other repository parts the interaction is indirectly considered in the quantitative analysis of radionuclide release if deformation of the boundary leads to cracking of concrete barriers or to loss of swelling pressure of the bentonite barriers.

4.2.12 Biological state

Biological state refers to the amount and activity of microbes (see Table 4-1) in the waste and barriers in the Silo, BMA, 1BTF. 2BTF and BLA. The following interactions (processes) are potentially important to consider. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Microbial activity

The type and amount of organic materials and nutrients and energy sources in the various repository components and the physical properties of the components will affect the microbial activity in the components. Most of the organic material in the repository is probably contained in the waste (all types). The most favourable location for microbes should then be inside the waste containers.

The amount and composition of gas in gas phase in the different components of the repository system may affect the survival and activity of microbes and bacteria. Especially the amount of hydrogen and carbon dioxide is of importance for the state of microbes in SFR. At high concentrations, hydrogen may act as an inhibitor and carbon dioxide is important for the activity of autotrophic microbes, such as methane-forming microbes. Oxygen that is present in the initial phase is a very potent oxidant and will rapidly be consumed by microbial activity /Pedersen, 2001/.

According to Pedersen /2001/ microbial activity in the repository parts in SFR is possible provided that sufficient supply of nutrients and energy sources take place and that degradation products are removed and not accumulated. This indicates that microbial activity inside the waste packages should be limited in all repository parts, except in BLA, due to the expected stagnant hydraulic conditions. Microbial activity is therefore not considered in the analyses within SAFE, other than as a source for gas via degradation of organic materials (see Gas generation through degradation of organic material in Section 4.2.9).

Advection

The magnitude, direction and distribution of water flow in the different components of the repository system will affect the advective transport of microbes and bacteria (and other types of biomass) and thus the type and amount of these in the different parts.

According to Pedersen /2001/ microbes can swim and this mobility ensures that microbes will inhibit any space that has degradable material that can be reached by mobile bacteria. This implies that advective transport of microbes is of less importance for the position of microbes in the repository parts than the location of degradable materials. This interaction is therefore discarded from further analysis within SAFE. The actual survival and growth of the microbes at places where degradable organic materials are present is, however, dependent on the advective supply of nutrients and energy and the removal of degradation products (see above).

Boundary conditions

Growth and/or transport of biomass from the tunnels and from the rock into the vaults (Silo, BMA, BTF and BLA) will affect the biological state in the vaults. Root penetration and potential intrusion is judged to not propagate further into the repository. In general it is judged that the influence from the boundaries probably is small and that the biological state much more will depend on the conditions inside the repository. This interaction is therefore not further considered in the analyses.

4.2.13 Radionuclides and toxicants

The following interactions (processes) are judged to be potentially important when assessing the amount, state and migration of radionuclides and toxicants (see Table 4-1) in solid, aqueous and gas phase in waste and barriers in the Silo, BMA, 1BTF, 2BTF and BLA. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Dissolution/precipitation

The type and amount radionuclides/toxicants, their chemical form and the water composition, through its effect on speciation, affect the dissolution and precipitation of radionuclides and toxicants. The concentration of stabile isotopes can also have an impact via isotope dilution. In addition, the water composition affects the extent of precipitation of cementitious components like calcite/aragonite and corrosion products with which co-precipitation of radionuclides and toxicants may take place. Precipitation of calcite may also entrap dissolved $^{14}CO_2$ in the water.

The process is generally described in the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.8.1/. In past assessments it has been judged that radionuclide concentrations will be too low to make solubility limits important. This standpoint is withheld in SAFE despite that a more detailed analysis of the different repository parts may reveal areas with potential for higher concentration. In addition, effects of isotope dilution and co-precipitation with e.g. calcite are neglected.

Degradation of organic matter

The chemical and microbial degradation of organic matter affects the release of radio-nuclides and toxicants included in these. The process is potentially worth considering in the bitumen waste /Pettersson and Elert, 2001/. Even if the process also happens within other waste types it is conservatively discarded by assuming instant release.

Advection

The magnitude, direction and distribution of water flow in the different components of the repository system will affect the advective transport of radionuclides and toxicants and thereby the spatial and temporal distribution of radionuclides and toxicant. The process has been considered in past assessments /SKB, 1993/ and is also considered in the analysis of radionuclide release in SAFE.

Dispersion

The distribution of the water flow in different flow paths in the components of the repository system will affect the dispersion of radionuclides and toxicants and thereby the temporal distribution of radionuclides and toxicants in the water in the components. Hydrodynamic dispersion within each flow path is probably of less importance than dispersion due to differences in flow between different flow paths. Dispersion, is a scale dependent phenomenon, i.e. its importance depends upon the degree of resolution of the flow field. In past assessment, dispersion and mixing was often treated by simplifying assumptions ("mixing tank" etc.). In SAFE the process is considered by using a finer degree of resolution of the flow field in the migration modelling.

Diffusion

Diffusion is the main transport mechanism of radionuclides from intact waste packages and may also be important inside cracked waste packages. The physical properties (porosity etc) of the different repository components affect the diffusive transport of dissolved radionuclides and toxicants through the components. In the bitumen waste the importance of diffusion depends on the rate of diffusion in relation to the rate of water uptake and creation of a connected porosity in the bitumen matrix.

Diffusion is also affected by the water composition in the different components of the system. Anions have lower diffusivity in clays in water with a low ionic strength than in water with a high ionic strength. The ionic strength of the water is also important for the diffusion of cations that sorb via an ion-exchange mechanism. These aspects are important at least in the bentonite barriers for certain anions and cations and could also be important for diffusion in concrete. Diffusion in bentonite is generally described in the SR 97 Process Report /SKB, 1999c, Section 4.8.6/ and diffusion in cement/concrete in the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.8.2/.

The impact of physical properties of the barriers and the water composition on the diffusion process is considered within SAFE in the selection of calculation cases and data for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.3.6).

Sorption

Sorption affects the distribution between mobile and immobile radionuclides and toxicants in the different repository components, and is in fact one of the major retarding mechanisms in the engineered barriers in SFR. Sorption is affected by the type and amount of materials and by the water composition, mainly pH, complexing agents, Eh for redox sensitive elements, and ionic strength for radionuclides that sorb via ion exchange.

Cement/concrete is a good sorbent. Metal corrosion products are potential sorbents for radionuclides and toxicants, and co-precipitation with corrosion products may also take place. This retardation mechanism is usually neglected in systems where also cement/concrete is present since the cement/concrete is more abundant. In BLA where there are very small amounts of concrete, it could have an effect. There is negligible sorption, if any, on bitumen. Ion-exchange resins may have a certain retention capacity depending on the type and concentration of exchangeable anions or cations in the water in contact with the resins. There is probably little or no sorption on the other types of waste materials present in SFR. The bentonite barriers and the backfill of crushed rock and/or sand will also sorb radionuclides.

Sorption of radionuclides in bentonite is generally described in the SR 97 Process Report /SKB, 1999c, Section 4.8.5/ and sorption on cement/concrete and rock fill in the preliminary safety assessment of SFL 3-5 /SKB, 1999b, Section 6.8.2/. Sorption on steel corrosion products and also on concrete are described by Savage *et al* /2000/.

Within SAFE sorption on bentonite, cement/concrete and rock fill is considered in the analysis of radionuclide release, while the potential sorption capacity of other materials is neglected. The influence of physical properties of the materials and water composition is addressed in the selection of data and calculation cases /SKB, 2001b/ (see also Section 5.3.6).

Colloid transport and filtering

Radionuclides may sorb onto mobile colloids, thereby making sorption on the different repository parts or in the rock less effective. The process is generally described in the SR 97 Process Report /SKB, 1999c/ and in the preliminary safety assessment of SFL 3-5 /SKB, 1999b/. The effect depends upon the type and amount of colloids/particles in the water in the different components of the repository system. Since the amount of colloids in the water in the cementitious environment in the Silo, BMA and BTF vaults probably is low, radionuclide transport with colloids in the engineered barriers in those repository parts is discarded (see Erosion/colloid formation/colloid transport in Section 4.2.7).

Microbes are other potential carriers of radionuclides. However, the mobility of microbes will probably not transport significant amounts of radionuclides, since microbes more likely will inhabit spaces where degradable material is present /Pedersen, 2001/, i.e. in the waste containers. Furthermore, the expected stagnant hydraulic conditions in these locations is unfavourable for microbial life (see e.g. Microbial activity in Section 4.2.7) and this mechanism is not further considered in the analysis of radionuclide release within SAFE.

Advection of radioactive gas

The magnitude, direction and distribution of gas flow in the different components of the repository system will affect the transport of radionuclides and toxicants in gas phase and thereby the amount of radionuclides and toxicants in gas phase. Gas flow is certainly the main transport mechanism for radioactive gas from the repository. How this is considered in the analysis of radionuclide release within SAFE is described in Section 5.3.6.

Methylation/transformation

Microbes may change the chemical form of radionuclides and toxicants. Examples are the methylation of metals, turning inorganic species to organic, the carbon fixation of $^{14}CO_2$ to organic carbon, and the degradation of organic ^{14}C-carbon to $^{14}CO_2$. Such transformations will change the migration properties, e.g. sorptivity, of these radionuclides. To what extent the processes occur and the potential impact on radionuclide release is uncertain, but it cannot be excluded that there are some effects. The degradation of organic ^{14}C to inorganic would increase the retention of carbon in the barriers while the transformation in the other direction would have the opposite effect. Methylation/alkylation would make the radionuclide more mobile and the organic character of methylated and alkylated radionuclides also makes them more bio-available and thus more toxic /Pedersen, 2001/. According to Pedersen /2001/ methylation and alkylation processes may proliferate under stagnant hydraulic conditions until a stationary phase is reached. Whether this is enough for significant methylation or alkylation of metals in SFR is presently not known.

These processes are not analysed in detail within SAFE nor considered in the analysis of radionuclide release from the engineered barriers in SFR.

Radioactive decay

Radioactive decay will affect the type and amount of radionuclides at different locations in the repository system. The process is well known as is considered in the analyses within SAFE.

Boundary conditions

The flux from the rock of radionuclides naturally occurring at the site or released and transported from other repository parts is discarded from the analysis of radionuclide release.

4.3 Geosphere

The geosphere matrix represents the rock and tunnel system. The geosphere matrix is graphically displayed in Appendix F. The upper extension of the system is from the rock walls in the Silo and repository vaults up to an arbitrary border between deeper rock and surface rock. The surface rock, mainly in terms of outcrops, is included in the biosphere matrix in order to facilitate the treatment of the geosphere/biosphere interface. The horizontal and depth extension of the system is an arbitrary distance into the rock surrounding the repository vaults.

The geosphere matrix should display interactions (processes) between the different physical components in the geosphere system, but also interactions over the boundaries of the geosphere system. Therefore, the Silo and the repository vaults as well as the biosphere and the deep rock outside the system are included in the geosphere matrix as diagonal elements that represent different boundary conditions to the geosphere system.

4.3.1 Diagonal elements –system state variables

In similarity to the repository matrix, the diagonal elements are defined in terms of the variables that characterise the physical components of the system. The physical components of the geosphere matrix are (see Table 4-2):

- Access tunnels with backfill (gravel/rock)
- Rock reinforcements in access tunnels in terms of shotcrete and rock bolts
- Investigation bore holes with backfill
- Plugs at the entrance to the repository vaults and at the entrance of the access tunnel
- Rock in terms of rock matrix and fracture systems
- Water
- Gas

For the same reason as in the repository matrix, some variables that characterise the physical components are lumped together in one diagonal element. The definition of the diagonal elements in the geosphere matrix is given in Table 4-2 in terms of a short description and the variables that are assigned to the diagonal elements.

Table 4-2. Definition of the diagonal elements in the geosphere matrix

Element name	Short description	Variables
1.1 Silo (Boundary condition)	*The geometry of the Silo repository and the physical components in the Silo that via interactions can affect and be affected by properties and conditions in the physical components of the geosphere, i.e. bentonite barriers, sand/gravel, water and gas*	*Those variables assigned to diagonal elements 7.7, 8.8, 10.10, 11.11, 12.12, 13.13, 14.14, 15.15 and 16.16 in the repository matrix (see Table 4-1)*
2.2 BMA (Boundary condition	*The geometry of the BMA vault and the physical components in the BMA that via interactions can affect and be affected by properties and conditions in the physical components of the geosphere*	
3.3 BTF (Boundary condition)	*The geometry of the BTF vaults and the physical components in 1BTF and 2 BTF that via interactions can affect and be affected by properties and conditions in the physical components of the geosphere*	
4.4 BLA (Boundary condition)	*The geometry of the BLA vault and the physical components in the BLA that via interactions can affect and be affected by properties and conditions in the physical components of the geosphere*	
5.5 Tunnel/bore holes/backfill	The physical components included in this diagonal element are the access tunnels with their backfill (crushed rock) and rock reinforce-ments (shotcrete and rock bolts) and investigation bore holes and ventilation shafts and backfill in these.	Geometry, dimensions, volume Density, homogeneity Voids, pore and fracture characteristics Amount, composition, mineralogy, surface characteristics Type and amount of organic materials and components that can be utilised by microbes as nutrients and energy sources Type and amount of naturally occurring radionuclides in rock minerals
6.6 Plugs	Plugs at the entrance of the Silo and repository vaults and at the entrance of the access tunnels, made of concrete and bentonite	
7.7 Repository rock matrix	The matrix of the rock in between as well as around the vaults and the Silo to a distance of about 20 to 30 m from the repository. The matrix of the rock in the disturbed zone around vaults and tunnels is also included.	
8.8 Repository rock fracture system	The fracture systems, including fracture coatings, in the rock in between as well as around the vaults and the Silo to a distance of about 20 to 30 m from the repository. The fractures in the disturbed zone around vaults and tunnels are also included.	
9.9 Rock	Rock matrix, fracture systems and coating materials on fracture surfaces in the rock outside the repository rock.	
10.10 Water composition	Water composition, including colloids/ particles and dissolved gas, in tunnels, plugs, and investigation boreholes and in rock matrix and fractures in all rock in the geosphere system.	Redox, pH, ionic strength, Concentration of dissolved species, Type and amount of colloids/particles, Amount and composition of dissolved gas, Density and viscosity
11.11 Hydrology	Water in all physical components of the geosphere system and water movement in plugs, tunnels boreholes, and fracture systems in the rock.	Magnitude, direction and distribution of water flow, Degree of saturation, Amount of water, Water pressure, Aggregation state (water/ice)
12.12 Gas	Gas and movement of gas in tunnels, plugs, investigation boreholes and in the matrix and fractures in rock. Naturally occurring radionuclides in gaseous phase are also included here.	Amount, composition, volume, pressure, degree of saturation Magnitude, direction and distribution of gas flow
13.13 Temperature	Temperature in plugs, tunnels, investigation bore holes, rock and fracture systems	Temperature
14.14 Stress conditions	Stress and strain in tunnels, plugs, investigation bore holes, rock and fracture systems	Stress and strain, Swelling pressure in bentonite
15.15 Biological state	The biological state of plugs, tunnels, investigation bore holes, rock and fracture systems	Type, amount, mobility of microbes and bacteria (and other types of biomass)
16.16 Radio-nuclides and toxicants	Radionuclides and toxicants, originating from the repository, in solid, aqueous and gas phase in plugs, tunnels, investigation boreholes, rock and fracture systems.	Amount, type, chemical and physical form, concentration
17.17 Biosphere (Boundary condition)	*Physical and biological components in the biosphere that via interactions can affect and be affected by properties and conditions in the physical components of the geosphere*	*Those variables assigned to diagonal elements 2.2 to 7.7 and 10.10 to 15.15 in the biosphere matrix (see Table 4-3)*
18.18 External rock (Boundary condition)	*Rock beneath and around the rock included in the geosphere system.*	*Variables that can affect water composition, hydrology, gas, temperature, stress conditions and biological state in the geosphere components*

The diagonal elements that define the properties and conditions in the *physical components* of the geosphere system are elements *5.5* to *16.16*. The first five of these diagonal elements, i.e. *5.5* to *9.9*, include variables that define the geometry, physical and chemical characteristics of the solid materials as a function of time and space within each component. Investigation bore holes and ventilation shafts are lumped together with the access tunnels into diagonal element *5.5*. It is assumed in the definition that investigation boreholes and ventilation shafts are filled, and that bentonite is an option for this. The design of the plugs in the access tunnels is not yet finally decided, but it is judged that both concrete and bentonite are potential candidate materials for such plugs. Therefore, the definition of diagonal element *6.6 Plugs* is based on the assumption that the plugs are made of concrete and bentonite. The rock in between the repository vaults and around the repository vaults is treated separately from the rock outside this fictive border. In addition, the variables characterising the 'Repository rock' is separated in two diagonal elements with variables characterising the matrix of the rock in one diagonal element (*7.7*) and variables characterising the fracture systems in the other diagonal element (*8.8*).

The definitions of the diagonal elements *10.10* to *16.16* are the same as in the repository matrix, but for the physical components of the geosphere system. It should be pointed out that diagonal element *16.16 Radionuclides and toxicants* includes radionuclides and toxicants originating from the repository only. Any naturally occurring radionuclides are included in the other diagonal elements of the matrix.

The *interactions* between the repository vaults and the physical components of the geosphere system are taken care of via the boundary conditions expressed through the elements *1.1* to *4.4* and the interactions between the components of the biosphere system and geosphere system in diagonal element *17.17*. Any impact from the rock outside the geosphere system on properties and conditions in the geosphere system are taken care of via the boundary element *18.18*.

4.3.2 Access tunnels and boreholes

Access tunnels and boreholes refers to the properties of the access tunnels with their backfill (crushed rock) and rock reinforcements (shotcrete and rock bolts) and investigation boreholes and ventilation shafts and backfill in these (see Table 4-2). The following processes are judged to be important to consider when evaluating the physical components of these parts. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Dissolution/precipitation

The composition of the water in the tunnel will affect the dissolution of primary minerals in the rock fill and in shotcrete and the precipitation of secondary minerals. This will affect the composition, porosity and permeability of these materials. However, dissolution/precipitation is assessed to have negligible effect on the overall function of the shotcrete and tunnel backfill because only small local changes are expected.

The importance of dissolution/precipitation in backfill material in investigation boreholes is more uncertain, but probably also small. The changes in properties that might arise are probably smaller than what is required to significantly change the hydrology and migration paths in the geosphere.

The impact of this process for the hydraulic properties of the backfill in access tunnels and investigation boreholes is therefore discarded from further analysis.

Ionic strength effects

Bentonite used as backfill in the investigation bore holes can be altered by ion exchange processes and by expansion and dispersion of clay particles into adjacent fractures in the rock, compare Ion exchange and Dispersion of clay particles in Section 4.2.5. This could change the homogeneity, expandability and hydraulic and gas conductivity of the bentonite in the investigation bore holes. The changes in properties that might arise are probably smaller than what is required to significantly change the hydrology and migration paths in the geosphere and this process is not further considered in the analysis within SAFE.

Redistribution of particles in the flowing water

Under transient conditions, the water flowing in the tunnels may transport smaller particles. This may lead to a redistribution of the rock fill in the tunnels. Under steady state conditions the water flow rate is expected to be too low for this process to be important. If the primary function of the backfill is to limit water flow in the tunnels then a low permeability backfill is needed and inflow of water during the saturation phase may cause settling of the backfill resulting in increased permeability. However, currently the tunnel backfill is not intended to have such properties and the influence can be discarded.

Microbial activity

Microbes that consume components of the backfill and shotcrete in tunnels can affect the composition and porosity of the materials. Microbes may also affect the amount of surfaces of the materials that are accessible to chemical reactions. The changes in properties that might arise are probably smaller than what is required to significantly change the hydrology and migration paths in the geosphere. Furthermore, backfill in tunnels and boreholes is not included as a chemical barrier for radionuclides released from the different repository parts and this process is therefore not considered in the analysis of radionuclide release within SAFE.

4.3.3 Plugs

There are several processes, which may affect the physical properties of the plugs. The relative importance depends on the type of plug being used. This is not yet decided. The following interactions are judged to be potentially important (some only for bentonite plugs others only for concrete plugs). None of these processes have actually been analysed in detail within SAFE. When the final selection of plugs is made a more careful analysis of these processes may be warranted. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Water uptake in bentonite

The uptake of water and thus the density, geometry, structure and volume of the bentonite plugs is dependent on the amount of water (degree of saturation) and the water pressure in the bentonite plugs and in adjacent components. The water composition in terms of salinity and gradients in ionic strength will affect the saturation time and the resulting properties of the plug (compare Water uptake in Section 4.2.5).

Bentonite expansion/dispersion

Bentonite in plugs may expand into fractures in the rock adjacent to the plugs. Bentonite may also expand into adjacent voids in the backfill in tunnels. The extent of swelling will depend on the amount and apertures of fractures and the size of voids in the tunnels as well as on the water composition (compare Bentonite expansion and contraction and

Dispersion of clay particles in Section 4.2.5). Expansion/dispersion may affect the density and homogeneity of the bentonite in the plugs.

Recrystallisation

Recrystallisation of the hydration products in cement in the concrete of the plugs may change the composition and internal physical structure of the concrete. This could be of importance for the long-term properties of the plugs (see e.g. Recrystallisation in Section 4.2.4).

Cracking of concrete in plugs

The swelling pressure of the bentonite in the plugs may cause cracking/damaging of the concrete in plugs.

Corrosion

Corrosion of reinforcement in plugs will change the composition and pore and fracture characteristics of the plugs and potentially also cause volume changes due to formation of corrosion products. The process is dependent on the composition of the water and may change the properties of the plugs.

Dissolution/precipitation

The composition of the water in the plugs will affect the dissolution of primary minerals in bentonite and concrete in plugs and the precipitation of secondary minerals. This will affect the composition, pore- and fracture characteristics of these materials (see Dissolution/precipitation in Section 4.2.4 and Dissolution/precipitation in Section 4.2.5).

Ion exchange and sorption

The composition of the water in the bentonite plugs can change the type of adsorbed cation in bentonite through ion exchange (sorption) by which the physical properties of the adsorbed (interlamellar) water and the ability to form intergranular clay gels are altered. This causes changes in homogeneity, expandability and hydraulic and gas conductivity of the bentonite in the plugs (compare Ion exchange in Section 4.2.5).

Microbial activity

Microbes that consume components of the plugs, e.g. sulphate, or produce species that react with the components of the plugs, e.g. acids, can by this process affect the composition and porosity of the plugs. Microbes may also affect the amount of surfaces of the materials that are accessible to chemical reactions such as dissolution.

4.3.4 Rock matrix and rock fractures

The physical properties (fracture and porous structure) of the rock fractures and rock matrix are covered in three different diagonal elements (7.7 to 9.9 in Table 4-2). The processes influencing them are quite similar and could thus be discussed under one heading. The following interactions are judged to be potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Dissolution/precipitation

The composition of the water in the rock matrix of the repository rock will affect the dissolution and precipitation of minerals. This may change the porosity and composition of the rock matrix and the apertures, connectivity and the mineral composition of the fracture surfaces. In particular, reactions with OH in the water released from the repository and with calcium and carbonate may result in formation of secondary minerals in fractures and pores in the rock close to the different repository parts.

The dispersion of high pH and other species from the cementitious near field out into the surrounding rock is not specifically analysed within SAFE. If the alkaline plume reaches the rock the reaction products are likely to be different calcium silicate hydrate gels and minerals (compare Dissolution/precipitation in Section 4.2.6). This would probably reduce the permeability of the rock close to the repository vaults and possibly also affect the sorption capacity of the rock. This is not considered in the analysis of radionuclide release within SAFE since the effect most likely would be a lower water turnover in the vaults and higher sorption. A reduction in permeability could make it harder for gas to escape from the repository vaults, but it seems unlikely that this process effectively should seal all gas escape routes in the rock.

Redistribution of stress

Redistribution of stress may change the fracture apertures and the porosity of the rock matrix, or even initiate new fractures. This hydro-mechanical interaction is well know, see e.g. the SR 97 Process Report /SKB, 1999c, Section 5.6/, but the future stress changes in SFR-1 are considered to be too small to warrant a quantitative evaluation, possibly apart from the absolute vicinity of the tunnel system.

Microbial growth

Microbial growth on repository rock surfaces may change the chemical properties of these surfaces thereby affecting chemical processes like mineral dissolution and sorption. The microbes may also cause clogging of pores and affect fracture apertures. These effects on the properties of fractures and rock are probably insignificant and discarded from further analysis.

4.3.5 Groundwater composition

The groundwater composition, i.e. dissolved species and dissolved gas as well as colloids and particles in the water in tunnels, plugs, investigation boreholes and in rock matrix and fractures in all rock in the geosphere system (see Table 4-2), is affected by several processes. The following interactions are judged to be potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Dissolution/precipitation

Dissolution and precipitation of components of the rock, backfill, plugs, fracture mineral etc. affect the water composition and the potential for colloid formation. Under steady state conditions the reactions between rock and fracture minerals and ground-water are in general very slow. The process is described in the SR 97 Process Report /SKB, 1999c, Sections 5.7.4 and 5.7.5/. In SAFE, data from groundwater analyses and some geochemical modelling /Höglund, 2001/ are used to define the groundwater composition for the quantitative analyses.

One important transient effect can be the buffering of pH by dissolution of silica in tunnel backfill materials and in rock close to the repository vaults and precipitation of CSH phases that also can generate colloids. Colloids and pH of the water is important for the geosphere retention of radionuclides. This interaction is not specifically analysed within SAFE, but effects that significantly reduces the retention in the geosphere are indirectly considered in the selection of data and calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.4.3).

Diffusion

The geometry, porosity and connectivity of the tunnel backfill, plugs, rock fractures and rock matrix affect the diffusive transport of dissolved components through the tunnels and thereby the composition of the water. This process is not quantitatively addressed within SAFE when defining the composition of the water in access tunnels and rock. A general description of the diffusion process and impacts on groundwater composition is given in the SR 97 Process Report /SKB, 1999c, Section 5.7.3/.

Advection/dispersion

The magnitude, distribution and direction of water flow in the different parts of the geosphere system will determine the advective and dispersive transport of species in the waters, see e.g. SKB SR 97 Process report /SKB, 1999c, Section 5.7.2/. Within SAFE, the impact of advection on groundwater composition is considered in estimating the time for the saline-fresh water interface to reach the SFR repository /Holmén and Stigsson, 2001/.

Colloid formation and transport

The chemical and physical properties of the tunnel backfill and the backfill in investigation boreholes affect its ability to withstand mechanical erosion and thus the amount of colloids/particles in the water in the backfill. Also the magnitude of water flow (velocity) in the different parts of the geosphere system will affect the extent of mechanical erosion of the barrier materials and thus the amount of colloids/particles in the water in the different parts of the geosphere system. The formation and stability of colloids/particles depends also on the composition of the water, e.g. ionic strength.

Transport of colloids will take place with moving water in fractures in the rock, but it is possible that plugs in the access tunnels to some extent can act as filters for colloids. In addition, transport of colloids attached to the surface of gas bubbles could affect the amount of colloids in different parts of the geosphere system.

Colloid formation in rock is generally discussed in the SKB SR 97 Process Report /SKB, 1999c, Section 5.7.8/. During a short period after repository closure, when mixing of reducing and oxidising water occurs, colloid formation can be expected. In addition, it is possible that colloid formation takes place at the front of an alkaline plume moving outwards from the repository vaults. However, the saline groundwater in Forsmark, and also the fresh groundwater, is expected to have a calcium concentration high enough to ensure very low concentration of colloidal material in the groundwater (see Erosion/colloid formation/colloid transport in Section 4.2.7). Despite this, the effect of no radionuclide retention in the geosphere, e.g. due to the presence and transport with colloidal matter, is considered in the analysis of radionuclide release (see Section 5.4.6).

Gas dissolution/degassing

The water composition, e.g. concentration of dissolved species and amount and composition of dissolved gas, will be affected by the amount and composition of gas in gas phase in the different parts of the geosphere system via gas dissolution or degassing. This process is generally described in the SR 97 Process Report /SKB, 1999c, Section 5.7.9/.

The effect of naturally dissolved gases on the groundwater composition is indirectly considered in the definition of the groundwater composition from water analyses. Some degassing of gas generated and dissolved in the water in the repository parts may take place in the geosphere, but this effect on the groundwater composition in the geosphere is not further considered in SAFE.

Microbial degradation

The type and amount of microbes/bacteria will by their presence and growth affect the water composition in the different components of the geosphere system. Organic material present in the backfill and in the tunnels may serve as a carbon source. The process is described in the SR 97 Process Report /SKB, 1999c, Section 5.7.6/ and for SFR conditions in Pedersen /2001/ (see also Microbial activity in Section 4.2.7). Microbial degradation will both consume species and produce a series of degradation products that will alter the water composition. Consumption of oxygen will contribute to the establishment of reducing conditions. No obvious detrimental effects of microbial degradation in the geosphere system are identified and the process is not further considered in the analysis.

Boundary conditions

The boundary conditions, i.e. the transport of components in the water in the vaults into the geosphere, affect the composition of the water in the geosphere. Also the composition of the groundwater flowing into the geosphere from the external boundaries will of course also affect the composition of water in the geosphere components. These interactions are considered in the selection of groundwater composition in the geosphere (see Section 5.4.3).

4.3.6 Hydrology

The groundwater hydrology (element 11.11, see Table 4-2) refers to water in all physical components of the geosphere system and water movement in plugs, tunnels, boreholes and fracture systems in the rock. The following interactions (processes) are potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Rock permeability and its distribution

The groundwater flow depends upon the geometrical distribution of permeability of the rock (fractures and fracture connectivity), the tunnels and the plugs. The process, “Darcy´s law” is well known and has been considered in past assessments /SKB, 1993/ and is also considered in the updated modelling of the hydrogeological conditions at SFR /Holmén and Stigsson, 2001/.

Driving forces and salinity

The salinity of the water affects the density of the water and gradients in density. Gravity and pressure gradients generally drive the groundwater flow, which in general means that also fluid density needs to be considered (buoyancy effects). In case water density is constant this driving force can be simplified into the gradient of the hydraulic head (not the pressure gradient). For a general description of the process, see e.g. Bear /1976/. For SFR the salinity is relatively low and scoping calculations /Stigsson *et al.*, 1998/ show that neglecting density dependent flow is allowed considering the time variation of boundary conditions caused by the land rise. These conclusions are used in the subsequent hydraulic analysis of SAFE /Holmén and Stigsson, 2001)/.

Gas flow and saturation

The pore-size distribution of the backfill in the tunnels will affect the capillary suction of water into the backfill and thus the degree of saturation of the backfill during the saturation phase. Also the gas pressure in the different components affects the saturation process.

The saturation processes and the influence of gas on groundwater flow is described in Sections 5.5.1 and 5.5.2 of the SR 97 Process Report /SKB, 1999c/ and also in a joint EC/NEA status report on two-phase flow /Rodwell *et al.*, 1999/. In the SAFE analyses the two-phase flow aspects of the saturation process are discarded. The time for saturation is approximated with the time resulting from a “saturated “ analysis, see e.g. /Holmén and Stigsson, 2001/.

Boundary conditions

The driving force for the groundwater flow (i.e. the hydraulic head gradient) originates from the boundaries. The most important are the rock/biosphere interface and includes consideration of seawater level, infiltration, recharge/discharge and wells.

The internal boundaries at the different rock vaults are also important. In general, the flow inside the repository could not be treated as uncoupled to the flow inside the repository. This is certainly recognised in the hydraulic analysis by /Holmén and Stigsson, 2001/.

4.3.7 Gas

Gas refers (see Table 4-2) to the distribution and movement of gas in tunnels, plugs, investigation boreholes, in the rock matrix and the fractures in the rock. Naturally occurring radionuclides in gaseous phase are also included here. Flow of gas in rock is generally described in the SR 97 Process Report /SKB, 1999c, Section 5.5.2/ and in a joint EC/NEA status report on gas migration and two-phase flow /Rodwell *et al.*, 1999/. Based on these descriptions and on analyses of gas migration from SFR / Thunvik and Braester, 1986 and Berger and Braester, 2000/ it is for SAFE assumed that gas in the rock rapidly will migrate to the surface. No specific analyses are made of the following interactions (processes) that are potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Gas permeability

Tunnel geometry, properties of the rock fill in the tunnels and the geometry of the fractures in the rock affects gas permeability. In crystalline rock the gas permeability is usually significant and past scoping calculations /Thunvik and Braester, 1986/ as well as more recent analyses /Berger and Braester, 2000/ supports that gas in the rock will rapidly migrate to the surface.

Gas pressure

Buoyancy effects are combined with gas pressure gradients the main driving force for gas.

Water pressure

The water pressure in the different parts of the geosphere system will affect the gas pressure and the volume of the gas in the different geosphere system components. In addition, gradients in water pressure in can affect the magnitude, direction and distribution of gas flow, but the impact is probably of minor importance.

Gas solubility is also pressure dependent. The water pressure would then affect the amount and composition of gas in gas phase in the different parts of the geosphere system. Considering the limited depth of the SFR, this effect is probably of minor importance.

Boundary conditions

The transport and release of gas from the Silo, BMA, 1BTF, 2BTF and BLA will influence the amount and composition of gas in the tunnels and repository rock.

4.3.8 Rock mechanics

Rock mechanics (see Table 4-2) refers to changes in rock stress and in the rock stability. It also covers the stability of the vaults and the tunnels. Rock mechanics is generally discussed in the SR 97 Process Report /SKB, 1999c, Section 5.6/. The following interactions are potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Properties affecting deformation and stability

The rock type, mineralogy and microstructure will affect the deformation characteristics and strength of the intact rock. This, together with the fracture network geometry affects the strength and deformation characteristics of the rock mass and will thus affect the stress distribution and the rock mass stability.

The initial strength of the rock around the repository is expected to be good /Stille *et al.*, 1985/ and only small deformations are registered /Christiansson and Bolvede, 1987/. After repository closure, some changes in the fracture properties can take place, e.g. due to dissolution/precipitation of fracture coating minerals that may affect the stability of the rock. However, it is assessed that the function of the rock reinforcement is more important for the long-term stability of the rock than potential changes in fracture apertures (see below), so this is not further addressed within SAFE.

Also the properties of the bentonite in plugs, e.g. composition and density, affect the swelling of the bentonite in the plugs and thus the swelling pressure and stress conditions in the plugs. The geometry and mechanical properties of the concrete in plugs affect the swelling pressure of the bentonite in the plugs as well as the stress conditions in the surrounding rock. Since the final design of the plugs is not decided yet, these aspects are not addressed within SAFE, except for some calculations of the effect on groundwater flow in case of malfunctioning plugs /Holmén and Stigsson, 2001/.

Degradation of rock reinforcement

Degradation of rock reinforcement such as rock bolts and shotcrete will affect the resulting strength of the rock mass. An assessment of the effects of degraded rock reinforcement in the repository vaults on loosen up and fall out of rock into the vaults is made within SAFE /Fredriksson, 2000/.

Boundaries

Changes in stress and strain at the boundary between the rock in the disposal system and the external system affects the stress conditions in the rock in the geosphere. Of particular importance may be if a vault is back-filled – or not. A non-back-filled vault will not offer mechanical support unless it is filled with falling rock blocks. This is addressed by Fredriksson /2000/ in an assessment of rock fallout after degradation of the rock reinforcement.

4.3.9 Biological state

Biological state refers to the biological characteristics (see Table 4-2) of plugs, tunnels, investigation bore holes, rock and fracture systems. The following interactions (processes) are potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Microbial activity

The presence of degradable organic materials, nutrients and energy sources in the tunnel, backfill, investigation boreholes and rock will affect the population and activity of microbes and bacteria in those parts. The amount and composition of gas in the different parts of the geosphere system may also affect the survival and activity of organisms. Organic carbon present in the rock fill in the tunnels and in plugs may serve as a carbon source for microbes. However, the quantity of degradable carbon is much less than in the repository vaults. Furthermore, no obvious detrimental effects of microbial degradation in the geosphere system are identified (see Microbial degradation in Section 4.3.5). One exception could be methylation of radionuclides (see Methylation/transformation in Section 4.3.10).

Boundary conditions

Growth and/or transport of biomass from the vaults and exchange of biomass between the geosphere and the biosphere by recharging/discharging water will affect the type and amount of microorganisms in the geosphere.

4.3.10 Radionuclides and toxicants

Radionuclides and toxicants refers to type and quantity of these in solid, aqueous and gas phase in plugs, tunnels, investigation bore holes, rock and fracture systems that originates from the waste in the repository (see Table 4-2). The following interactions (processes) are potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Advection/dispersion

The magnitude, direction and distribution of water flow in the tunnels, repository rock and rock outside the repository area will affect the advective transport of radionuclides and toxicants. Transport of radionuclides by advection and dispersion in rock is generally described in the SR 97 Process Report /SKB, 1999c, Section 5.8.1/. Within SAFE, the characteristics of the groundwater flow are derived in the hydrogeological modelling /Holmén and Stigsson, 2001/ and used as input to the selection of data and calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.4.6).

Diffusion and matrix diffusion

The geometry and dimensions of the rock fill in the access tunnels will affect the diffusive transport of radionuclides and toxicants in the tunnels and thereby the concentration of contaminants in the water. Diffusion in the flow paths is important if the water flow rates are low. Diffusion into the matrix of the backfill material is of importance if the size of the backfill material is large. In the rock, the porosity of and diffusivity in the rock matrix as well as the spatial flow distribution are important for diffusion of radionuclides and toxicants into the rock matrix.

Molecular diffusion and matrix diffusion is generally described in the SR 97 Process Report /SKB, 1999c, Section 5.8.3/. Within SAFE, results from the hydrogeological modelling /Holmén and Stigsson, 2001/ are used as input to the selection of values of the transport resistance ("F-parameter") in the rock. The groundwater composition is considered in the selection of diffusion data for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.4.6).

Sorption

The mineralogy of the rock fill in access tunnels and of fracture coatings and host rock will affect the sorption of radionuclides and toxicants. Saturation of sorption sites and non-linear sorption effects could in some cases be important. Sorption is also strongly dependent on the water composition (e.g. pH, Eh, concentration of complexing agents, type and amount of colloids/particles) since it affects the speciation of radionuclides and toxicants. The concentration of stabile isotopes can also have an impact via isotopic dilution in case of a non-linear sorption isotherm. The water composition may also affect sorption via competition about available sorption sites.

Sorption in rock is generally described in the SR 97 Process Report in Section 5.8.2 /SKB, 1999c/. Within SAFE, the impact of mineralogy and water composition is considered in the selection of sorption data and calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.4.6).

Dissolution/precipitation

The water composition in the different parts of the geosphere system (e.g. pH, Eh, concentration of complexing agents) affects the speciation and solubility of radionuclides and toxicants and thus also the distribution between mobile and immobile radionuclides and toxicants in the different parts of the geosphere system. The concentration of stabile isotopes can also have an impact via isotopic dilution and also co-precipitation with e.g. iron corrosion products. Precipitation of radionuclides and toxicants is not expected because of low concentrations and minor changes in water composition. However, co-precipitation with calcite and/or iron hydroxides could be a potential sink for radionuclides and toxicants. Co-precipitation as a sink for radionuclides is not specifically analysed within SAFE and also discarded from the analysis of radionuclide release.

Transport with gas

The magnitude, direction and distribution of gas flow in different parts of the geosphere system will affect the transport of radionuclides and toxicants in gas phase. This is the main transport mechanism for radioactive gas. How the process is considered in the analysis of radionuclide release is described in Section 5.3.6.

Transport with colloids or microbes

Colloids/particles in the water in the different parts of the geosphere system may affect the mobility of radionuclides and toxicants by acting as carriers for these. These colloids can be transported by moving water or attached to the surface of gas bubbles. Transport by colloids in water and gas phase in rock are generally described in Sections 5.8.4 and 5.8.6 in the SR 97 Process Report /SKB, 1999c/. Due to the high concentration of calcium in the groundwater in the rock around SFR, the concentration of colloidal matter is expected to be low (see Colloid formation and transport in Section 4.3.5). Microbes/bacteria may also affect the transport of radionuclides and toxicants by acting as carrier for these. However, the mobility of microbes will probably not transport significant amounts of radionuclides /Pedersen, 2001/. Furthermore, microbes will move towards locations with degradable organic material /Pedersen, 2001/, which not necessarily means along the groundwater pathway. Nevertheless, the possibility of fast radionuclide transport with colloids/microbes in the rock is considered in the selection of calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also Section 5.4.6).

Methylation/transformation

As part of their metabolism, microbes may change the chemical form of radionuclides and toxicants. Examples are methylation/alkylation of metals, the carbon fixation of $^{14}CO_2$ to organic carbon and the degradation of organic ^{14}C-carbon to $^{14}CO_2$, which dissolved in the water can precipitate as calcite. Such transformations will change the mobility of metal species and carbon. Methylation/alkylation will also make the metals more bio-available and thus, more toxic /Pedersen, 2001/. Methylation/alkylation and the carbon fixation of inorganic ^{14}C to organic carbon would mean a lower retention in the rock, which indirectly is considered in the selection of calculation cases for the analysis of radionuclide release /SKB, 2001b/ (see also 5.4.6). A larger retention of ^{14}C because of degradation of organic ^{14}C-carbon to $^{14}CO_2$ and further to calcite is not considered in the analysis of radionuclide release.

Radioactive decay

Radioactive decay will affect the type and amount of radionuclides at different locations in the geosphere system. Decay may also affect the amount of radionuclides in gas phase, e.g. formation of Rn via decay. Obviously, radioactive decay is included in the analysis of radionuclide release.

Boundary conditions

The release of radionuclides and toxicants in water and gas phase from the Silo, BMA, 1BTF, 2BTF and BLA will affect the transport of radionuclides and toxicants in water and gas phase in the tunnels and the surrounding repository rock. This is the source term for migration in the geosphere and is of course included in the analysis of radionuclide release.

4.4 Biosphere

The biosphere matrix represents the surface environment in the repository area and should at least include:

- the parts of the surface environment that potentially may have an impact on the repository,
- potential discharge areas and regions where any significant parts of potentially released radionuclides may migrate and give significant concentrations.

The physical extent of the region covered is quite large and includes Öregrundsgrepen with inland areas.

The biosphere matrix is shown in Appendix F. It displays interactions (processes) between the different physical and biological components in the biosphere system, but also interactions between the biosphere and geosphere systems as well as potential impacts from the surface environment outside the border of the biosphere system. Therefore, the geosphere as well as the external surface environment are included in the biosphere matrix as diagonal elements that represent different boundary conditions to the system.

4.4.1 Diagonal elements – system state variables

The physical and biological components of the biosphere system are (see Table 4-3):

- Quaternary deposits
- Solid rock at the surface, out crops
- Buildings and structures such as roads, road-banks, bridges
- Vegetation
- Animals
- Humans
- Water
- Gas and atmosphere

Element *1.1* covers the biosphere interaction with the SFR-1. It has been judged that all such interactions occur through the geosphere/biosphere interface. Quaternary deposits, surface rock and buildings and other solid structures at the surface are included in element *2.2*. Elements *3.3* to *8.8* cover the biological life, defined according to their trophic level in the food web. The interface between solid, physical components in the biosphere and water or air is defined as the topography and was originally included as a separate element, *9.9*. However, it was later found that it was more appropriate to include topography in element *2.2 Quaternary deposits* since it concerns the geometry of quaternary deposits. In order to avoid the extra work of renumbering all interactions in the matrix, the diagonal element *9.9* is left as an empty element in the matrix.

Elements *10.10* to *12.12* take care of the water in the biosphere, separated into the hydrology in quaternary deposits, *10.10*, the hydrology of open surface waters in terms of sea, bays, lakes, rivers etc, *11.11*, and the composition of the water in the quaternary deposits and surface waters, *12.12*. Element *13.13* refers to the properties of gas in the physical components as well as to the atmosphere in the area and element *14.14* covers the temperature conditions in all physical components. Similar to the other matrices, radionuclides and toxicants in all components of the biosphere are included in a separate diagonal element, *15.15*. Element *16.16* includes all external conditions that can influence the local properties and conditions included in the biosphere matrix.

Table 4-3. Definition of the diagonal elements in the biosphere matrix

Element name	Short description	Variables
1.1 Geosphere (Boundary condition)	*The physical components in the geosphere that via interactions can affect and be affected by properties and conditions in the components of the biosphere, i.e. rock, backfill in tunnels and bore holes and ventilation shafts, plugs, water and gas*	*Those variables assigned to diagonal elements 5.5, 6.6, 9.9, 10.10, 11.11, 12.12, 13.13, 14.14, 15.15 and 16.16 in the geosphere matrix (see Table 3-2)*
2.2 Quaternary deposits	Loose deposits including recent materials (e.g. soil, fine grain sediments, large grain sediments and till) and surface rock (out crops). In addition, buildings and structures such as roads, road-banks, bridges and houses are included. Interface between rock or sediments and air, and rock or sediments and surface waters.	Amount, depth, location, spatial distribution, grain size distribution, pore- and fracture characteristics, composition, mineralogy, surface characteristics Baseline topography, e.g. land and bottom contours
3.3 Primary producers	Primary producers of organic matter (plants, algae, trees etc). Particles and solids deposited on surfaces of primary producers are also included	Type and amount Location and size Number of humans living at different places Behaviour, e.g. living habits, culture, technical development etc Rate of growth and life time Radiologic and toxic effects
4.4 Decomposers	Bacteria, worms, snails, fungi etc that decomposes dead organic matter. The decomposers live usually in the Quaternary deposits. Particles and solids deposited on surfaces of the decomposers are also included	
5.5 Filter feeders	Mussels, hydroids, sponges, insect larvae etc that filter water. Filter feeders are living on rock surfaces and on loose deposits in water	
6.6 Herbivores	Plant eaters (e.g. snails, insects, cow, sheep etc) that live both on land and in water. Omnivores are included here and in 7.7, e.g. bear.	
7.7 Carnivores	Animal eaters (e.g. fish, eagle, seal, fox, birds etc) that live both on land and in water. Mosquitoes, parasites and tics are also included. Omnivores are included here and in 6.6, e.g. bear.	
8.8 Humans	All humans living in the affected area	
9.9 None	*Comment: Originally topography that later was moved into 2.2*	
10.10 Water in Quaternary deposits	The hydrology in Quaternary deposits in terms of the pore water flow characteristics in the unsaturated zone and the groundwater flow characteristics in the saturated zone. The physical state of the water is also included, i.e. water/frost/ice	Level of groundwater table, water content, degree of saturation, water pressure, magnitude, direction and distribution of water flow, quantity of water in different physical states, i.e. water/frost/ice
11.11 Surface water	All surface waters except water in Quaternary deposits, i.e. Öregrundsgrepen and other water recipients such as rivers, lakes etc. Rainwater on surface rock and "droplets" sorbed on other surfaces, e.g. primary producers are also included as well as snow and ice on land.	Size, location, amount, pressure, wave lengths and velocities, water level, layering Magnitude, direction, distribution of water flow Amounts and movements of ice/snow on surfaces
12.12 Water composition	Composition of water in Quaternary deposits and of surface waters. Includes particles in the water as well as the composition of snow and ice.	Redox, pH, salinity, Concentration of dissolved species, Type and amount and size of colloids/particles, Amount and composition of dissolved gas, Density and viscosity
13.13 Gas/ Atmosphere	All gases in the biosphere including the atmosphere in terms of composition and movement. Composition includes the content of particulate (e.g. ice crystals, water droplets, pollen, etc.).	Amount, pressure, movements, composition, particulate content and type, wind velocity, wind field,
14.14 Temperature	Temperature in the physical components of the biosphere system	Temperature
15.15 Radio-nuclides and toxicants	Radionuclides and toxicants in all physical and biological components of the system. 1) from the repository 2) background levels (e.g. from Tjernobyl and the Forsmark Power plant	Amount, type, chemical and physical form Concentration Location
16.16 External conditions (Boundary condition)	*All external conditions that affect the local conditions that are considered in the biosphere matrix.*	Human behaviour, wind conditions, Large scale weather systems, Large scale water movements and water composition

4.4.2 Quaternary deposits

Quaternary deposits are defined as loose deposits including recent materials (e.g. soil, fine grain sediments, large grain sediments and till) and the surface of the rock. In addition, buildings and structures such as roads, road-banks, bridges and houses are included in this element. The topography is also included and defined as the interface between rock or sediments and air, and rock or sediments and surface waters (bottom topography). The following interactions are potentially important for the defined characteristics (see Table 4-3) of the deposits. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Relocation

Quaternary deposits may be relocated trough deposition and erosion, including landslides. The degree of relocation is influenced by the grain size and water content of the quaternary deposits and influences the height distribution of the topography. Also the erosion caused by buildings and structures (e g bridges) is included. The natural processes of changes in topography due to relocation of quaternary deposits can be significant. However, the effects on topography from land rise of rock will set the limits. The process is treated in the analysis of land rise and sediment re-suspension /Brydsten, 1999a/.

Bioturbation

The type and amount of decomposers affects the physical properties and the chemical composition of the Quaternary deposits, e.g. by homogenisation of the upper layers. Bioturbation is important in terrestrial environment when e.g. earthworm rework some soil /Müller-Lemans and van Dorp, 1996/. In lakes and the Baltic Sea the decomposer fauna has limited effect, at most the first decimetres is affected. In the dose assessment, the process is treated for terrestrial environments such as agriculture and forest (see Section 5.5.3).

Change in water content

The magnitude and direction of the water flowing in the Quaternary deposits influences the water content in the Quaternary deposits. This is mainly a question of whether the soil is saturated or not. In the assessment of radionuclide migration, estimates of the fluctuations in water table are considered when selecting the transfer factors between saturated and unsaturated parts of the soil (see Section 5.5.3).

Erosion

The magnitude and direction of the surface water flow influences the magnitude of erosion and thereby the structure and porosity of Quaternary deposits, e.g. beach drift. Other examples are frost ice and ice scouring. The turnover of sediments is dependent on this process. The process is treated when estimating the sedimentation that affects the future ecosystems in locations around SFR /Brydsten, 1999a/ and the result is considered in the selection of data for radionuclide migration /SKB, 2001b/ (see also Section 5.5.3).

Sedimentation

Sedimentation of particles in the water may change the composition, geometry and porosity of the Quaternary deposits. The long term, annual increase in sediment accumulation is about 0.5 mm/year to 1 cm/year in this area /Meili *et al.*, 2001, Brydsten, 2001/. The accumulation of sediment is considered in the description of land rise and in-growth of lakes and in the selection of data for the radionuclide migration/exposure analysis /SKB, 2001b/ (see also Section 5.5.3).

External boundary – land rise

The recovery from the load on the land from the last ice results in a still ongoing land rise /Påsse, 1997/. The changing land topography is a major driving force for the groundwater flow and is treated as a time-varying condition in the hydrogeological and ecosystem modelling.

4.4.3 Primary producers

Primary producers are defined as primary producers of organic matter, usually by photosynthesis (plants, algae, trees etc). This element also includes particles and solids deposited on surfaces of the primary producers. The following interactions are potentially important for the defined characteristics (see Table 4-3) of the primary producers. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Settlement

The settlement of primary producers (location and type) is influenced by grain size, porosity and composition of Quaternary deposits and the roughness and structure of rock surfaces. Also the inclination and contours of the land is important in terms of sheltering effects and level dependence on settlement. It is important for primary producers in water and land. In water hard substrates (e.g. rock, gravel and stone) are important for many macroalgae to settle. Soft substrates (sediments) are important for rooted plants. The type of substrates is considered in the assessment in the models used for aquatic and land system, cf. /Kumblad, 2001/.

The amount of water in Quaternary deposits affects the settlement of primary producers. Too little or too much water prevents settlement. In the assessment this interaction is not addressed directly, since the water table is assumed to remain near the surface and be constant.

The availability and movement of open surface waters influence the settlement of primary producers. Important factors are water depth, amounts, water currents etc. This process determines the vegetation structure. The result of this is reflected in species composition, which is determined as an "equilibrium" condition /Jerling *et al*., 2001/. The entire land rise process /Brydsten, 1999b/ as well the ontogeny of lakes is affected by this /Brunberg and Blomqvist, 2000/. In the assessment it is treated as different snapshots of the land rise and silting up process.

The water composition (e.g. trace elements, nutrients, toxicants, etc.,) in Quaternary deposits and open surface waters affects the settlement of primary producers. The salinity, alkalinity and turbidity are important factors affecting the settlement of plants in water and on land (not turbidity). In the assessment, it is assumed that this interaction is reflected by species composition in different ecosystems.

Feeding

The type and amount of filter feeders will affect the type, amount and location of plankton (primary producers) by eating them. The effect on primary producers can be large, but it is assumed that this is reflected in species composition. The amount of food the filter feeders eat is the amount of contaminants that will be ingested and thus important for the filter feeders. The transfer of food is included in the ecosystem models.

Stimulation/inhibition

The water composition (e.g. trace elements, nutrients, toxicants, etc.,) in Quaternary deposits and surface waters will affect the production of primary producers via stimulation/inhibition and thereby affecting the amount of primary producers living both in water and on land. Water droplets on land living producers are also included here. This impact is not treated explicitly in the assessment, but through species composition and concentrations in water registered by surveys (e.g. Kautsky *et al.* /1999/ and Jerling *et al.* /2001/).

Humans will also affect the type and amount of primary producers via cultivation, agriculture or selection (forest), weeding, etc. This type of activity of humans planting and forest plants and trees is important. In the assessment this is considered in the definition of the agricultural system.

Water uptake

The amount of water in Quaternary deposits affects the water uptake and living conditions for primary producers and thus the type, amount and life-time of primary producers in the area. Maximum availability is assumed in assessment.

The surface water (including water on leaves) is a supply for the plants. The supply of waters will be important for irrigated plants where water will intercept with leaves and trunk. In water bodies plant will be well supplied with sufficient of water. Root uptake is from groundwater and affect plants. In the assessment, this is treated in the irrigation models as amount of irrigation water and number of irrigation events /Karlsson *et al.*, 2001; SKB, 2001b; Lindgren *et al.*, 2001/ (see also Section 5.5.3).

Light attenuation

The water composition (e.g. dissolved species and particulate matter) in surface waters influences the adsorption and distribution of light and thereby the type and productivity of primary producers. The process is also dependent on the location of primary producers (fixed on bottom surfaces or as plankton). This set the limits how deep plants can grow in the sea and lakes. In the assessment, this process is treated by measurements of species composition at different depths from surveys.

Insolation

The extent of sun irradiation influences the photosynthesis and thereby the type and amount of primary producers. This determines the rate of fixation and is the driving mechanism in the ecosystem model. In the more simple exposure models it is indirectly considered by transfer factors.

Exposure

Concentration, location and type of radionuclides and other toxicants in primary producers affect the internal exposure and the radiologic and toxic effects on the primary producers. In addition, the concentration, location and type of radionuclides in surface waters, quaternary deposits and in the atmosphere, i.e. in all parts of the biosphere system, affect the external exposure and the radiologic and toxic effects on the primary producers. This is included in the ecosystem model /Kumblad, 2001/, but otherwise only discussed.

Import and export

Outflow/export of primary producers from the system can occur via e.g. detachment of macroalgae, timbering, and hay, grass and vegetables transported from the area. In aquatic systems the continuous outflow of pelagic organisms can be considerable. In terrestrial system the export is more occasional, e.g. timber. Not considering export is a conservative approach because the accumulation within the system will be higher than export, which also means dispersal. In the ecosystem model the export of particulate organic matter (POM) is calculated /Kumblad, 2001/. This is also used in the exposure models.

4.4.4 Decomposers

Decomposers are defined as bacteria, worms, snails, fungi etc that decomposes dead organic matter. The decomposers live usually in the quaternary deposits. This element also includes particles and solids deposited on the surfaces of the decomposers. The following interactions are potentially important for the defined characteristics (see Table 4-3) of the decomposers. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Settlement

The settlement of decomposers (location and type) is influenced by location, grain size and chemical composition of Quaternary deposits and the location and mineralogy of rock surfaces (substrates). Most macroscopic decomposers (e.g. worms) prefer soft substrates (e.g. sand, clay, mud, and soils). Microscopic organisms (e.g. bacteria) are dependent on the surface area. The water composition (e.g. salinity and alkalinity, dissolved and particulate organic matter (DOM and POM) also has large effects on decomposers. The process is considered in the models used for aquatic and land system by assuming a composition dependent on the type of water body or soil conditions. The mapping of vegetation or sediments/soils gives this information.

Consumption

Consumption of sediments or soils may be accidentally with the food or by purpose. This is a normal process for many macro-decomposer. In the assessment, this is considered either in the pathways for radionuclide flow or as a part of the distribution and bioaccumulation factor.

Food supply

The type and amount of primary producers affects the type and amount of decomposers by acting as food supply. Examples of processes influencing the food supply are detachment and sedimentation of e.g. leaves and needles. Also the mortality rate of herbivores and carnivores gives the supply amount of dead matter, sedimentation, debris production (faeces, mechanical fragmentation, horns, fur, feathers). This is an important supply of contaminated matter that is considered in the ecosystem model as a mechanism. In the more simple exposure model it is included as transfer factors.

Feeding

The feeding of pelagic decomposers (bacteria) is an important pathway. However, filter feeders have a low abundance in this area. This mechanism is included in the ecosystem model. In the more simple exposure model it is lumped into a transfer factor. Also the consumption of mushrooms by herbivores and the impact on the amount of mushrooms in the area is important since mushrooms are part of an important pathway for exposure. This is not explicitly addressed in the assessment.

Stimulation/inhibition

The temperature will affect the metabolism of decomposers. In the ecosystem model this is treated as annual degree-days and the effects on respiration and consequently on the metabolism /Kumblad, 2001/.

Water uptake

The amount of water in Quaternary deposits affects the water uptake and living conditions for decomposers and thus the type, amount and life-time of decomposers in the area. The maximum availability is assumed in the assessment.

Exposure

The concentration, location and type of radionuclides and other toxicants in decomposers affect the internal exposure and the radiologic and toxic effects on the decomposers. The concentration, location and type of radionuclides in surface waters, quaternary deposits and in the atmosphere, i.e. in all parts of the biosphere system, affect the external exposure and the radiologic and toxic effects on the decomposers. This is included in the ecosystem model /Kumblad, 2001/, but otherwise only discussed.

4.4.5 Filter feeders

Filter feeders are mussels, hydroids, sponges, insect larvae etc that filters water. Filter feeders are normally attached to rock surfaces and on loose deposits including recent materials. The following interactions are potentially important for the defined characteristics (see Table 4-3) of the filter feeders. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Settlement

The settlement (location and type) of filter feeders living in water is influenced by location, grain size distribution of sediments and the location and roughness of rock surfaces (substrates). Hard substrates are good settling areas for many filter feeders (e.g. blue mussels, zebra mussels, hydroids, and sponges), while a few filter feeders prefer soft substrates (e.g. insect larvae). The process is considered in the aquatic models used.

Filter feeders are also dependent on permanent and diurnal submergence in water, and on the water composition, especially salinity of the water. This is reflected in species composition dependent on where the water-bodies are and what their composition is.

Stimulation/inhibition

The water composition in surface waters will affect the stimulation/inhibition of production of filter feeders. The amount of particles in the water is important, since the uptake of these also affects the uptake of contaminants sorbed to particles. The particle content in the water is assumed or estimated in the assessment. Also the temperature will affect the metabolism. In the ecosystem model this is treated as the accumulated annual temperature in degree Celsius (annual degree-days) and the effects on respiration /Kumblad, 2001/.

Exposure

The concentration, location and type of radionuclides and other toxicants in filter feeders affect the internal exposure and the radiologic and toxic effects on the filter feeders. In addition, the concentration, location and type of radionuclides in surface waters, quaternary deposits and in the atmosphere, i.e. in all parts of the biosphere system, affect the external exposure and the radiologic and toxic effects on the filter feeders. This is included in the ecosystem model /Kumblad, 2001/, but otherwise only discussed.

4.4.6 Herbivores

Herbivores are defined as plant eaters (e.g. snails, insects, cow, and sheep). The herbivores live both on land and in waters. Also omnivores are included here (as well as under carnivores). The following interactions are potentially important for the defined characteristics (see Table 4-3) of the herbivores. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Settlement

The settlement of herbivores (location and type) is influenced by location and type of quaternary deposits as the herbivores are influenced primarily by the available resource (plants). In addition, some species need special locations for nests, e.g. a suitable substrate. Some herbivores live in water some other on land. Thus, the settlement of herbivores is also dependent on the existence of water. In the assessment this is treated as species composition depending on land rise.

Also the water composition (e.g. salinity, trace elements, toxicants, etc.) in quaternary deposits and surface waters affects the settlement of herbivores. In the assessment this is considered in the assumptions of species composition for different ecosystems.

Consumption

The herbivores may consume solid material accidentally with the food. This is an important pathway for herbivores consuming plants. It is considered in the exposure models for grazing cattle /Karlsson *et al.*, 2001/ (see also Section 5.5.3).

Food supply

The amount of primary producers and supply rate, i.e. the food supply, set the upper limit for what the population food intake can be. This is addressed as a maximum supply in models, but is usually not important.

Stimulation/inhibition

Stimulation/inhibition is affected by the quality of food. The quality of food is implicit in the food consumption. The importance of substrate is treated with the biomass estimates of the communities. These factors are not considered to change with time for a certain set of species, but they will change with different communities (e.g. Kautsky *et al.* /1999/). The cultivation and selection of domestic animals, by humans, is evidently important for the stimulation/inhibition of such species. The temperature will affect the metabolism of poikolithermic herbivores. In the ecosystem model this is treated as annual degree-days and the effect on respiration /Kumblad, 2001/.

Water uptake

Herbivores need large quantities of water and can be delimited by the supply of water. Water is important as a carrier of contaminants. This is treated in the exposure model as uptake of water by cattle, sheep etc /Karlsson *et al*., 2001/ (see also Section 5.5.3).

Exposure

The concentration, location and type of radionuclides and other toxicants in herbivores affect the internal exposure and the radiologic and toxic effects on the herbivores. The concentration, location and type of radionuclides in surface waters, quaternary deposits and in the atmosphere, i.e. in all parts of the biosphere system, affect the external exposure and the radiologic and toxic effects on the herbivores. This is included in the ecosystem model /Kumblad, 2001/, but otherwise only discussed.

4.4.7 Carnivores

Carnivores are defined as animal eaters or predators (e.g. fish, eagle, seal, fox, and birds). Also omnivores are included here, as well as in herbivores. This element includes also mosquitoes, parasites and tics. The following interactions are potentially important for the defined characteristics (see Table 4-3) of the carnivores. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Settlement

The settlement (location and type) of carnivores is influenced by location and properties off the quaternary deposits and by the location and properties of rock surfaces. This affects manly the habitat and thus the occurrence of certain species. However, its prey and how the prey is dependent on the substrate will determine the major pathway for radionuclides. This is considered in the models as a description of the ecosystem structure.

Carnivores live in water (e.g. fish) or on land (e.g. fox). Thus, the settlement of carnivores is also dependent on the existence of surface water and on the water composition. In the assessment this is considered in the assumptions of species composition for different ecosystems developing during land rise.

Food supply and feeding

The food supply of decomposers can be delimiting for the carnivore population. The supply is also a pathway for contamination. In assessment the species composition is assumed an optimal resource, it is thus not treated as a mechanism explicitly. The supply rate of filter feeders seems not to be a limiting factor, but the transfer of contaminant is affected by this supply. The consumption of herbivores is an important pathway for ingestion of contaminants by carnivores. Carnivores could also eat other (species) of carnivores, but it is assumed that this is covered by estimates of species composition. The amount of contaminated food is estimated in transfer factors in the exposure model /Karlsson *et al.*, 2001/ (see also Section 5.5.3) and as food/energy intake in the ecosystem model /Kumblad, 2001/.

Stimulation/inhibition

The temperature will affect the metabolism of poikolithermic carnivores. In the ecosystem model this is treated as annual degree-days and the effect on respiration /Kumblad, 2001/.

Exposure

The concentration, location and type of radionuclides and other toxicants in carnivores affect the internal exposure and the radiologic and toxic effects on the carnivores. In addition, the concentration, location and type of radionuclides in surface waters, quaternary deposits and in the atmosphere, i.e. in all parts of the biosphere system, affect the external exposure and the radiologic and toxic effects on the carnivores. This is included in the ecosystem model /Kumblad, 2001/, but otherwise only discussed.

4.4.8 Humans

The following interactions are judged important regarding the settlement and habits of humans in the area. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Settlement – living and building

The use of quaternary deposits as a building material may affect the settlement. In addition, the type of construction, construction method and the location of the building are influenced by the physical properties of the materials used. Also the size and location of surface waters affects the settlement of humans in the area. The place where humans settle is important for exposure to gas and external radiation. In the assessment humans are assumed to have settled on the worst places on land. Thus all areas with surface waters do not contain human settlement.

Food supply

The existence and supply of seed, herbs and roots for eating is essential for the intake of radionuclides. The supply of filter feeder, of mussels, oysters etc, is usually not a limiting factor for humans, but the existence of these products and amount of supply is essential for the intake of radionuclides. In the SFR- area the production of edible filter feeders is limited. Consumption of animals, cows, sheep etc, is an important pathway for ingestion of contaminants. Carnivorous seafood (shellfish and fish) is the only carnivore normally consumed by man. It is unusual to eat carnivorous terrestrial animals. The supply rate does not delimit humans, but the contents of contaminants should be considered. The process is treated as food intake and diet in the exposure model /Karlsson *et al.*, 2001/ (see also Section 5.5.3) and in the ecosystem model /Kumblad, 2001/.

Material supply

The use of different material as building or furniture can give external exposure. The burning of wood gives ashes, which may contain high amounts of radionuclides. However, in most cases the external exposure is very small /Bergström and Nordlinder, 1992/.

Water use

The amount of accessible water in quaternary deposits affects the way and how much of the water is used by humans living in the area, e.g. how much of the water that is used as drinking water and for bathing, washing etc. An excavated well is an important alternative water supply to drilled wells, but excavated wells are not included in the assessment since such wells give lower doses than drilled wells. Humans use water for many different purposes. The supply, habits and number of humans determine dilution and transfer of contaminants. This is treated in the exposure models as water use, drinking etc /Karlsson *et al.*, 2001/ (see also Section 5.5.3).

Stimulation/inhibition

The water composition (e.g. trace elements, toxicants, etc.,) in Quaternary deposits and surface waters can affect the stimulation/inhibition of humans. Especially human behaviour is affected (drinking water, swimming etc) by the water composition. This is treated in the exposure model by assumptions about behaviour /Karlsson *et al.*, 2001 and SKB, 2001b/ (see also Section 5.5.3).

Exposure

The concentration, location and type of radionuclides and other toxicants in humans affect the internal exposure and the radiologic and toxic effects on humans. Assessing these affects is one of the main endpoints of the safety assessment. The concentration, location and type of radionuclides in surface waters, quaternary deposits and in the atmosphere, i.e. in all parts of the biosphere system, affect the external exposure and the radiologic and toxic effects on humans. External exposure could be small compared to internal, but is certainly included in the assessment.

4.4.9 Water in quaternary deposits

This element is defined as the hydrology in the quaternary deposits. It includes the pore water flow characteristics in the unsaturated zone and the groundwater flow characteristics in the saturated zone (see Table 4-3). The following interactions are judged to be potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Water transport

The magnitude and distribution of the water flow in the quaternary deposits is influenced by the hydraulic conductivity and storage capacity (porosity) of these deposits and by the topography. Changes in the upper layer properties may occur as a result of natural processes or human actions, e.g. asphalt. The atmospheric pressure and the pressure of existing gas will affect the location of the groundwater table and thus also the water content and the water movement in the quaternary deposits. The processes are generally considered in the hydrogeological modelling /Holmén and Stigsson, 2001/ and upward and downward movements of water in the quaternary deposits is included in transfer factors in the exposure models /Karlsson *et al*., 2001/ (see also Section 5.5.3).

Recharge/discharge

Infiltration and percolation of surface waters into the quaternary deposits will affect the hydraulic situation as well as the dilution. In the exposure model recharge is disregarded as a dilution mechanism, which gives a conservative estimate. Recharge/discharge is certainly considered in the overall hydrogeological modelling /Holmén and Stigsson, 2001/.

Evaporation/condensation

Evaporation of water and condensation of gas in quaternary deposits will change the water content. The atmospheric conditions, e.g. pressure, humidity and content of particles will have an influence on the degree of evaporation/ condensation. The process is part of precipitation and runoff calculations. It is included in precipitation and runoff data.

Water extraction

Extraction of water by humans, e.g. from wells, may affect the water flow and water content in the Quaternary deposits. Dug wells are not included in the assessment and the impact from such wells on the water conditions in the quaternary deposits is therefore not considered.

External boundary conditions – import

The inflow of water to quaternary deposits from water in quaternary deposits outside the defined system needs to be considered. It is treated in Holmén and Stigsson /2001/.

4.4.10 Surface water

This element is defined as all surface waters (i.e. not the water in quaternary deposits). It includes the Öregrundsgrepen and other water recipients such as rivers, lakes etc. and also rainwater on surface rock, “droplets” sorbed on other surfaces and snow on land. The following interactions are judged to be potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Discharge/recharge

Discharge of water in Quaternary deposits to surface waters and the reverse is important for the contaminant transport from groundwater to surface water. It is considered in the hydrogeological model. The discharge is assumed in the exposure model and in the ecosystem model.

Water transport and convection

The topography determines the gravitational flow and influences thereby the amount of water infiltrating and the run off to surface waters. The topography determines the location and size of water reservoirs both on land and in the surface waters and influences thereby the water exchange. In addition, the topography can lead to choking of the water flow that results in higher water velocities. The impact of topography is considered in the assessment in the predictions of the location and geometry of future surface waters and in the estimates of water turnover in lakes in the exposure model /SKB, 2001b/ and in the oceanographic models /Engqvist and Andrejev, 1999/.

The composition of surface waters will affect the density and viscosity of the water, which in turn will affect the magnitude, distribution and direction of surface water movements and stratification. The stratification and turnover of lakes and sea are dependent on the density (salinity and temperature). It is taken into account in the oceanographic model /Engqvist and Andrejev, 1999/ and assumed as the annual water turnover in lakes.

The atmospheric pressure will affect the location of the sea water level. This affects the water turnover and is also considered in the oceanographic model /Engqvist and Andrejev, 1999/.

Wind stress and wave formation

The bottom topography determines the water depth and influences thereby the height of the waves. The strength and direction of the wind will affect the movement of surface waters, e.g. wave formation. In addition, it will influence the amount of water droplets and snow particles that are released to the atmosphere and thus the amounts of surface waters and amounts of snow/ice on surfaces. It is treated as statistic wind stress in oceanographic models /Engqvist and Andrejev, 1999/. The impact of wave characteristics is important for resuspension and sedimentation and considered in the sedimentation analysis /Brydsten, 1999a/.

Movement – human induced

The movement of humans (e.g. swimming) in surface waters may have an influence on the surface water movement. In addition, other human activities e.g. large-scale export, piping, wave generation etc will have an influence on the amount and movement of surface waters. At SFR the situation is not considered likely at a scale which would warrant any special analysis, because it is assumed that the nuclear power plant will be closed in the future.

Uptake of surface water by humans for consumption can influence the amount and movement of surface waters. This is an important exposure pathway for humans and can affect a water body (see above).

Evaporation/condensation

Evaporation of surface waters and condensation of humidity will have an influence on surface water amounts. The atmospheric conditions, e.g. pressure, humidity and content of particles will have an influence on the degree of evaporation/ condensation. The process is part of precipitation and runoff calculations. It is included in precipitation and runoff data.

Precipitation

The magnitude of the precipitation, e.g. rainfall, snow and hail, will influence the amounts of surface waters and the amounts of ice/snow on surfaces. Together with evaporation this also determines the amount available for groundwater recharge, but it is usually not the delimiting factor.

External boundary conditions – sea currents

Ekman transport is a result of the wind fields and the rotation of the earth. The coriolis forces result in a right angular water movement to the wind direction. This is one of the driving forces for water turnover of the sea. It is calculated in the oceanographic model /Engqvist and Andrejev, 1999/.

External boundary conditions – sea level changes

Sea level changes will affect the amount and movement of surface waters. Sea level changes can be caused by e.g. earthquakes (tsunamis), clathrates, global heating, land slides, earth tides, weather and climatic changes. For SFR, the only sea-level changes considered are shoreline displacement due to the ongoing land rise and the potential impact of the climate (see Chapter 3).

4.4.11 Water composition

The element concerns the composition of water in Quaternary deposits and surface waters. The composition of snow is also included in this element. The following interactions are potentially important for the defined characteristics (see Table 4-3) of the water composition. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Boundary condition – mass flux

Transport of groundwater components will affect the composition of water in quaternary deposits and surface waters. This could be important for the composition of the water in quaternary deposits in terms of supply of elements that only occur in the rock and the repository, but is not specifically addressed in the assessment.

Re-suspension

The size distribution of the particles in the quaternary deposits influence the amount of material re-suspended in the water and thereby the particulate content in the water. This is an important way of transfer from sediments to water. It is also important to determine where there will be future soft bottoms. The process is treated as erosion of bottoms in a study of the sedimentation in the SFR area /Brydsten, 1999a/, and as a generic re-suspension of particles in the exposure model /Karlsson *et al.*, 2001/ (see also Section 5.5.3).

Uptake/excretion

The type and amount of primary producers and decomposers will by uptake and excretion influence the water composition. This concerns for example the uptake of nutrients and CO_2 (by primary producers) or O_2 (by decomposers) and the excretion of O_2 (by primary producers) or CO_2 (by decomposers) and dissolved organic species. In addition, the uptake of pure water can lead to increased concentrations of dissolved salts and nutrients. The exchange of CO_2 is addressed regarding the ^{14}C turnover. The other changes on water chemistry are not coupled to primary producers. They are assumed to be included in the variation of water chemistry. The CO_2 dynamics is modelled in a carbon flow model /Kumblad, 2001/.

Particle production and trapping

The existence of decomposers in the surface waters is a source for particle production. The type and amount of decomposers will thus influence the water composition. Decomposers as bacteria are an indistinguishable part of the organic particle content in water. Larger decomposers also produce particles due to sloppy feeding or bioturbation, which affects the particle content in water. This is not explicitly modelled in the assessment, but the measured/estimated particle content is assumed to represent this process.

Mixing

The magnitude, direction and distribution of surface water flow will affect the mixing of the water and thereby also the composition of the water. This is an important process for dilution and substitution of particulate matter. It is considered in the ecosystem model as a driver of dissolved inorganic carbon (DIC) and exchange between particulate and dissolved organic carbon (POC/DOC exchange) /Kumblad, 2001/. It is not used in the exposure model, where it goes over contaminant mixing.

Property changes

The temperature will affect density and viscosity and this is the driving force for the turnover of water. In the assessment, this is treated as stratification of e.g. lakes or sea (see Water transport and convection in Section 4.4.10).

External boundary condition – import

The composition of the surrounding waters outside the system will by import affect the composition of the surface waters and the water in the quaternary deposits. This is treated in the ecosystem model and in the exposure model.

4.4.12 Gas – atmosphere

Gas is defined as all gases in the biosphere including gas in pores and atmosphere. The gas composition and the gas flow are included in this element. The gas composition includes the content of particles (e.g. ice crystals, water droplets, pollen, etc.). This element also includes atmospheric flow and wind. The following interactions are judged potentially important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Boundary condition – gas transport

The transport and release of gas from the geosphere will influence the amount and composition of gas in the biosphere. The supply of gas from the repository and the geosphere has no influence on surface waters, but may be of importance locally in the atmosphere. The turnover velocities influence the importance. Examples of gases from below are: H_2, CO_2, CH_4, Rn and H_2S. This is not specifically addressed in the assessment.

Re-suspension

The size distribution of the grains in the quaternary deposits influence the amount of material re-suspended in the air and thereby the particle content in the air. Re-suspension of particles is important for forming dust in air. In the assessment, it is treated as general dust occurrence in air and is thus not directly connected to the properties of quaternary deposits (see also Section 5.5.3).

Particle production – trapping

Humans can generate particles, for example by ploughing. This is potentially important and addressed in the dose assessment (see above).

External boundaries – import

The global wind directions, magnitudes and compositions affect these entities in the studied system. The wind velocity and direction are important parameters for the water turnover and shore erosion in the sea and lakes. This is treated in the shore erosion model /Brydsten, 1999a/.

4.4.13 Temperature

The following interactions are judged to be potentially important for the temperature in the quaternary deposits, in the surface waters and in the atmosphere. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Heat storage

The amount and thermal properties of surface waters affect the heat storage capacity and thus the temperature in the surface waters. The heat storage is an essential drive for the convection in the circulation.

Heat convection

Heat convection affects the temperature stratification (and vices versa). Heat convection is addressed in oceanographic models /Engqvist and Andrejev, 1999/, which results in effects on water turnover used in the exposure models and in the carbon-flow model.

Light absorption

The amount of particles in surface waters will affect light absorption and thus the temperature in surface waters. This is an important process responsible for the thermal stratification of surface waters. It is assumed that the process is reflected by the temperature profile of the water and therefore not treated explicitly in the assessment more than using information on vertical temperature distribution in water.

External boundaries – import of heat

Import of heat by different materials (wind, water etc) entering the system will influence the temperature in the different components of the studied system. This is the main forcing function for the temperature in the system and in the analyses annual statistic for the temperature is used.

4.4.14 Radionuclides and toxicants

Radionuclides and toxicants refer to all radionuclides in all components, including both those potentially released from the repository as well as background levels (e.g. from

Tjernobyl and the Forsmark Power plant). The following interactions are judged to be important. The interactions/processes that are judged to be of negligible importance are listed in Appendix E.

Boundary condition – release from the geosphere

The release of radionuclides and other toxicants in water and gas phase from the geosphere affects the transport of radionuclides and toxicants in aqueous and gaseous form in the biosphere. It is the source term for migration of radionuclides and toxicants in biosphere and certainly included in the exposure models.

Sorption/desorption

The distribution of radionuclides and toxicants between the solid phase and the aqueous phase is influenced by the composition and grain size distribution (available surfaces for sorption) of Quaternary deposits and by the mineralogy and porosity of the surface rock as well as on the water chemistry. This process is considered in the exposure models /Karlsson *et al.*, 2001/ and the impact of composition in the selection of data /SKB, 2001b/ (see also Section 5.5.3).

Also the amount of particles in the water in the different parts of the biosphere system affects the sorption/desorption of radionuclides and other toxicants. This affects the concentration of radionuclides and toxicants in the water and on the solid phases in the different parts of the biosphere system. This mechanism is considered for surface waters in the exposure models.

Sorption/uptake and excretion

The uptake of radionuclides and other toxicants by primary producers, decomposers, filter feeders, herbivores and carnivores affect the concentration of radionuclides and other toxicants in these organisms as well as in other components of the biosphere system. Accumulation in the organisms is the net effect of uptake and excretion. Excretion is assumed to be less than uptake. The net effect of uptake/sorption and excretion is considered in the exposure models (see Section 5.5.3).

The uptake of radionuclides and other toxicants by humans affects the concentration of radionuclides and other toxicants in humans as well as in other components of the biosphere system. Accumulation in humans is the net effect of uptake and excretion. This is important for the estimates of dose. In the exposure models, it is considered as ingested amount of radionuclides from diet and concentration in sources /Karlsson *et al.*, 2001/.

Degradation

Degradation of toxicants (non-radiologic) by the biological components of the system affects the type and concentration of toxicants in the different parts of the biosphere system. This is only important for toxicants and is not treated in the assessment.

Growth

The rate of growth of the biological components of the system affects the concentration of radionuclides and other toxicants in them. It could be of importance but should normally give a dilution in organisms. It is included as a lumped parameter for some uptakes in the exposure models (primary producers, decomposers). For humans, growth is already accounted for in the establishment of dose coefficients and permitted doses.

Mixing

The distribution, magnitude and direction of water flow in quaternary deposits affect the concentration of radionuclides and other toxicants in the water by mixing. Presently the concentration is assumed to be homogenous in the compartments of the exposure model. However, the flow situation in the deposits is discussed in the hydrogeological modelling addressing the geosphere/biosphere interface /Holmén and Stigsson, 2001/.

Also the characteristics of surface water flow affect the concentration of radionuclides and other toxicants in the water by mixing. Mixing and dilution are important processes for radionuclide transport. The size, amount, direction and water turnover is considered in present modelling.

Phase transitions

The temperature influences the distribution of species between different phases (solid, liquid, and gas). This could be of importance for iodine, but for no other radionuclides. This is not treated explicitly in the assessment.

Decay

Radionuclide decay is evidently important and considered in the models.

External boundaries – export

Radionuclides will be transported out from the local system, e.g. by moving water, and this will affect the concentration of radionuclides in the local system. This is considered both in the ecosystem model /Kumblad, 2001/ and in the exposure models /Karlsson *et al.*, 2001/.

5 Treatment of processes and interactions in the quantitative analysis

5.1 General

The interaction matrix and the list of scenario initiating events and conditions do not provide quantitative information on the repository performance. For that purpose quantitative analyses and models of the evolution of barrier properties and conditions and migration of radionuclides and toxicants are required. What the system description model does provide, is a list of processes and aspects of processes that should be considered in the quantitative analyses and models.

The procedure used here for incorporating the system description model into the quantitative assessments is by the use of an information flow diagram. This diagram graphically displays the information exchange between different models and analyses selected for the quantitative assessment. This diagram is used to check the consistency between the models and analyses selected and the system description model derived by the interaction matrix. In addition to this, the diagram provides a framework for assuring consistency in data transfer between different analyses.

The information flow diagrams developed for the quantitative analyses are shown and described in this chapter as well as how the system description models enter into the different analyses. The next section provides an overview of the whole system focussing on information exchange between the repository, geosphere and biosphere analyses and on information that should be consistently used in analyses of the repository, geosphere and biosphere. The analyses and treatment of processes in the repository, geosphere and biosphere are described in the following sections.

The final section addresses to what extent the used modelling structure represents the processes and interactions identified to be important in the interaction matrices. A formal check has been undertaken, and its results are reported.

5.2 Overview of repository, geosphere and biosphere analyses and processes

A flow diagram showing the information exchange between the repository, geosphere and biosphere analyses are shown in *Figure 5-1*. This diagram also defines analyses that delivers the same information to analyses of different parts of the system and therefore needs to be consistently treated. Rectangular boxes represent analyses requiring and/or delivering quantitative information. Physical constants, initial and boundary conditions are indicated by hexagons. Thin arrows display information transfer, the type of information being transferred is indicated (rounded rectangles). Flux of radionuclides and toxicants through and out from the system is displayed by thick arrows.

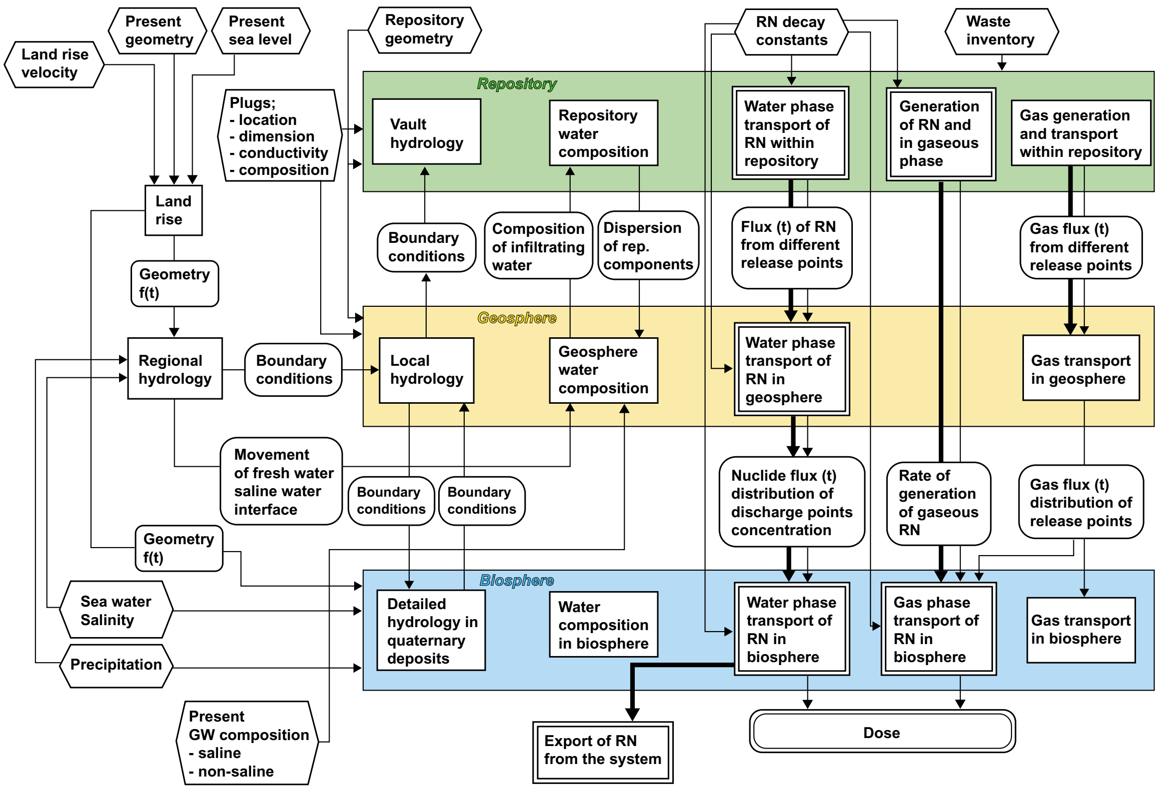

Figure 5-1. *Information flow diagram showing the information exchange between repository, geosphere and biosphere analyses in the performance assessment of SFR.*

5.2.1 Migration of radionuclides and toxicants

A key analysis of the performance assessment is to calculate the migration of radionuclides and toxicants in the repository, the geosphere and the biosphere. The input to these calculations is the waste inventory and the results are dose to man and radiation environment for biota as well as concentrations of toxic metals in biosphere recipients. For that purpose, different models will be used in the different parts of the system. The information exchange between these migration models is the flux of radionuclides and toxicants as a function of time and the location of the release points. The processes considered in these models and other types of information that these models require are described in the next sections. However, radioactive decay is considered in all migration models and it is therefore essential that the same set of decay constants is used in the models.

Radionuclides and toxicants generated as gas in the repository may be carried to the biosphere by inactive gas generated in the repository. The information required for analysis of the release of radioactive and toxic gas to the biosphere is then the rate of generation of these gases and the release points for gas to the biosphere. How the release of radioactive gas is treated in the analysis is described in the following sections.

5.2.2 Hydrogeology

The groundwater flow in the geosphere of the system is analysed by a local hydrogeology model with boundary conditions defined by the results of a regional model. The local model in turn provides boundary conditions to a more detailed model for determining the water flow in the repository vaults. It also provides boundary conditions to a more detailed model of the water flow in the quaternary deposits at the ground surface. The processes that are considered in these models and information exchange between these models and other analyses are described in the next sections. For details, see Holmén and Stigsson /2001/.

5.2.3 Gas generation and transport

Different processes in the waste and barriers in the repository will generate gas. The analyses of gas generation and gas transport in the repository barriers deliver results in terms of gas flux at different release points as a function of time. These results are used to analyse the gas transport in the geosphere to give the gas flux to the biosphere at different release points. The results of the analysis of gas transport in the geosphere should also give information on likely locations for the release of radioactive and toxic gas to the biosphere. Gas generation and transport is not fully explored within SAFE. The aspects that are analysed are described in the following sections.

5.2.4 Water composition

The water composition in the biosphere, geosphere and repository is important for many chemical processes taking place in the different parts of the system. In addition, there are processes, especially in the repository, that affects the water composition and advection and diffusion will lead to an exchange of components in the water between the different systems.

The water composition in the geosphere is affected by the composition of water infiltrating through the biosphere and thus on the processes taking place in the biosphere. According to the definition of the Base Scenario, no other future changes in the biosphere are included than those arising from land rise. The main implication of this for the water composition in the geosphere is assessed to be the switch from the present saline water to a more non-saline groundwater in the future. Therefore, a saline groundwater and a non-saline groundwater is defined for the analyses in the performance assessment using information on the composition of present day saline groundwater in the rock at the SFR site as well as on the composition of non-saline water in the Forsmark area.

5.2.5 Microbial activity

The impact from microbial activity in the repository and in the geosphere will not be considered directly in the quantitative analyses. For this reason such analyses are not indicated in the model information flow diagrams. However, the interaction matrices indicate several instances where microbial activity may possibly be of importance, even if the initial judgement is that the impact is insignificant. For this reason, a directed effort has been undertaken /Pedersen 2001/ for exploring the impact of microbes. This analysis supports the decision not to include microbial activity in the model flow chain.

5.2.6 Dose

The output from the calculation scheme is the estimated dose. The dose calculations are described in Section 5.5.

5.2.7 Initial and boundary conditions

The quantitative analyses require the setting of the following initial and boundary conditions.

- Radionuclide inventory, decay constants, and distribution of the inventory.
- Waste and barrier materials, dimensions, geometry, chemicals, dimensions, voids etc.
- Vault geometry.
- Composition, location and properties of plugs.
- Surface geometry, soil cover, shore line displacement over time etc.
- Rock structure and permeability distribution.
- Surface water chemistry
- Climatic conditions such as precipitation, wind etc
- Present groundwater composition

The actual values (or time evolution) selected depends upon the scenario to be analysed. The selection of most of these data is presented in the data report /SKB, 2001b/. Others, such as land rise and climatic conditions, are given in the hydrogeological report /Holmén and Stigsson, 2001/ and in the reports of the analyses of shore level displacement /Brydsten, 1999b/ and water exchange in Öregrundsgrepen /Engqvist and Andrejev, 1999/.

5.3 Repository analyses and processes

The information exchange between the quantitative analysis of the performance of the repository is shown in the information flow diagram in *Figure 5-2*. The analyses of the migration of radionuclides and toxicants includes a quantification of the source term in the different waste forms, the analysis of migration through the repository barriers and an estimation of the generation and release of gaseous radionuclides and toxicants from the repository barriers. These analyses need information and data from supporting analyses of the hydrology in the repository, gas generation and transport in the repository, alteration of waste and barrier materials and of the evolution of the water composition in the repository. In addition, the inventory and distribution of radio-nuclides and toxicants in the waste are required. A description of how the processes included in the system description model are treated in the different analyses of the repository performance is given in the following sub-sections.

5.3.1 Temperature

Section 4.2.10 discusses the processes influencing the temperature in the repository parts in SFR. However, based on the potential temperature impact on other conditions and the expected moderate future evolution of the temperature, it is judged that temperatures would not play a significant role for the repository evolution. The temperature impact will thus be discarded, but the potential temperature increase is estimated in conjunction with analysis of gas generation since it is the same or similar processes that are the source in both cases /Moreno *et al.*, 2001/.

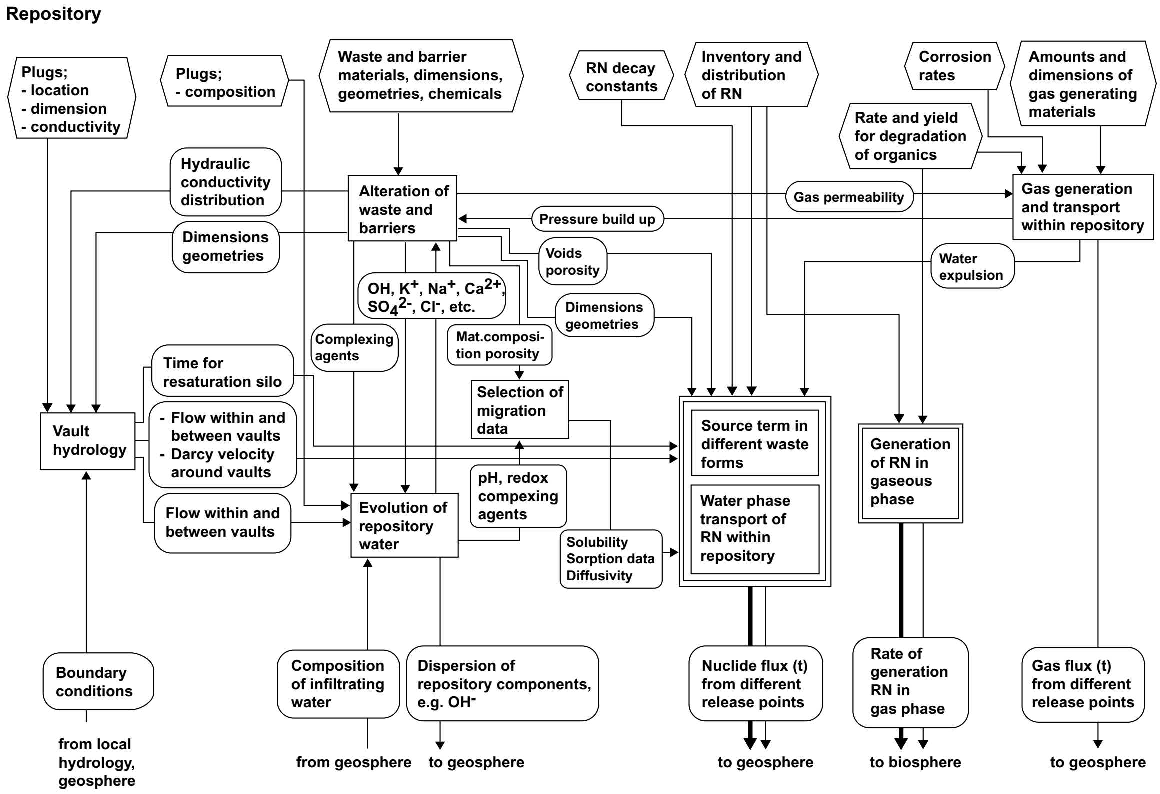

Figure 5-2. *Information flow diagram showing the information exchange between different analyses of the repository performance.*

5.3.2 Hydrogeology

Section 4.2.8 discusses the processes influencing the hydrogeology of the repository. The hydrogeological modelling /Holmén and Stigsson, 2001/ within SAFE is made with an approach integrating many different scales ranging from regional scale, local scale and detailed repository scale. The modelling considers most of the listed interactions.

Groundwater flow after saturation

According to the system description model (Section 4.2.8) the water flow in the repository barriers after saturation will mainly be determined by the water flow in the surrounding rock and access tunnels and by the hydraulic properties of the repository barriers. Gas generation and build-up of gas pressure can also be of importance for how the water flow in the different repository vaults and in the Silo.

Dimensions and hydraulic properties are given by the initial state of the materials and by potential changes due to alteration of barriers. In the modelling of the vault hydrology, the impact of water flow in the surrounding rock is considered by using boundary conditions delivered by the local hydrogeology model. The temporal change of these boundary conditions reflects the impact of e.g. shore line displacement or various assumptions on plugs in the access tunnels etc.

The model of Holmén and Stigsson /2001/ does not directly include the buoyancy effects of varying salinity. However, for the SFR the salinity is relatively low and scoping calculations show that neglecting density dependent flow is allowed considering the time variation of boundary conditions caused by the land rise /Stigsson *et al*., 1998/. These conclusions are used in the subsequent hydraulic analysis of SAFE /Holmén and Stigsson, 2001)/.

Effects of gas and gas pressure build-up is not considered. It is assumed that presence of gas would decrease the hydraulic conductivity (see e.g. Bear /1976/) and thus decrease the flow. The simplification thus implies that groundwater flow, if anything would be slightly overestimated in regions with gas production.

Saturation

According to the system description (Section 4.2.8), the increase in water pressure in the rock outside the repository vaults and the Silo as well as capillary suction in the repository barriers and osmosis in the bentonite barriers are important for the time to saturate the repository after closure. Since these processes act together, at least in the bentonite barriers, the system is complex and it is difficult to make a detailed description of the saturation process. Therefore the vault hydrogeology model is used to make simple estimates of the time for saturation of repository vaults and Silo after repository closure /Holmén and Stigsson, 2001/. This is done considering the restoration of the water pressure in the nearby rock and by choosing values of the hydraulic conductivity, porosity and initial water content, which do not overestimate the time for saturation.

Redistribution of backfill material in repository vault during saturation phase is not included in the model. However, this does not affect the total flow in the vaults only the distribution of flow inside the vault. Neglecting this effect will not underestimate the flow through the interior of the vault or the transport of radionuclides and toxicants through the repository barriers.

5.3.3 Gas generation and transport

Processes and interactions affecting gas generation and gas transport are discussed in Section 4.2.9 and in a special report /Moreno *et al*., 2001/. The following is considered in the modelling:

Gas generation

Gas generation by corrosion and microbial degradation of organic materials considering water composition, materials and solubility of gases is handled by literature data on corrosion rates in alkaline environment and amount and dimensions of corroding material from waste inventory.

Changes in gas amounts and composition due to consumption of hydrogen by microbes to produce methane is not quantitatively addressed, but discussed in a state of the art study on microbial activity in SFR like environment /Pedersen, 2001/.

Gas transport

Gas transport and gas pressure build up is analysed by simple calculations for a number of assumptions regarding the hydraulic and gas transport properties of the engineered barriers /Moreno *et al*., 2001/. The aim of the study is to estimate water expulsion and potential effects on radionuclide release from the different repository parts.

5.3.4 Evolution of water composition in the repository

The evolution of the water composition is discussed in Section 4.2.7. Many of the processes affecting water composition are strongly coupled to alteration of barrier properties. Some of the processes are explored in special analyses while others are more qualitatively addressed. This is described in Section 4.2.7. The resulting groundwater composition is achieved by assessing the results of these special analyses and qualitative considerations and used as input to the selection of radionuclide migration data. The main characteristics of the water affecting the dissolution and migration of radionuclides in the engineered barriers are redox conditions, pH, ionic strength and concentration of complexing agents and colloids. The expected evolution of these characteristics and how this is treated in the selection of data for the quantitative analysis of radionuclide release is further described in the "SAFE Data Report" /SKB, 2001b/.

5.3.5 Alteration of waste and barriers

Processes or aspects of processes affecting the properties of waste and engineered barriers in the repository are discussed in Sections 4.2.2 to 4.2.6. Likewise to the water composition, some of the processes are analysed in more detail while other are just qualitatively assessed (see Sections 4.2.2 to 4.2.6). The main characteristics of the barriers of importance for radionuclide migration are pore- and fracture characteristics and the chemical composition. These characteristics may change due to the processes occurring in the repository, e.g. it cannot be excluded that some of the processes lead to cracking of the barriers. The expected evolution of these characteristics and how this is treated in the selection of data for the quantitative analysis of radionuclide release is further described in the "SAFE Data Report" /SKB, 2001b/.

5.3.6 Migration of radionuclides and toxicants

In Section 4.2.13, processes/interactions potentially important for the analysis of radionuclide transport are discussed. The following processes are considered in the quantitative analysis /Lindgren *et al.*, 2001/.

Source term – Dissolution/precipitation

The analyses of the characteristics of bitumenised waste /Pettersson and Elert, 2001/ indicates that the release of radionuclides from the waste in a bitumen matrix will be delayed due to the slow uptake of water. This is considered in the analyses by assuming a time-distributed dissolution and release of radionuclides from a bitumen waste matrix. For all other waste forms the radionuclides are assumed to dissolve immediately, neglecting potential restrictions in accessibility as well as limits in solubility.

Water phase transport

The model used to simulate the migration of radionuclides in the engineered barriers in the vaults, NUCFLOW, is a modified version of the compartment model NUCTRAN /Romero, 1995 and Romero *et al*., 1999/. The model considers advection, diffusion, sorption and radioactive decay. The model structure is based on repository layout and dimensions of the repository barriers and voids/porosity as well as on distribution of water flow in the repository vaults. The migration data to the model are selected based on the expected composition of materials and water in the repository /SKB, 2001b/. The concentration of complexing agents affects the speciation of radionuclides and thus needs to be considered in the selection of K_d-values. Precipitation of radionuclides and toxicants is not considered, nor expected, because of low concentrations and minor changes in water composition, even if sorption/precipitation with calcite and/or ironhydroxides could be a potential sink for radionuclides and toxicants.

Expulsion of contaminated water from the interior of the repository due to gas generation and pressure build-up is also considered /Moreno *et al*., 2001/. The impact of water expulsion on the release of radionuclides from the engineered barriers in the Silo, BMA and 1BTF is estimated. The waste in 2BTF contains ion-exchange resins only, which is expected to produce gas at a very slow rate, if they at all degrade. It is therefore assumed that gas that is generated inside the waste containers in 2BTF can escape without affecting the release of radionuclides. In BLA, large amounts of gas can theoretically be generated, but BLA contains no engineered barriers. It is therefore assumed that gas can escape from BLA without affecting the release of radionuclides.

Colloid transport in the engineered barriers is not considered in the analyses. The main reason for this is that the concentration of colloids is expected to be small in a cementitious environment (see e.g. Colloid transport and filtering in Section 4.2.13 and SKB /2001b/). This may not be the case in BLA, but it is anyway assumed to be no restrictions to migrations inside the BLA. Colloids transport in the geosphere may not be neglected (see Section 5.4).

Another process not considered in the analysis is the potential change in migration properties of metal ions, methylation, and transformations between organic and inorganic ^{14}C due to the actions of microbes (see Methylation/transformation in Section 4.2.13). Due to the slow turnover of water that restricts the supply of nutrients and energy as well as the removal of reaction products, microbial activity in the waste containers in all repository parts except BLA is expected to be low. However, methylation and alkylation processes may proliferate under stagnant hydraulic conditions until a stationary phase is reached /Pedersen, 2001/. Whether this is enough for significant methylation or alkylation of metals in SFR is not presently known.

Gas phase transport

The waste in SFR does not contain any radionuclides in gaseous phase. However, the possibility that organic ^{14}C will be transformed into carbon dioxide and possibly also methane cannot be ruled out. Carbon dioxide can dissolve in the water and via reactions with calcium in the water precipitate as calcite. Methane has a low solubility and will remain in gaseous phase and can be released from the repository mixed with inactive gas from e.g. metal corrosion. Once released from the repository, the further transport through the rock to the biosphere is expected to be fast.

This release mode to the biosphere is not considered quantitatively in the analysis of radionuclide release. Instead it is assumed that the total inventory of organic ^{14}C is dissolved in the water that leaves the repository and that migration in the near-field barriers and also in the rock occurs without any retention. Release in gaseous phase could result in higher release rates of organic ^{14}C during early times after repository closure than in the cases analysed. However, during this time period the biosphere recipient is the Öregrundsgrepen with a high dilution potential and thus also low dose impact. It is therefore assessed that the consequence of release of gaseous ^{14}C is well covered by the analysis of the consequence of releases via the groundwater pathway.

5.4 Geosphere analyses and processes

The information exchange between the analysis of the migration of radionuclides and toxicants in the geosphere and supporting analyses is shown in the information flow diagram in *Figure 5-3*. Pathlines and flows for the *water phase transport* are obtained from the local hydrogeology analyses. The input nuclide flux is obtained from the repository analysis (see Section 5.3.6) and the distribution of discharge points is obtained from the hydrogeology analysis. *Gas transpor*t in the geosphere can essentially be treated independent of the water phase transport. Boundary conditions to *the local hydrogeology* in rock surrounding the vaults are controlled by the regional hydrogeology and the hydrogeology of the repository itself. *The evolution of the groundwater composition* affects the repository (as boundary conditions) and the migration properties (sorption) of the geosphere.

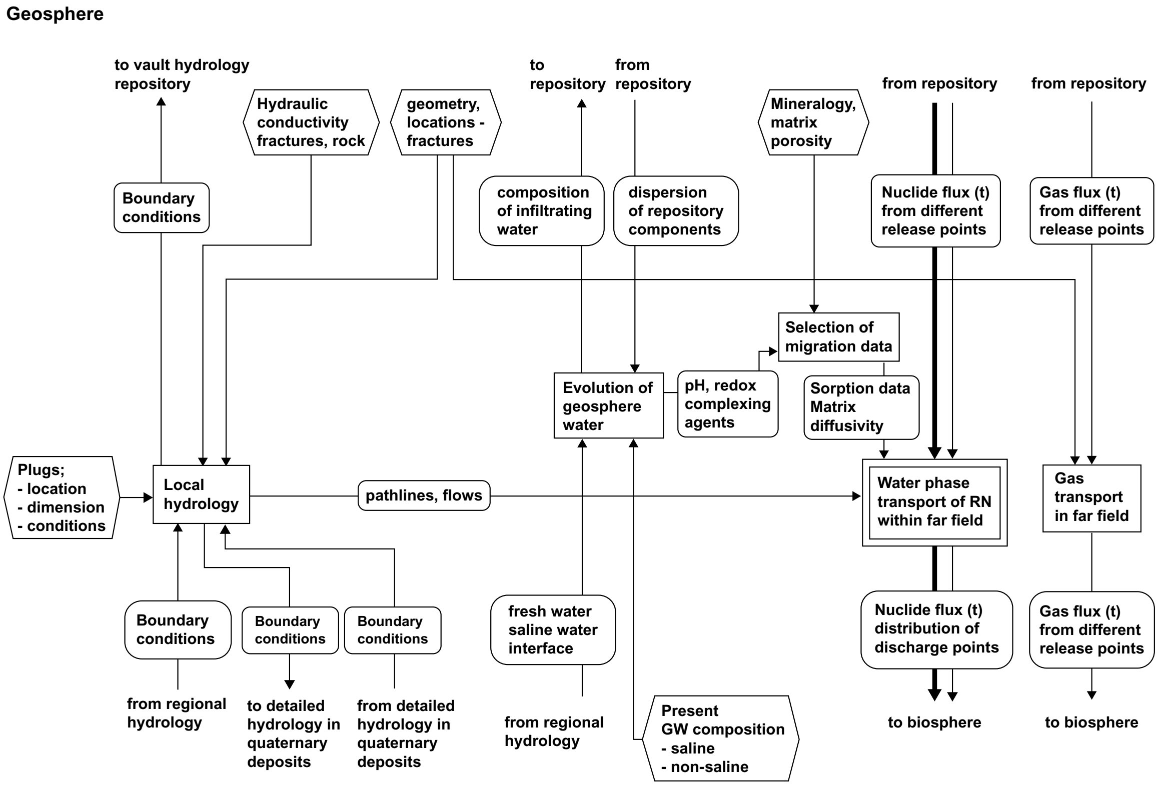

Figure 5-3. *Information flow diagram showing the information exchange between different analyses of the geosphere performance.*

5.4.1 Hydrogeology

The processes influencing the hydrogeology of the geosphere are discussed in section 4.3.6. The hydrogeological modelling within SAFE is made with an approach integrating many different scales ranging from regional scale, local scale and detailed repository scale /Holmén and Stigsson, 2001/.

Saturated flow

The model handles time dependent boundary conditions and describes the medium as a three-dimensional, equivalent heterogeneous porous medium with a high spatial resolution. The modelling considers most of the listed interactions.

According to the system description model (Section 4.3.6) the water flow in the geosphere will mainly be determined by the hydraulic properties of the repository and the rock and by the external boundary conditions as provided from the regional hydrogeological model. The temporal change of these boundary conditions reflects the impact of e.g. shore line displacement or other changes of the surface conditions as well as various assumptions on plugs in the access tunnels etc.

Groundwater wells can be directly included in the model.

The model of Holmén and Stigsson /2001/ does not directly include the buoyancy effects of varying salinity. However, for the SFR the salinity is relatively low and scoping calculations show that neglecting density dependent flow is allowed considering the time variation of boundary conditions caused by the land rise /Stigsson *et al*., 1998/. These conclusions are used in the subsequent hydraulic analysis in SAFE /Holmén and Stigsson, 2001/.

Effects of gas and gas pressure build-up is not considered. It is assumed that presence of gas would decrease the hydraulic conductivity (see e.g. Bear /1976/) and thus decrease the flow. The simplification thus implies that groundwater flow, if anything, would be slightly overestimated in regions with gas production.

Saturation

In the SAFE analyses the two-phase flow aspects of the saturation process is discarded. The time for saturation is approximated by estimating the time to fill the vaults with water, but the effects of capillary suction and two-phase flow impact on hydraulic conductivity are neglected. The time for saturation that is estimated in this simplified manner is quite short /Holmén and Stigsson, 2001/ and neglecting two-phase flow aspects is considered as a minor problem in this respect.

5.4.2 Gas transport

Gas transport and gas pressure build up in the repository is analysed in Moreno *et al.* /2001/. Processes and interactions affecting gas transport in the geosphere are discussed in Section 4.3.7. However, based on the general evaluation of the significance of various processes and on results of past assessments of gas transport /Thunvik and Braester, 1986/ it is assumed that any gas released from the repository will be quickly transported through the geosphere and up to the surface above the release point.

5.4.3 Evolution of water composition in the geosphere

The evolution of the water composition is discussed in Section 4.3.5. Changes in water composition in the geosphere are mainly due to changes in the origin of the groundwater and due to dispersal of dissolved components from the waste and engineered barriers in the repository.

The ongoing land rise implies that fresh water will infiltrate in the rock and replace the currently saline water in the rock surrounding the SFR. Two different groundwater compositions are assumed: one representing present day saline conditions and a future one representing fresh conditions. The latter composition is taken from relevant fresh water analyses in the Forsmark area upstream the SFR, i.e. a situation mimicking the future conditions at the site. The approximate timing for the changes of conditions is obtained from the hydrogeological analysis.

A detailed transport analysis of the “expulsion” of saline water is not included in the analyses within SAFE. The transition may take longer time due to exchange of water in the rock matrix or in the different repository barriers, but these effects are considered relatively insignificant.

The most likely impact on the groundwater composition from the Silo and the vaults with concrete barriers is the dispersion of concrete pore water. This is not analysed in detail, but the plume with elevated pH will probably not reach far out into the rock in the time period considered in the analysis. In addition, it is assumed dissolution of concrete in plugs in the vaults and tunnels will have negligible effects on water composition in tunnels outside the repository vaults. This judgement may, however, need to be reconsidered once the plug design is finalised.

The expected evolution of the characteristics of groundwater composition that is of importance for radionuclide migration and how this is treated in the selection of data for the quantitative analysis of radionuclide release is further described in the “SAFE Data Report” /SKB, 2001b/.’

5.4.4 Tunnel backfill, rock and fracture alteration

There are several potentially important interactions affecting properties of the tunnel backfill (see Section 4.3.2) as well as rock and fracture properties (see Section 4.3.4). However, the alteration of backfill in access tunnels and of fractures in the rock is not studied within SAFE. The main expected change in the groundwater composition (from saline to non-saline conditions) does not seem to warrant significant dissolution/precipitation. Dispersion of high pH from the repository vaults could cause some alteration of the backfill and fractures via dissolution/precipitation, but this would probably reduce the permeability of the backfill and the rock and is therefore discarded. The future stress changes in SFR-1 are considered too small to warrant quantitative evaluation, possibly apart from the absolute vicinity of the tunnel system. Also clogging by microbes and bio-films are neglected.

It seems reasonable to assume that none of these processes would significantly alter the hydraulic conductivity of the backfill in the tunnels or of the rock even if the exact location of some water paths may be altered.

5.4.5 Plugs

Plugs will be present at the end of the repository vaults and possibly also at different locations in the access tunnels. The design and composition of these plugs are not yet finally decided, but it is possible that they will contain concrete and/or bentonite. The location and properties of the plugs will mainly affect the hydraulic situation in the repository and in the rock. There are a number of processes by which the properties of the plugs might be altered in the time perspective considered (see Section 4.3.3).

Since the design and composition of the plugs are not yet decided, no specific analyses of the long-term properties of the plugs are made in the performance assessment. However, the effect of changing the flow resistance in the plugs on the water flow in the repository is studied in the Initial Defect Scenario (see Section 3.3.1). This is done by assuming that (some) plugs have no flow resistance after a certain time. This is described in Holmén and Stigsson /2001/.

5.4.6 Migration of radionuclides and toxicants

Processes/interactions potentially important for the analysis of radionuclide transport in the geosphere are discussed in Section 4.3.10. The following processes are considered in the quantitative analysis /Lindgren *et al.*, 2001/.

Water phase transport

The migration model that is used, FAR31, /Norman and Kjellbert, 1990/ considers advection, dispersion, matrix diffusion, sorption and radioactive decay. Input data are based on expected mineralogy and porosity of the rock and expected water composition as well as path lines and magnitude of water flow through the rock. The concentration of complexing agents affects the speciation of radionuclides and thus needs to be considered in the selection of K_d-values. Precipitation of radionuclides and toxicants is not considered, nor expected, because of low concentrations and minor changes in water composition, even if co-precipitation with calcite and/or ironhydroxides could be a potential sink for radionuclides and toxicants.

Transport of radionuclides attached to colloidal matter is not explicitly included in the calculations. However, the presence of colloids as well as other processes that can have a negative impact on the radionuclide retention in the rock is indirectly considered by exploring the effect of no retention in the rock (see SKB /2001b/ and Lindgren *et al.* /2001/).

Gas phase transport

Radionuclides generated in gaseous phase in the repository are immediately released to the biosphere where it is dissolved. No specific analysis of the release of radioactive gas is made in SAFE, since it is judged that the dose impact from gaseous release is covered by the analysis of the groundwater pathway (see Gas phase transport in Section 5.3.6.

5.4.7 Rock mechanics

A special study evaluates the possibilities of rock fallout in the different vaults /Fredriksson, 2000/. The analysis is essentially qualitative and assesses the maximum rock fallout possible in case there is no backfill in the tunnels or in the vaults. The analysis assumes a complete degradation of rock reinforcement (rock bolts, shotcrete etc.) and is thus quite pessimistic. The analysis shows that a loosen up of rock may occur up to a distance of about 2 m into the rock around a vault that contains backfill. Furthermore, if BLA is left without backfill it cannot be ruled out that connections are created locally between the BMA and BLA vaults. The possibility of a zone with higher permeability around the repository vaults containing backfill is not included in the analysis, since this would not increase the water flow through the waste domain. In regard to the creation of local connections between the BMA and BLA vaults it is presumed that appropriate engineering actions will be taken to minimise this risk. This situation is therefore not analysed.

5.5 Biosphere analyses and processes

The information exchange between the analysis of the migration of radionuclides and toxicants in the biosphere and supporting analyses is shown in the information flow diagram in *Figure 5-4*.

A summary of how the processes included in the system description model are treated in the different analyses of the biosphere is given in the following sub-sections. The description is focussed on processes that are deemed to have a major influence on the transport of radionuclides in the system and the uptake in biota. The aspects of processes that are of importance for the future development of the biosphere in the SFR area are only briefly mentioned here (see also Section 4.4). Furthermore, these processes and a prediction of the future characteristics of the surface environment is summarised in a separate report /Kautsky (ed.), 2001/. The interpreted time evolution of the biosphere system is given in the final report of the SAFE project /SKB, 2001a/.

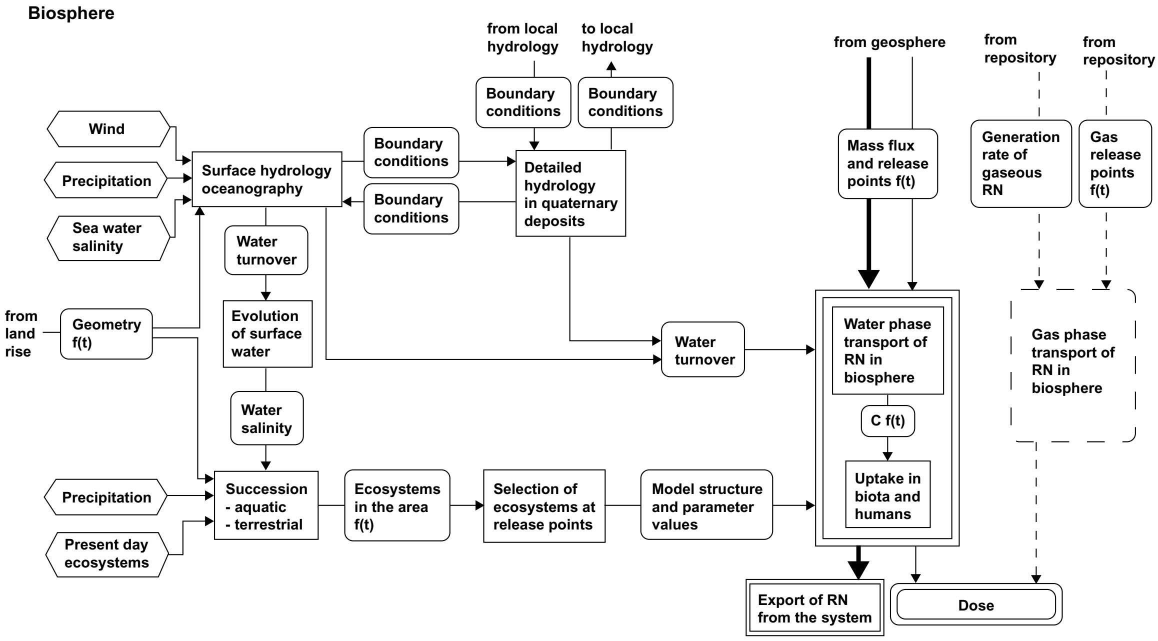

Figure 5-4. *Information flow diagram showing the information exchange between different analyses of the biosphere.*

5.5.1 Aquatic and terrestrial succession

The aquatic and terrestrial succession in the SFR area will determine the characteristics of the ecosystems in the discharge area from the repository. The driving force for the succession is the land rise and the shore level displacement, which causes redistribution between land and sea in the area. This is analysed and reported by Brydsten /1999b/ and the formation and development of lakes is addressed by Brunberg and Blomqvist /2000/. Other processes that will contribute to the evolution of the system characteristics and that are considered in the analysis are sedimentation /Brydsten, 1999a/ and changes in species composition due to smaller water volumes and different water composition.

The input to the analysis of radionuclide migration concerns the timing of the development of different ecosystems as well as the geometry of the systems, e.g. depth of the surface waters and size and location of sedimentation bottoms, as well as data related to certain processes such as sedimentation rates. In regard to biota and vegetation, it is assumed that the species composition in the different ecosystems is reflected by the species composition in the same type of ecosystems that are present in the Forsmark area today. A number of studies address this issue. The distribution of aquatic plants and animal communities is reported by Kautsky *et al.* /1999/ and the vegetation in the SFR region by Jerling *et al.* /2001/. Lindborg and Schüldt /1998/ give a description of the terrestrial biosphere and primary production in the coastal area and a compilation of the data for the coastal area is made in Kumblad /1999 and 2001/.

In the assessment it is also assumed that the present day human behaviour will be applicable for the whole time period considered in the assessment.

5.5.2 Surface hydrology

The main input from surface hydrology to the analysis of radionuclide migration and uptake in biota are the water turnover in Öregrundsgrepen and in the lakes that will develop as well as surface runoff and water flow in quaternary deposits. The surface hydrology will also affect processes involved in the succession of the ecosystem, e.g. sedimentation and the evolution of water composition, change in salinity.

The water turnover in Öregrundsgrepen as well as the development of water salinity is analysed and estimated by Engqvist and Andrejev /1999/. This study addresses both the present situation and the potential effects of land rise. The water turnover in future lakes in the area is estimated by Brunberg and Blomqvist /2000/ and values on surface runoff are given in Lindborg and Schüldt /1998/. In addition, the impact of sedimentation in the discharge area on the location of the discharge points of groundwater is analysed as a part of the hydrogeological modelling /Holmén and Stigsson, 2001/.

5.5.3 Transport of radionuclides and uptake in biota and humans

The model used in the assessment, ACTIVI/PRISM /Bergström *et al.*, 1982 and 1995 and Gardner *et al.*, 1983/, is a compartment model that can be used to simulate the turnover of radionuclides in different ecosystems and the resulting dose to man. In the model, different compartments are used for solid phases and water and processes occurring in the different parts of the system are simulated by lumped parameters in the model. A more detailed description is given in Karlsson *et al.* /2001/. A model with higher resolution is used to simulate the turnover of ^{14}C in Öregrundsgrepen /Kumblad, 2001/. In this model, the different processes that can contribute to the turnover are considered separately and thus, the model has a higher resolution than in the exposure model ACTIVI/PRISM. How processes are treated in the ecosystem model for ^{14}C are indicated in Section 4.4.

The following description is focussed on the treatment of processes in the ACTIVI/PRISM model. More detailed information is given in the report describing the model /Karlsson *et al*., 2001/ and in the SAFE Data report /SKB, 2001b/.

Water phase transport

In the *aquatic exposure model* the transfer of radionuclides with moving water between different parts of the system is considered in terms of the retention time for water in each part. Data on water retention times in Öregrundsgrepen and in the bays and lakes that will be formed in the future are given by the site-specific analyses carried out (e.g. Engqvist and Andrejev /1999/; Brunberg and Blomqvist /2000/). Sorption/desorption is considered in terms of element-specific, generic values of the distribution coefficient for suspended matter in brackish water and in lakes. Radionuclides on suspended matter can via sedimentation accumulate in the bottom sediments, but also via resuspension be transferred back to the water phase. Sedimentation and resuspension is considered in terms of a sink velocity of particles, the growth of sediments and the fraction of accumulation bottoms. The values selected are based on both site-specific studies (e.g. Brydsten /1999a/) and on other information available in the literature.

In the *terrestrial exposure model*, radionuclides are transported with groundwater in the saturated zone as well as with is upward moving water from the saturated zone to the soil above and with infiltrating water from the soil down to the saturated zone. To determine the different transfer coefficients site-specific data are used for surface runoff, while generic data are selected for the vertical water movement. Change in water content is implicitly considered by assuming an average water content based on general data on soil porosity. Evaporation (evapotranspiration) and precipitation are also indirectly considered in the model since the selected value of surface runoff is the net of precipitation and evapotranspiration. Radionuclides can also be transferred to vegetation and soil via irrigation. In the model this is considered by assuming the annual number of irrigation events and the quantity of water per irrigation event.

Sorption/desorption will affect the distribution of radionuclides between water and soil, and this is considered in the model in terms of generic, element-specific distribution coefficients for soil and peat. Bioturbation causes among other things a homogenisation of soils. It is included as a transport process in the soil compartments of the exposure model as it transports a fraction of the upper soil to deeper layer and vice versa. This is expressed as an annual transport of soil and generic values are selected in the calculations. In addition, radionuclides will be removed from the soil by erosion of the soil surface. This is expressed as an annual loss and generic values are selected in the calculations.

Gas phase transport

No specific analysis of the release of radioactive gas is made in SAFE, since it is judged that the dose impact from gaseous release is covered by the analysis of the groundwater pathway (see Gas phase transport in Section 5.3.6).

Uptake of radionuclides in biota

The concentration of radionuclides in biota is affected by uptake via water and food and by excretion. In the exposure models this is considered in terms of the net effect of uptake/sorption and excretion. However, the mechanism is not considered as a major pathway for redistribution of radionuclides since the aim of the calculations only is to estimate the exposure to man.

The uptake (accumulation) of radionuclides is simulated by root uptake factors, by bioaccumulation factors and by transfer coefficients for milk and meat. Root uptake factors are used to calculate the concentration of radionuclides in crops grown on the agricultural field and bioaccumulation factors are used to calculate the concentration in aquatic biota. Transfer coefficients for milk and meat are used to calculate the transfer to milk and meat from cattle's daily intake of contaminated fodder, soil and water. For all these factors and transfer coefficients, generic, but element-specific, data are selected. To calculate the transfer of radionuclides to milk and meat, typical data on the daily consumption of food items for dairy cows are used. The cattle's intake of soil adhering to plant food is also considered in the calculations.

For crops that are irrigated, the retention of irrigated water on the vegetation surface and translocation from plant surface to edible parts are considered. In addition, effects of vegetation growth and of wind and precipitation on the concentration of radionuclides on the surface of vegetation are indirectly considered in terms of a weathering half-life for the vegetation.

The radiologic effects on biota from ^{14}C are assessed in the aquatic ecosystem model /Kumblad, 2001/. However, the exposure model provides no quantitative estimates of the radiologic effects on biota, as already indicated above. The presentation of these effects will thus be limited to a qualitative discussion, in awaiting the outcome of an ongoing EC-project FASSET that address these issues.

Human intake of radionuclides and assessment of dose

For humans to be exposed to radionuclides from SFR they must live in the area where discharge of radionuclides take place. In the assessment it is assumed that humans live in the area and that the present living habits will remain over the whole time period considered in the assessment. Therefore, values of the parameters related to the production and consumption of food and water are chosen to reflect Swedish conditions of today.

In the assessment, internal exposure from intake of radionuclides via consumption of water, fish, vegetables, root crops, cereals, milk and meat are considered. In addition, unintentional intake of soil adhered to vegetables and root crops are included. Intake is also assumed to occur via inhalation of contaminated particles in the air emanating from re-suspension of soil or peat or from peat combustion. External exposure is considered from radionuclides in soil and in peat.

Dose conversion factors for ingestion, inhalation and external exposure are used to calculate dose to man.

6 Conclusions

Considerable efforts have been spent in developing a comprehensive system and scenario description. The systematic and documented methodology, using experts of different competence, is by itself a means for focusing on completeness.

The completeness of the system description is demonstrated by the outcome of the audit against the NEA FEPs database. It showed very few relevant processes not already considered in the interaction matrices. The FEPs audit and the experiences from past safety assessment also provided a broad selection of potentially important scenario initiating events and conditions. Together, these FEPs will cover most of the potential future evolution of the SFR.

The system description is reflected in the selection of quantitative modelling tools for the consequence analysis. A check has been made to ensure that the models represent the important processes and interactions in the system description.

A qualitative analysis of the different scenario initiating events and conditions resulted in that the future evolution of the SFR to a large extent will be covered within the different assumptions made for the Base Scenario. In addition, a few other scenarios will require quantitative analysis. However, it is expected that the analysis of the Base Scenario to a large extent will be relevant also for other scenarios, or that other scenarios often can be handled as parameter variations in the models used to assess the Base Scenario.

Finally, it should be emphasised that an interaction matrix primarily is a tool for a systematic identification and structuring of processes/interactions in the disposal system, while there are other tools available that are more suitable in displaying the results in a transparent way. One such tool is the THMC-diagram that was used in SR 97 to graphically display and structure the description of processes in the repository evolution /SKB, 1999c/.

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Appendix A: Matrix group members

The members of the group taking part in the construction of the matrices and the assignment of priorities to interactions in the Repository-, Geosphere- and Biosphere-matrix are given below.

Group member	Matrix	Expertise
Johan Andersson, JA Streamflow AB	Repository and Geosphere	Hydrogeology Performance Assessment
Ulla Bergström, Studsvik Ecosafe AB	Biosphere	Radiochemistry
Lars Brydsten, Umeå University	Biosphere	Physical geography
Anders Engqvist, A&I Engqvist konsult AB	Biosphere	Oceanography
Martin Isaeus, Stockholm University	Biosphere	Botany
Linda Kumblad, Stockholm University	Biosphere	Systems ecology
Ulrik Kautsky, SKB	Biosphere	Systems ecology, Radioecology Performance assessment
Tobias Lindborg, NaturRådet	Biosphere	Terrestrial ecology
Marcus Meili, Uppsala University	Biosphere	Limnology
Luis Moreno, Royal Institute of Technology	Repository and Geosphere	Transport processes
Karin Pers, Kemakta Konsult AB	Repository and Geosphere	Performance Assessment Technical secretary
Per Riggare, SKB	Repository and Geosphere	Waste inventory, construction of SFR-1
Jan-Olof Selroos, SKB	Repository and Geosphere	Hydrogeology Performance Assessment
Kristina Skagius, Kemakta Konsult AB	Repository, Geosphere and Biosphere	Migration processes Performance Assessment Technical secretary
Marie Wiborgh, Kemakta Konsult AB	Repository, Geosphere and Biosphere	Chemistry Performance Assessment Technical secretary

Appendix B : The International NEA FEP list

FEP no	FEP name	FEP definition (NEA FEP Database Version 1.0)
0	ASSESSMENT BASIS	Assessment basis factors are factors that the analyst will consider in determining the scope of the analysis; these may include factors related to regulatory requirements, definition of desired calculation end-points and requirements in a particular phase of assessment. Decisions at this point will affect the phenomenological scope of a particular phase of assessment, i.e. what “physical FEPs” will be included. "Assessment Basis" is a category in the International FEP List and is subdivided into individual FEPs.
0.01	Impacts of concern	The impacts of concern are the long-term human health and environmental effects or risks that may arise from the disposed wastes and repository. FEPs mapped to this heading should include health or environmental effects of concern in an assessment (what effect and to whom/what), and health or environmental effects ruled to be of no concern.
0.02	Timescales of concern	The timescales of concern are the time periods over which the disposed wastes and repository may present some significant human health or environmental hazard.
0.03	Spatial domain of concern	The spatial domain of concern is the domain over which the disposed wastes and repository may present some significant human health or environmental hazard.
0.04	Repository assumptions	Repository assumptions refer to the assumptions that are made in the assessment about the construction, operation and administration of the repository.
0.05	Future human action assumptions	Future human action assumptions are the assumptions made in the assessment concerning general boundary conditions for assessing future human action.
0.06	Future human behaviour (target group) assumptions	Future human behaviour (target group) assumptions are the assumptions made concerning potentially exposed individuals or population groups that are considered in the assessment.
0.07	Dose response assumptions	Dose response assumptions are those assumptions made in an assessment order to convert received dose to a measure of risk to an individual or population.
0.08	Aims of the assessment	The aims of the assessment relate to the purpose for which the assessment is being undertaken.
0.09	Regulatory requirements and exclusions	Regulatory requirements and exclusions are the specific terms or conditions in the national regulations or guidance relating to repository post closure safety assessment.
0.10	Model and data issues	Model and data issues are general (i.e. methodological) issues affecting the assessment modelling process and use of data.
1	EXTERNAL FACTORS	External factors are FEPs with causes or origin outside the disposal system domain, i.e. natural or human factors of a more global nature and their immediate effects. Included in this category are decisions related to repository design, operation and closure since these are outside the temporal bound of the disposal system domain for post-closure assessment. "External Factors" is a category in the International FEP List and is divided into sub-categories.
1.1	REPOSITORY ISSUES	Repository issues are decisions on designs and waste allocation, and also events related to site investigation, operations and closure. “Repository Issues” is a sub-category in the International FEP List and is divided into individual FEPs.
1.1.01	Site investigation	Site investigation refers to FEPs related to the investigations that are carried out at a potential repository site in order to characterize the site both prior to repository excavation and during construction and operation.
1.1.02	Excavation/construction	Excavation/construction refers to FEPs related to the excavation of shafts, tunnels, disposal galleries, silos etc. of a repository, the stabilisation of these openings and installation/assembly of structural elements.
1.1.03	Emplacement of wastes and backfilling	Emplacement of wastes and backfilling refers to FEPs related to the placing of wastes (usually in containers) at their final position within the repository and placing of buffer and/of backfill materials.
1.1.04	Closure and repository sealing	Closure and repository sealing refers to FEPs related to the cessation of waste disposal operations at a site and the backfilling and sealing of access tunnels and shafts.
1.1.05	Records and markers, repository	Repository records and markers refers to FEPs related to the retention of records of the content and nature of a repository after closure and also the placing of permanent markers at or near the site.
1.1.06	Waste allocation	Waste allocation refers to FEPs related to the choices on allocation of wastes to the repository, including waste type(s) and amount(s).
1.1.07	Repository design	Repository design refers to FEPs related to the design of the repository including both the design safety concept, i.e. the general features of design and how they are expected to lead to a satisfactory performance, and the more detailed engineering specification for excavation, construction and operation.
1.1.08	Quality control	Quality control refers to FEPs related to quality assurance and control procedures and tests during the design, construction and operation of the repository, as well as the manufacture of the waste forms, containers and engineered features.

FEP no	FEP name	FEP definition (NEA FEP Database Version 1.0)
1.1.09	Schedule and planning	Schedule and planning refers to FEPs related to the sequence of events and activities occurring during repository excavation, construction, waste emplacement and sealing.
1.1.10	Administrative control, repository site	Repository site administrative control refers to FEPs related to measures to control events at or around the repository site both during the operational period and after closure.
1.1.11	Monitoring of repository	Monitoring of repository refers to FEPs related to any monitoring that is carried out during operations or following closure of sections of, or the total, repository. This includes monitoring for operational safety and also monitoring of parameters related to the long-term safety and performance.
1.1.12	Accidents and unplanned events	Accidents and unplanned events refers to FEPs related to accidents and unplanned events during excavation, construction, waste emplacement and closure which might have an impact on long-term performance or safety.
1.1.13	Retrievability	Retrievability refers to FEPs related to any special design, emplacement, operational or administrative measures that might be applied or considered in order to enable or ease retrieval of wastes.
1.2	GEOLOGICAL PROCESSES AND EFFECTS	Geological processes and effects are processes arising from the wider geological setting and long-term processes. "Geological Processes and Effects" is a sub-category in the International FEP List and is divided into individual FEPs.
1.2.01	Tectonic movements and orogeny	Tectonic movements are movements of rock masses as a result of movements of the Earth's crustal plates; regionally the surface rocks respond to the underlying movements of plates. Orogeny is the process or period of mountain-building, often occurring over periods of hundreds of millions of years.
1.2.02	Deformation, elastic, plastic or brittle	Deformation, elastic, plastic or brittle refers to FEPs related to the physical deformation of geological structures in response to geological forces. This includes faulting, fracturing, extrusion and compression of rocks.
1.2.03	Seismicity	Seismicity refers to FEPs related to seismic events and also the potential for seismic events. A seismic event is caused by rapid relative movements within the Earth's crust usually along existing faults of geological interfaces. The accompanying release of energy may result in ground movement and/or rupture, e.g. earthquakes.
1.2.04	Volcanic and magmatic activity	Magma is molten, mobile rock material, generated below the Earth's crust, which gives rise to igneous rocks when solidified. Magmatic activity occurs when there is intrusion of magma into the crust; volcanic activity occurs when magma is extruded onto the Earth's surface.
1.2.05	Metamorphism	Metamorphism refers to the processes by which rocks are changed by the action of heat (T>200 C) and pressure at greater depths (usually several kilometres) beneath the Earth's surface or in the vicinity of magmatic activity.
1.2.06	Hydrothermal activity	Hydrothermal activity refers to FEPs associated with high temperature groundwaters, including processes such as density-driven groundwater flow and hydrothermal alteration of minerals in the rocks through which the high temperature groundwater flows.
1.2.07	Erosion and sedimentation	Erosion and sedimentation refers to FEPs related the large scale (geological) removal and accumulation of rocks and sediments, with associated changes in topography and geological/hydrogeological situation of the repository host rock. (c.f. FEP 2.3.12 which is concerned more local processes over shorter periods of time).
1.2.08	Diagenesis	Diagenesis refers to the processes by which deposited sediments at or near the Earth's surface are formed into rocks by compaction, cementation and crystallization, i.e. under conditions of temperature and pressure normal to the upper few kilometres of the earth's crust.
1.2.09	Salt diapirism and dissolution	Salt diapirism and dissolution refers to the large scale evolution of salt formations. Diapirism is the lateral or vertical intrusion of any symmetry, or upwelling of either buoyant or non-buoyant rock, into overlying strata (the overburden) from a source layer. Dissolution of the salt may occur where the evolving salt formation is in contact with groundwaters with salt content below saturation.
1.2.10	Hydrological/hydrogeological response to geological changes	Hydrological/hydrogeological response to geological changes refers to FEPs arising from large scale geological changes. These could include changes of hydrological boundary conditions due to effects of erosion on topography, and changes of hydraulic properties of geological units due to changes in rock stress or fault movements.
1.3	CLIMATIC PROCESSES AND EFFECTS	Climatic processes and effects are processes related to global climate change and consequent regional effects. "Climatic Processes and Effects" is a sub-category in the International FEP List and is divided into individual FEPs.
1.3.01	Climate change, global	Global climate change refers to FEPs related to the possible future, and evidence for past, long term change of global climate. This is distinct from resulting changes that may occur at specific locations according to their regional setting and also climate fluctuations, c.f. FEP 1.3.02.
1.3.02	Climate change, regional and local	Regional and local climate change refers to FEPs related to the possible future changes, and evidence for past changes, of climate at a repository site. This is likely to occur in response to global climate change, but the changes will be specific to situation, and may include shorter term fluctuations, c.f. FEP 1.3.01.
1.3.03	Sea level change	Sea level change refers to FEPs related to changes in sea level which may occur as a result of global (eustatic) change and regional geological change, e.g. isostatic movements.

FEP no	FEP name	FEP definition (NEA FEP Database Version 1.0)
1.3.04	Periglacial effects	Periglacial effects refers to FEPs related to the physical processes and associated landforms in cold but ice-sheet-free environments.
1.3.05	Glacial and ice sheet effects, local	Local glacial and ice sheet effects refers to FEPs related to the effects of glaciers and ice sheets within the region of a repository, e.g. changes in the geomorphology, erosion, meltwater and hydraulic effects. This is distinct from the effect of large ice masses on global and regional climate, c.f. FEPs 1.3.01, 1.3.02.
1.3.06	Warm climate effects (tropical and desert)	Warm climate effects refers to FEPs related to warm tropical and desert climates, including seasonal effects, meteorological and geomorphological effect special to these climates.
1.3.07	Hydrological/hydrogeological response to climate changes	Hydrological/hydrogeological response to climate changes refers to FEPs related to changes in hydrology and hydrogeology, e.g. recharge, sediment load and seasonality, in response to climate change in a region.
1.3.08	Ecological response to climate changes	Ecological response to climate changes refers to FEPs related to changes in ecology, e.g. vegetation, plant and animal populations, in response to climate change in a region.
1.3.09	Human response to climate changes	Human response to climate changes refers to FEPs related to changes in human behaviour, e.g. habits, diet, size of communities, in response to climate change in a region.
1.4	FUTURE HUMAN ACTIONS (ACTIVE)	Human actions (active) are human actions and regional practices, in the post-closure period, that can potentially affect the performance of the engineered and/or geological barriers, e.g. intrusive actions, but not the passive behaviour and habits of the local population, c.f. 2.4. "Human Actions (Active)" is a sub-category in the International FEP List and is divided into individual FEPs.
1.4.01	Human influences on climate	Human influences on climate refers to FEPs related to human activities that could affect the change of climate either globally or in a region.
1.4.02	Motivation and knowledge issues (inadvertent/deliberate human actions)	Motivation and knowledge issues refers to FEPs related to the degree of knowledge of the existence and nature of the repository and reasons for deliberate interference with, or intrusion into, a repository after closure with complete or incomplete knowledge.
1.4.03	Un-intrusive site investigation	Un-intrusive site investigation refers to FEPs related to airborne, geophysical or other surface-based investigation of a repository site after repository closure.
1.4.04	Drilling activities (human intrusion)	Drilling activities refers to FEPs related to any type of drilling activity in the repository environment. These may be taken with or without knowledge of the repository (see FEP 1.4.02).
1.4.05	Mining and other underground activities (human intrusion)	Mining and other underground activities refers to FEPs related to any type of mining or excavation activity carried out in the repository environment. These may be taken with or without knowledge of the repository (see FEP 1.4.02).
1.4.06	Surface environment, human activities	Human surface environment activities refers to FEPs related to any type of human activities that may be carried out by humans in the surface environment that can potentially affect the performance of the engineered and/or geological barriers, or the exposure pathways, excepting those FEPs related to water management which are at FEP 1.4.07.
1.4.07	Water management (wells, reservoirs, dams)	Water management refers to FEPs related to groundwater and surface water management including water extraction, reservoirs, dams, river management.
1.4.08	Social and institutional developments	Social and institutional developments refers to FEPs related to changes in social patterns and degree of local government, planning and regulation.
1.4.09	Technological developments	Technological developments refers to FEPs related to future developments in human technology and changes in the capacity and motivation to implement technologies. This may include retrograde developments, e.g. loss of capacity to implement a technology.
1.4.10	Remedial actions	Remedial actions refers to FEPs related to actions that might be taken following repository closure to remedy problems with a waste repository that, either, was not performing to the standards required, had been disrupted by some natural event or process, or had been inadvertantly or deliberately damaged by human actions.
1.4.11	Explosions and crashes	Explosions, crashes refers to FEPs related to deliberate or accidental explosions and crashes such as might have some impact on a closed repository, e.g. underground nuclear testing, aircraft crash on the site, acts of war.
1.5	OTHER	Other is a “catch-all” for any external factor not accommodated in 1.1 to 1.4, e.g. meteorite impact. “Other” is a sub-category in the International FEP List and is divided into individual FEPs.
1.5.01	Meteorite impact	Meteorite impact refers to the possibility of a large meteorite impact occurring at or close to the repository site and related consequences.
1.5.02	Species evolution	Species evolution refers to FEPs related to the biological evolution of humans, other animal or plant species, by both natural selection and selective breeding/culturing.
1.5.03	Miscellaneous and FEPs of uncertain relevance	Miscellaneous and of uncertain relevance/effect refers to any FEPs cannot be mapped anywhere else on the International FEP List and also FEPs which may have been thought of but no connection made to any possible effect on repository safety or performance.

FEP no	FEP name	FEP definition (NEA FEP Database Version 1.0)
2	DISPOSAL SYSTEM DOMAIN: ENVIRONMENTAL FACTORS	Disposal system domain environmental factors are features and processes occurring within that spatial and temporal (postclosure) domain whose principal effect is to determine the evolution of the physical, chemical, biological and human conditions of the domain that are relevant to estimating the release and migration of radionuclides and consequent exposure to man. "Disposal System Domain: Environmental Factors" is a category in the International FEP List and is divided into sub-categories.
2.1	WASTES AND ENGINEERED FEATURES	Wastes and engineered features are features and processes within these components of the disposal system. "Wastes and Engineered Features" is a sub-category in the International FEP List and is divided into individual FEPs.
2.1.01	Inventory, radionuclide and other material	Radionuclide and material inventory refers to FEPs related to the total content of the repository of a given type of material, substance, element, individual radionuclides, total radioactivity or inventory of toxic substances.
2.1.02	Waste form materials and characteristics	Waste form materials and characteristics refers to FEPs related to the physical, chemical, biological etc. characteristics of the waste form at the time of disposal and also as they may evolve in the repository, including FEPs which are relevant specifically as waste degradation processes.
2.1.03	Container materials and characteristics	Container materials and characteristics refers to FEPs related to the physical, chemical, biological etc. characteristics of the container at the time of disposal and also as they may evolve in the repository, including FEPs which are relevant specifically as container degradation/failure processes.
2.1.04	Buffer/backfill materials and characteristics	Buffer/backfill materials and characteristics refers to FEPs related to the physical, chemical, biological etc. characteristics of the buffer and/or backfill at the time of disposal and also as they may evolve in the repository, including FEPs which are relevant specifically as buffer/backfill degradation processes.
2.1.05	Seals, cavern/tunnel/shaft	Cavern/tunnel/shaft seals refers to FEPs related to the design, physical, chemical, hydraulic etc. characteristics of the cavern/tunnel/shaft seals at the time of sealing and also as they may evolve in the repository, including FEPs which are relevant specifically as cavern/tunnel/shaft seal degradation processes.
2.1.06	Other engineered features materials and characteristics	Other engineered features materials and characteristics refers to FEPs related to the physical, chemical, biological etc. characteristics of the engineered features (other than containers, buffer/backfill, and seals) at the time of disposal and also as they may evolve in the repository, including FEPs which are relevant specifically as degradation processes acting on the engineered features.
2.1.07	Mechanical processes and conditions (in wastes and EBS)	Mechanical processes and evolution of conditions refers to FEPs related to the mechanical processes that affect the wastes, containers, seals and other engineered features, and the overall mechanical evolution of near field with time. This includes the effects of hydraulic and mechanical loads imposed on wastes, containers and repository components by the surrounding geology.
2.1.08	Hydraulic/hydrogeological processes and conditions (in wastes and EBS)	Hydraulic/hydrogeological processes and evolution of conditions refers to FEPs related to the hydraulic/hydrogeological processes that affect the wastes, containers, seals and other engineered features, and the overall hydraulic/hydrogeological evolution of near field with time. This includes the effects of hydraulic/hydrogeological influences on wastes, containers and repository components by the surrounding geology.
2.1.09	Chemical/geochemical processes and conditions (in wastes and EBS)	Chemical/geochemical processes and evolution of conditions refers to FEPs related to the chemical/geochemical processes that affect the wastes, containers, seals and other engineered features, and the overall chemical/geochemical evolution of near field with time. This includes the effects of chemical/geochemical influences on wastes, containers and repository components by the surrounding geology.
2.1.10	Biological/biochemical processes and conditions (in wastes and EBS)	Biological/biochemical processes and evolution of conditions refers to FEPs related to the biological/biochemical processes that affect the wastes, containers, seals and other engineered features, and the overall biological/biochemical evolution of near field with time. This includes the effects of biological/biochemical influences on wastes, containers and repository components by the surrounding geology.
2.1.11	Thermal processes and conditions (in wastes and EBS)	Thermal processes and evolution of conditions refers to FEPs related to the thermal processes that affect the wastes, containers, seals and other engineered features, and the overall thermal evolution of near field with time. This includes the effects of thermal influences on wastes, containers and repository components from the surrounding geology.
2.1.12	Gas sources and effects (in wastes and EBS)	Gas production and effects refers to FEPs within and around the wastes, containers and engineered features resulting in the generation of gases and their subsequent effects on the repository system.
2.1.13	Radiation effects (in wastes and EBS)	Radiation effects refers to FEPs related to the effects that result from the radiation emitted from the wastes that affect the wastes, containers, seals and other engineered features, and the overall radiogenic evolution of near field with time.
2.1.14	Nuclear criticality	Nuclear criticality refers to FEPs related to the possibility and effects of spontaneous nuclear fission chain reactions within the repository.

FEP no	FEP name	FEP definition (NEA FEP Database Version 1.0)
2.2	GEOLOGICAL ENVIRONMENT	Geological environment is the features and processes within this environment including, for example, the hydrogeological, geomechanical and geochemical features and processes, both in pre-emplacement state and as modified by the presence of the repository and other long-term changes. "Geological Environment" is a sub-category in the International FEP List and is divided into individual FEPs.
2.2.01	Excavation disturbed zone, host rock	The host rock excavation damaged zone refers to FEPs related to the zone of rock around caverns, tunnels, shafts or other underground openings that may be mechanically disturbed during excavation, and the properties and characteristics as they may evolve both before and after repository closure.
2.2.02	Host rock	The host rock refers to FEPs related to the properties and characteristics of the rock in which the repository is sited (excluding that which may be mechanically disturbed by the excavation) as they may evolve both before and after repository closure.
2.2.03	Geological units, other	Other geological units refers to FEPs related to the properties and characteristics of rocks other than the host rock as they may evolve both before and after repository closure.
2.2.04	Discontinuities, large scale (in geosphere)	Large scale discontinuities refers to FEPs related to the properties and characteristics of discontinuities in and between the host rock and geological units, including faults, shear zones, intrusive dykes and interfaces between different rock types.
2.2.05	Contaminant transport path characteristics (in geosphere)	Contaminant transport path characteristics refers to FEPs related to the properties and characteristics of smaller discontinuities and features within the host rock and other geological units that are expected to be the main paths for contaminant transport through the geosphere, as they may evolve both before and after repository closure.
2.2.06	Mechanical processes and conditions (in geosphere)	Mechanical processes and evolution of conditions refers to FEPs related to the mechanical processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. rock stress, due to the excavation, construction and long-term presence of the repository.
2.2.07	Hydraulic/hydrogeological processes and conditions (in geosphere)	Hydraulic/hydrogeological processes and evolution of conditions refers to FEPs related to the hydraulic and hydrogeological processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. hydraulic head, due to the excavation, construction and long-term presence of the repository.
2.2.08	Chemical/geochemical processes and conditions (in geosphere)	Chemical/geochemical processes and evolution of conditions refers to FEPs related to the chemical and geochemical processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. Eh, pH, due to the excavation, construction and long-term presence of the repository.
2.2.09	Biological/biochemical processes and conditions (in geosphere)	Biological/biochemical processes and evolution of conditions refers to FEPs related to the biological and biochemical processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. microbe populations, due to the excavation, construction and long-term presence of the repository.
2.2.10	Thermal processes and conditions (in geosphere)	Thermal processes and evolution of conditions refers to FEPs related to the thermal processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. temperature, due to the excavation, construction and long-term presence of the repository.
2.2.11	Gas sources and effects (in geosphere)	Gas sources and effects refers to FEPs related to natural gas sources and production of gas within the geosphere and also the effect of natural and repository produced gas on the geosphere, including the transport of bulk gases and the overall evolution of conditions with time.
2.2.12	Undetected features (in geosphere)	Undetected features refers to FEPs related to natural or man-made features within the geology that may not be detected during the site investigation.
2.2.13	Geological resources	Geological resources refers to FEPs related to natural resources within the geosphere, particularly those that might encourage investigation or excavation at or near the repository site.
2.3	SURFACE ENVIRONMENT	Surface environment covers the features and processes within this environment, including near-surface aquifers and unconsolidated sediments but excluding human activities and behaviour, see 1.4 and 2.4. "Surface Environment" is a sub-category in the International FEP List and is divided into individual FEPs.
2.3.01	Topography and morphology	Topography and morphology refers to FEPs related to the relief and shape of the surface environment and its evolution.
2.3.02	Soil and sediment	Soil and sediment characteristics refers to FEPs related to the characteristics of the soils and sediments and their evolution.
2.3.03	Aquifers and water-bearing features, near surface	Near surface aquifers and water-bearing features refers to FEPs related to the characteristics of aquifers and water-bearing features within a few metres of the land surface and their evolution.
2.3.04	Lakes, rivers, streams and springs	Lakes, rivers, streams and springs refers to FEPs related to the characteristics of surface water bodies, excluding seas and oceans, and their evolution.
2.3.05	Coastal features	Coastal features refers to FEPs related to the characteristics of coasts and the near shore, and their evolution.

FEP no	FEP name	FEP definition (NEA FEP Database Version 1.0)
2.3.06	Marine features	Marine features refers to FEPs related to the characteristics of seas and oceans, including the sea bed, and their evolution.
2.3.07	Atmosphere	Atmosphere refers to FEPs related to the characteristics of the atmosphere, including capacity for transport, and their evolution.
2.3.08	Vegetation	Vegetation refers to FEPs related to the characteristics of the terrestrial and aquatic vegetation both as individual plants and in mass, and their evolution.
2.3.09	Animal populations	Animal populations refers to FEPs related to the characteristics of the terrestrial and aquatic animals both as individual animals and as populations, and their evolution.
2.3.10	Meteorology	Meteorology refers to FEPs related to the characteristics of weather and climate, and their evolution.
2.3.11	Hydrological regime and water balance (near-surface)	Hydrological regime and water balance refers to FEPs related to near surface hydrology at a catchment scale and also soil water balance, and their evolution.
2.3.12	Erosion and deposition	Erosion and deposition refers to FEPs related to all the erosional and depositional processes that operate in the surface environment, and their evolution.
2.3.13	Ecological/biological/microbial systems	Ecological/biological/microbial systems refers to FEPs related to living organisms and relations between populations of animals, plants etc. , and their evolution.
2.4	HUMAN BEHAVIOUR	Human behaviour (passive) covers the habits and characteristics of the individuals or populations, e.g. critical groups, to whom exposures are calculated, not including intrusive or other activities which will have an impact on the performance of the engineered or geological barriers, see 1.4. "Human Behaviour (passive)" is a sub-category in the International FEP List and is divided into individual FEPs.
2.4.01	Human characteristics (physiology, metabolism)	Human characteristics refers to FEPs related to characteristics, e.g. physiology, metabolism, of individual humans.
2.4.02	Adults, children, infants and other variations	Adults, children, infants and other variations refers to FEPs related to considerations of variability in individual humans of physiology, metabolism and habits.
2.4.03	Diet and fluid intake	Diet refers to FEPs related to intake of food and water by individual humans and the compositions and origin of intake.
2.4.04	Habits (non-diet-related behaviour)	Habits refers to FEPs related to non-diet related behaviour of individual humans, including time spent in various environments, pursuit of activities and uses of materials.
2.4.05	Community characteristics	Community characteristics refers to FEPs related to characteristics, behaviour and lifestyle of groups of humans that might be considered as target groups in an assessment.
2.4.06	Food and water processing and preparation	Food and water processing and preparation refers to FEPs related to treatment of food stuffs and water between raw origin and consumption.
2.4.07	Dwellings	Dwellings refers to FEPs related to houses or other structures or shelter in which humans spend time.
2.4.08	Wild and natural land and water use	Wild and natural land and water use refers to FEPs related to use of natural or semi-natural tracts of land and water such as forest, bush, lakes etc.
2.4.09	Rural and agricultural land and water use (incl. fisheries)	Rural and agricultural land and water use refers to FEPs related to use of permanently or sporadically agriculturally managed land and managed fisheries.
2.4.10	Urban and industrial land and water use	Urban and industrial land and water use refers to FEPs related to urban and industrial developments, including transport, and the effects on hydrology and potential contaminant pathways.
2.4.11	Leisure and other uses of environment	Leisure and other uses of environment refers to FEPs related to leisure activities, the effects on the surface environment and implications for contaminant exposure pathways.
3	RADIONUCLIDE/CONTAMINANT FACTORS	Radionuclide/contaminant factors are features, events and processes that take place in the disposal system domain that directly affect the release and migration of radionuclides and other contaminants, or directly affect the dose to members of a critical group from given concentrations of radiotoxic and chemotoxic species in environmental media. "Disposal System Domain: Radionuclide Factors" is a category in the International FEP List and is divided into sub-categories.
3.1	CONTAMINANT CHARACTERISTICS	Contaminant characteristics are the characteristics of the radiotoxic and chemotoxic species that might be considered in a postclosure safety assessment. "Contaminant Characteristics" is a sub-category in the International FEP List and is divided into individual FEPs.“
3.1.01	Radioactive decay and in-growth	Radioactivity is the spontaneous disintegration of an unstable atomic nucleus resulting in the emission of sub-atomic particles. Radioactive isotopes are known as radionuclides. Where a parent radionuclide decays to a daughter nuclide so that the population of the daughter nuclide increases this is known as in-growth.
3.1.02	Chemical/organic toxin stability	Chemical/organic toxin stability refers to FEPs related to chemical stability of chemotoxic species that may be considered.
3.1.03	Inorganic solids/solutes	Inorganic solids/solutes refers to FEPs related to the characteristics of inorganic solids/solutes that may be considered.

FEP no	FEP name	FEP definition (NEA FEP Database Version 1.0)
3.1.04	Volatiles and potential for volatility	Volatiles and potential for volatility refers to FEPs related to the characteristics of radiotoxic and chemotoxic species that are volatile or have the potential for volatility in repository or environmental conditions.
3.1.05	Organics and potential for organic forms	Organics and potential for organic forms refers to FEPs related to the characteristics of radiotoxic and chemotoxic species that are organic or have the potential to form organics in repository or environmental conditions.
3.1.06	Noble gases	Noble gases refers to FEPs related to the characteristics of radiotoxic noble gases.
3.2	CONTAMINANT RELEASE/MIGRATION FACTORS	Release/migration factors are the processes that directly affect the release and/or migration of radionuclides in the disposal system domain. "Release/Migration Factors" is a sub-category in the International FEP List and is divided into individual FEPs.
3.2.01	Dissolution, precipitation and crystallisation, contaminant	Contaminant dissolution, precipitation and crystallisation refers to FEPs related to the dissolution, precipitation and crystallisation of radiotoxic and chemotoxic species in repository or environmental conditions.
3.2.02	Speciation and solubility, contaminant	Contaminant speciation and solubility refers to FEPs related to the chemical speciation and solubility of radiotoxic and chemotoxic species in repository or environmental conditions.
3.2.03	Sorption/desorption processes, contaminant	Contaminant sorption/desorption processes refers to FEPs related to sorption/desorption of radiotoxic and chemotoxic species in repository or environmental conditions.
3.2.04	Colloids, contaminant interactions and transport with	Contaminant interactions and transport with colloids refers to FEPs related to the transport and interaction of radiotoxic and chemotoxic species with colloids in repository or environmental conditions.
3.2.05	Chemical/complexing agents, effects on contaminant speciation/transport	Effects on contaminant speciation/transport of chemical/complexing agents refers to FEPs related to the modification of speciation or transport of radiotoxic and chemotoxic species in repository or environmental conditions due to association with chemical and complexing agents.
3.2.06	Microbial/biological/plant-mediated processes, contaminant	Microbial/biological/plant mediated processes refers to FEPs related to the modification of speciation or phase change due to microbial/biological/plant activity.
3.2.07	Water-mediated transport of contaminants	Water-mediated transport of contaminants refers to FEPs related to transport of radiotoxic and chemotoxic species in groundwater and surface water in aqueous phase and as sediments in surface water bodies.
3.2.08	Solid-mediated transport of contaminants	Solid-mediated transport of contaminants refers to FEPs related to transport of radiotoxic and chemotoxic species in solid phase, for example large-scale movements of sediments, landslide, solifluction and volcanic activity.
3.2.09	Gas-mediated transport of contaminants	Gas-mediated transport of contaminants refers to FEPs related to transport of radiotoxic and chemotoxic species in gas or vapour phase or as fine particulate or aerosol in gas or vapour.
3.2.10	Atmospheric transport of contaminants	Atmospheric transport of contaminants refers to FEPs related to transport of radiotoxic and chemotoxic species in the air as gas, vapour, fine particulate or aerosol.
3.2.11	Animal, plant and microbe mediated transport of contaminants	Animal, plant and microbe mediated transport of contaminants refers to FEPs related to transport of radiotoxic and chemotoxic species as a result of animal, plant and microbial activity.
3.2.12	Human-action-mediated transport of contaminants	Human-action-mediated transport of contaminants refers to FEPs related to transport of radiotoxic and chemotoxic species as a direct result of human actions.
3.2.13	Foodchains, uptake of contaminants in	Uptake of contaminants in foodchains refers to FEPs related to incorporation of radiotoxic and chemotoxic species into plant or animal species that are part of the possible eventual food chain to humans.
3.3	EXPOSURE FACTORS	Exposure factors are processes and conditions that directly affect the dose to members of the critical group, from given concentrations of radionuclides in environmental media. "Exposure Factors" is a sub-category in the International FEP List and is divided into individual FEPs.
3.3.01	Drinking water, foodstuffs and drugs, contaminant concentrations in	Contaminant concentrations in drinking water, foodstuffs and drugs refers to FEPs related to the presence of radiotoxic and chemotoxic species in drinking water, foodstuffs or drugs that may be consumed by human.
3.3.02	Environmental media, contaminant concentrations in	Contaminant concentrations in environmental media refers to FEPs related to the presence of radiotoxic and chemotoxic species in environmental media other than drinking water, foodstuffs or drugs.
3.3.03	Non-food products, contaminant concentrations in	Contaminant concentrations in non-food products refers to FEPs related to the presence of radiotoxic and chemotoxic species in human manufactured materials or environmental materials that have special uses, e.g. clothing, building materials, peat.
3.3.04	Exposure modes	Exposure modes refers to FEPs related to the exposure of man (or other organisms) to radiotoxic and chemotoxic species.
3.3.05	Dosimetry	Dosimetry refers to FEPs related to the dependence between radiation or chemotoxic effect and amount and distribution of radiation or chemical agent in organs of the body.
3.3.06	Radiological toxicity/effects	Radiological toxicity/effects refers to FEPs related to effect of radiation on man or other organisms.

FEP no	FEP name	FEP definition (NEA FEP Database Version 1.0)
3.3.07	Non-radiological toxicity/effects	Non-radiological toxicity/effects refers to FEPs related to effect of chemotoxic species on man or other organisms.
3.3.08	Radon and radon daughter exposure	Radon and radon daughter exposure refers to FEPs related to exposure to radon and radon daughters.

Appendix C: Outcome of the FEPs audit

The outcome of the audit of the content in the Repository-, Geosphere- and Biosphere-matrix against the 1261 projects FEPs compiled in the NEA FEP Database version 1.0 (NEA, 1997) is given below.

The 978 NEA project FEPs that are identified to be relevant for SFR are given in alphabetical order on page C-1 to C-22. Of these, 731 project FEPs are mapped to diagonal elements and/or interactions in the SFR matrices, 235 project FEPs are treated as EFEPs and 12 project FEPs are considered to be of negligible importance. NEA project FEPs added to the matrices during the audit are marked (#).

NEA project FEPs with unclear definitions (181 FEPs) and FEPs that are not applicable for SFR design and/or conditions (102 FEPs) are not considered. The audit is documented in a separate database linked to the SFR matrices.

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Abandonment of unsealed repository	N 2.2.9				EFEP
Access tunnels and shafts	K 4.16		Geosphere		
Accidental intrusion	H 5.2.4				EFEP
Accumulation in peat	J 7.02			Biosphere	
Accumulation in sediments	J 7.01			Biosphere	
Accumulation in soil	W 2.103			Biosphere	
Accumulation in soils and organic debris	N 1.6.12			Biosphere	
Accumulation of gases under permafrost	J 5.22				EFEP
Acid rain	A 3.001				EFEP
Acid rain	W 3.048				EFEP
Actinide sorption	W 2.061	Repository	Geosphere		
Advection	W 2.090	Repository	Geosphere		
Advection and dispersion	N 1.6.1	Repository	Geosphere		
Aeolian deposition	W 1.046			Biosphere	
Aeolian erosion	W 1.043			Biosphere	
Agricultural and fisheries practice changes	N 2.4.7				EFEP
Agricultural practices	K 8.39			Biosphere	
Alkali flats	A 3.002				EFEP
Alteration/weathering of flow paths	S 001		Geosphere		
Altered soil or water surface chemistry by human activities	W 3.046			Biosphere	
Altered surface water chemistry by humans	J 7.08			Biosphere	
Animal diets	A 3.003			Biosphere	
Animal grooming and fighting	A 3.004			Biosphere	
Animal soil ingestion	A 3.005			Biosphere	
Animal uptake	W 2.102			Biosphere	
Animals	W 1.070			Biosphere	
Anion-exclusion	S 002	Repository			
Anoxic corrosion	K 2.06	Repository	Geosphere		
Anthropogenic climate change	N 2.4.9				EFEP

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Arable farming	W 3.053			Biosphere	
Archaeological investigation	N 2.3.9				EFEP
Archeological excavations	W 3.017				EFEP
Archeological intrusion	J 5.37				EFEP
Archeological investigations	W 3.006				EFEP
Ashes and sewage sludge fertilizers	A 3.006			Biosphere	
Atmosphere	K 8.27			Biosphere	
Backfill characteristics	A 1.01	Repository	Geosphere		
Backfill chemical composition	W 2.010	Repository	Geosphere		
Backfill material deficiencies	J 3.2.11				EFEP
Backfill physical composition	W 2.009	Repository	Geosphere		
Bacteria and microbes in soil	A 3.007			Biosphere	
Basement alteration	K 9.08		Geosphere	Biosphere	
Bentonite emplacement and composition	K 3.01	Repository	Geosphere		
Bentonite erosion	K 3.06	Repository	Geosphere		
Bentonite plasticity	K 3.05	Repository	Geosphere		
Bentonite porewater chemistry	K 3.09	Repository	Geosphere		
Bentonite saturation	K 3.03	Repository	Geosphere		
Bentonite swelling pressure	K.3.04	Repository	Geosphere		
Bentonite swelling, buffer	S 003	Repository	Geosphere		
Bioaccumulation	A 3.008			Biosphere	
Bioaccumulation and translocation	H 4.2.5			Biosphere	
Bioconcentration	A 3.009			Biosphere	
Biofilms	W 2.088	Repository	Geosphere		
Biogas production	A 3.010			Biosphere	
Biogeochemical processes	H 4.2.6			Biosphere	
Biological activity	A 1.03	Repository	Geosphere		
Biological evolution	A 3.011			Biosphere	
Biomagnification	A 3.012			Biosphere	
Biotoxicity	A 3.013			Biosphere	
Bioturbation	K 8.35			Biosphere	
Bioturbation of soil and sediment	A 3.014			Biosphere	
Blasting and vibration	A 2.01		Geosphere		
Blowouts	W 3.023				EFEP
Bomb blast	A 2.02				EFEP
Borehole - well	A 2.03				EFEP
Borehole seal failure #	A 2.04		Geosphere		
Borehole-induced geochemical changes	W 3.036		Geosphere		
Borehole-induced mineralization	W 3.035		Geosphere		
Borehole-induced solution and subsidence	W 3.034		Geosphere		
Boreholes - exploration	A 2.05				EFEP
Boundary conditions	A 1.04		Geosphere	Biosphere	
Boundary conditions for flow	K 7.05		Geosphere		
Buffer additives	A 1.05				EFEP
Buffer characteristics	A 1.06	Repository	Geosphere		
Buffer impermeability	K 3.08	Repository	Geosphere		
Building materials	A 3.015			Biosphere	
Burrowing animals	A 3.016			Biosphere	
Capillary rise	K 8.31			Biosphere	
Capillary rise in soil	A 3.017			Biosphere	

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Carcasses	A 3.018			Biosphere	
Carcinogenic contaminants	A 3.019	Repository	Geosphere	Biosphere	
Cave in	S 004	Repository	Geosphere		
Cave ins	A 1.08	Repository	Geosphere		
Cavings	W 2.085				EFEP
Cellulosic degradation	N 3.2.5	Repository	Geosphere		
Change in sealevel	J 5.31			Biosphere	
Change of groundwater chemistry in nearby rock	J 4.1.08	Repository	Geosphere		
Changes in fracture properties	W 1.009		Geosphere		
Changes in geochemistry due to mining	W 3.038				EFEP
Changes in geometry and driving forces of the flow system	H 2.2.1			Biosphere	
Changes in groundwater Eh	W 1.036	Repository	Geosphere	Biosphere	
Changes in Groundwater Flow	J 4.2.05		Geosphere		
Changes in groundwater flow due to explosions	W 3.039				EFEP
Changes in groundwater flow due to mining	W 3.037				EFEP
Changes in groundwater pH	W 1.037	Repository	Geosphere	Biosphere	
Changes in groundwater recharge and discharge	W 1.056		Geosphere	Biosphere	
Changes in in-situ stress field	N 3.3.2	Repository	Geosphere		
Changes in radionuclide inventory	S 005	Repository	Geosphere		
Changes in regional stress	W 1.003				EFEP
Changes in sorptive surfaces	W 2.063		Geosphere		
Changes in the Earth's magnetic field	N 1.2.2				EFEP
Changes of the magnetic field	J 5.20				EFEP
Charcoal production	A 3.020			Biosphere	
Chemical alteration of buffer/backfill	S 006	Repository	Geosphere		
Chemical buffering (canister corrosion products)	K 2.14	Repository	Geosphere		
Chemical degradation of backfill	W 2.075	Repository	Geosphere		
Chemical degradation of seals	W 2.074	Repository			
Chemical effects of corrosion	W 2.051	Repository	Geosphere		
Chemical effects of rock reinforcement	J 4.2.10	Repository	Geosphere		
Chemical gradients	A 1.09	Repository	Geosphere		
Chemical gradients	W 2.097	Repository	Geosphere		
Chemical kinetics	A 1.11		Geosphere	Biosphere	
Chemical precipitation	A 3.021			Biosphere	
Chemical sabotage	J 5.05				EFEP
Chemical toxicity	A 3.022	Repository	Geosphere	Biosphere	
Chemical toxicity of wastes	J 7.04	Repository			
Chemical weathering	W 1.042			Biosphere	
Chemotoxic gases	H 1.2.5	Repository	Geosphere	Biosphere	
City on the site	J 7.11				EFEP
Climate	A 3.023			Biosphere	
Climate change	A 1.12				EFEP
Climate change	W 1.061				EFEP
Climate change	A 2.07				EFEP
Climate change	A 3.024				EFEP

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Climate change: Human induced	H 3.1.1				EFEP
Climate change: Natural	H 3.1.2				EFEP
Coagulation of bentonite #	J 3.1.05	Repository	Geosphere		
Coagulation of bentonite #	S 007	Repository	Geosphere		
Coastal erosion	W 1.066			Biosphere	
Coastal water use	W 3.050			Biosphere	
Collisions, explosions and impacts	A 3.025				EFEP
Colloid filtration	W 2.080	Repository	Geosphere		
Colloid formation	A 2.08	Repository	Geosphere		
Colloid formation and stability	W 2.079	Repository	Geosphere		
Colloid generation - source	J 3.1.04	Repository	Geosphere		
Colloid generation and transport	J 5.45	Repository	Geosphere		
Colloid generation and transport	S 008	Repository	Geosphere		
Colloid generation-source	S 009	Repository	Geosphere		
Colloid sorption	W 2.081	Repository	Geosphere		
Colloid transport	W 2.078	Repository	Geosphere		
Colloids	A 1.13	Repository	Geosphere		
Colloids	A 3.026	Repository	Geosphere		
Colloids	K 4.12	Repository	Geosphere		
Complexation by organics	A 1.14	Repository	Geosphere		
Complexation by organics	A 2.09	Repository	Geosphere		
Complexing agents	N 1.6.10	Repository	Geosphere		
Complexing agents	J 4.1.09	Repository	Geosphere		
Concrete	A 1.15	Repository	Geosphere		
Concrete hydration	W 2.073	Repository			
Construction of underground facilities (for example storage, disposal, accomodation)	W 3.016				EFEP
Consumption of uncontaminated products	K 8.44			Biosphere	
Container corrosion products	A 1.16	Repository			
Container failure (early)	A 1.17	Repository			
Container failure (mechanical processes)	A 1.19	Repository			
Container form	W 2.004	Repository			
Container healing	A 1.20	Repository			
Container integrity	W 2.034	Repository			
Container material inventory	W 2.005	Repository			
Container metal corrosion	H 1.1.1	Repository			
Containers - partial corrosion	A 1.21	Repository			
Contaminated products (non-food)	K 8.42			Biosphere	
Convection	A 1.22	Repository	Geosphere		
Convection	W 2.043	Repository	Geosphere		
Convection	A 2.11	Repository	Geosphere		
Convection, turbulence and diffusion (atmospheric)	A 3.027			Biosphere	
Corrosion	A 1.24	Repository			
Corrosion of metal parts	S 012	Repository			
Corrosion on wetting	K 2.03	Repository			
Corrosion products (physical effects)	K 2.18	Repository			
Co-storage of other waste	J 5.06				EFEP
Coupled processes	A 1.25	Repository	Geosphere		

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Creeping of rock mass	J 4.2.09		Geosphere		
Creeping of rock mass, near-field	S 015		Geosphere		
Critical group - agricultural labour	A 3.029			Biosphere	
Critical group - clothing and home furnishings	A 3.030			Biosphere	
Critical group - evolution	A 3.031				EFEP
Critical group - house location	A 3.032			Biosphere	
Critical group - individuality	A 3.033			Biosphere	
Critical group - leisure pursuits	A 3.034			Biosphere	
Critical group - pets	A 3.035			Biosphere	
Dermal sorption	W 2.107			Biosphere	
Dermal sorption (except tritium)	A 3.040			Biosphere	
Dermal sorption (tritium)	A 3.041			Biosphere	
Crop fertilizers and soil conditioners	A 3.036			Biosphere	
Crop storage	A 3.037			Biosphere	
Cure for cancer	A 3.038				EFEP
Cuttings	W 2.084				EFEP
Damage to the ozone layer	W 3.049				EFEP
Damaged zone	A 2.13		Geosphere		
Damming of streams or rivers	W 3.042				EFEP
Dams	A 2.14				EFEP
Dams and reservoirs, built/drained	N 2.4.2				EFEP
Decontamination materials left	J 5.04				EFEP
Deep groundwater abstraction	K 11.05		Geosphere		
Deep saline water intrusion	S 018		Geosphere		
Degradation of hole and shaft seals	S 020		Geosphere		
Degradation of hole- and shaft seals	J 5.11		Geosphere		
Degradation of organic material	W 2.044	Repository	Geosphere		
Degradation of rock reinforcement and grout	S 021	Repository	Geosphere		
Degradation of the bentonite by chemical reactions	J 3.1.01	Repository	Geosphere		
Deliberate drilling intrusion	W 3.012				EFEP
Deliberate intrusion	H 5.2.2				EFEP
Deliberate mining intrusion	W 3.018				EFEP
Demographic change and urban development	W 3.056				EFEP
Demographic change, urban development	N 2.4.8				EFEP
Density effects on groundwater flow	W 1.026	Repository	Geosphere		
Density-driven groundwater flow (thermal)	K 5.12	Repository	Geosphere		
Density-driven groundwater flows (temperature/salinity differences)	K 7.13	Repository	Geosphere		
Density-driven groundwater flows (thermal)	K 6.12	Repository	Geosphere		
Deposition (wet and dry)	A 3.039			Biosphere	
Desaturation (pumping) effects	H 1.5.1		Geosphere		
Desaturation/resaturation of EDZ	K 4.03		Geosphere		
Desert and unsaturation	J 5.32				EFEP
Dewatering	A 2.15		Geosphere		

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Deviant inventory flask	K 1.27				EFEP
Diagenesis	N 1.2.5			Biosphere	
Diagenesis	H 2.1.4			Biosphere	
Diagenesis	J 7.10			Biosphere	
Differential thermal expansion of near-field barriers	S 022	Repository	Geosphere		
Differing thermal expansion of repository components	W 2.031	Repository	Geosphere		
Diffusion	A 1.27	Repository	Geosphere		
Diffusion	N 1.6.2	Repository	Geosphere		
Diffusion	W 2.091	Repository	Geosphere		
Diffusion	A 2.16	Repository	Geosphere		
Diffusion	S 023	Repository	Geosphere		
Diffusion - surface diffusion	J 3.2.06	Repository	Geosphere		
Dilution	J 6.05	Repository	Geosphere		
Dilution of buffer/backfill	S 025	Repository	Geosphere		
Dilution of radionuclides in groundwater (LPD to HPD or MWCF)	K 5.23	Repository	Geosphere		
Dilution of radionuclides in groundwater (MWCF to HPD & Biosph.)	K 6.23	Repository	Geosphere		
Dilution of radionuclides in HPD #	K 7.07	Repository	Geosphere		
Dilution of radionuclides in surface water (aquifer, river, lake etc.)	K 8.21			Biosphere	
Discharge zones	A 2.17	Repository	Geosphere		
Dispersion	A 3.042			Biosphere	
Dispersion	A 1.28	Repository	Geosphere		
Dispersion	A 2.18	Repository	Geosphere		
Dispersion	S 026	Repository	Geosphere		
Dispersion	J 6.04	Repository	Geosphere		
Disruption due to gas effects	W 2.025	Repository	Geosphere		
Dissolution of fracture fillings/precipitations	J 5.25		Geosphere		
Dissolution of waste	W 2.058	Repository			
Distribution and release of nuclides from the geosphere	S 027		Geosphere		
Disturbed rock zone	W 2.018		Geosphere		
Disturbed zone (hydromechanical) effects	H 1.5.2		Geosphere		
Drilling fluid flow	W 3.021				EFEP
Drilling fluid loss	W 3.022				EFEP
Drilling-induced geochemical changes	W 3.024				EFEP
Drought	A 2.19				EFEP
Dust storms and desertification	A 3.043				EFEP
Earthmoving	A 2.20				EFEP
Earthmoving projects	A 3.044				EFEP
Earthquakes	A 1.29				EFEP
Earthquakes	A 2.21				EFEP
Earthquakes	A 3.045				EFEP
Earthquakes	J 5.15				EFEP
Earthworks (human actions, dredging, etc.)	K 8.37				EFEP

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Ecological response to climate (e.g. desert formation)	N 1.7.9				EFEP
Effect of bentonite swelling on EDZ	K 4.04		Geosphere		
Effect of biofilms on microbial gas generation	W 2.048	Repository	Geosphere		
Effect of hydrogen on corrosion	K 2.17	Repository	Geosphere		
Effect of metal corrosion	W 2.064	Repository	Geosphere		
Effect of pressure on microbial gas generation	W 2.046	Repository	Geosphere		
Effect of radiation on microbial gas generation	W 2.047	Repository	Geosphere		
Effect of temperature on microbial gas generation	W 2.045	Repository	Geosphere		
Effective moisture (recharge)	K 10.02		Geosphere		
Effects of bentonite on groundwater chemistry	J 3.1.03	Repository	Geosphere		
Effects of dissolution	W 1.038		Geosphere		
Effects of natural gases.	H 2.1.9		Geosphere		
Effects of preferential pathways	W 1.027	Repository	Geosphere		
Electro-chemical cracking	J 2.3.02	Repository			
Elemental solubility	K 4.10		Geosphere		
Elemental solubility/precipitation	K 3.18	Repository	Geosphere		
Enhanced diffusion	W 2.100	Repository	Geosphere		
Enhanced rock fracturing	S 030		Geosphere		
Enhanced rock fracturing	J 4.2.08		Geosphere		
Erosion	A 2.22		Geosphere		
Erosion	K 7.11		Geosphere		
Erosion - lateral transport	A 3.046			Biosphere	
Erosion (wind)	A 3.047			Biosphere	
Erosion of buffer/backfill	J 3.2.04	Repository	Geosphere		
Erosion of buffer/backfill	S 031	Repository	Geosphere		
Erosion on surface/sediments	J 5.26			Biosphere	
Erosion/denudation	K 9.07			Biosphere	
Erosion/deposition	K 8.22			Biosphere	
Evapotranspiration	K 8.30			Biosphere	
Excavation effects on nearby rock	S 032		Geosphere		
Excavation/backfilling effects on nearby rock	J 4.2.02.1		Geosphere		
Excavation-disturbed zone (EDZ)	K 4.01		Geosphere		
Excavation-induced changes in stress	W 2.019		Geosphere		
Exfiltration to a local aquifer	K 8.03			Biosphere	
Exfiltration to surface waters	K 8.04			Biosphere	
Exit from glacial/interglacial cycling	H 3.1.3				EFEP
Exothermic reactions	W 2.072	Repository			
Exploratory boreholes (sealing)	K 5.25		Geosphere		
Exploratory drilling	K 11.01				EFEP
Explosion	A 2.23				EFEP
Explosions	A 1.32				EFEP
Explosions	J 5.38				EFEP
Explosions for resource recovery	W 3.019				EFEP
Exposure pathways	K 8.13			Biosphere	

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
External flow boundary conditions	S 033		Geosphere		
External stress	J 2.3.07.1	Repository	Geosphere		
Extraterrestrial events	K 9.11				EFEP
Extreme channel flow of oxidants and nuclides	J 4.2.03		Geosphere		
Far field hydrochemistry - acids, oxidants, nitrate	J 6.03		Geosphere		
Far-field transport: Advection	H 2.3.1		Geosphere		
Far-field transport: Biogeochemical changes	H 2.3.13		Geosphere		
Far-field transport: Changes in groundwater chemistry and flow direction	H 2.3.7		Geosphere		
Far-field transport: Changes in sorptive surfaces	H 2.3.6		Geosphere		
Far-field transport: Colloid transport	H 2.3.8		Geosphere		
Far-field transport: Diffusion	H 2.3.2		Geosphere		
Far-field transport: Gas induced groundwater transport	H 2.3.11		Geosphere		
Far-field transport: Hydrodynamic dispersion	H 2.3.3		Geosphere		
Far-field transport: Solubility constraints	H 2.3.4		Geosphere		
Far-field transport: Sorption including ion-exchange	H 2.3.5		Geosphere		
Far-field transport: Thermal effects on hydrochemistry	H 2.3.12		Geosphere		
Far-field transport: Transport of radioactive gases	H 2.3.10		Geosphere		
Far-field transport: Transport of radionuclides bound to microbes	H 2.3.9		Geosphere		
Fault movement	W 1.011				EFEP
Faulting	A 2.24				EFEP
Faulting	S 036				EFEP
Faulting	J 4.2.06				EFEP
Faulting/fracturing	H 2.1.7				EFEP
Filtration	K 8.08			Biosphere	
Fires (agricultural)	A 3.048			Biosphere	
Fires (forest and grass)	A 3.049			Biosphere	
Fish farming	A 3.050			Biosphere	
Fish farming	W 3.055			Biosphere	
Flammability	H 1.2.7				EFEP
Flipping of earth's magnetic poles	A 3.051				EFEP
Flood	A 2.25				EFEP
Flooding	A 3.052				EFEP
Flow through buffer/backfill	J 3.2.09	Repository	Geosphere		
Flow through buffer/backfill	S 037	Repository	Geosphere		
Flow through undetected boreholes	W 3.033				EFEP
Fluid flow due to gas production	W 2.042	Repository	Geosphere		
Fluid injection-induced geochemical changes	W 3.030				EFEP
Flushing of water bodies	A 3.053			Biosphere	
Fluvial deposition	W 1.047			Biosphere	

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Fluvial erosion	W 1.044			Biosphere	
Fluvial erosion/sedimentation	K 10.11			Biosphere	
Food preparation	A 3.054			Biosphere	
Formation of cracks	A 1.34		Geosphere		
Formation of fractures	W 1.008		Geosphere		
Formation of gases	A 1.35	Repository	Geosphere		
Formation of new faults	W 1.010				EFEP
Fracture flow	W 1.025		Geosphere		
Fracture infills	W 1.022		Geosphere		
Fracture mineralisation and weathering	N 1.6.11		Geosphere		
Freshwater intrusion	W 1.030	Repository	Geosphere	Biosphere	
Freshwater intrusion	W 1.035	Repository	Geosphere	Biosphere	
Fulvic acid	A 2.26	Repository	Geosphere	Biosphere	
Future biosphere conditions	K 8.02				EFEP
Future boreholes and undetected past boreholes	J 5.21				EFEP
Future climatic conditions	K 10.04				EFEP
Game ranching	A 3.055			Biosphere	
Gas discharge	H 4.1.3		Geosphere		
Gas explosions	W 2.027				EFEP
Gas flow and transport, buffer/backfill	S 041	Repository	Geosphere		
Gas flow and transport, near-field rock/far-field	S 042		Geosphere		
Gas generation	J 1.2.04	Repository	Geosphere		
Gas generation and gas sources, far-field	S 043		Geosphere		
Gas generation from concrete	H 1.2.3	Repository	Geosphere		
Gas generation, buffer/backfill	S 044	Repository	Geosphere		
Gas generation, near-field rock	S 046		Geosphere		
Gas leakage into basements	A 3.056			Biosphere	
Gas permeability	K 3.15	Repository	Geosphere		
Gas pressure effects	K 5.17		Geosphere		
Gas pressure effects	K 6.17		Geosphere		
Gas transport	H 1.2.6	Repository	Geosphere		
Gas transport	J 6.02	Repository	Geosphere		
Gas transport in bentonite	J 3.2.12	Repository	Geosphere		
Gas transport/dissolution	K 4.11		Geosphere		
Gaseous and volatile isotopes	K 0.3	Repository	Geosphere	Biosphere	
Gases and gas transport	A 2.27		Geosphere		
Gases from metal corrosion	W 2.049	Repository	Geosphere		
Generalised denudation	H 2.4.1				EFEP
Geochemical alteration	K 4.05		Geosphere		
Geochemical interactions	A 2.29		Geosphere		
Geochemical pump	A 1.37	Repository	Geosphere		
Geogas	K 5.24	Repository	Geosphere		
Geogas	K 6.24	Repository	Geosphere		
Geothermal	W 3.007				EFEP
Geothermal energy production	N 2.3.5				EFEP
Geothermal energy production	J 5.34				EFEP
Geothermal exploitation	K 11.03				EFEP
Geothermal gradient effects	A 2.28	Repository	Geosphere		
Geothermal regime	K 5.13		Geosphere		
Geothermal regime	K 6.13		Geosphere		

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
– Geothermally induced flow .	J 6.13	Repository	Geosphere		
Glacial climate	K 10.06				EFEP
Glacial erosion/sedimentation	K 10.14				EFEP
Glacial-fluvial erosion/sedimentation	K 10.15				EFEP
Glaciation	N 1.3.6				EFEP
Glaciation	A 1.38				EFEP
Glaciation	W 1.062				EFEP
Glaciation	A 2.30				EFEP
Glaciation	A 3.057				EFEP
Glaciation	S 047				EFEP
Glaciation	J 5.42				EFEP
Global effects	A 1.39				EFEP
Greenhouse effect	K 10.10				EFEP
Greenhouse effect	A 2.31				EFEP
Greenhouse effect	A 3.059				EFEP
Greenhouse food production	A 3.058			Biosphere	
Greenhouse gas effects	W 3.047				EFEP
Groundshine	A 3.060			Biosphere	
Groundwater - evolution	A 2.33		Geosphere		
Groundwater abstraction	N 2.3.11		Geosphere	Biosphere	
Groundwater chemistry	K 4.06		Geosphere		
Groundwater chemistry	S 048		Geosphere		
Groundwater chemistry	K 5.08		Geosphere		
Groundwater chemistry	K 6.08		Geosphere		
Groundwater chemistry	K 7.08		Geosphere		
Groundwater composition	A 2.32		Geosphere		
Groundwater conditions	N 1.5.6		Geosphere		
Groundwater discharge	W 1.053	Repository	Geosphere		
Groundwater discharge to soils and surface waters	H 4.1.1		Geosphere		
Groundwater exploitation	W 3.005		Geosphere	Biosphere	
Groundwater extraction	W 3.026		Geosphere	Biosphere	
Groundwater flow	H 2.2.3		Geosphere		
Groundwater flow	S 049		Geosphere		
Groundwater flow	K 7.04		Geosphere		
Groundwater flow path	K 5.04		Geosphere		
Groundwater flow path	K 6.04		Geosphere		
Groundwater flow path	K 7.06		Geosphere		
Groundwater geochemistry	W 1.033		Geosphere		
Groundwater pollution	K 11.07		Geosphere	Biosphere	
Groundwater recharge	W 1.054		Geosphere		
Groundwater recharge/discharge	J 5.46		Geosphere		
H2/O2 explosions	J 1.2.02				EFEP
Handling accidents	K 1.26				EFEP
Heat from radioactive decay	W 2.013	Repository	Geosphere		
Heat output (RN decay heat)	K 1.08	Repository	Geosphere		
Heat storage in lakes or underground	A 3.061				EFEP
Herbicides, pesticides and fungicides	A 3.062			Biosphere	
Heterogeneity of wasteforms	W 2.003	Repository			

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Host rock fracture aperture changes	N 3.1.3		Geosphere		
Household dust and fumes	A 3.063			Biosphere	
Houseplants	A 3.064			Biosphere	
HPD effective hydraulic properties	K 7.01		Geosphere		
Human diet	A 3.065			Biosphere	
Human exposure: External	H 4.4.1			Biosphere	
Human exposure: Ingestion	H 4.4.2			Biosphere	
Human exposure: Inhalation	H 4.4.3			Biosphere	
Human induced actions on groundwater recharge	J 5.27				EFEP
Human induced changes in surface hydrology	J 7.07				EFEP
Human induced climate change	J 6.08				EFEP
Human lifestyle	K 8.14			Biosphere	
Human soil ingestion	A 3.066			Biosphere	
Human-induced climate change	K 11.09				EFEP
Humic acid	A 2.34	Repository	Geosphere	Biosphere	
Humic and fulvic acids	W 2.070	Repository	Geosphere	Biosphere	
Hunter/gathering lifestyle	K 8.41				EFEP
Hydraulic conductivity	A 1.40	Repository	Geosphere		
Hydraulic gradient (magnitude, regional direction)	K 7.12		Geosphere	Biosphere	
Hydraulic gradient changes (magnitude, direction)	K 5.18		Geosphere	Biosphere	
Hydraulic gradient changes (magnitude, direction)	K 6.18		Geosphere	Biosphere	
Hydraulic head	A 1.41	Repository	Geosphere		
Hydraulic properties - evolution	A 2.35		Geosphere		
Hydrocarbon storage	W 3.011				EFEP
Hydrocarbon storage	W 3.029				EFEP
Hydrogen by metal corrosion	H 1.2.1	Repository	Geosphere		
Hydrogen production	K 2.16	Repository	Geosphere		
Hydrological response to earthquakes	W 1.031				EFEP
Hydroponics	A 3.067			Biosphere	
Hydrothermal activity	K 9.10				EFEP
Hydrothermal alteration	A 1.43	Repository	Geosphere		
Ice sheet effects (loading, melt water recharge)	K 10.16				EFEP
Impact of a large meteorite	W 1.040				EFEP
Improper operation	A 1.44				EFEP
Inadequate backfill or compaction, voidage	N 2.2.2				EFEP
Inadvertant inclusion of undesirable materials	N 2.2.4				EFEP
Incomplete closure	A 1.45				EFEP
Incomplete near-field chemical conditioning	H 5.1.3	Repository			
Industrial water use	A 3.068				EFEP
Infiltration	W 1.055		Geosphere	Biosphere	
Influx of oxidising water	K 5.19		Geosphere		
Influx of oxidising water	K 6.19		Geosphere		
Ingestion	W 2.104			Biosphere	
Inhalation	W 2.105			Biosphere	

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Inhomogeneities (properties and evolution)	K 3.21	Repository	Geosphere		
Injection	W 2.108			Biosphere	
Intake of drugs	A 3.069			Biosphere	
Intensification of natural climate change	H 3.1.4				EFEP
Interaction with cement components	K 3.25	Repository	Geosphere		
Interaction with corrosion products	S 051	Repository	Geosphere		
Interactions with corrosion products and waste	J 3.1.10	Repository	Geosphere		
Interface different waters	S 052		Geosphere		
Interface effects	K 8.28		Geosphere	Biosphere	
Interfaces (boundary conditions)	A 1.47	Repository	Geosphere		
Internal pressure	S 053	Repository			
Introduced complexing agents and cellulosics	N 3.2.6	Repository	Geosphere		
Intrusion (animal)	A 1.48				EFEP
Intrusion (deliberate)	A 3.070				EFEP
Intrusion (human)	A 1.49				EFEP
Intrusion (inadvertent)	A 3.071				EFEP
Intrusion (magmatic)	A 2.36				EFEP
Intrusion (mines)	A 2.37				EFEP
Intrusion of saline groundwater	K 5.11		Geosphere		
Intrusion of saline groundwater	K 6.11		Geosphere		
Inventory	A 1.50	Repository			
Investigation borehole seal failure and degradation #	N 2.1.2		Geosphere		
Investigation boreholes #	W 2.038		Geosphere		
Ion exchange in soil	A 3.072			Biosphere	
Irradiation	W 2.106			Biosphere	
Irrigation	N 2.4.4			Biosphere	
Irrigation	A 3.073			Biosphere	
Irrigation	W 3.044			Biosphere	
Irrigation	K 8.33			Biosphere	
Isostatic rebound	A 2.38				EFEP
Isotopic dilution	J 7.05	Repository	Geosphere		
Kinetics of organic complexation	W 2.071	Repository	Geosphere		
Kinetics of precipitation and dissolution	W 2.060	Repository	Geosphere		
Kinetics of sorption	W 2.062	Repository	Geosphere		
Kinetics of speciation	W 2.057	Repository	Geosphere		
Lacustrine deposition	W 1.048			Biosphere	
Lake formation	W 1.057			Biosphere	
Lake infilling	A 3.074			Biosphere	
Lake mixing (artificial)	A 3.075				EFEP
Lake usage	W 3.045			Biosphere	
Land and surface water use: Coastal waters	H 4.3.3			Biosphere	
Land and surface water use: Estuarine	H 4.3.2			Biosphere	
Land and surface water use: Seas	H 4.3.4			Biosphere	
Land and surface water use: Terrestrial	H 4.3.1			Biosphere	

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Land slide	N 1.4.1			Biosphere	
Land use changes	N 2.4.6				EFEP
Land use changes	W 3.040				EFEP
Liquid waste disposal	W 3.010				EFEP
Liquid waste disposal	W 3.027				EFEP
Liquid waste injection	K 11.04				EFEP
Localised corrosion	K 2.07	Repository			
Localised denudation	H 2.4.2		Geosphere	Biosphere	
Long-term physical stability	A 1.51	Repository	Geosphere		
Long-term transients	A 1.52	Repository	Geosphere		
Loss of integrity of borehole seals	H 5.1.1		Geosphere		
Loss of integrity of shaft or access tunnel seals	H 5.1.2		Geosphere		
Loss of records	N 2.4.1				EFEP
Loss of records	W 3.057				EFEP
Loss of records	J 7.09				EFEP
LPD effective hydraulic properties	K 5.01		Geosphere		
Magmatic activity	W 1.014				EFEP
Magmatic activity	N 1.2.3				EFEP
Magmatic activity	H 2.1.2				EFEP
Magmatic activity	A 2.39				EFEP
Magmatic activity (volcanism and plutonism)	K 9.09				EFEP
Magnetic poles (reversal)	A 2.40				EFEP
Major incision	H 2.1.8				EFEP
Malicious intrusion	N 2.3.2				EFEP
Malicious intrusion	H 5.2.3				EFEP
Marine sediment transport and deposition	N 1.4.7			Biosphere	
Marine sediment transport and deposition	W 1.067			Biosphere	
Mass wasting	W 1.045			Biosphere	
Mass wasting	W 1.049			Biosphere	
Material defects	N 2.1.6				EFEP
Matrix diffusion	N 1.6.3		Geosphere		
Matrix diffusion	W 2.092		Geosphere		
Matrix diffusion	A 2.41		Geosphere		
Matrix diffusion	J 4.1.05		Geosphere		
Matrix diffusion	K 5.06		Geosphere		
Matrix diffusion	S 054		Geosphere		
Matrix diffusion	K 6.06		Geosphere		
Mechanical degradation of seals	W 2.037		Geosphere		
Mechanical effects of backfill	W 2.035	Repository	Geosphere		
Mechanical failure of buffer/backfill	J 3.2.03	Repository	Geosphere		
Mechanical failure of repository	J 4.2.01				EFEP
Mechanical impact on canister	S 055	Repository	Geosphere		
Mechanical impact/failure, buffer/backfill	S 056	Repository	Geosphere		
Mechanical weathering	W 1.041			Biosphere	
Mesozoic sedimentary cover	K 7.02			Biosphere	
Metallic corrosion	N 3.2.1	Repository	Geosphere		
Metamorphic activity	W 1.015				EFEP
Metamorphic activity	N 1.2.4				EFEP

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Metamorphic activity	A 2.42				EFEP
Meteorite	J 5.29				EFEP
Meteorite Impact	N 1.1.1				EFEP
Meteorite impact	A 2.43				EFEP
Meteorite impact	H 5.2.1				EFEP
Methane	A 2.44	Repository	Geosphere		
Methane and carbon dioxide by microbial degradation	H 1.2.2	Repository			
Methane intrusion	J 5.43		Geosphere		
Microbes	W 1.071			Biosphere	
Microbes	A 1.54	Repository	Geosphere		
Microbes	J 2.1.10	Repository	Geosphere		
Microbes	A 2.45	Repository	Geosphere		
Microbial activity	K 5.22		Geosphere		
Microbial activity	K 6.22		Geosphere		
Microbial activity	K 1.22	Repository	Geosphere		
Microbial activity	K 3.17	Repository	Geosphere		
Microbial activity	S 057	Repository	Geosphere		
Microbial growth on concrete	W 2.076	Repository			
Microbial transport	W 2.087	Repository	Geosphere		
Microbially-mediated corrosion	K 2.05	Repository	Geosphere		
Microorganisms	A 1.55	Repository	Geosphere		
Mineralogical alteration - long term	K 3.12b	Repository	Geosphere		
Mineralogy	K 5.07		Geosphere		
Mineralogy	K 6.07		Geosphere		
Mines	A 2.46				EFEP
Mining activities	K 11.02				EFEP
Monitoring and remedial activities	A 1.56				EFEP
Movements along major faults	K 9.03				EFEP
Movements along small-scale faults	K 9.04				EFEP
Multiphase flow and gas driven flow	N 1.6.5	Repository	Geosphere		
Mutagenic contaminants	A 3.076	Repository	Geosphere	Biosphere	
Mutation	A 1.57	Repository	Geosphere		
MWCF effective hydraulic properties	K 6.01		Geosphere		
Natural and semi-natural environments	K 8.40			Biosphere	
Natural borehole fluid flow	W 3.031		Geosphere		
Natural colloids	K 5.15	Repository	Geosphere		
Natural colloids	K 6.15	Repository	Geosphere		
Natural ecological development	W 1.072			Biosphere	
Natural gas intrusion	N 1.2.13	Repository	Geosphere		
Natural gas intrusion	W 1.032	Repository	Geosphere		
Natural radionuclides/elements	K 4.02		Geosphere		
Near storage of other waste	J 5.12				EFEP
No ice age	N 1.3.7				EFEP
No ice age	J 6.10				EFEP
Non-linear sorption	K 5.10	Repository	Geosphere		
Non-linear sorption	K 6.10	Repository	Geosphere		
Non-radioactive solute plume in geosphere	N 3.2.4		Geosphere		
Non-sealed repository	J 5.02				EFEP

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Nuclear war	J 6.07				EFEP
Oil and gas exploitation	W 3.004				EFEP
Oil and gas exploration	W 3.001				EFEP
Oil and gas extraction	W 3.025				EFEP
Oil or organic fluid spill	K 4.18				EFEP
Open boreholes	A 2.47				EFEP
Organic complexation	W 2.068	Repository	Geosphere		
Organic ligands	W 2.069	Repository	Geosphere		
Organics	K 5.21	Repository	Geosphere		
Organics	K 6.21	Repository	Geosphere		
Organics/contamination of bentonite	K 3.24				EFEP
Osmotic processes	W 2.098	Repository	Geosphere		
Other future uses of crystalline rock	J 5.35				EFEP
Other resources	W 3.008				EFEP
Other resources	W 3.014				EFEP
Outdoor spraying of water	A 3.077			Biosphere	
Oxic corrosion	K 2.04	Repository	Geosphere		
Oxidizing conditions	J 4.1.01	Repository	Geosphere		
Ozone layer	A 2.48				EFEP
Ozone layer failure	A 3.078				EFEP
Peat and leaf litter harvesting	A 3.079			Biosphere	
Percolation	K 8.32			Biosphere	
Percolation in shafts	A 1.59	Repository	Geosphere		
Permafrost	W 1.063				EFEP
Permafrost	K 10.13				EFEP
Permafrost	J 5.17				EFEP
Permafrost	S 059				EFEP
Perturbed buffer material chemistry	J 3.1.12	Repository			
pH-deviations	J 4.1.02	Repository	Geosphere		
Physico-chemical degradation of concrete	H 1.1.2	Repository	Geosphere		
Physiography	W 1.039		Geosphere	Biosphere	
Pitting	A 1.60	Repository			
Pitting	J 2.1.07	Repository			
Plant roots	A 3.080			Biosphere	
Plant uptake	N 1.7.1			Biosphere	
Plant uptake	W 2.101			Biosphere	
Plants	W 1.069			Biosphere	
Ploughing	K 8.38			Biosphere	
Poor emplacement of buffer	K 3.23				EFEP
Postclosure monitoring	W 2.011				EFEP
Postclosure monitoring	J 5.39				EFEP
Precipitation	K 8.29			Biosphere	
Precipitation	W 2.059		Geosphere		
Precipitation (for example, rainfall)	W 1.059			Biosphere	
Precipitation (meteoric)	A 3.081			Biosphere	
Precipitation and dissolution	A 2.49		Geosphere		
Precipitation and dissolution	A 1.62	Repository			
Precipitation/dissolution	S 060	Repository	Geosphere		
Preferential pathways in canister	S 061	Repository			

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Preferential pathways in the buffer/backfill	J 3.2.08	Repository	Geosphere		
Present-day biosphere	K 8.01			Biosphere	
Present-day climatic conditions	K 10.01			Biosphere	
Properties of bentonite buffer	S 062	Repository	Geosphere		
Properties of far-field rock	S 064		Geosphere		
Properties of near-field rock	S 065		Geosphere		
Properties of tunnel backfill	S 066	Repository			
Pseudo-colloids	A 2.50	Repository	Geosphere		
Psuedo-colloids	A 1.63	Repository	Geosphere		
Quarrying, near surface extraction	N 2.4.10				EFEP
Radiation doses	K 8.15			Biosphere	
Radiation effects	A 2.52	Repository	Geosphere		
Radiation effects on bentonite	J 3.1.13	Repository			
Radiation effects on buffer/backfill	S 067	Repository	Geosphere		
Radiation shielding	K 2.11	Repository			
Radioactive decay	K 0.1	Repository	Geosphere	Biosphere	
Radioactive decay	A 1.65	Repository	Geosphere	Biosphere	
Radioactive decay	A 2.51	Repository	Geosphere	Biosphere	
Radioactive decay	A 3.082	Repository	Geosphere	Biosphere	
Radioactive decay and ingrowth	H 1.3.1	Repository	Geosphere	Biosphere	
Radioactive decay and ingrowth	N 3.4.4	Repository	Geosphere	Biosphere	
Radioactive decay of mobile nuclides	S 070	Repository	Geosphere	Biosphere	
Radioactive Decay, fuel	S 069	Repository	Geosphere	Biosphere	
Radioactive decay; heat	J 1.1.02	Repository	Geosphere		
Radioactive gases	H 1.2.4	Repository			
Radioactive gases	W 2.055	Repository			
Radiological effects on containers	W 2.016	Repository			
Radiological effects on seals	W 2.017	Repository			
Radiological effects on waste	W 2.015	Repository			
Radiolysis	J 1.2.01	Repository	Geosphere		
Radiolysis	K 1.23	Repository	Geosphere		
Radiolysis	A 1.66	Repository	Geosphere		
Radiolysis	J 3.1.09	Repository	Geosphere		
Radiolysis	K 3.19	Repository	Geosphere		
Radiolysis	N 3.4.1	Repository	Geosphere		
Radiolysis	S 071	Repository	Geosphere		
Radiolysis of cellulose	W 2.053	Repository			
Radionuclide accumulation in sediments	K 8.05			Biosphere	
Radionuclide accumulation in soils	K 8.06			Biosphere	
Radionuclide decay and ingrowth	W 2.012	Repository	Geosphere	Biosphere	
Radionuclide inventory	K 1.02	Repository			
Radionuclide migration	K 4.08		Geosphere		
Radionuclide retardation	K 4.09		Geosphere		
Radionuclide retardation	K 3.10	Repository	Geosphere		
Radionuclide sorption	K 8.17			Biosphere	
Radionuclide sorption	K 7.09	Repository	Geosphere		
Radionuclide sorption and co-precipitation	K 2.15	Repository	Geosphere		

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Radionuclide transport through buffer	K 3.16	Repository	Geosphere		
Radionuclide transport through LPD	K 5.05		Geosphere		
Radionuclide transport through MWCF	K 6.05		Geosphere		
Radionuclide volatilisation/aerosol/dust production	K 8.12			Biosphere	
Radiotoxic contaminants	A 3.083			Biosphere	
Radon emission	A 3.084			Biosphere	
Radon pathways and doses	K 8.45			Biosphere	
Ranching	W 3.054			Biosphere	
Reactions with cement pore water	J 3.1.07	Repository	Geosphere		
Recharge groundwater	A 1.67	Repository	Geosphere		
Recharge groundwater	A 2.53	Repository	Geosphere		
Reconcentration	J 4.1.06	Repository	Geosphere		
Reconcentration	S 073	Repository	Geosphere		
Recovery of repository materials	N 2.3.1				EFEP
Recrystallization #	J 1.2.07	Repository	Geosphere		
Recycling	A 3.085			Biosphere	
Redox front	J 3.1.11	Repository	Geosphere		
Redox front	S 074	Repository	Geosphere		
Redox potential	J 1.2.08	Repository	Geosphere		
Reduced mechanical strength	S 075	Repository			
Reduction-oxidation fronts	W 2.065	Repository	Geosphere		
Reduction-oxidation kinetics	W 2.066	Repository	Geosphere		
Reflooding	A 1.68	Repository			
Regional horizontal movements	K 9.01				EFEP
Regional stress regime	K 5.14		Geosphere		
Regional stress regime	K 6.14		Geosphere		
Regional tectonic activity	H 2.1.1				EFEP
Regional tectonics	W 1.004				EFEP
Regional uplift and subsidence	W 1.005			Biosphere	
Regional vertical movements	K 9.02				EFEP
Release from metal parts	S 077	Repository			
Removal mechanisms	K 8.43			Biosphere	
Repository records, markers	K 11.10				EFEP
Resaturation	J 5.14	Repository	Geosphere		
Resaturation of bentonite buffer	S 079	Repository			
Resaturation of tunnel backfill	S 080	Repository			
Resaturation, near-field rock	S 078		Geosphere		
Reservoirs	W 3.043				EFEP
Resource mining	N 2.3.6				EFEP
Reuse of boreholes	J 5.36				EFEP
Rinse	W 2.083	Repository	Geosphere		
River flooding	W 1.058			Biosphere	
River meandering	J 6.09			Biosphere	
River, stream, channel erosion	N 1.4.3			Biosphere	
Rivercourse meander	A 3.086			Biosphere	
Rock properties	A 2.54		Geosphere		
Rock properties - undetected features	A 2.55		Geosphere		
Rock property changes	H 2.2.2		Geosphere		
Roof falls	W 2.022	Repository	Geosphere		

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Runoff	A 3.087			Biosphere	
Sabotage	N 2.2.7				EFEP
Sabotage	A 2.56				EFEP
Sabotage and improper operation	A 1.70				EFEP
Saline (or fresh) groundwater intrusion	J 5.01	Repository	Geosphere		
Saline or freshwater intrusion	N 1.5.7	Repository	Geosphere		
Salinity effects on flow	A 2.57		Geosphere		
Saltation	A 3.088			Biosphere	
Saturated groundwater flow	W 1.023	Repository	Geosphere		
Saturated groundwater flow	H 1.5.4	Repository	Geosphere		
Saturation	A 2.58	Repository	Geosphere		
Saturation of sorption sites	J 3.1.02	Repository	Geosphere		
Scavengers and predators	A 3.089			Biosphere	
Sea level change	A 2.59			Biosphere	
Sea level changes	W 1.068			Biosphere	
Sea level changes	S 081			Biosphere	
Sea water use	W 3.051			Biosphere	
Seal chemical composition	W 2.008		Geosphere		
Seal evolution	A 1.71		Geosphere		
Seal failure	A 1.72		Geosphere		
Seal geometry	W 2.006		Geosphere		
Seal physical properties	W 2.007		Geosphere		
Sea-level rise/fall	N 1.3.4			Biosphere	
Seas and oceans	W 1.064			Biosphere	
Seasonality of climate	K 10.03			Biosphere	
Seasons	A 3.090			Biosphere	
Sediment resuspension in water bodies	A 3.091			Biosphere	
Sediment transport including bioturbation	H 4.2.3			Biosphere	
Sediment/water/gas interaction with the atmosphere.	H 4.2.4			Biosphere	
Sedimentation	K 8.23			Biosphere	
Sedimentation in water bodies	A 3.092			Biosphere	
Sedimentation of bentonite	J 3.1.06	Repository	Geosphere		
Sedimentation of bentonite	S 082	Repository	Geosphere		
Seismic activity	W 1.012				EFEP
Seismic activity	K 9.05				EFEP
Seismicity	N 1.2.8				EFEP
Seismicity	H 2.1.6				EFEP
Sensitization to radiation	A 3.093			Biosphere	
Shaft and tunnel seals	K 4.17		Geosphere		
Shaft seal failure	A 2.60		Geosphere		
Shallow dissolution	W 1.016		Geosphere		
Showers and humidifiers	A 3.094			Biosphere	
Smoking	A 3.095			Biosphere	
Soil	A 3.096			Biosphere	
Soil	K 8.25			Biosphere	
Soil and sediment bioturbation	N 1.7.4			Biosphere	
Soil depth	A 3.097			Biosphere	
Soil development	W 1.050			Biosphere	
Soil formation	K 8.24			Biosphere	
Soil leaching	A 3.098			Biosphere	

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Soil moisture and evaporation.	H 4.2.1			Biosphere	
Soil porewater pH	A 3.099			Biosphere	
Soil sorption	A 3.100			Biosphere	
Soil type	A 3.101			Biosphere	
Solar insolation	N 1.1.2			Biosphere	
Solid discharge via erosional processes	H 4.1.2			Biosphere	
Solubility and precipitation	J 5.44	Repository	Geosphere		
Solubility limits/colloid formation	K 5.16	Repository	Geosphere		
Solubility limits/colloid formation	K 6.16	Repository	Geosphere		
Solute transport	W 2.077	Repository	Geosphere		
Solution mining	A 2.61				EFEP
Soret effect	W 2.093	Repository	Geosphere		
Soret effect	J 3.2.10	Repository	Geosphere		
Soret effect	S 083	Repository	Geosphere		
Sorption	N 1.6.7	Repository	Geosphere		
Sorption	A 1.73	Repository	Geosphere		
Sorption	A 2.62	Repository	Geosphere		
Sorption	J 4.1.04	Repository	Geosphere		
Sorption	K 5.09	Repository	Geosphere		
Sorption	K 6.09	Repository	Geosphere		
Sorption	S 084	Repository	Geosphere		
Sorption - nonlinear	A 1.74	Repository	Geosphere		
Sorption - nonlinear	A 2.63	Repository	Geosphere		
Sorption on filling material	S 085	Repository	Geosphere		
Space heating	A 3.102			Biosphere	
Speciation	K 0.2	Repository	Geosphere		
Speciation	A 1.77	Repository	Geosphere		
Speciation	W 2.056	Repository	Geosphere		
Speciation	A 2.64	Repository	Geosphere		
Stray materials left	J 5.03				EFEP
Stream and river flow	W 1.051			Biosphere	
Stress changes - hydrogeological effects	K 9.06				EFEP
Stress field	S 086		Geosphere		
Stress regime	K 7.10		Geosphere		
Subsidence	W 2.023	Repository	Geosphere		
Surface denudation	K 10.12		Geosphere	Biosphere	
Surface disruptions	W 3.041				EFEP
Surface pollution (soils, rivers)	K 11.08			Biosphere	
Surface run-off	K 8.34			Biosphere	
Surface water bodies	W 1.052			Biosphere	
Surface water bodies	A 3.103			Biosphere	
Surface water bodies	K 8.26			Biosphere	
Surface water chemistry	S 087		Geosphere	Biosphere	
Surface water mixing	H 4.2.2			Biosphere	
Surface water pH	A 3.104			Biosphere	
Suspended sediment transport	K 8.36			Biosphere	
Suspension in air	A 3.105			Biosphere	
Swelling of bentonite into tunnels and cracks	J 3.2.01.1	Repository	Geosphere		
Swelling of corrosion products	J 3.2.07	Repository	Geosphere		
Swelling of tunnel backfill	S 088	Repository	Geosphere		
Swelling pressure	A 1.80	Repository	Geosphere		

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Technological advances in food production	A 3.106			Biosphere	
Tectonic activity - large scale	J 6.14				EFEP
Temperature	W 1.060			Biosphere	
Temperature effects	A 1.81	Repository			
Temperature, bentonite buffer	S 089	Repository	Geosphere		
Temperature, far-field	S 091		Geosphere		
Temperature, near-field rock	S 092		Geosphere		
Temperature, tunnel backfill	S 093		Geosphere		
Teratogenic contaminants	A 3.107			Biosphere	
Terrestrial surface	A 3.108			Biosphere	
Thermal buoyancy	J 4.2.04	Repository	Geosphere		
Thermal degradation of buffer/backfill	S 094	Repository	Geosphere		
Thermal effects on groundwater flow	W 1.028		Geosphere		
Thermal effects on material properties	W 2.029	Repository	Geosphere		
Thermal effects on the buffer material	J 3.2.05	Repository	Geosphere		
Thermal effects: Chemical and microbiological changes	H 1.6.3	Repository	Geosphere		
Thermal effects: Hydrogeological changes	H 1.6.2	Repository	Geosphere		
Thermal effects: Rock-mass changes	H 1.6.1		Geosphere		
Thermal effects: Transport (diffusion) effects	H 1.6.4	Repository	Geosphere		
Thermal evolution	K 3.02	Repository	Geosphere		
Thermally-induced stress changes	W 2.030	Repository	Geosphere		
Thermochemical change	J 4.1.07	Repository	Geosphere		
Thermo-chemical effects	H 1.2.8	Repository	Geosphere		
Thermo-hydro-mechanical effects	J 4.2.07		Geosphere		
Time dependence	A 1.83	Repository	Geosphere		
Topography (current)	A 2.65			Biosphere	
Topography (future)	A 2.66			Biosphere	
Total corrosion rate	K 2.08	Repository	Geosphere		
Toxicity of mined rock	A 3.109				EFEP
Transport and release of nuclides, bentonite buffer	S 096	Repository	Geosphere		
Transport and release of nuclides, near-field rock	S 098		Geosphere		
Transport and release of nuclides, tunnel backfill	S 099		Geosphere		
Transport in gases or of gases	A 1.84	Repository	Geosphere		
Transport of chemically-active substances into the near-field	H 1.5.5	Repository	Geosphere		
Transport of radioactive gases	W 2.089	Repository	Geosphere	Biosphere	
Tree sap	A 3.110			Biosphere	
TRU alkaline or organic plume	K 5.20	Repository	Geosphere		
TRU alkaline or organics plume	K 6.20	Repository	Geosphere		
Tundra climate	K 10.05				EFEP
Tunneling	W 3.015				EFEP
Tunnelling	N 2.3.7				EFEP
Underground boreholes #	W 2.039		Geosphere		

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Underground construction	N 2.3.8				EFEP
Underground dwellings	J 5.28				EFEP
Underground nuclear device testing	W 3.020				EFEP
Underground nuclear testing	N 2.3.12				EFEP
Underground test of nuclear devices	J 5.30				EFEP
Undetected fracture zones	J 6.01		Geosphere		
Uneven swelling of bentonite	J 3.2.01.2	Repository	Geosphere		
Uniform corrosion	A 1.86	Repository			
Unmodelled design features	A 1.87				EFEP
Unsaturated flow due to gas production	H 1.5.3	Repository	Geosphere		
Unsaturated rock	A 2.69		Geosphere		
Unsaturated transport	A 1.88	Repository			
Unsealed boreholes and/or shafts	J 5.09				EFEP
Unsuccessful attempt of site improvement	J 5.40				EFEP
Uplift and subsidence	N 1.2.6			Biosphere	
Uplift and subsidence	J 5.16			Biosphere	
Uptake by crops	K 8.09			Biosphere	
Uptake by livestock	K 8.10			Biosphere	
Uptake in fish	K 8.11			Biosphere	
Urbanization on the discharge site	A 3.112				EFEP
Warmer climate - arid	K 10.07				EFEP
Warmer climate - equable humid	K 10.09				EFEP
Warmer climate - seasonal humid	K 10.08				EFEP
Waste corrosion and solubility and speciation of radionuclides	H 1.1.3	Repository			
Waste inventory	W 2.002	Repository			
Waste retrieval, mining	J 5.33				EFEP
Waste-form and backfill consolidation	H 1.4.1	Repository			
Waste-induced borehole flow	W 3.032				EFEP
Water chemistry in near-field rock	S 103		Geosphere		
Water chemistry, bentonite buffer	S 101	Repository			
Water chemistry, canister	S 102	Repository			
Water chemistry, tunnel backfill	S 104	Repository	Geosphere		
Water flow at the bentonite-host rock interface	K 4.07		Geosphere		
Water leaking into basements	A 3.114			Biosphere	
Water management projects	A 3.115				EFEP
Water management schemes	K 11.06				EFEP
Water producing well	J 5.41		Geosphere	Biosphere	
Water resource exploitation	K 8.07			Biosphere	
Water resources exploration	W 3.003			Biosphere	
Water source	A 3.116			Biosphere	
Water-conducting features (types)	K 5.02		Geosphere		
Water-conducting features (types)	K 6.02		Geosphere		
Vault closure (incomplete)	A 2.70				EFEP

NEA Projects FEPs considered in SFR matrices or as EFEPs

NEA project FEP	Unique number	Interaction matrix			EFEP
Vault collapse	H 1.4.2		Geosphere		
Vault geometry	A 1.89	Repository			
Vault heating effects	A 2.71	Repository			
Vault heating effects	A 3.113	Repository			
Weathering of flow paths	J 6.06		Geosphere		
Wells	A 2.73		Geosphere	Biosphere	
Wells (high-demand)	A 2.74		Geosphere		
Wetlands	A 3.117			Biosphere	
Wicking	W 2.041	Repository	Geosphere		
Wind	A 3.118			Biosphere	
Volcanic activity	W 1.013				EFEP
Volcanism	A 2.72				EFEP
Volcanism	J 5.13				EFEP
Volume increase of corrosion products	S 100	Repository	Geosphere		

NEA Project FEPs with negligible effects

NEA Project FEP	Unique number	Comment
Coupled effects (electrophoresis)	J 2.1.02	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Earth tides	S 028	Potential effects are assessed to be small compared to other processes and can therefore be neglected
Electrochemical effects	W 2.094	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Electrochemical effects of metal corrosion	H 1.1.4	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Electrochemical effects/gradients	S 029	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Electrochemical gradients	A 1.30	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Electrophoresis	W 2.096	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Galvanic coupling	A 1.36	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Galvanic coupling	W 2.050	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Galvanic coupling	W 2.095	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms
Hydride cracking	A 1.42	The steel containers in SFR have a very short life-time
Natural telluric electrochemical reactions	J 2.1.06.2	Missing in matrices, but the effect on radionuclide migration assessed to be negligible in comparison to other migration mechanisms

Appendix D: EFEPs sorted into categories

The external FEPs to be considered within SAFE have been sorted into six categories: Climate, Human-induced climate change, Initial defect, Human activities, Tectonics and Others. The FEPs considered within these categories are summarised in the first table below.

In the selection of external FEPs for SFR a compilation of potential EFEPs from the NEA project FEP database was used. The FEPs were sorted into the same categories as given above and with similar FEPs grouped together. The NEA project FEPs considered to be potential EFEPs together with suggested treatment for the SFR assessment are compiled in the remaining tables of this Appendix.

1. Climate

- **Permafrost** including **Accumulation of gases under permafrost, Arctic desert, Denudation (glacial, fluvial, aeolian erosion), Drought and Tundra climate**
- Effects on sea levels due to **Glaciation at the mountains.**
- **Flood** due to increase in meteoric precipitation

2. Human-induced climate change

- **Acid rain**
- **Greenhouse effect** including **Warmer climate – arid, Warmer climate - equable humid Warmer climate - seasonal humid**

3. Initial defect

- **Material defects** such as **Backfill material deficiencies, Inadequate backfill or compaction, voidage**
- **Open boreholes** including **Flow through undetected boreholes**
- **Inadvertent inclusion of undesirable materials** such as **Oil or organic fluid spill Organics/contamination of bentonite Decontamination materials left Stray materials left**
- **(Unmodelled design features** - differences between designed and constructed, unforeseen modifications in design, features required for operation but not considered part of the conceptual design)

4. Human actions

- **Accidental intrusion** in terms of drilling into the repository covering aspects such as; **Hydro and chemical effects** of drilling fluid flow and drilling fluid loss**,** drilling-induced geochemical changes, fluid injection-induced geochemical changes, **Blowouts** of fluid during drilling, **Cavings and Cuttings** – material brought to surface during drilling

5. Tectonics

- **Earthquakes** including **Hydrological response to earthquakes, Mechanical failure of repository**
- **Fault movement**
- **Faulting**

6 Others

- **Deviation in RN inventory**
- **Gas explosions** - hydrogen, methane, air - early after closure. (Probably not important, but a written motivation is needed)

1. Climate

Unique number	NEA Project FEP	Comment
K 10.04	**Future climatic conditions** climate change-natural or human induced	Too general
A 2.40 A 3.051	**Magnetic poles (reversal)** changes earth's ionization layer thus affecting climate	Secondary
H 3.1.4	**Intensification of natural climate change** more frequent and intense glaciations	Included in uncertainties
A 2.07 A 3.024 W 1.061 A 1.12 H 3.1.2	**Climate change** wetter, dryer, warmer, cooler, permafrost, glaciation	Too general
J 5.17 S 059 K 10.13 W 1.063	**Permafrost**	To be analysed
J 5.22	**Accumulation of gases under permafrost**	Screened to permafrost
K 10.06 A 3.057 A 1.38 A 2.30 J 5.42 N 1.3.6 S 047 W 1.062	**Glacial climate - Glaciation**	Not expected to occur within 10 000 years. If it starts earlier glacial conditions will continue past 10 000 years after closure. Glaciation at the mountains will affect sea levels which should be considered
H 3.1.3	**Exit from glacial/interglacial cycling** accumulation of surface waters	Not relevant – no glaciation
K 10.14 K 10.15	**Glacial-fluvial erosion/sedimentation** erosion/deposition by ice and meltwater	Not relevant – no glaciation
K 10.16	**Ice sheet effects** loading, melt water recharge	Not relevant – no glaciation
A 2.38	**Isostatic rebound** removal of ice load	Not relevant – no glaciation
A 2.24 S 036 J 4.2.06 H 2.1.7	**Faulting**	Not relevant due to ice-load– no glaciation
H 2.1.8	**Major incision** due to glacial erosion	Not relevant – no glaciation
J 6.10 N 1.3.7	**No ice age**	Included in base scenario
A 2.25	**Flood** increase in meteoric precipitation	Should be considered
H 2.4.1	**Generalised denudation** glacial, fluvial, aeolian erosion	Partly in permafrost scenario
J 5.32	**Desert and unsaturation**	Arctic desert as a part of permafrost scenario
N 1.7.9	**Ecological response to climate** (e.g. desert formation)	Included in biosphere matrix
A 2.19	**Drought**	Part of permafrost scenario
A 3.043	**Dust storms and desertification**	If relevant for SFR already included in base scenario
A 3.002	**Alkali flats** accumulation of salts due to extreme and continuous dry weather	Not relevant – too small amounts of salt and no such extreme weather conditions
K 10.05	**Tundra climate**	Included in permafrost scenario
K 10.07	**Warmer climate – arid**	Classify as Climate Human Action and couple to Greenhouse effects
K 10.09	**Warmer climate - equable humid**	Classify as Climate Human Action and couple to Greenhouse effects

1. Climate

Unique number	NEA Project FEP	Comment
K 10.08	**Warmer climate - seasonal humid**	Classify as Climate Human Action and couple to Greenhouse effects

2. Climate – Human action

Unique number	NEA Project FEP	Comment
K 11.09 N 2.4.9 H 3.1.1 J 6.08	**Human-induced climate change** warming e.g. greenhouse effect or cooling	Too general
W 3.048 A 3.001	**Acid rain**	Should be considered
K 10.10 A 2.31 A 3.059 W 3.047	**Greenhouse effect**	Should be considered
A 3.078 A 2.48 W 3.049	**Ozone layer failure**	Not relevant
A 1.39	**Global effects** climate, greenhouse, drought, flooding	Too general
K 8.02	**Future biosphere conditions** due to climate change and future human behaviour	Too general

3. Initial defect

Unique number	NEA Project FEP	Comment
N 2.1.6	**Material defects**	Should be considered
J 3.2.11	**Backfill material deficiencies**	Part of backfill material deficiencies
N 2.2.2	**Inadequate backfill or compaction, voidage**	Part of backfill material deficiencies
K 3.23	**Poor emplacement of buffer**	Not relevant
A 2.70	**Vault closure (incomplete)**	Not relevant
A 1.45	**Incomplete closure**	Not relevant
J 5.02	**Non-sealed repository**	Not relevant
N 2.2.9	**Abandonment of unsealed repository**	Not relevant
J 5.09	**Unsealed boreholes and/or shafts**	Not relevant
A 2.47	**Open boreholes**	Should be considered
K 1.26	**Handling accidents**	Not relevant
N 2.2.4	**Inadvertent inclusion of undesirable materials**	Should be considered
K 4.18	**Oil or organic fluid spill**	Should be considered – part of Inadvertent inclusion
K 3.24	**Organics/contamination of bentonite**	Should be considered – part of Inadvertent inclusion
J 5.04	**Decontamination materials left**	Should be considered – part of Inadvertent inclusion
J 5.03	**Stray materials left**	Should be considered – part of Inadvertent inclusion

4. Human actions

Unique number	NEA Project FEP	Comment
H 5.2.4 A 3.071	**Accidental intrusion**	Included in terms of drilling into the repository

4. Human actions

Unique number	NEA Project FEP	Comment
N 2.3.2 H 5.2.3	**Malicious intrusion** with purpose to release RN	No deliberate actions are relevant
H 5.2.2 A 1.49 A 3.070 W 3.012 N 2.3.1	**Deliberate intrusion** drilling, mining, recovery of repository material	No deliberate actions are relevant
K 11.01 A 2.05 J 5.21 W 3.032	**Exploratory drilling** in search of resources	Covered by drilling intrusion scenario
J 5.39 W 2.011	**Postclosure monitoring**	No deliberate actions are relevant
A 1.56	**Monitoring and remedial activities**	No deliberate actions are relevant
J 5.36 A 2.03	**Reuse of boreholes** e.g. as wells	Covered by drilling intrusion scenario or base scenario where wells are included
W 3.021 W 3.022 W 3.024	**Drilling fluid flow** **Drilling fluid loss** **Drilling-induced geochemical changes** hydro and chemical effects	Part of drilling intrusion scenario
W 3.023	**Blowouts** of fluid during drilling	Part of drilling intrusion scenario
W 2.085	**Cavings** material eroded from the bore hole wall by drill fluid brought to surface during drilling	Part of drilling intrusion scenario
W 2.084	**Cuttings** material intersected by the drill brought to surface during drilling	Part of drilling intrusion scenario
A 2.37 W 3.018 A 2.46 K 11.02 J 5.33 N 2.3.6 A 2.61	**Intrusion (mines)** in or near the repository	Only drilling intrusion scenario selected
W 3.038	**Changes in geochemistry due to mining**	Drilling scenario selected
W 3.037	**Changes in groundwater flow due to mining**	Drilling scenario selected
A 3.109	**Toxicity of mined rock** from repository excavation	Drilling scenario selected
W 3.016 N 2.3.8 W 3.015 N 2.3.7 J 5.28	**Construction of underground facilities** (for example storage, disposal, accommodation)	Drilling scenario selected and not a scenario involving underground constructions
J 5.12	**Near storage of other waste**	Analysis of Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
J 5.06	**Co-storage of other waste**	Analysis of Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
W 3.011 W 3.029	**Hydrocarbon storage**	Drilling scenario selected and not a scenario involving underground constructions
W 3.010 W 3.027 K 11.04	**Liquid waste disposal**	Drilling scenario selected and not a scenario involving underground constructions
W 3.030	**Fluid injection-induced geochemical changes** fluid injection through boreholes	Part of drilling scenario

4. Human actions

Unique number	NEA Project FEP	Comment
J 5.34 W 3.007 N 2.3.5 K 11.03	**Geothermal energy production**	Covered by drilling scenario
A 3.061	**Heat storage in lakes or underground**	Analysis of Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
W 3.004 W 3.001 W 3.025	**Oil and gas exploitation**	Covered by drilling scenario
J 5.35	**Other future uses of crystalline rock**	Covered by drilling scenario
W 3.008 W 3.014	**Other resources**	Covered by drilling scenario
N 2.3.9 W 3.017 J 5.37 W 3.006	**Archaeological investigation**	Covered by drilling scenario
A 2.23 A 1.32 A 2.02 J 5.38 W 3.019	**Explosions** Underground, at surface, bombs, for resource recovery	Analysis of Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
A 3.025	**Collisions, explosions and impacts** e.g. aircraft crash, bombs	Analysis of Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
W 3.039	**Changes in groundwater flow due to explosions**	Consequence of Explosions, which are screened out
J 6.07	**Nuclear war**	Not relevant
W 3.020 N 2.3.12 J 5.30	**Underground nuclear device testing**	Not relevant
A 1.70 A 2.56 N 2.2.7 J 5.05 A 1.44	**Sabotage and improper operation** during operation or after closure to impair barrier functions	Not relevant. Deliberate action
K 11.10 J 7.09 N 2.4.1 W 3.057	**Loss of records**	Prerequisite for unconscious action
J 5.40	**Unsuccessful attempt of site improvement**	Not relevant. Deliberate action
J 5.27	**Human induced actions on groundwater recharge** agriculture, vegetation, dams polders, cities	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
J 7.07	**Human induced changes in surface hydrology** dams, polders, cities	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
J 7.11	**City on the site** affects gw discharge/recharge	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
A 3.115	**Water management projects**	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository

4. Human actions

Unique number	NEA Project FEP	Comment
K 11.06	**Water management schemes**	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
A 3.068	**Industrial water use**	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
A 2.14 N 2.4.2 W 3.042 W 3.043	**Dams and reservoirs, built/drained**	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
A 3.052	**Flooding** intentional or accidental by humans	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
A 3.075	**Lake mixing (artificial)** aeration, wave makers, purifiers, heat storage	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
K 8.37 A 2.20 A 3.044 N 2.4.10	**Earthworks (human actions, dredging, etc.)** quarrying, mining, earth moving actions	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
W 3.041	**Surface disruptions** actions taking place at surface	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
N 2.4.6 W 3.040	**Land use changes** surface activities	Human Actions in SR 97 concluded that drilling and/or construction of underground facilities have the highest potential for affecting the function of the repository
N 2.4.7	**Agricultural and fisheries practice changes**	Treatment according to SSI regulations
W 3.056 N 2.4.8	**Demographic change and urban development** development of new communities and new activities	Treatment according to SSI regulations
A 3.112	**Urbanization on the discharge site** affects critical group characters	Treatment according to SSI regulations
A 3.031	**Critical group – evolution** life-style and activities	Treatment according to SSI regulations
K 8.41	**Hunter/gathering lifestyle** nomadic community	Treatment according to SSI regulations
A 3.038	**Cure for cancer** due to scientific and technological advances	Treatment according to SSI regulations

5. Tectonics

Unique number	NEA Project FEP	Comment
H 2.1.1 W 1.004 J 6.14 W 1.003	**Regional tectonic activity**	Too general
K 9.05 W 1.012 N 1.2.8 H 2.1.6	**Seismic activity**	Too general
A 1.29 A 2.21 A 3.045 J 5.15	**Earthquakes**	Should be considered
A 2.42 N 1.2.4 W 1.015	**Metamorphic activity**	Too short time and too small depth

5. Tectonics

Unique number	NEA Project FEP	Comment
A 2.39 N 1.2.3 H 2.1.2 W 1.014 K 9.09 A 2.36	**Magmatic activity**	Not relevant
W 1.013 A 2.72 J 5.13	**Volcanic activity**	Not relevant
W 1.011 K 9.03 K 9.04 K 9.01 K 9.02	**Fault movement**	Should be considered
A 2.24 S 036 J 4.2.06 H 2.1.7 W 1.010	**Faulting**	Should be considered
W 1.031	**Hydrological response to earthquakes** e.g. change in surface water flow directions from fault movements	Include in Earthquake scenario
J 4.2.01	**Mechanical failure of repository** due to earthquakes, loading-unloading, plate motions	Include in Earthquake scenario
K 9.06	**Stress changes - hydrogeological effects** due to fault movements	Included in geosphere matrix

6. Others

Unique number	NEA Project FEP	Comment
K 1.27	**Deviant inventory flask** deviation in RN inventory	Should be included
A 1.05	**Buffer additives** to enhance performance	Not relevant, deliberate action
W 2.027 J 1.2.02 H 1.2.7	**Gas explosions** hydrogen, methane, air - early after closure	Probably not relevant, but a motivation is needed
K 9.11	**Extraterrestrial events**	Not relevant
J 5.29 A 2.43 N 1.1.1 H 5.2.1 W 1.040	**Meteorite**	Not relevant, see motivation in SKB/SKI Joint scenario project
K 9.10	**Hydrothermal activity**	Not relevant
N 1.2.2 J 5.20	**Changes in the Earth's magnetic field**	Do not affect the function of the repository
W 3.033	**Flow through undetected boreholes**	Part of Open boreholes
A 1.48	**Intrusion (animal)**	Included in base scenario
A 1.87	**Unmodelled design features** differences between designed and constructed, unforeseen modifications in design, features required for operation but not considered part of the conceptual design	Include in Initial defect

Appendix E: Interactions/processes in the matrices judged to be of negligible importance

Identified interactions/processes assessed to be of negligible importance (colour coding green in the matrix) for the performance and evolution of the repository system for the Base Scenario are listed below for the Repository, Geosphere and Biosphere matrices. In the first column the name of the interaction is given together with the number indicating the position in matrix. In the second column the description of the interaction is found and in the third the motivation for the assigned priority.

Interaction/process in Repository matrix	Description	Motivation
1.4 Expansion/contraction	Changes in volume and dimensions of the waste and matrix may cause expansion/contraction of the materials and voids in the concrete packaging thereby affecting the volume and dimensions of the materials and voids in the concrete packaging	Change in volume and dimensions of the waste and waste matrix will probably primarily affect the stress conditions in the waste matrix and surrounding packaging, i.e. interaction 4.14, which in turn may affect the volume and dimensions of the concrete packaging, interaction 14.4.
1.5 Expansion/contraction	Changes in volume and dimensions of the waste and matrix may cause expansion/contraction of the materials and voids in the steel packaging thereby affecting the volume and dimensions of the materials and voids in the steel packaging	Change in volume and dimensions of the waste and waste matrix will probably primarily affect the stress conditions in the waste matrix and surrounding packaging, i.e. interaction 4.14, which in turn may affect the volume and dimensions of the steel packaging, interaction 14.5.
1.13a Cement hydration	The hydration of cement in the waste matrix will generate heat that can affect the temperature in the waste matrix, dependent on the extent of hydration after repository closure. The extent of hydration is in turn dependent on the type and amount of cement in the waste matrix and the time since the production of the waste package.	Time between production of the cement-conditioned waste packages and repository closure is assessed to be long enough for total decay of heat generation due to cement hydration.
1.16b Corrosion	The type and amount of metals in the waste matrix will affect the mode and rate of corrosion of these and thereby the liberation of radionuclides and toxicants included in the metals. This will affect the distribution between mobile and immobile radionuclides and toxicants in the waste/cement matrix. Includes also colloid formation. The presence of different type of metals may give rise to galvanic corrosion.	Negligible amount, if any, of induced activity in metal waste
2.5 Expansion/contraction	Changes in volume and dimensions of the waste and matrix may cause expansion/contraction of the materials and voids in the steel packaging thereby affecting the volume and dimensions of the materials and voids in the steel packaging	Salt and ion exchange resins in the bitumen matrix will take up water and expand in volume. This will affect the stress conditions in the bitumen matrix and make the whole bitumen matrix to expand. This change in volume and dimensions of the waste and bitumen matrix will probably primarily affect the stress conditions, i.e. interaction 2.14, which in turn will affect the volume and dimensions of the surrounding steel packaging, interaction 14.5.
2.10d Sorption	The type and amount of materials in the waste matrix will affect the sorption of dissolved components and colloids and thereby the composition of the water in the the waste/bitumen matrix.	Sorption on bitumen negligibly small, if any.

Interaction/process in Repository matrix	Description	Motivation
2.10e Colloid filtering	The amount and size of pores/fractures in the waste matrix will affect the filtering of colloids/particles and thus the amount of colloids/particles in the water in the waste matrix and in surrounding system components.	Difficult to quantify. Furthermore a positive effect.
2.16e Colloid filtering	The amount and size of pores/fractures in the waste matrix will affect the filtering of radioactive and toxic colloids/particles and thus the amount of radioactive and toxic colloids/particles in the water in the waste matrix and in surrounding system components.	Difficult to quantify. Furthermore a positive effect.
3.4 Expansion/contraction	Changes in volume and dimensions of the waste and void may cause expansion/contraction of the materials and voids in the concrete packaging thereby affecting the volume and dimensions of the materials and voids in the concrete packaging	Should be enough expansion volume inside the waste package to take up any changes in waste volume that may occur without significantly affecting the stress conditions in the waste package and/or the volume and dimensions of the concrete packaging
3.5 Expansion/contraction	Changes in volume and dimensions of the waste and void may cause expansion/contraction of the materials and voids in the steel packaging thereby affecting the volume and dimensions of the materials and voids in the steel packaging	Should be enough expansion volume inside the waste package to take up any changes in waste volume that may occur without significantly affecting the stress conditions in the waste package and/or the volume and dimensions of the steel packaging
3.10d Diffusion	The physical properties (porosity etc) of the waste affect the diffusive transport of dissolved components through the waste and thereby the composition of the water inside the waste packaging and in surrounding system components.	Could have some effect on the dissolution and transport in some waste types. However, difficult to quantify and probably conservative to assume immediate mixing inside the waste container.
3.10e Sorption	The type and amount of materials in the waste will affect the sorption of dissolved components and colloids and thereby the composition of the water inside the waste packaging.	Of negligible importance for the main constituents in the water. Sorption onto steel corrosion products could maybe be of importance for complexing agents and colloids, but small amounts and conservative to neglect.
3.10f Colloid filtering	The amount and size of pores/voids in the waste will affect the filtering of colloids/particles and thus the amount of colloids/particles in the water inside the waste packaging and in surrounding system components.	Probably small effect, if any, and difficult to quantify. Furthermore, a positive effect.
3.11b Capillary suction	The poresize distribution of the waste will affect the capillary suction of water into the waste and thus the degree of saturation of the waste and packagings during the saturation phase	Difficult to quantify the poresize distribution of the waste and the surrounding void inside the waste packages is quite large. The size of this void will affect the time for saturation after repository closure, see 3.11a, but other effects are probably negligible.
3.13a Heat conduction	The thermal properties of the waste, i.e. heat capacity and heat conductivity, and dimensions will affect the heat conduction inside the packaging and thereby the temperature in the waste and surrounding system components	Even if there are uncertainties regarding the importance of heat generating processes in this type of waste after repository closure (see 3.13b) this interaction is assessed as being of negligible importance for the temperature in the waste package and in the surroundings. This is because the waste is non-solidified and the temperature in the waste packages is therefore more dependent on the heat transport in the surrounding barriers.

Interaction/process in Repository matrix	Description	Motivation
3.14 Expansion/ contraction	Changes in geometry and dimensions of the waste may affect the stress conditions in the waste and surrounding packaging	Should be enough expansion volume inside the waste package to take up any changes in waste volume that may occur without affecting the stress conditions in the waste package.
3.16b Corrosion	The type and amount of metals in the waste will affect the mode and rate of corrosion of these and thereby the liberation of radionuclides and toxicants included in these. This will affect the distribution between mobile and immobile radionuclides and toxicants inside the waste packaging. Includes also colloid formation. The presence of different type of metals may give rise to galvanic corrosion.	Negligible amount, if any, of induced activity in metal waste
3.16d Diffusion	The physical properties (porosity etc) of the waste affect the diffusive transport of dissolved radionuclides and toxicants through the waste and thereby the concentration of radionuclides and toxicants in the water inside the waste packaging and in surrounding system components.	Could have some effect on the dissolution and transport in some waste types. However, difficult to quantify and probably conservative to assume immediate mixing inside the waste container.
3.16f Colloid filtering	The amount and size of pores/voids in the waste will affect the filtering of radioactive and toxic colloids/particles and thus the amount of radioactive and toxic colloids/particles in the water inside the waste packaging and in surrounding system components.	Probably small effect, if any, and difficult to quantify. Furthermore, a positive effect.
4.1 Expansion/contraction	Changes in volume and dimensions of the materials and voids in the concrete packaging may cause expansion/contraction of the waste and matrix thereby affecting the volume and dimensions of the materials and voids in the waste and matrix	Change in volume and dimensions of the concrete packaging will probably primarily affect the stress conditions, i.e. interaction 4.14, and not the volume and dimensions of the cement-conditioned waste.
4.6 Expansion/contraction	Changes in volume and dimensions of the materials and voids in the concrete packaging may cause expansion/contraction of the concrete backfill thereby affecting the volume and dimensions of the concrete backfill	Change in volume and dimensions of the concrete packaging will probably primarily affect the stress conditions, i.e. interaction 4.14, and not the volume and dimensions of the concrete backfill.
4.13a Cement hydration	The hydration of cement in the concrete packaging will generate heat that can affect the temperature in the packaging, dependent on the extent of hydration after repository closure. The extent of hydration is in turn dependent on the type and amount of cement in the packaging and the time since the production of the packaging	Time between production of the concrete waste packages and repository closure is assessed to be long enough for total decay of heat generation due to cement hydration.
5.1 Expansion/contraction	Changes in volume and dimensions of the materials and voids in the steel packaging may cause expansion/contraction of the waste and matrix thereby affecting the volume and dimensions of the materials and voids in the waste and matrix	Change in volume and dimensions of the steel packaging will probably primarily affect the stress conditions, i.e. interaction 5.14, or the internal void in waste packages with non-solidified waste, i.e. interaction 5.3, and not the volume and dimensions of the cement-conditioned waste.

Interaction/process in Repository matrix	Description	Motivation
5.2 Expansion/contraction	Changes in volume and dimensions of the materials and voids in the steel packaging may cause expansion/contraction of the waste and bitumen matrix thereby affecting the volume and dimensions of the materials and voids in the waste and bitumen matrix	Change in volume and dimensions of the steel packaging will probably primarily affect the stress conditions, i.e. interaction 5.14, or the internal void in waste packages with non-solidified waste, i.e. interaction 5.3, and not the volume and dimensions of the bituminised waste.
5.6 Expansion/contraction	Changes in volume and dimensions of the materials and voids in the steel packaging may cause expansion/contraction of the concrete backfill thereby affecting the volume and dimensions of the concrete backfill	Change in volume and dimensions of the steel packaging will probably primarily affect the stress conditions, i.e. interaction 5.14, or the internal void in waste packages with non-solidified waste, i.e. interaction 5.3, and not the volume and dimensions of the concrete backfill.
5.10c Degradation of organics	The type and amount of organic materials on/in the steel packaging will affect the chemical and microbial degradation of these organics and thus the water composition in the steel packaging. Includes also colloid formation.	The amount of organics (paint on the outside of the packaging) is assessed to be too small to be of any importance. Organics in the waste and as cement and concrete additives will be more important in this aspect.
5.10d Diffusion	The physical properties (porosity etc) of the steel packaging affect the diffusive transport of dissolved components through the waste matrix and thereby the composition of the water in the steel packaging and in surrounding system components.	Could be important for the release of components dissolved from cement/concrete inside the packagings, but it is conservative to neglect the potential diffusion resistance in the packaging
5.10e Sorption	The type and amount of materials in the steel packaging will affect the sorption of dissolved components and colloids and thereby the composition of the water in the the steel packaging.	Of negligible importance for the main constituents in the water. Could maybe be of importance for complexing agents and colloids, but conservative to neglect.
5.10f Colloid filtering	The amount and size of pores/fractures in the steel packaging will affect the filtering of colloids/particles and thus the amount of colloids/particles in the water in the steel packaging and in surrounding system components.	Probably small effect and difficult to quantify. Furthermore, a positive effect.
5.10g Erosion	The chemical and physical properties of the steel packaging affects its ability to withstand mechanical erosion and thus the amount of colloids/particles in the water in contact with the steel packaging.	Small water velocities expected and therefore colloid formation due to mechanical erosion assessed to be negligible compared to colloids formed by dissolution/precipitation reactions.
5.11b Capillary suction	The poresize distribution of the steel packaging will affect the capillary suction of water into the steel packaging and thus the degree of saturation of the steel packaging, waste and concrete backfill during the saturation phase	Negligible amount of corrosion products is present during the resaturation phase. Furthermore capillary suction in corrosion products assessed to be less important than capillary suction in cement/concrete.
5.12b Degradation of organics	The type and amount of organic materials in the steel packaging (surface coating) will affect the microbial and chemical degradation of these and thus the amount and composition of gas outside the steel packaging.	Negligible gas source compared to corrosion.

Interaction/process in Repository matrix	Description	Motivation
5.12c Gas flow	Dimensions and physical properties of the steel packaging will affect the magnitude, direction and distribution of gas flow in the steel packaging and in surrounding components of the repository system.	Will be of negligible importance for gas generated outside the waste packages. Gas generation inside the steel waste packages requires water intrusion into the packages, e.g. the steel packaging is not water tight. If water can penetrate the steel packaging then gas can leave.
5.13 Heat conduction	The thermal properties of the steel packaging, i.e. heat capacity and heat conductivity, and dimensions will affect the heat conduction in the packaging and thereby the temperature in the waste packages and surrounding system components	Heat transport in the steel packaging is important in order to keep the temperature increase in the waste packages low if there are heat -enerating processes in the waste packages. However, heat transport in steel is fast and the thickness is small compared to the transport distance for heat in concrete. It is therefore assessed that it is not important to address the heat transport in steel packagings in SFR.
5.15 Microbial activity	Type and amount of organic materials and nutrients and energy sources on/in the steel packaging and physical properties of the packaging will affect the microbial activity in the packaging and thus the type and amount of microbes in the packaging	Microbial activity may occur on the steel packaging, but this activity will most likely not be dependent on the properties of the steel packaging.
5.16c Colloid filtering	The amount and size of pores/fractures in the steel packaging will affect the filtering of radioactive and toxic colloids/particles and thus the amount of radioactive and toxic colloids/particles in the water in the steel packaging and in surrounding system components.	Probably small effect and difficult to quantify. Furthermore conservative to neglect.
6.4 Expansion/contraction	Changes in volume and dimensions of the materials and voids in the concrete backfill may cause expansion/contraction of the concrete packaging thereby affecting the volume and dimensions of the concrete packaging	Change in volume and dimensions of the concrete backfill will probably primarily affect the stress conditions, i.e. interaction 6.14, and not the volume and dimensions of the concrete packaging.
6.5 Expansion/contraction	Changes in volume and dimensions of the materials and voids in the concrete backfill may cause expansion/contraction of the steel packaging thereby affecting the volume and dimensions of the steel packaging	Change in volume and dimensions of the concrete backfill will probably primarily affect the stress conditions, i.e. interaction 6.14, and not the volume and dimensions of the steel packaging.
6.7 Expansion/contraction	Changes in volume and dimensions of the concrete backfill may affect the dimensions and volume of the concrete structures	Change in volume and dimensions of the concrete backfill will primarily affect the stress conditions, i.e. interaction 6.14, and not the volume and dimensions of the concrete structures.
6.12a Degradation of organics	The type and amount of organic materials in the concrete backfill will affect the microbial and chemical degradation of these and thus the amount and composition of gas in the concrete backfill.	Small amount of organics in concrete backfill and therefore negligible gas source compared to gas from degradation of organics in waste and corrosion of metals in the repository.
6.13a Cement hydration	The hydration of cement in the concrete backfill will generate heat that can affect the temperature in the backfill, dependent on the extent of hydration after repository closure. The extent of hydration is in turn dependent on the type and amount of cement in the backfill and the time since the emplacement of the backfill.	Time between construction of the concrete structures and repository closure is assessed to be long enough for total decay of heat generation due to cement hydration.

Interaction/process in Repository matrix	Description	Motivation
7.6 Expansion/contraction	Changes in volume and dimensions of the concrete structures may affect the dimensions and volume of the concrete backfill	Change in volume and dimensions of the concrete structures will primarily affect the stress conditions, i.e. interaction 7.14, and not the volume and dimensions of the concrete backfill.
7.12b Degradation of organics	The type and amount of organic materials in the concrete structures will affect the microbial and chemical degradation of these and thus the amount and composition of gas in the concrete structures.	Small amount of organics in concrete structures and therefore negligible gas source compared to gas from corrosion of reinforcements.
7.13a Cement hydration	The hydration of cement in the concrete structures will generate heat that can affect the temperature in the structures, dependent on the extent of hydration after repository closure. The extent of hydration is in turn dependent on the type and amount of cement in the concrete structures and the time since the construction of the concrete structures.	Time between construction of the concrete structures and repository closure is assessed to be long enough for total decay of heat generation due to cement hydration.
8.7 Bentonite expansion	Intrusion of bentonite into fractures in the concrete structures in the Silo. Includes also the potential sedimentation of liberated bentonite particles in the fractures.	Probably small and positiv effect.
8.12a Degradation of organics	The type and amount of organic materials in the bentonite barriers in the Silo will affect the microbial and chemical degradation of these and thus the amount and composition of gas in the bentonite barriers.	Too small amount of organics in the bentonite barriers to contribute to the gas in the barriers compared to the amount of gas generated in the interior of the Silo and subsequently flowing through the bentonite barriers.
8.18a Bentonite expansion	Bentonite expansion into fractures in the surrounding rock affecting the permeability of these fractures. Includes also the potential sedimentation of liberated bentonite particles in the fractures. (GEO 1.8)	Probably small and positive effect.
9.4 Expansion/contraction	Changes in volume and dimensions of the backfill material and voids in the vault may cause expansion/contraction of the materials and voids in the concrete packaging thereby affecting the volume and dimensions of the materials and voids in the concrete packaging.	No such volume changes of the backfill material are expected in the base scenario.
9.5 Expansion/contraction	Changes in volume and dimensions of the backfill material and voids in the vault may cause expansion/contraction of the materials and voids in the steel packaging thereby affecting the volume and dimensions of the materials and voids in the steel packaging.	No such volume changes of the backfill material are expected in the base scenario.
9.6 Expansion/contraction	Changes in dimensions and volume of vaults and backfill in BTF may affect the dimension and volume of the concrete backfill in BTF.	No such volume changes of the backfill material are expected in the base scenario.
9.7 Expansion/contraction	Changes in volume and dimensions of the repository vaults and the backfill in the vaults may affect the volume and dimensions of the concrete structures.	No such volume changes of the backfill material are expected in the base scenario.

Interaction/process in Repository matrix	Description	Motivation
9.8a Expansion/contraction	Changes in volume and dimensions of the vault and sand layers and backfill at the top of the Silo may affect the volume and dimensions and thereby the density and swelling pressure of the bentonite barriers.	No such volume changes of the backfill material are expected in the base scenario.
9.10d Sorption	The amount and composition of backfill in the vaults will affect the sorption of dissolved components and colloids and thereby the composition of the water in the the backfill and voids in the vaults.	Of no importance for the main constituents in the water. Since colloids could enhance migration of contaminants, sorption of colloids would give a positive effect which here is disregarded.
9.10e Colloid filtering	The amount and size of pores/fractures in the backfill in the vaults will affect the filtering of colloids/particles and thus the amount of colloids/particles in the water in the backfill and voids in the vaults and in other repository system components.	Too large voids/pores in the tunnel backfill to give any filtering effects.
9.12a Degradation of organics	The type and amount of organic materials in the backfill in the vaults will affect the microbial and chemical degradation of these and thus the amount and composition of gas in the backfill in the vaults.	Negligible contribution to gas generation from organic material in the backfill compared to organic material in the waste and gas from corrosion.
9.14 Expansion/ contraction	Geometry and dimensions of the vaults and backfill in vaults will affect the stress conditions in the vaults and adjacent repository system components	Too small chnges in volume and dimensions expected for this to be of importance for the stress conditions in the repository vaults and barriers.
9.16c Colloid filtering	The amount and size of pores/fractures in the backfill and voids in the vaults will affect the filtering of radioactive and toxic colloids/particles and thus the amount of radioactive and toxic colloids/particles in the water in the backfill and voids in the vaults and in surrounding system components.	Too large voids/pores in the tunnel backfill to give any filtering effects.
10.2a Dissolution/precipitation	The water composition in the waste/bitumen matrix affects the dissolution/ precipitation of waste and matrix components and thus the amount, composition, dimensions and porosity of the waste and bitumen matrix.	The composition of water inside the bitumen matrix will affect the dissolution of the waste. The effect of waste dissolution on the properties of the waste and waste matrix is, however, most likely much less important than the effect of the preeceding water uptake, see 10.2c.
10.2b Degradation of organics	The water composition in the waste and bitumen matrix affects the chemical and microbial degradation of organics in the waste and matrix and thus the amount, composition, dimensions and porosity of the waste and bitumen matrix.	Microbes can degrade organic waste and the bitumen matrix, but the effect is assessed to be small compared to the effect of water uptake.
10.3a Dissolution/precipitation	The water composition in the waste affects the dissolution/ precipitation of waste components and thus the amount, composition, dimensions and porosity of the waste.	Dissolution/precipitation of waste components may lead to volume and geometry changes of the waste, but these changes are probably of negligible importance for the function of the waste packages. The initial void in the packages with unconditioned waste is probably large enough.

Interaction/process in Repository matrix	Description	Motivation
10.3c Degradation of organics	The water composition in the waste affects the chemical and microbial degradation of organics in the waste and thus the amount, composition, dimensions and porosity of the waste.	Degradation of organic waste components may lead to volume and geometry changes of the waste, but these changes are probably of negligible importance for the function of the waste packages. The initial void in the packages with unconditioned waste is probably large enough.
10.3d Water uptake	The gradient in ionic strength in the waste (ion-exchange resins) affects the uptake of water and thus the geometry, structure and volume of the waste	The ion-exchange resins are not dried, only dewatered, and the expansion will therefore be small. Furthermore, there is an expansion volume inside the package.
10.4c Degradation of organics	The water composition in the concrete packaging affects the chemical and microbial degradation of organics in the concrete packaging and thus the composition, dimensions and porosity of the concrete packaging.	Too small amounts of organics for degradation of these to have any affect on concrete properties.
10.5a Dissolution/precipitation	The water composition in the steel packaging affects the dissolution/precipitation of components in the packaging and thus the composition, dimensions and porosity of the steel packaging.	Corrosion products are the only components that are identified as being exposed to dissolution/precipitation. This should be treated as a part of corrosion, see 10.5.b.
10.5c Degradation of organics	The water composition in the steel packaging affects the chemical and microbial degradation of organics in the steel packaging (e.g. surface coating) and thus the composition, dimensions and porosity of the steel packaging.	Effects on packaging properties of negligible importance in comparison to other processes, e.g. corrosion.
10.6b Degradation of organics	The water composition in the concrete backfill affects the chemical and microbial degradation of organics in the backfill and thus the composition, dimensions and porosity of the concrete backfill.	Too small amounts of organics in the backfill for degradation of these to affect the properties of the backfill
10.7c Degradation of organics	The water composition in the concrete structures affects the chemical and microbial degradation of organics in the concrete structures and thus the composition, dimensions and porosity of the concrete structures.	Too small amounts of organics for degradation of these to have any effect on the overall properties of the concrete.
10.8b Degradation of organics	The water composition in the bentonite barriers in the Silo affects the chemical and microbial degradation of organics in the bentonite barriers and thus the composition and porosity of the bentonite barriers.	Small amount of organics and degradation of these is not expected to affect the properties of the bentonite barriers.
10.9b Degradation of organics	The water composition in the backfill in the vaults (including sand backfill in the Silo) affects the chemical and microbial degradation of organics in the backfill and thus the composition and porosity of the backfill in the vaults.	Too small amounts of organics to result in any changes in backfill properties if consumed.
10.11a Water flow	The water composition in the different components of the system will affect the density and viscosity of the water and thus the magnitude of the water flow in the different components of the repository system.	Too small variations in water composition to be of importance compared to uncertainties in hydraulic properties of the near-field barriers.

Interaction/process in Repository matrix	Description	Motivation
10.11b Convection	The salinity of the water will affect the density of the water and gradients in density will affect the magnitude, direction and distribution of water flow in the different components of the repository system. The water density is also affected by changes in temperature, see 13.10b.	Too small gradients in salinity in the repository scale. However, could be of importance in a larger scale since gradients in salinity are expected as a consequence of land rise, see GEO 10.11a.
10.12a Gas dissolution/degassing	The water composition, e.g. concentration of dissolved species and amount and composition of dissolved gas, affects the dissolution of gas and degassing. This will influence the amount and composition of gas in gas phase in the different parts of the repository system	Small effect of water composition on gas solubilities and thus negligible effect on the amount and composition of gas
10.12b Chemical reactions	Changes in water composition that causes gas generation or consumption of gas, e.g. changes in pH that affects the amount of CO2.	The amount of gas consumed or generated by this mechanism is expected to be small compared to the amount of gas generated in the repository by degradation of organics and by corrosion.
10.13 Heat transport	The water composition in the different components of the repository system will affect the thermal properties of the water and thus the heat transport by conduction and advection in the water phase and the temperature in the different parts of the repository system	The effect of water composition on thermal properties is negligibly small and thus also on heat transport and temperature
10.16b Corrosion	The composition of the water in contact with metal waste affects the corrosion and the liberation of induced activity from metal waste and toxic metal elements and thus the distribution of mobile and immobile radionuclides and toxicants in the waste.	The amount of induced activity in SFR is very small. Furthermore, conservative to neglect limitations in release of induced activity.
11.1a Dissolution/precipitation	The amount of water (degree of saturation) in the waste and cement matrix affects the dissolution/ precipitation of waste and matrix components and thus the amount, composition, dimensions and porosity of the waste and cement matrix.	Gas inside the waste matrix, e.g. from corrosion of metal waste, could delay the dissolution. However, difficult to quantify and conservative to neglect.
11.1b Corrosion	The amount of water (degree of saturation) in the waste and cement matrix affects the corrosion of metals in the waste and thus the amount, composition, dimensions and porosity of the waste and cement matrix. Induces volume changes due to formation of corrosion products.	Even if not fully water saturated there is probably enough water to maintain steel corrosion. Furthermore, conservative to neglect potential reduction in corrosion due to presence of gas.
11.1c Degradation of organics	The amount of water (degree of saturation) in the waste and cement matrix affects the chemical and microbial degradation of organics in the waste and matrix and thus the amount, composition, dimensions and porosity of the waste and cement matrix.	Gas inside the waste matrix, e.g. from corrosion of metal waste, could delay the degradation. However, difficult to quantify and conservative to neglect.
11.2a Dissolution/precipitation	The amount of water (degree of saturation) in the waste/bitumen matrix affects the dissolution/ precipitation of waste and matrix components and thus the amount, composition, dimensions and porosity of the waste and bitumen matrix.	The amount of water inside the bitumen matrix will affect the dissolution of the waste. The effect of waste dissolution on the properties of the waste and waste matrix is, however, most likely much less important than the effect of the preeceding water uptake, see 11.2c.

Interaction/process in Repository matrix	Description	Motivation
11.2b Degradation of organics	The amount of water (degree of saturation) in the waste and bitumen matrix affects the chemical and microbial degradation of organics in the waste and matrix and thus the amount, composition, dimensions and porosity of the waste and bitumen matrix.	Microbes can degrade organic waste and the bitumen matrix, but the effect is assessed to be small compared to the effect of water uptake.
11.3a Dissolution/precipitation	The amount of water (degree of saturation) in the waste affects the dissolution/ precipitation of waste components and thus the amount, composition, dimensions and porosity of the waste.	Gas inside the waste packages, e.g. from corrosion of metal waste, could delay the dissolution. However, difficult to quantify and conservative to neglect.
11.3b Corrosion	The amount of water (degree of saturation) in the waste affects the corrosion of metals in the waste and thus the amount, composition, dimensions and porosity of the waste. Induces volume changes due to formation of corrosion products.	The supply of water should be enough to maintain corrosion.
11.3c Degradation of organics	The amount of water (degree of saturation) in the waste affects the chemical and microbial degradation of organics in the waste and thus the amount, composition, dimensions and porosity of the waste.	Corrosion gases can be present inside the waste packages, but the effect of unsaturated conditions on degradation of organics in the waste is probably small. Furthermore, conservative to neglect the potential presence of gas.
11.3d Water uptake	The amount of water (degree of saturation) and water pressure in the waste and in surrounding system components affects the uptake of water in the waste and thus the geometry, structure and volume of the waste	The ion-exchange resins are not dried, only dewatered, and the expansion will therefore be small. Furthermore, there is an expansion volume inside the package.
11.3e Redistribution	The magnitude, direction and distribution of water flow through the waste packages in BLA will affect the potential for redistribution of the waste material in these packages. Redistribution of the waste materials will affect the geometry of the waste materials and voids in the packages.	Probably too small water flow rates to cause a redistribution of the waste materials inside the containers. Even if redistribution occurs, the resulting changes in geometries and voids inside the containers should be of negligible importance for the function of the repository.
11.4a Dissolution/precipitation	The amount of water (degree of saturation) in the concrete packaging affects the dissolution/precipitation of components in the concrete packaging and thus the composition, dimensions and porosity of the concrete packaging.	Unsaturated conditions in the concrete could delay the dissolution of cement components and concrete additives. However, the water content is probably quite high already at repository closure and the composition of the water is more important for the dissolution.
11.4b Corrosion	The amount of water (degree of saturation) in the concrete packaging affects the corrosion of metal reinforcements in the packaging and thus the composition, dimensions and porosity of the concrete packaging. Induces volume changes due to formation of corrosion products.	The supply of water is assessed to be enough to maintain corrosion
11.4c Degradation of organics	The amount of water (degree of saturation) in the concrete packaging affects the chemical and microbial degradation of organics in the concrete packaging and thus the composition, dimensions and porosity of the concrete packaging.	Unsaturated conditions in the concrete could delay the degradation of organics. However, the water content is probably quite high already at repository closure and the composition of the water is more important.

Interaction/process in Repository matrix	Description	Motivation
11.4d Erosion	Water flowing around and through concrete packaging not surrounded by concrete backfill may cause mechanical erosion of the packaging. This could affect the geometry and porosity of the packaging.	Expected water velocities too small to make effects of erosion significant compared to effects of chemical processes and mechanical impact.
11.5a Dissolution/precipitation	The amount of water (degree of saturation) in the steel packaging affects the dissolution/precipitation of components in the packaging and thus the composition, dimensions and porosity of the steel packaging.	Unsaturated conditions during the saturation phase (short time period) and potential small deviations from water saturated conditions in the long-term perspective are of negligible importance for dissolution/precipitation compared to the composition of the water.
11.5b Corrosion	The amount of water (degree of saturation) in the steel packaging affects the corrosion of the packaging and thus the composition, dimensions and porosity of the steel packaging. Induces volume changes due to formation of corrosion products.	Even during unsaturated conditions the supply of water should be enough to maintain corrosion.
11.5d Erosion	Water flowing around and through the steel packaging in BLA (not surrounded by concrete backfill) may cause mechanical erosion of the corrosion products on the packaging. This could affect the composition as well as the geometry and porosity of the packaging.	The water velocity is probably too low to make effects of erosion of corrosion products important for the poperties of the packaging compared to the effects of chemical processes and mechanical impact.
11.6a Dissolution/precipitation	The amount of water (degree of saturation) in the concrete backfill affects the dissolution/precipitation of components in the backfill and thus the composition, dimensions and porosity of the concrete backfill.	Unsaturated conditions in the concrete could delay the dissolution of cement components and concrete additives. However, the water content is probably quite high already at repository closure and the composition of the water is more important for the dissolution.
11.6b Degradation of organics	The amount of water (degree of saturation) in the concrete backfill affects the chemical and microbial degradation of organics in the backfill and thus the composition, dimensions and porosity of the concrete backfill.	Unsaturated conditions in the concrete could delay the degradation of organics. However, the water content is probably quite high already at repository closure and the composition of the water is more important.
11.6c Erosion	Water flow may cause mechanical erosion of the concrete backfill in 2BTF. This could affect the geometry and porosity of the backfill.	Expected water velocities too small to make effects of erosion significant compared to effects of chemical processes and mechanical impact.
11.7a Dissolution/precipitation	The amount of water (degree of saturation) in the concrete structures affects the dissolution/precipitation of components in the concrete structures and thus the composition, dimensions and porosity of the concrete packaging.	Unsaturated conditions in the concrete could delay the dissolution of cement components and concrete additives. However, the water content is probably quite high already at repository closure and the composition of the water is more important for the dissolution. Furthermore, concrete dissolution is in itself a slow process.
11.7b Corrosion	The amount of water (degree of saturation) in the concrete structures affects the corrosion of metal reinforcements in the structures and thus the composition, dimensions and porosity of the concrete structures. Induces volume changes due to formation of corrosion products.	Even during unsaturated conditions the supply of water should be enough to maintain corrosion.

Interaction/process in Repository matrix	Description	Motivation
11.7c Degradation of organics	The amount of water (degree of saturation) in the concrete structures affects the chemical and microbial degradation of organics in the concrete packaging and thus the composition, dimensions and porosity of the concrete packaging.	Unsaturated conditions in the concrete could delay the degradation of organics. However, the water content is probably quite high already at repository closure or soon after and the composition of the water is more important.
11.7d Erosion	Water flowing around the concrete structures in BMA and shotcrete in all vaults may cause mechanical erosion of these. This could affect the geometry and porosity of the concrete structures in BMA and chotcrete in all vaults.	Expected water velocities too small to make effects of erosion significant compared to effects of chemical processes and mechanical impact.
11.8a Dissolution/precipitation	The amount of water (degree of saturation) in the bentonite barriers in the Silo affects the dissolution/precipitation of components in the bentonite barriers and thus the composition, porosity, homogeneity of the bentonite barriers.	Unsaturated conditions in the bentonite barriers during the saturation phase could delay dissolution reactions. In a long-term perspective this potential delay is probably negligible. Gas produced in the repository and released through the bentonite barriers will only occupy a very small amount of the porosity and the effect should be negligible.
11.8b Degradation of organics	The amount of water (degree of saturation) in the bentonite barriers in the Silo affects the chemical and microbial degradation of organics in the bentonite barriers and thus the composition and porosity of the bentonite barriers.	Unsaturated conditions in the bentonite barriers during the saturation phase could delay degradation reactions. In a long-term perspective this potential delay is probably negligible. Gas produced in the repository and released through the bentonite barriers will only occupy a very small amount of the porosity and the effect should be negligible.
11.8c Ion-exchange	The amount of water (degree of saturation) in the bentonite barriers in the Silo can change the type of adsorbed cation through ion exchange (sorption) by which the physical properties of the adsorbed (interlamellar) water and the ability to form intergranular clay gels are altered. This causes changes in homogeneity, expandability and hydraulic and gas conductivities of the bentonite barriers.	Unsaturated conditions in the bentonite barriers during the saturation phase could delay ion-exchange reactions. In a long-term perspective this potential delay is probably negligible. Gas produced in the repository and released through the bentonite barriers will only occupy a very small amount of the porosity and the effect should be negligible.
11.8e Erosion	Water flowing around and through the bentonite barriers in the Silo may cause mechanical erosion of these. This could affect the composition, geometry, density and porosity of the bentonite barriers in the Silo.	The amount that will be carried away is a fraction of the material that expands into fractures in adjacent rock and thus less important for the properties of the bentonite barriers than expansion into the fractures.
11.9a Dissolution/precipitation	The amount of water (degree of saturation) in the backfill in the vaults (including sand backfill in the Silo) affects the dissolution/precipitation of components in the backfill in the vaults and thus the composition and porosity of the backfill in the vaults.	Unsaturated conditions during the saturation phase could delay dissolution reactions. In a long-term perspective this potential delay is negligible. Gas produced in the repository will only occupy a very small amount of the porosity and the effect should be negligible.
11.9b Degradation of organics	The amount of water (degree of saturation) in the backfill in the vaults (including sand backfill in the Silo) affects the chemical and microbial degradation of organics in the backfill and thus the composition and porosity of the backfill in the vaults.	Unsaturated conditions during the saturation phase could delay degradation reactions. In a long-term perspective this potential delay is negligible. Gas produced in the repository will only occupy a very small amount of the porosity and the effect should be negligible.

Interaction/process in Repository matrix	Description	Motivation
11.9c Erosion	The water flow in the backfill in the vaults (including sand backfill in the Silo) affects the mechanical erosion of the backfill materials and thus the geometry, porosity and homogeneity of the backfill in the vaults.	Expected water velocities too small to make effects of erosion significant compared to effects of chemical processes and mechanical impact.
11.10b Chemical equilibria	The porewater pressure in the different components of the repository system affects the chemical equilibria and thus the water composition in the different components of the repository system.	Too small pressure differences.
11.12b Gas dissolution/degassing	The water pressure in the different components of the repository system affects the gas solubility and thus the amount and composition of gas in gas phase in the different components of the repository system.	Too small pressure differences
11.13 Heat advection	The magnitude, direction and distribution of water flow in the different components of the repository system will affect the heat transport by advection (forced convection) and thus the temperature in the different components of the repository system.	Heat transport by advection negligibly small compared to heat transport by conduction
11.16c Gas dissolution/degassing	The water pressure in the different components of the repository system will affect the solubility of radioactive and chemotoxic gases and thereby the distribution of radionuclides and toxicants between gas and water phase	Too small pressure differences in the repository components
12.13a Heat advection	The magnitude, direction and distribution of gas flow in different components of the repository system may affect the heat transport by advection and thus the temperature in the different components of the repository system.	Heat generation too small for any differences in heat transport parameters to have effect.
12.13b Heat conduction	The degree of saturation in the different components of the repository system affects the heat transport by conduction and thus the temperature in the different components of the repository system	Heat generation too small for any differences in heat transport parameters to have effect.
12.15b Advection-gas	Transport of microbes and bacteria by gas flowing in the different components of the repository system may affect the type and amount of microbes and bacteria in the different components of the repository system.	Negligible transport mechanism for microbes compared to transport by advection
13.1a Kinetics and equilibria	The temperature in the waste/cement matrix will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the materials in the waste/cement matrix.	Too small differences in temperature is expected
13.1b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the waste/cement matrix thereby affecting the dimensions and geometries of these materials.	Too small differences in temperature is expected

Interaction/process in Repository matrix	Description	Motivation
13.2a Kinetics and equilibria	The temperature in the waste/bitumen matrix will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the materials in the waste/bitumen matrix.	Too small differences in temperature is expected
13.2b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the waste/bitumen matrix thereby affecting the dimensions and geometries of these materials.	Too small differences in temperature is expected
13.3a Kinetics and equilibria	The temperature in the non-solidified waste will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the materials in the waste.	Too small differences in temperature is expected
13.3b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the non-solidified waste thereby affecting the dimensions and geometries of these materials.	Too small differences in temperature is expected
13.4a Kinetics and equilibria	The temperature in the concrete packaging will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the materials in the concrete packaging.	Too small differences in temperature is expected
13.4b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the concrete packaging thereby affecting the dimensions and geometries of these materials.	Too small differences in temperature is expected
13.5a Kinetics and equilibria	The temperature in the steel packaging will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the steel packaging.	Too small differences in temperature is expected
13.5b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the steel packaging thereby affecting the dimensions and geometries of the steel packaging.	Too small differences in temperature is expected
13.6a Kinetics and equilibria	The temperature in the concrete backfill will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the materials in the concrete backfill.	Too small differences in temperature is expected
13.6b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the concrete backfill thereby affecting the dimensions and geometries of these materials.	Too small differences in temperature is expected
13.7a Kinetics and equilibria	The temperature in the concrete structures will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the materials in the concrete structures.	Too small differences in temperature is expected

Interaction/process in Repository matrix	Description	Motivation
13.7b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the concrete structures thereby affecting the dimensions and geometries of these materials.	Too small differences in temperature is expected
13.8a Kinetics and equilibria	The temperature in the bentonite barriers in the Silo will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the bentonite barriers in the Silo.	Too small differences in temperature is expected
13.8b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the bentonite barriers in the Silo thereby affecting the dimensions and geometries of these materials.	Too small differences in temperature is expected
13.9a Kinetics and equilibria	The temperature in the backfill in the vaults (including sand layers in the Silo) will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the backfill in the vaults.	Too small differences in temperature is expected
13.9b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the backfill in the vaults (including sand layers in the Silo) thereby affecting the dimensions and geometries of these materials.	Too small differences in temperature is expected
13.10a Kinetics and equilibria	The temperature in the different components of the repository system will affect the kinetics and equilibria of chemical reactions and gas solubilities and thereby the composition of the water in the different components of the repository system.	Too small differences in temperature is expected
13.10b Property changes	The temperature in the different components of the repository system will affect the density and viscosity of the water in the different components of the repository system.	Too small differences in temperature is expected
13.10c Diffusion	The temperature in the different components of the repository system will affect the rate of diffusion of dissolved species and thereby the water composition in the different components of the repository system.	Too small differences in temperature is expected
13.11 Phase changes	The temperature in the different components of the repository system affects the water pressure in the components. Extreme changes in temperature will lead to phase changes like freezing or evaporation. These extreme changes will affect both the water pressure and the amount of water.	Too small differences in temperature is expected
13.12a Expansion/contraction	The temperature in the different components of the repository system will affect the volume and pressure of gas in the system components.	Too small differences in temperature is expected

Interaction/process in Repository matrix	Description	Motivation
13.12b Convection	The temperature in the different components of the repository system will affect the density of the gas and thus the magnitude, directions and distribution of gas flow in the different components of the repository system.	Too small differences in temperature is expected
13.14 Thermal stress interaction	Changes in temperature in the different components of the repository system will affect the stress conditions in components that cannot expand in volume. For components where volume expansion can take place, effects of temperature on stress conditions are considered via volume changes, e.g. by interactions 13.1b - 13.9b and 1.14 - 9.14. Effects of temperature on water flow and thereby on stress go via 13.11 and 11.14.	Too small differences in temperature is expected
13.15 Microbial activity	The temperaure in the different parts of the repository system will affect the microbial activity and thereby the type and amount of microbes and bacteria in the different components of the repository system.	Too small differences in temperature is expected
13.16a Kinetics and equilibria	The temperature in the different components of the repository system will affect the kinetics and equilibria of sorption and dissolution/precipitation reactions and thereby the distribution between mobile and immobile radionuclides and toxicants in the different components of the repository system.	Too small differences in temperature is expected
13.16b Diffusion	The temperature in the different components of the repository system will affect the rate of diffusion of dissolved species and thereby the concentration of radionuclides and toxicants in the water in the different components of the repository system.	Too small differences in temperature is expected
13.16c Soret effect	Temperature gradients in the different components of the repository system may cause diffusion of dissolved species by the Soret mechanism and thereby affect the concentration of radionuclides and toxicants in the water in the different components of the repository system.	Too small differences in temperature is expected
13.17 Heat transport	Heat transport from the silo, BMA, BTF and BLA will affect the temperature in the tunnels (GEO 1.13, GEO 2.13, GEO 3.13, GEO 4.13)	Negligibly small temperature gradients
13.18 Heat transport	Heat transport from the silo, BMA, BTF and BLA will affect the temperature in the repository rock (GEO 1.13, GEO 2.13, GEO 3.13, GEO 4.13)	Negligibly small temperature gradients
14.3 Redistribution	Changes in stress conditions in the non-solidified waste and voids inside the packaging and in surrounding barriers may cause a redistribution of the waste materials thereby affecting the geometry and size of voids and the porosity and homogeneity of the waste materials.	A redistribution of waste materials inside the waste packages may occur, but the effects of such redistribution are assessed to be negligible for the overall function of the repository.

Interaction/process in Repository matrix	Description	Motivation
14.9 Redistribution (subsidence)	Changes in stress conditions in the backfill and voids in the vaults may cause a redistribution of the backfill materials thereby affecting the geometry and size of voids and the porosity and homogeneity of the backfill materials. For example via subsidence.	No subsidence and/or material redistribution caused by changes in stress conditions is believed to give important changes in the properties of vaults and backfill. Effects of rock creep and volume changes of barriers are taken care of in other interactions, i.e. 4.9 - 8.9, and the subsidence that make take place during the water saturation phase is taken care of in interaction 11.9.
14.11 Water pressure interaction	The stress conditions in the different components of the repository system affect the porewater pressure in the system components.	Expected changes in stress conditions not large enough.
16.4 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the concrete packaging.	No influence on composition or structures of the concrete packaging expected because of small amounts of radionuclides and toxicants.
16.5 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the steel packaging.	No influence on composition or structures of the steel packaging expected because of small amounts of radionuclides and toxicants.
16.6 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the concrete backfill.	No influence on composition or structures of the concrete backfill expected because of small amounts of radionuclides and toxicants.
16.7 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the concrete structures.	No influence on composition or structures of the concrete structures expected because of small amounts of radionuclides and toxicants.
16.8 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the bentonite barriers.	No influence on composition or structures of the bentonite barriers expected because of small amounts of radionuclides and toxicants.
16.9 Irradtiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the backfill in vaults.	No influence on composition or structures of the backfill in vaults expected because of small amounts of radionuclides and toxicants.
16.10a Radiolysis	The type and amount of radionuclides in the different components of the repository system may affect the water composition in the components via radiolysis.	Too low activity and large amounts of dissolved Fe(II) from steel corrosion and dissolution of corrosion products.
16.10b Radionuclide decay	Decay of radionuclides to stable isotopes that affect the water composition in the different components of the repository system.	Will most likely result in trace concentrations and not affect the major composition of the water.
16.10c Degradation	Degradation of toxicants from the repository that affects the water composition in the different components of the repository system.	Depends on type and amount of toxicant. Can be of importance if degradation results in complexing agents. However, the amount of toxicants is most likely small and organic toxicants and the degradation of these should be included in interactions 1.10 to 9.10.
16.12b Degradation	The type and amount of organic toxicants from the repository affects the amount and composition of gas via degradation processes.	Negligible compared to gas from steel corrosion
16.15 Irradiation (mutation)	Effects on the biological state of irradiation by decaying radionuclides (mutation).	The amount of radionuclides and other toxicants that originates from the repository is assessed to be too low to have any effect on the biological state in the repository.
17.12 Gas transport	Gas transport in the tunnels will influence the amount and composition of gas in the silo, BMA, BTF and BLA (GEO 12.1, GEO 12.2, GEO 12.3, GEO 12.4)	The gas transport capacity in rock and tunnels is sufficient and does not influence the amount and composition of gas in the repository parts.

Interaction/process in Repository matrix	Description	Motivation
17.13 Heat transport	Heat transport in the tunnels will affect the temperature in the silo, BMA, BTF and BLA (GEO 13.1, GEO 13.2, GEO 13.3, GEO 13.4))	Too small temperature gradients
17.16 Contaminant transport	Transport of radionuclides and toxicants in water and gas phase from the tunnels into the silo, BMA, BTF or BLA will affect the amount of these in the silo, BMA, BTF and BLA. The origin of these contaminants may be the waste and barrier materials in the other repository parts and contaminated water, gas and solids in the biosphere. (GEO 16.1, GEO 16.2, GEO 16.3, GEO 16.4, GEO 11.1, GEO 11.2, GEO 11.3, GEO 11.4,)	It is a positive effect if the radionuclides and toxicants return to repository (the expected transport pathways are treated elsewhere)
18.5 Rock fall out	Changes in stress condition in the repository rock may cause rock fall out that damages the waste packages in BLA. (GEO 14.4)	The containers are not considered as a barrier
18.8b Erosion	Erosion of the external surfaces of the bentonite barriers may affect the density of the barriers bay carrying away material (GEO 11.1c) Comment: interaction added by KS when compiling the documentation from the meeting 1998-02-11	The amount that will be carried away is a fraction of the material that expands into fractures in adjacent rock and thus less important for the properties of the bentonite barriers than expansion into the fractures.
18.8c Rock creep	Changes in stress conditions in the repository rock may cause rock creep that may affect the geometry, homogeneity, density etc of the bentonite barriers in the Silo (GEO 14.1)	Not a large-scale process at considered time. Only marginal effects is expected on bentonite buffer
18.8d Rock fallout	Changes in stress conditions in the repository rock may cause rock creep that may affect the geometry, homogeneity, density etc of the bentonite barriers in the Silo (GEO 14.1)	Not a large-scale process at considered time. Only marginal effects is expected on bentonite buffer
18.9a Rock fall out	Changes in stress conditions in the repository rock may cause rock fall out that affects the dimensions of the silo and the vaults as well as geometry and homogeneity of the backfill in the vaults and in the silo. (GEO 14.1b, GEO 14.2b, GEO 14.3b, GEO 14.4b)	The impact on backfill of rock fallout is judged to be of less importance than the impact on concrete structures in BMA and BTF and on the bentonite buffer in the Silo.
18.9b Rock creep	Changes in stress conditions in the repository rock may cause rock creep that affects the dimensions and geometry of the vaults and homogeneity of the backfill in the vaults. (GEO 14.2c, GEO 14.3c, GEO 14.4c)	Not a large-scale process at considered time. Only marginal effects are expected
18.12 Gas transport	Gas transport in the repository rock will influence the amount and composition of gas in the silo, BMA, BTF and BLA (GEO 12.1, GEO 12.2, GEO 12.3, GEO 12.4)	The gas transport capacity in rock and tunnels is sufficient and does not influence the amount and composition of gas in the repository parts.

Interaction/process in Repository matrix	Description	Motivation
18.13 Heat transport	Heat transport in the repository rock will affect the temperature in the silo, BMA, BTF and BLA (GEO 13.1, GEO 13.2, GEO 13.3, GEO 13.4))	Too small temperature gradients
18.16 Contaminant transport	Transport of radionuclides and toxicants in water and gas phase from the repository rock into the silo, BMA, BTF or BLA will affect the amount of these in the silo, BMA, BTF and BLA. The origin of these contaminants may be the waste and barrier materials in the other repository parts and contaminated water, gas and solids in the biosphere. (GEO 16.1, GEO 16.2, GEO 16.3, GEO 16.4, GEO 11.1, GEO 11.2, GEO 11.3, GEO 11.4)	It is a positive effect if the radionuclides and toxicants return to repository (the expected transport pathways are treated elsewhere)

Interaction/process in Geosphere matrix	Description	Motivation
1.8 Bentonite expansion	Bentonite expansion into fractures in the surrounding rock affecting the permeability of these fractures. Includes also the potential sedimentation of liberated bentonite particles in the fractures. (REP 8.18a)	Probably small and positiv effect.
1.13 Heat transport	Heat transport from the silo will affect the temperature in the tunnels and in the repository rock (REP 13.17, REP 13.18)	Negligibly small temperature gradient between the Silo and its surroundings
2.13 Heat transport	Heat transport from the BMA will affect the temperature in the tunnels and in the repository rock (REP 13.17, REP 13.18)	Negligibly small temperature gradient between the BMA and its surroundings
3.13 Heat transport	Heat transport from the BTF will affect the temperature in the tunnels and in the repository rock (REP 13.17, REP 13.18)	Negligibly small temperature gradient between the BTF and its surroundings
4.13 Heat transport	Heat transport from the BLA will affect the temperature in the tunnels and in the repository rock (REP 13.17, REP 13.18)	Negligibly small temperature gradient between the BLA and its surroundings
4.14 Stress and strain changes	Changes in stress and strain at the boundary between the BLA and the tunnels or repository rock affects the stress conditions in the tunnels and in the rock (REP 14.17, REP 14.18)	No backfill in BLA and thus no impact
5.8 Bentonite expansion	Expansion of bentonite used as backfill in investigation bore holes into fractures in the rock adjacent to the boreholes may affect the apertures and connectivity of these fractures. Includes also the potential sedimentation of liberated bentonite particles in the fractures.	Probably small and positiv effect.

Interaction/process in Geosphere matrix	Description	Motivation
5.9 Bentonite expansion	Expansion of bentonite used as backfill in investigation bore holes into fractures in the rock adjacent to the boreholes may affect the apertures and connectivity of these fractures. Includes also the potential sedimentation of liberated bentonite particles in the fractures.	Probably small and positiv effect.
5.10b Corrosion	Corrosion of rock bolts and reinforcement in shotcrete on the tunnel walls may affect the composition of the water in the tunnels. Includes also colloid formation.	Too small amounts to have any significant effects
5.10d Sorption	The mineralogy and surface area of the tunnel backfill and shotcrete on tunnel walls affects the sorption of dissolved components and colloids and thereby the composition of the water in the tunnels.	Of no importance for the main constituents in the water and of negligible effect on colloid amounts because of small surface area of tunnel walls and backfill (the tunnels will most likely be backfilled with large sized rock pieces/blocks). Since colloids could enhance migration of contaminants, sorption of colloids would give a positive effect, which here is disregarded.
5.10e Colloid filtering	The porosity of the tunnel backfill and backfill in investigation boreholes affects the filtering of colloids/particles and thus the amount of these in the water in the plugs, tunnels and rock.	Too large voids/pores in the tunnel backfill to give any filtering effects. The effect in the backfill in the investigation boreholes depends on the type of backfill material, but it is conservative to neglect any effects.
5.12b Corrosion-gas generation	Corrosion of rock bolts and reinforcement in shotcrete on the tunnel walls may generate hydrogen gas and thereby affect the amount, composition and pressure of gas in the tunnels.	Small amounts of iron and thus a negligible gas source compared to gas from the repository.
5.12c Microbial activity-gas generation	Microbial degradation of organic materials in the tunnels and in the boreholes may generate gas and thereby affect the amount, composition and pressure of gas in the tunnels and the boreholes.	Negligible gas source compared to gas from the repository. Gas potentially generated in backfilled boreholes would be small enough to either dissolve in the water or escape through fractures in surrounding rock without creating any over-pressures.
5.13 Heat conduction	The thermal properties of the tunnels and backfilled rock (geometries and composition) affect the heat conduction in the materials and thereby the temperature in the tunnels as well as in plugs and rock. Includes also the effect of boreholes and backfill in boreholes.	Too small gradient in temperature
6.5a Redistribution	Changes in the dimensions of plugs (e.g. due to degradation of the concrete part) may cause movements of the tunnel backfill which in turn may affect the geometry and physical properties of the backfill (porosity etc)	The primary function of the plugs is not to act as a support for the backfill, and any movement of the backfill that can take place is of minor concern.
6.5b Bentonite expansion	If the concrete part of the plugs are degraded and lost the bentonite in the plugs may expand into the surrounding backfill and thereby affect the porosity of the backfill close to the plugs. Includes also the potential sedimentation of liberated bentonite particles in the backfill.	Since this is a very local effect the overall effect on the backfill properties is negligible. Furthermore the result is an improvement of the backfill properties close to the plugs and thus conservative to neglect.

Interaction/process in Geosphere matrix	Description	Motivation
6.8 Bentonite expansion	Expansion of bentonite in plugs into fractures in the rock adjacent to the plugs may affect the apertures and connectivity of these fractures. Includes also the potential sedimentation of liberated bentonite particles in the fractures.	Probably small and positiv effect.
6.10d Sorption/ion exchange	The composition of concrete and bentonite in plugs affects the sorption/ion-exchange of dissolved components and colloids and thereby the composition of the water in the plugs.	Small amounts of concrete and bentonite and will only affect trace components and not the main constituents in the water. Small amounts also mean small surface areas available for sorption/ ion exchange and thereby negligible effect on sorption of colloids/particles.
6.10e Corrosion	Corrosion of steel reinforcement in plugs on may affect the composition of the water in the plugs. Includes also colloid formation.	Negligible effect on water composition due to very small amounts of reinforcement in plugs.
6.10g Colloid formation	The chemical and physical properties of the plugs affects its ability to withstand mechanical erosion and dispersion of clay particles and thus the amount of colloids/particles in the water in the backfill	The amount of material in the plugs is very small compared to the amount of other materials in the repository and its surroundings that can generate colloids.
6.11b Capillary suction	The poresize distribution of the materials in the plugs will affect the capillary suction of water into the plugs and thus the degree of saturation of the plugs during the saturation phase	Of minor importance for the overall saturation process. Not meaningful to analyse at that level of detail before the exact design and location of plugs are finally decided.
6.12b Corrosion-gas generation	Corrosion of reinforcement in plugs may generate hydrogen gas and thereby affect the amount, composition and pressure of gas in the plugs.	Small amounts of iron and thus a negligible gas source compared to gas from the repository.
6.12c Microbial activity-gas generation	Microbial degradation of organic materials in the plugs may generate gas and thereby affect the amount, composition and pressure of gas in the plugs.	Small amounts of organic materials and thus a negligible gas source compared to gas from the repository.
6.13 Heat conduction	The thermal properties of the plugs (geometries and composition) affect the heat conduction in the plugs and thereby the temperature in the plugs as well as in tunnels and rock.	Too small temperature gradients
6.15 Microbial activity	The presence of organic materials, nutrients and energy sources in the plugs will affect the population and activity of microbes and bacteria in the plugs	Too small amounts from the plugs to give a significant contribution compared to the contribution from other sources.
6.16a Sorption	The amount and composition of bentonite and concrete in plugs will affect the sorption of radionuclides and toxicants on these materials and thereby the concentration of mobile contaminants in the water in the plugs. Saturation of sorption sites and non-linear sorption effects should be considered.	Negligible sorption capacity in the plugs compared to the sorption capacity of other materials in the geosphere, e.g. tunnel backfill and rock
6.16b Diffusion	The dimensions and porosity of the bentonite and concrete in plugs will affect the diffusive transport of radionuclides and toxicants in the plugs and thereby the concentration of contaminants in the water in the plugs, tunnels and rock.	Too short diffusion lengths to have any effect on the overall migration in the geosphere.

Interaction/process in Geosphere matrix	Description	Motivation
7.10c Sorption	The composition of the repository rock matrix and internal pore surfaces will affect the sorption of dissolved species and colloids and thereby the composition of the water in the repository rock.	Will have negligible effect on the main composition of the water. Could have som effect on the sorption of colloids if colloids can move in pores in the matrix. This effect probably small compared to the sorption of colloids on fracture surfaces and anyhow conservative to neglect.
7.11 Capillary suction	The pore-size distribution of the rock matrix in the repository rock will affect the capillary suction of water into the rock matrix and thus the degree of saturation of the rock matrix during the saturation phase	Should have a marginal effect only on the time for resaturation and the flow paths during the resaturation phase.
7.12a Microbial activity	Microbial degradation of organic materials in the rock matrix in the repository rock may generate gas and thereby affect the amount, composition and pressure of gas in the rock matrix.	Negligible gas source compared to gas released from the repository
7.12b Radon generation	Radon generation in the matrix of the repository rock due to decay of naturally occurring radionuclides in the rock minerals.	Negligible gas source compared to gas release from the repository. In addition radon gas is a natural radionuclide and in the analysis only radionuclides from the repository is included.
7.13 Heat conduction	The mineralogy of the rock matrix in the repository rock affects the heat conduction in the rock and thereby the temperature in the repository rock, tunnels and rock outside the repository area.	Too small temperature gradients
7.15 Microbial activity	The presence of organic materials, nutrients and energy sources in the rock matrix in the repository rock will affect the population and activity of microbes and bacteria in the repository rock	Microbial activity in the rock matrix is assessed to be negligibly small compared to microbial activity on fracture surfaces, because of small space and limited supply of organics, nutrients and energy sources.
8.5 Bentonite expansion	Bentonite used as backfill in investigation boreholes may expand into fractures in the rock adjacent to the holes. The extent of swelling will depend on the amount and apertures of these fractures and the expansion may affect the density and homogeneity of the bentonite in the boreholes.	Most likely only small, local effects that do not influence the overall function of the backfill in the investigation boreholes.
8.10c Sorption	The composition of the fracture minerals in the repository rock will affect the sorption of dissolved species and colloids and thereby the composition of the water in the repository rock.	Will have negligible effect on the main composition of the water. Could have som effect on the sorption of colloids and thus on the amount of colloids in the water, but this effect is conservative to neglect.
8.10d Colloid filtering	The porosity and the fracture apertures in the repository rock fracture system affects the filtering of colloids/particles and thus the amount of these in the water	Most of the colloids will be transported in the larger fractures where there are no filtering effects. Moreover, filtering of colloids is a positive effect and thus conservative to neglect.
8.10e Erosion	The chemical and physical properties of the fractures in the repository rock affects its ability to withstand mechanical erosion and thus the amount of colloids/particles in the water in the backfill	The expected flow rates are low and liberation of colloids/particles by erosion should therefore be small compared to chemical formation of colloids/particles (e.g. natural organic colloids in the water).

Interaction/process in Geosphere matrix	Description	Motivation
8.11b Capillary suction	The apertures of fractures in the repository rock will affect the capillary suction of water into the fractures and thus the degree of saturation of the fractures during the saturation phase	Large fractures do not have any capillary suction. Small fractures have such small volume that they will not affect the hydrology. Pores in fracture minerals will not be drained during the pre-closure phase because even if the interior of the fractures is drained some water will flow on the surface of the fractures.
8.12b Microbial activity	Microbial degradation of organic materials on the fracture surfaces in the repository rock may generate gas and thereby affect the amount, composition and pressure of gas in the repository rock.	Too small gas source to be of importance. Much more gas is generated in the repository and this gas has to escape through the geosphere.
8.12c Radon generation	Radon generation in the fractures of the repository rock due to decay of naturally occurring radionuclides in the minerals of fracture coatings.	Negligible radon source compared to the rock matrix, which in turn generates small amounts of gas in relation to the gas released from the repository. In addition radon gas is a natural radionuclide and in the analysis only radionuclides from the repository is included.
8.13 Heat conduction	The mineralogy of fracture coatings as well as the frequency, apertures and connectivity of fractures in the repository rock affect the heat conduction in the fractures and thereby the temperature in the repository rock, tunnels and rock outside the repository area	Too small temperature gradients
9.5 Bentonite expansion	Bentonite used as backfill in investigation bore holes may expand into fractures in the rock adjacent to the holes. The extent of swelling will depend on the amount and apertures of these fractures and the expansion may affect the density and homogeneity of the bentonite in the boreholes.	Most likely only small, local effects that do not influence the overall function of the backfill in the investigation boreholes.
9.10c Sorption	The composition of the rock matrix and fracture minerals will affect the sorption of dissolved species and colloids and thereby the composition of the water in the rock outside the repository area.	Will have negligible effect on the main composition of the water. Could have som effect on the sorption of colloids and thus on the amount of colloids in the water, but this effect is conservative to neglect.
9.10d Colloid filtering	The porosity and the fracture apertures in the rock outside the repository area affects the filtering of colloids/particles and thus the amount of these in the water	Most of the colloids will be transported in the larger fractures where there are no filtering effects. Moreover, filtering of colloids is a positive effect and thus conservative to neglect.
9.10e Erosion	The chemical and physical properties of the rock matrix and fractures affects its ability to withstand mechanical erosion and thus the amount of colloids/particles in the water in the rock outside the repository area	The expected flow rates are low and liberation of colloids/particles by erosion should therefore be small compared to chemical formation of colloids/particles (e.g. natural organic colloids in the water).
9.12b Microbial activity	Microbial degradation of organic materials in the rock outside the repository area may generate gas and thereby affect the amount, composition and pressure of gas in the rock outside the repsority area.	Too small gas source to be of importance. Much more gas is generated in the repository and this gas has to escape through the geosphere.
9.12c Radon generation	Radon generation in the rock outside the repository area due to decay of naturally occurring radionuclides in the rock minerals.	Small amounts of gas in relation to the gas released from the repository, which has to escape through the geosphere. In addition radon gas is a natural radionuclide and in the analysis only radionuclides from the repository is included.

Interaction/process in Geosphere matrix	Description	Motivation
9.13 Heat conduction	The mineralogy of fracture coatings and the rock matrix as well as the frequency, apertures and connectivity of fractures in the rock outside the repository area affect the heat conduction in the rock and thereby the temperature in the rock outside the repository area, in the repository rock and in the tunnels	Too small temperature gradients
9.17 Erosion/weathering	Formation of Quaternary deposits by erosion/weathering (BIO1.2a)	Erosion of the rock minor influence on the formation of sediments compared to other sediment formation processes e.g. average erosion rates for soil-materials app. 0.1mm/y (see BIO 1.2a and BIO 1.9)
10.5b Corrosion	The composition of the water in the tunnel will affect the corrosion of rock bolts and reinforcement in shotcrete, which will change the composition and structure of these materials. Includes also volume changes due to formation of corrosion products.	Water composition is of importance for corrosion rates and modes but corrosion of rock bolts and reinforcement in shotcrete in tunnels are assessed to be of minor importance for the overall function of the tunnels in the post-closure phase.
10.11b Water flow	The water composition in the different parts of the geosphere system will affect the density and viscosity of the water and thus the magnitude of the water flow in the different parts of the geosphere system.	The variability in rock properties is much more important for the water flow than potential variations in water viscosity due to changes in water composition.
10.11c Osmosis	Gradients in concentration in the different components of the system, e.g. bentonite plugs and bentonite in investigation boreholes, may cause osmotic potentials that affect the magnitude, direction and distribution of water flow in the system components, e.g. bentonite plugs.	Could somewhat affect the water flow through plugs during the resaturation phase, but this is assessed to be of negligible importance for the long-term function of the repository.
10.12a Gas dissolution/degassing	The water composition, e.g. concentration of dissolved species and amount and composition of dissolved gas, affects the dissolution of gas and degassing. This will influence the amount and composition of gas in gas phase in the different parts of the geosphere system	Small effect of water composition on gas solubilities and thus negligible effect on the amount and composition of gas
10.12b Chemical reactions	Changes in water composition that causes gas generation or consumption of gas, e.g. changes in pH that affects the amount of CO2.	The amount of gas consumed or generated, e.g. degassing of dissolved carbon dioxide from the repository, is expected to be small compared to the amount of gas generated in the repository and that escapes through the geosphere.
10.13 Heat conduction	The water composition in the different parts of the geosphere system will affect the heat transfer by conduction in the water phase and thus the temperature in the different parts of the geosphere system	Too small temperature gradients
10.18 Mass exchange	Exchange of groundwater components between the geosphere in the disposal system and the geosphere outside the disposal system will affect the composition of water in the geosphere outside the disposal system.	By definition, this interaction is of no interest in the present analysis

Interaction/process in Geosphere matrix	Description	Motivation
11.1c Erosion	Erosion of the external surfaces of the bentonite barriers may affect the density of the barriers by carrying away material (REP 18.8) Comment: interaction added by KS when compiling the documentation from the meeting 1998-02-11	The amount that will be carried away is a fraction of the material that expands into fractures in adjacent rock and thus less important for the properties of the bentonite barriers than expansion into the fractures.
11.5a Dissolution/precipitation	The amount of water (degree of saturation) in the tunnel will affect the dissolution of primary minerals in backfilled rock and shotcrete and the precipitation of secondary minerals. This will affect the composition, porosity and permeability of these materials.	Short duration of unsaturated conditions and any dissolution/precipitation that will occur migth give rise to small local changes in properties, but will most likely be of negligible importance for the long-term function of the repository.
11.5b Corrosion	The amount of water (degree of saturation) in the tunnel will affect the corrosion of rock bolts and reinforcement in shotcrete which will change the composition and structure of these materials.	Short duration of the resaturation phase and probably anyhow enough water during the resaturation phase to maintain corrosion.
11.6a Dissolution/precipitation	The amount of water (degree of saturation) in the plugs will affect the dissolution of primary minerals in bentonite and concrete in plugs and the precipitation of secondary minerals. This will affect the composition, pore and fracture characteristics of these materials.	The duration of the resaturation phase is expected to be short and any effects of dissolution/precipitation during the resaturation phase are probably small.
11.6b Corrosion	The amount of water (degree of saturation) in the plugs will affect the corrosion of reinforcement in plugs which will change the composition and pore and fracture charactersitics of the plugs.	Short duration of the resaturation phase and probably anyhow enough water during the resaturation phase to maintain corrosion.
11.6c Erosion	Water flowing in the tunnels and plugs and in the repository rock adjacent to the plugs may cause mechanical erosion of the plugs. This could affect the geometry and porosity of the plugs.	The expected water velocities are too low for erosion to be of any importance for the properties of the plugs
11.7 Dissolution/precipitation	The amount of water (degree of saturation) in the rock matrix of the repository rock will affect the dissolution and precipitation of minerals. This may change the porosity and composition of the rock matrix.	Too short duartio of the resaturation phase to be of any importance.
11.8a Dissolution/precipitation	The amount of water (degree of saturation) in the fractures in the repository rock will affect the dissolution and precipitation of minerals on the fracture surfaces. This may change the apertures and connectivity of the fractures and the mineralogic composition of the fracture surfaces.	Too short duartio of the resaturation phase to be of any importance.
11.8b Erosion	Water flowing in fractures in the repository rock may cause mechanical erosion of the fracture surfaces. This could affect the apertures of the fractures.	The expected water velocity is too low for erosion to be of any importance for the properties of the rock

Interaction/process in Geosphere matrix	Description	Motivation
11.9a Dissolution/precipitation	The amount of water (degree of saturation) in the rock outside the repository area will affect the dissolution and precipitation of minerals on the fracture surfaces and in the rock matrix. This may change the apertures and connectivity of the fractures and the porosity of the rock matrix as well as the composition of the fracture surfaces and rock matrix.	Unsaturated conditions not expected in the rock outside the repository area
11.9b Erosion	Water flowing in fractures in the rock outside the repository area may cause mechanical erosion of the fracture surfaces. This could affect the apertures of the fractures.	The expected water velocity is too low for erosion to be of any importance for the properties of the rock
11.10b Chemical equilibria	The porewater pressure in the different parts of the geosphere system affects the chemical equilibria and thus the water composition in the different parts of the geosphere system.	Too small pressure differences.
11.13 Heat advection	The magnitude, direction and distribution of water flow in the different components of the geosphere system will affect the heat transport by advection and thus the temperature in the different components of the geosphere system.	Too small temperature gradients
11.14 Water pressure interaction	The water pressure in the different components of the geosphere system, e.g. due to phase changes, affects the stress conditions in the components of the geosphere system.	No phase changes expected in the rock, tunnel and backfill except for the upper few meters (biosphere). The changes in water pressure due to landrise are small compared to present pressure.
11.17b Discharge/recharge and pressure	The hydrology in the geosphere influences the discharge and recharge of groundwater and thereby the hydrology in the quaternary deposits and the surface water hydrolgy. (BIO1.10+BIO1.11)	The amount of water in Quaternary deposits are determined by surface water and not by water in the geosphere (see BIO 1.10). Precipitation and hydrology in Quaternary deposits of more importance for surface water conditions (see BIO 1.11)
11.17c Biomass flow	Transport of biomass from the geosphere will affect the type and amount of biomass in the biosphere.	Negligible contribution
11.18a Mass exchange	The magnitude and direction of groundwater flow in the geosphere will affect the exchange of groundwater components between the geosphere in the disposal system and the geosphere in the external system and thereby the water composition in the external system.	By definition this interaction is of no interest in the present analysis.
11.18b Discharge/ recharge and pressure	Hydraulic situation in the geosphere affects recharge/discharge of water from/to the external system and thereby the hydraulic situation in the external system	By definition this interaction is of no interest in the present analysis.
11.18c Biomass exchange	The magnitude and direction of groundwater flow in the geosphere will affect the exchange of biomass between the geosphere in the disposal system and the geosphere in the external system and thereby the type ad amount of biomass in the external system.	By definition this interaction is of no interest in the present analysis.

Interaction/process in Geosphere matrix	Description	Motivation
12.1 Gas transport	Gas transport in the tunnels and repository rock will influence the amount and composition of gas in the silo (REP 17.12, REP 18.12)	The gas transport capacity in rock and tunnels is sufficient and does not influence the amount and composition of gas in the silo.
12.2 Gas transport	Gas transport in the tunnels and repository rock will influence the amount and composition of gas in the BMA (REP 17.12, REP 18.12)	The gas transport capacity in rock and tunnels is sufficient and does not influence the amount and composition of gas in the BMA.
12.3 Gas transport	Gas transport in the tunnels and repository rock will influence the amount and composition of gas in the BTF (REP 17.12, REP 18.12)	The gas transport capacity in rock and tunnels is sufficient and does not influence the amount and composition of gas in the BTF.
12.4 Gas transport	Gas transport in the tunnels and repository rock will influence the amount and composition of gas in the BLA (REP 17.12, REP 18.12)	The gas transport capacity in rock and tunnels is sufficient and does not influence the amount and composition of gas in the BLA.
12.11b Two phase flow	The gas pressure, gas flow and saturation degree in the different components of the geosphere system will affect the magnitude, direction and distribution of water flow in the geosphere system components	Minor influence due to small amounts of gas.
12.13a Heat advection	The magnitude, direction and distribution of gas flow in different parts of the geosphere system may affect the heat transport by advection and thus the temperature in the different parts of the geosphere system	Too small temperature gradients.
12.13b Heat conduction	The degree of saturation in different parts of the geosphere system affects the heat transport by conduction and thus the temperature in the different parts of the geosphere system	Too small temperature gradients.
12.14 Gas pressure interaction	The gas pressure in the different parts of the geosphere system affects the stress conditions in the geosphere system components	The gas transport capacity is sufficient and no gas pressure will build up.
12.15b Advection-gas	Transport of organisms by gas flowing in the different parts of the geosphere system may affect the type and amount of organisms in different parts of the geosphere system.	Negligible compared to advection
12.18 Gas exchange	Exchange of gas between the geosphere in the disposal system and the geosphere in the system outside the disposal system (external system).	By definition this interaction is of no interest in the present analysis.
13.1 Heat transport	Heat transport in the tunnels and repository rock will affect the temperature in the silo (REP 17.13, REP 18.13)	Too small temperature gradients
13.2 Heat transport	Heat transport in the tunnels and repository rock will affect the temperature in the BMA (REP 17.13, REP 18.13)	Too small temperature gradients
13.3 Heat transport	Heat transport in the tunnels and repository rock will affect the temperature in the BTF (REP 17.13, REP 18.13)	Too small temperature gradients

Interaction/process in Geosphere matrix	Description	Motivation
13.4 Heat transport	Heat transport in the tunnels and repository rock will affect the temperature in the BLA (REP 17.13, REP 18.13)	Too small temperature gradients
13.5a Kinetics and equilibria	The temperature in the tunnels and investigation boreholes will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the materials in the tunnels and boreholes.	Too small temperature gradients
13.5b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the tunnels and in the boreholes thereby affecting the dimensions and geometries of these materials.	Too small temperature gradients
13.6a Kinetics and equilibria	The temperature in the plugs will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the amount and composition of the materials in the plugs as well as the porosity of the plugs.	Too small temperature gradients
13.6b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the materials in the plugs thereby affecting the dimensions and geometries of these materials.	Too small temperature gradients
13.7a Kinetics and equilibria	The temperature in the repository rock will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the mineralogy and porosity of the matrix of the repository rock.	Too small temperature gradients
13.7b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the rock minerals thereby affecting the porosity of the rock matrix in the repository rock.	Too small temperature gradients
13.8a Kinetics and equilibria	The temperature in the repository rock will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the mineralogy and porosity of the fracture coatings and the aperture and connectivity of fractures in the repository rock.	Too small temperature gradients
13.8b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the rock minerals thereby affecting the apertures of the fractures in the repository rock.	Too small temperature gradients
13.9a Kinetics and equilibria	The temperature in the rock outside the repository area will affect the kinetics and equilibria of dissolution and precipitation reactions and thereby the mineralogy and porosity of the rock matrix and fracture coatings and the aperture and connectivity of fractures in the rock.	Only for the upper few meters
13.9b Expansion/contraction	Changes in temperature may cause thermal expansion/contraction of the rock minerals thereby affecting the porosity of the rock matrix and the apertures of the fractures in the rock outside the repository area.	Only for the upper few meters

Interaction/process in Geosphere matrix	Description	Motivation
13.10a Kinetics and equilibria	The temperature in the tunnels, plugs, repository rock and rock outside the repository area will affect the kinetics and equilibria of chemical reactions and gas solubilities and thereby the composition of the water in the tunnels, plugs, repository rock and rock outside the repository area.	Too small temperature changes except for the upper few meters, where the effect is small
13.10b Property changes	The temperature in the tunnels, plugs, repository rock and rock outside the repository area will affect the density and viscosity of the water in the tunnels, plugs, repository rock and rock outside the repository area.	Too small temperature changes except for the upper few meters, where the effect is small
13.10c Diffusion	The temperature in the different components of the geosphere system will affect the rate of diffusion of dissolved species and thereby the water composition in the different components of the geosphere system.	Too small temperature changes except for the upper few meters, where the effect is small
13.11 Phase changes	The temperature in the different components of the geosphere system affects the water pressure in the components. Extreme changes in temperature will lead to phase changes like freezing or evaporation. These extreme changes will affect both the water pressure and the amount of water.	Too small temperature changes except for the upper few meters, where the effect is marginal
13.12a Expansion/contraction	The temperature in the different components of the geosphere system will affect the volume and pressure of gas in the system components.	Too small temperature changes
13.12b Convection	The temperature in the different components of the geosphere system will affect the density of the gas and thus the magnitude, directions and distribution of gas flow in the different components of the geosphere system.	Too small temperature changes
13.14 Thermal stress interaction	Changes in temperature in the different components of the geosphere system will affect the stress conditions in components that cannot expand in volume. For components where volume expansion can take place, effects of temperature on stress conditions are considered via volume changes, e.g. by interactions 13.5b - 13.9b and 5.14 - 9.14. Effects of temperature on water flow and thereby on stress go via 13.11 and 11.14.	Too small temperature changes except for the upper few meters, where unimportant increase in stress may occur
13.15 Microbial activity	The temperaure in the different parts of the geosphere system will affect the microbial activity and thereby the type and amount of microbes and bacteria in the different geosphere system components.	Too small temperature changes except for the upper few meters, whiche has marginal effect
13.16a Kinetics and equilibria	The temperature in the different components of the geosphere system will affect the kinetics and equilibria of sorption and dissolution/precipitation reactions and thereby the distribution between mobile and immobile radionuclides and toxicants in the different components of the geosphere system.	Too small temperature changes, which has minor influence

Interaction/process in Geosphere matrix	Description	Motivation
13.16b Diffusion	The temperature in the different components of the geosphere system will affect the rate of diffusion of dissolved species and thereby the concentration of radionuclides and toxicants in the water in the different components of the geosphere system.	Too small temperature changes, which has minor influence
13.16c Soret effect	Temperature gradients in the different components of the geosphere system may cause diffusion of dissolved species by the Soret mechanism and thereby affect the concentration of radionuclides and toxicants in the water in the different components of the geosphere system.	Too small temperature gradients, which has minor influence
13.17 Heat transport	The heat exchange between geosphere and biosphere will affect the temperature in the biosphere (BIO1.14)	Surface temperature and radiation balance determines mainly the temperature in quaternary deposits and surface waters. Could be of importance during permafrost conditions. (see BIO 1.14)
13.18 Heat exchange	The heat exchange between the geosphere in the disposal system and the geosphere in the external system will affect the temperature in the external system	By definition this interaction is of no interest in the present analysis.
14.1b Rock fallout	Changes in stress conditions in the repository rock may cause rock fallout that affects the dimensions, geometry and homogeneity of the backfill in the silo. (REP 18.9)	A fallout is judged to be of minor importance for the function of the buffer
14.1c Rock creep	Changes in stress conditions in the repository rock may cause rock creep that may affect the geometry, homogeneity, density etc of the bentonite barriers in the Silo (REP 18.8)	Not a large-scale process at considered time. Only marginal effects is expected on bentonite buffer
14.2c Rock creep	Changes in stress conditions in the repository rock may cause rock creep that affects the dimensions and geometry of the BMA vault and the homogeneity of the backfill in the BMA. (REP 18.9)	Not a large-scale process at considered time.
14.3c Rock creep	Changes in stress conditions in the repository rock may cause rock creep that affects the dimensions and geometry of the BTF vaults and homogeneity of any backfill in the BTF. (REP 18.9)	Not a large-scale process at considered time.
14.4a Stress and strain changes	Changes in stress and strain at the boundary between the tunnels or repository rock and the BLA affects the stress conditions in the BLA. (REP 17.14, REP 18.14)	No backfill in BLA
14.4b Rock fallout	Changes in stress conditions in the repository rock may cause rock fallout that affects the dimensions and geometry of the BLA vault and damages the waste containers in BLA. (REP 18.9, REP 18.5)	The containers are not considered as a barrier

Interaction/process in Geosphere matrix	Description	Motivation
14.4c Rock creep	Changes in stress conditions in the repository rock may cause rock creep that affects the dimensions and geometry of the BLA vault. (REP 18.9)	Not a large-scale process at considered time, only marginal effects are expected
14.5a Stress redistribution, backfill	Redistribution of stress inside the tunnel and borehole backfill may change the geometry and porosity and homogeneity of the backfill	Little relevance of mechanical changes on backfill
14.5b Rock fallout	Changes in stress conditions in the repository rock may cause rock fall out that affects the dimensions, geometry and distribution of the tunnel backfill	Will not change the relative permeability in the tunnels, which already have high permeability.
14.5c Rock creep	Rock creep due to stress changes in the repository rock may change the geometry of the tunnel and the backfill. Rock creep may also change the geometry of the investigation boreholes and backfill in boreholes.	Not a large scale process, only marginal effects on the relative permeability in the tunnels, which have relatively high permeability.
14.6b Rock creep	Rock creep due to stress changes in the repository rock may change the dimensions and pore and fracture characteristics of the plugs.	Not a large scale process, only marginal effects
14.11 Water pressure interaction	The stress conditions in the different components of the geosphere system affects the porewater pressure in the system components.	The process is negligible
14.17 Changes in rock surface location	Repository induced changes in rock surface location (eg collapse of caverns). The initiating event is eg cavern collapse that affects the stress conditions in the surrounding rock. These changes in stress may result in cave in of surrounding rock (subsidence). (BIO1.9b)	The thickness of Quarternary deposits is between 4-14 m [Sigurdsson, 1997]. If caverns collapse or neotektonics occur the impact has to be in the order of several meters to influence the surface location. Therefore other processes affecting relocation of Quarternary deposits are more important for the topography (see BIO 1.9b)
14.18 Stress and strain changes	Changes in stress and strain at the boundary between the rock in the disposal system and the external system affects the stress conditions in the external system.	By definition this interaction is of no interest in the present analysis.
15.13 Microbial activity	The type and amounts of microbes in the different parts of the geosphere system will, due to their presence and activity, generate heat. This may affect the temperature in the different parts of the repository system.	Small amount of heat generated due to expcted low activity and together with effective heat transport the effect on temperature is expected to be negligible.
15.17 Biomass exchange	Exchange of biomass between the rock in the disposal system and the biosphere will affect the type and amount of biomass in the biosphere.	Negligible contribution
15.18 Biomass exchange	Exchange of biomass between the rock in the disposal system and the external system will affect the biological state in the external system.	By definition this interaction is of no interest in the present analysis.

Interaction/process in Geosphere matrix	Description	Motivation
16.1 Contaminant transport	Transport of radionuclides and toxicants in water and gas phase from the tunnels and repository rock into the silo will affect the amount of these in the silo. The origin of these contaminants may be the waste and barrier materials in the other repository parts and contaminated water, gas and solids in the biosphere. (REP 17.16, REP 18.16)	It is a positive effect if the radionuclides and toxicants return to repository (the expected transport pathways are treated elsewhere)
16.2 Contaminant transport	Transport of radionuclides and toxicants in water and gas phase from the tunnels and repository rock into the BMA will affect the amount of these in the BMA. The origin of these contaminants may be the waste and barrier materials in the other repository parts and contaminated water, gas and solids in the biosphere. (REP 17.16, REP 18.16)	It is a positive effect if the radionuclides and toxicants return to repository (the expected transport pathways are treated elsewhere)
16.3 Contaminant transport	Transport of radionuclides and toxicants in water and gas phase from the tunnels and repository rock into the BTF will affect the amount of these in the BTF. The origin of these contaminants may be the waste and barrier materials in the other repository parts and contaminated water, gas and solids in the biosphere. (REP 17.16, REP 18.16)	It is a positive effect if the radionuclides and toxicants return to repository (the expected transport pathways are treated elsewhere)
16.4 Contaminant transport	Transport of radionuclides and toxicants in water and gas phase from the tunnels and repository rock into the BLA will affect the amount of these in the BLA. The origin of these contaminants may be the waste and barrier materials in the other repository parts and contaminated water, gas and solids in the biosphere. (REP 17.16, REP 18.16)	It is a positive effect if the radionuclides and toxicants return to repository (the expected transport pathways are treated elsewhere)
16.5 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the backfill in tunnels and boreholes.	No influence on tunnel backfill geometry and mineralogy because of small amounts of radionuclides and toxicants.
16.6 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the plugs.	No influence on plug geometry and mineralogy because of small amounts of radionuclides and toxicants.
16.7 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the rock matrix in the repository rock.	No influence on "Repository rock - rock matrix" geometry and mineralogy because of small amounts of radionuclides and toxicants.
16.8a Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the fractures in the repository rock.	No influence on "Repository rock - fracture system" geometry and mineralogy because of small amounts of radionuclides and toxicants.
16.8b Precipitation	Precipitation of RN and toxicants in fractures affecting fracture properties.	Small amounts compared to other potential sources for precipitation
16.9 Irradiation	Irradiation by decaying radionuclides affecting the chemical and physical properties of the fractures and rock matrix in the rock outside the repository.	No influence on "Rock - rock matrix and fracture system" geometry and mineralogy because of small amounts of radionuclides and toxicants.

Interaction/process in Geosphere matrix	Description	Motivation
16.10a Radiolysis	The type and amount of radionuclides may affect the water composition via radiolysis.	Low concentration of radionuclides. Negligible effects
16.10b Radionuclide decay	Decay of radionuclides to stable isotopes that affect the water composition in the different components of the geosphere system.	Low concentration of radionuclides. Negligible effects
16.10c Degradation	Degradation of toxicants from the repository that affects the water composition in the different components of the geosphere system.	No effects on large scale water chemistry
16.12a Radiolysis	The type and amount of radionuclides affects the extent of radiolysis and thus the amounts of gas formed and the composition of the gas. (e.g. type of decay and energi levels)	Low concentration of radionuclides. Negligible effects
16.12b Degradation	The type and amount of organic toxicants from the repository affects the amount and composition of gas via degradation processes.	Small amounts of organic toxicants from the repository. Negligible effects
16.13 Heat from decay	Decay of radionuclides may generate heat and affect the temperature in different parts of the geosphere system.	Low concentration of radionuclides. Negligible effects
16.15 Irradiation (mutation)	Effects on the biological state of irradiation by decaying radionuclides (mutation).	The amount of radionuclides and toxicants that originates from the repository is assesed to be too low to have any effect on the biological state in the geosphere.
17.5 Root penetration (Tunnels)	The penetration of roots into the plugged and backfilled access tunnels and investigation boreholes (BIO3.1b)	Influence the upper few meters
17.6 Root penetration (Tunnels)	The penetration of roots into the plugged and backfilled access tunnels (BIO3.1b)	Influence the upper few meters
17.9a Consolidation	The slow transformation of quaternary deposits to solid rock. The time is important for the extent of consolidation. (BIO2.1b)	Too slow process in the time-scale of interest
17.9b Root penetration (Rock)	The penetration of roots into fractures in the solid rock (BIO3.1a)	Influence the upper few meters
17.9c Erosion/ weathering	Wind, running water at the surface and the composition of this water will affect the erosion/weathering of rock (outcrops). Moving ice blocks during the winter season and during glacial periods may also cause erosion of rock (outcrops). (BIO 10.1d, BIO 11.1d, BIO 12.1b, BIO14.1c)	The erosion and weathering of the rock is assumed to low for this type of rock and time perspective. Erosion of surface rock included in the biosphere matrix.
17.12 Gas transport	Air intrusion can take place via human activities and can also be a consequence of landrise and climatic changes leading to unsaturated conditions (BIO13.1)	Influence only the upper few meters. Negligible effect

Interaction/process in Geosphere matrix	Description	Motivation
17.13 Heat transport	The heat exchange between geosphere and biosphere will affect the temperature in the geosphere. (BIO14.1a)	Influence only the upper few meters. Negligible effect
17.14a Mechanical load	Changes in mechanical load and thereby stress conditions in the geosphere due to changes in geometry and composition of Quaternary deposits (BIO 2.1a)	Normal variations. Negligible effects
17.14b Ice load	Changes in thickness of the ice sheet due to seasonal variations and during periods of glaciation and deglaciation will affect the mechanical stress in the rock. (BIO 11.1e) (glaciation treated as a scenario)	Normal seasonal variations. Negligible effects No glaciation will take place within the time period considered
17.15a Root penetration (biological)	The penetration of roots via fractures in the rock and via the plugged and backfilled tunnels (and ventilation shafts??) will affect the biological mass in the geosphere (BIO3.1c)	It is unlikly that roots will penetrate 50 m down in the rock. Especially during climates conditions considered here, beacuse water will be available much shallower
17.15b Intrusion	Potential intrusion of decomposers, filter feeders, herbivores and carnivores through degraded plugs at the surface BIO4.1+BIO5.1+BIO6.1+BIO7.1)	Influence only the upper few meters
17.16 Contaminant transport	The transport of radionuclides and toxicants from the biosphere to the geosphere. The source of these nuclides can be radionuclides released from SFR or radionuclides from other sources (BIO15.1, BIO 10.1a, BIO 11.1a)	Negligible effects
18.12 Gas exchange	The amount and composition of gas and the magnitude and direction of gas flow in the external system affects the amount, composition, magnitude and direction of gas flow in the rock in the geosphere.	Judged to be negligible
18.13 Heat exchange	The exchange of heat between the rock in the geosphere and the external system will affect the temperature in the rock in the geosphere.	Judged to be negligible
18.14 Stress and strain changes	Changes in stress and strain at the boundary between the rock in the disposal system and the external system affects the stress conditions in the rock in the geosphere.	Judged to be negligible
18.15 Biomass exchange	Exchange of biomass between the rock in the disposal system and the external system will affect the biological state in the rock in the geosphere (disposal system).	Judged to be negligible

Interaction/process in Biosphere matrix	Description	Motivation
1.2a Erosion / weathering	Formation of Quaternary deposits and changes in topography by erosion/weathering (GEO9.17a)	Erosion of the rock has minor influence on the formation of sediments compared to other sediment formation processes e.g. average erosion rates for soil-materials approximately 0.1mm/y No effect on topography expected compared to the land rise during the first 1000 years.
1.14 Heat transport	The heat exchange between geosphere and biosphere will affect the temperature in the biosphere (GEO13.17)	Surface temperature and radiation balance determines mainly the temperature in quaternary deposits and surface waters. Could be of importance during permafrost conditions.
2.1a Mechanical load	Changes in mechanical load (GEO17.14)	Normal variations. Negligible effects (see GEO 17.14)
4.10 Decomposition	During decomposition of material the decomposers will release water from pores and cells which can influence the water content in the Quaternary deposits.	For normal Swedish climate conditions this is assumed to be of limited importance compared to precipitation.
3.11a Interception	The avaiable surface area of primary producers influence the amount of water from irrigation and precipitation that is retarded on the primary producers and influence thereby the amount of surface waters Remark: The droplets on primary producers are included in the definition of surface waters	The interceptions is only interesting when the plants are irrigated, because the source term will be a contaminated water body. This is treated in 11.3. Moreover the effect interception will have on surface water is that more stays on leaves and less on lower places. This delay effect is not considered since the effects on surface water probably are of minor importance
3.2 Root growth	Type and way of growing influence the depth of root penetration and thereby the physical properties of the Quaternary deposits, e.g. porosity Dead primary producers can influence the composition of the Quaternary deposits but this interaction goes via "Decomposers"	This is important for the quaternary deposits. However, treated as a description of the soil profile and not as this mechanism
3.10 Root uptake	Transpiration driven root uptake of water by plants may affect the water content in the Quaternary deposits. Primary producers living in the water have less influence than primary producers on land. Uptake of water from the air affects the need of water uptake by roots, and could in some cases result in the supply of water through roots.	In Sweden there is generally an excess of water and groundwater table varies little. This is valid at Forsmark also, but this is climate dependent
3.14a Radiation	The type, amount and location of primary producers determines the degree of sheltering, absorbtion and reflection (albedo) of radiation and influence thereby the temperature in the biosphere.	Due to the variation of albedo and absorption of vegetation it is assumed that the air temperature as well as wind is the mean of a larger area. In soil the temperature is affected by different vegetation. There is no obvious way how this might affect radionuclide turnover significantly.
8.12a Excretion	Humans excrete nutrients and thus affects chemical composition of water	Assumed that this already is reflected in water composition
4.1 Potential intrusion	Potential intrusion of decomposers through degraded plugs at the surface (GEO17.15)	Decomposers can intrude if the passage is open to the repository. But under normal conditions the plugs will submerge below the grundwater surface. Thus it is unlikely that any macro decomposer will have a significant impact. Micro decomposers are assumed to be existent in the repository and are treated as microbial interactions.

Interaction/process in Biosphere matrix	Description	Motivation
4.2a Decomposition	The type and efficiency of decomposers affects the content of non-degraded organic material in the Quaternary deposits and also the content of non-organics, e.g. shells	The decompsers affect the content of organic matter in sediment and soil. The process is not explicitly considered. The net accumulation of organic matter is calculated from sediment profiles or terrestial modell or peat accumulation measurement from bog profiles
10.8a Settlement	The presence, location and amount of accessible water in Quaternary deposits affects the settlement of humans in the area	It is assumed that there is sufficient of water available
10.12a Erosion	The magnitude and direction of the water flow influence the extent of erosion of the Quaternary deposits and thereby the amount and type of particulates in the water	This interaction is assumed to be already in equilibrium. Thus the water composition is assumed to be represented by measured or estimated values
10.13a Evaporation/ condensation	Transformation of water in liquid phase to gas phase by evaporation in the Quaternary deposits.	This is transport of water, but it is assumed that contaminants are not directly related to this.
10.14a Heat transport	The water content as well as the magnitude, direction and distribution of water flow in the Quaternary deposits affect the heat transport in the biosphere system and thus the temperature in the system components.	This can affect surface temperature especially in winter. However, assumed that these effects will be reflected in species composition and therefore not specifically taken into account
12.13a Spray/ Snowdrift	The composition of surface waters and snow will affect the composition of water droplets and snow particles that are part of the atmosphere.	The interaction is important, but the local atmosphere is assumed to be affected more by exhange of wind
14.2a Weathering	The temperature will affect the volume of the materials and thus changes may cause physical weathering e.g. frost ice. In addition, the temperature will affect the kinetics of chemical reactions and thus the chemical weathering and the properties of the Quaternary deposits.	Under normal condition (no climate changes) there is a seasonal change of this, which however is included in the annual average and thus assumed to be reflected by the actual estimates for the deposits
14.3a Settlement	The temperature will affect the settlement of plants	The estimated species distribution is assumed to reflect the temperature dependence on settlement
15.1 Contaminant transport	Transport of radionuclides and toxicants in water and gas phase from the biosphere into the geosphere will affect the amount of these in the geosphere. The origin of these contaminants may be the SPHERE itself as well as contaminants from other sources (GEO17.16)	Negligible effects (see GEO 17.16)
15.12a Radiolysis	Radiation from decaying radionuclides causing radiolytic decomposition of the water and thereby affecting the water composition in the different components of the biosphere system.	Too small amounts.
15.13 Phase transition	Formation of elements in gas phase due to decay of radionuclides and/or decomposition of organic toxicants.	Phase transition of Ra to Rn will not affect gas atmosphere?
15.14 Heat from decay	Decaying radionuclides will generate heat that may influence the temperature in the different components of the biosphere system.	Too small amounts of radionuclides.

Interaction/process in Biosphere matrix	Description	Motivation
14.1a Heat transport	The heat exchange between geosphere and biosphere will affect the temperature in the geosphere. (GEO17.13)	Influence only the upper few meters. Negligible effect (see GEO 17.13)
14.10 Phase transitions	Freezing of water, melting of snow and evaporation of water in Quaternary deposits as a result of changes in temperature will affect the water content, water pressure and water flow in the Quaternary deposits.	It is an important process, which however is included in most annual averages in normal climate scenario. In a cooler climate this interaction is important
14.12a Kinetics and chemical equlibria	The kinetics and chemical equilibria are affected by temperature,especially kinetics	Although the kinetics is largely affected, the annual variation encompasses the extreme variations and thus the annual mean is not sensitive
14.13a Pressure change	Changes in temperature gives pressure changes that affects gas and wind movements. Inversion effects are included in this interaction.	The temperature effect on gas is an important driving mechanism for the turnover of the atmosphere. The external influences are assumed to be larger than the local effect of temperature differences
15.2a Surface deposition/uptake	Deposition or uptake of radionuclides and other toxicants on the surfaces of Quaternary deposits may change the physical and chemical properties (mineralogy) of the surfaces.	Too small amounts of radionuclides to have any significant effect.
13.14a Radiation	The composition of the atmosphere affects the absorption/scattering/reflection of radiation and thus the temperature.	The atmosphere changes are rapid and it is assumed that the annual average temperature reflects the influence
1.10 Discharge/recharge	The hydrology in the geosphere influences the discharge and recharge of groundwater and thereby the hydrology in the Quaternary deposits. (GEO11.17)	The amount of water in Quaternary deposits are determined by surface water and not by water in the geosphere. If the Quaternary deposits and surface waters are frozen groundwater could rise in holes in the frost and saturate upper layers of Quarternary deposits. Remark: Frost penetration can not occur 0-1000 years in the 4-15 m thick Quaternary deposits. However, could be of importance for permafrost conditions.
3.1a Root penetration (Rock)	The penetration of roots into fractures in the solid rock (GEO17.9)	It is unlikely that roots will penetrate 50 m down in the rock. Especially during climate conditions considered here, because water will be available much shallower
3.13a Gas uptake and release	Primary producers will by their respiration (uptake of CO2, H2Ogas and N2 and the release of O2) influence the amount of gas and the gas composition. Here is also included the root uptake in the unsaturated zone.	The gas is affected by primary producers, but due to the high exchanges of gas there are small concentration gradients. Therefore the effects from primary producers are disregarded because external factors like wind will have a higher influence.
8.2 Disturbance	Humans can by different activities e.g. dredging, digging, covering etc., change the composition and properties of the Quaternary deposits and the base line topography. Normal activities are thought to be included in the Base Scenario whereas other disruptive events are treated as separate scenarios. Dead humans can influence the composition of the Quaternary deposits, but this interaction goes via "Decomposers"	Ploughing is affecting deposits. However it is assumed to be independent of human living in the area in the assessment

Interaction/process in Biosphere matrix	Description	Motivation
13.1 Gas transport	Air intrusion can take place via human activities and can also be a consequence of land rise and climatic changes leading to unsaturated conditions (GEO17.12)	Influence only the upper few meters. Negligible effect. (see GEO 17.12)
13.2a Erosion	The strenght of the wind determines the amount of particles that will get airborn and influence thereby by erosion the geometry and amount of Quaternary deposits. In addition, high wind velocities can demolish buildings and structures included in the definition of Quaternary deposits.	In this area with wave-washed till there is a small amount of fine particles in deposits and thus the erosion is small
13.12a Precipitation	The precipitation of rain/snow will influence the water composition by dilution. Remark: only the amounts are included in this interaction	The amount of water is included in interaction with surface water. The primary source of contamination is assumed to be through the ground. Thus secondary deposition does not provide higher levels
10.2a Erosion	The magnitude and direction of the water flow influences the magnitude of erosion and thereby the structure and porosity of Quaternary deposits	The water in the deposits is assumed to be equiliberated with the erosion process in the assessment
2.16 Export	Transport of Quaternary deposits out from the system	The main export is through resuspended matter thus dependent on water/air composition exported
4.16 Export	Export of decomposers is mainly through outflow of e.g.microbs with water. Also hatching of e.g. insect larvae is an export of decomposers when the larvae change from decomposers to a herbivor or predator. Migration by animals is another type of export	The major loss of decomposers is planktonic decomposers, which follow the surface water. Most decomposers (eg. worms and snails) are limited in migration distance and thus disregarded.
5.16 Export	Export of filter feeders is detachment and sinking to deeper parts, detachment of macroalgae with filter feeders, spawn	Because filter feeders are normally sessile, the main rout of export could be through spawn. Probably quantitatively of minor importance. Ususally treated as export of POM
6.16 Export	Export of herbivores is migration, hunting and e.g sinking out with detached algae	This will give a dilution of radionuclides in the system. Is normally quantitatively of minor importance. Not addressing the effect gives an overestimate of exposure within the system
7.16 Export	Export of carnivores is migration, hunting	This will give a dilution of radionuclides in the system. Is normally quantitatively of minor importance. Not addressing the effect gives an overestimate of exposure within the system
8.16a Export of energy	Export of energy???	Have no idea ??
10.16 Export	The export is groundwater flow out of the system	The outflow is assumed to be minor because there are discharges in lakes or sea from where the export will go.
Export/import	The exchange of surface water with the surrounding surface water	The effect of a local surface water with its surrounding water is assumed to be negligible compared to the effect of the surrounding water on the local water
12.16 Export	The outflow of water composition to the surrounding	It has a minor effect to the surrunding due to the high volumes compared with the small flows
13.16 Export	The wind and exchange with the surrounding enviroment	The export is assumed to be of little importance and not driven by internal composition of gas

Interaction/process in Biosphere matrix	Description	Motivation
14.16 Export of heat	Export of heat from the system	Not regarded as quantitatively important compared with the surroundings
16.2a Import	Import of different materials e.g. building materials, dredging materials, earth, coal, crushed rock and gravel will influnce the composition, amount and type of Quaternary deposits.	The import of matter in this time perspective is assumed to be negligible except for human actions. Human actions are handled under human scenarios
16.3a Import	Import of plants and seeds by some natural way e.g. spreading of seeds with the wind and by humans by plantation	It is assumed to be reflected by the estimates of species distribution
16.4 Import	Immigration of animals	It is assumed to be reflected by the estimates of species distribution
16.5 Import	Immigration of animals	It is assumed to be reflected by the estimates of species distribution
16.6 Import	Immigration of animals	It is assumed to be reflected in the estimates of species distribution
16.8a Import of energy	Import of energy affects human behaviour and living conditions.	It is assumed that human behaviour is predefined to give highest doses. Thus most imports of material that are uncontaminated will be disregarded because it will be a dilution of the contamination
16.15 External load of contaminants	Contaminated surrounding can give higher loads of contaminants than possible sources assessed	It is assumed that the only soruce of contaminants are internal
2.1b Consolidation	The slow transformation of Quaternary deposits to solid rock. The time is important for the extent of consolidation. (GEO17.9)	Too slow process in the time-scale of interest (see GEO 17.9)
14.1b Erosion / weathering	Erosion caused by temperature changes (GEO17.9)	The erosion and weathering of the rock is expected to be low for this type of rock and time perspective. Erosion of surface rock included in the biosphere matrix. (see GEO 17.9)
1.8a Material supply	Mineral resources and supply of water influence the location of human settlements. The sources for supply of water will also have an influence on the use of water e.g. showering and/or bathing	In this area there are no mineral resources of importance. Water usage is determined also by the supply and quality of water from other sources such as quaternary deposits and surface waters. The area will be protected for some hundred years. Human activities caused by the existence of the repository are treated as separate scenarios.
1.11 Discharge/recharge	The hydrology in the geosphere influences the discharge and recharge of groundwater and thereby the surface water hydrology. (GEO11.17)	Precipitation and hydrology in Quaternary deposits of more importance for surface water conditions
3.1b Root penetration (Tunnels)	The penetration of roots into the plugged and backfilled access tunnels. (GEO17.5+17.6)	It is unlikly that roots will penetrate 50 m down in the rock. Especially during climate conditions considered here, beacuse water will be available much shallower
3.1c Root penetration (biological)	The penetration of roots via fractures in the rock and via the plugged and backfilled tunnels will affect the biological mass in the geosphere (GEO 17.15)	It is unlikly that roots will penetrate 50 m down in the rock. Especially during climate conditions considered here, beacuse water will be available much shallower

Interaction/process in Biosphere matrix	Description	Motivation
5.1 Potential intrusion	Potential intrusion of filter feeders through degraded plugs at the surface (GEO17.15)	Filter feeders penetrate a few dm through a sediment surface or e.g wooden constructions in marine conditions. Filter feeders can have a substantial effect in open tunnels with flowing water. However, that condition itself is more serious than the effect of filter feeders
6.1 Potential intrusion	Potential intrusion of herbivores through degraded plugs at the surface (GEO17.15)	Normally it is unlikely that herbivores would be able to enter repository due to the depth of water
7.1 Potential intrusion	Potential intrusion of predators through degraded plugs at the surface (GEO17.15)	Normally it is unlikely that carnivores would be able to enter repository due to the depth of water
10.1d Erosion / weathering	The water flow in the quaternary deposits influences the erosion of rock (GEO 17.9c)	The erosion and weathering of the rock is expected to be low for this type of rock and time perspective. Erosion of surface rock included in the biosphere matrix. (see GEO 17.9c)
11.1d Erosion / weathering	The surface water hydrology influences the erosion of rock (GEO 17.9c) Remark: includes also the erosion caused by ice movement and snow mowements e.g. avalanches	The erosion and weathering of the rock is expected to be low for this type of rock and time perspective. Erosion of surface rock included in the biosphere matrix. (see GEO 17.9c)
12.1b Erosion / weathering	The composition of water in Quaternary deposits and surface waters influences the erosion/weathering of rock (GEO 17.9c)	The erosion and weathering of the rock is expected to be low for this type of rock and time perspective.
2.3b Deposition in water	Deposition of sediments on e.g. algae and other macrophytes will influence their location. The degree of deposition on primary producers is influenced by the location and the properties of Quaternary deposits. Examples are shading, high sediment load on the primary producers or changes in spore growth.	In water of limited importance because effects occur locally and the primary producers will recolonisate in a relatively short term. The continous sediment load on surface of algae is determined by water turnover and particle content in water. Not considered because the dominating time scale is <1 year
2.5b Consumption	Consumption of sediments accidentally with the food or by purpose	Filter feeders consume resuspended sediment particles. Thus they are not directly affected by quaternary deposits, but through water composition.
2.8b Consumption	Consumption of solid material accidentally with the food or by purpose e.g. children	If there are high concentrations of RN the exposure is handled in other pathways e.g. consumption of food
2.12b Dissolution	The location of and the chemical composition of the Quaternary deposits and the mineralogy of rock surfaces influence the chemical composition of the water.	This affects the chemistry of fresh water but not brackish water
2.14a Radiation	The reflection properties of the Quaternary deposits and the rock surfaces influence the amount of sunlight absorbed and thereby the temperature. The topography affects the extent of radiation (e.g. the angle for radiation and sheltering effects) and thereby the temperature distribution in the system.	This is an important process for soil and air temperatures. However, not considered as a process and might be described by temperature statistics

Interaction/process in Biosphere matrix	Description	Motivation
5.2 Bioturbation	The type and amount of filter feeders in the waters affects the physical properties and the chemical composition of the Quaternary deposits e.g. by homogenisation of the upper layers. Dead filter feeders can influence the composition of the Quaternary deposits, but this interaction goes via "Decomposers"	Filter feeders (e.g mussels, clams) penetrate the sediment the first dm and cause bioturbation. But if sediment is regarded as a homogeneous compartment this will have a limited effect
6.2 Bioturbation	The type and amount of herbivores affects the physical properties and the chemical composition of the Quaternary deposits e.g. by homogenisation of the upper layers. Dead herbivores can influence the composition of the Quaternary deposits, but this interaction goes via "Decomposers"	Even larger herbivores (e.g. cattle) have a local and limited direct effect on quaternary deposits.
7.2 Bioturbation	The type and amount of predators affects the physical properties and the chemical composition of the Quaternary deposits e.g. by homogenisation of the upper layers. Remark: Dead predators can influence the composition of the Quaternary deposits but this interaction goes via "Decomposers"	Even larger carnivores (e.g fox) have a local and limited direct effect on quaternary deposits, since the deposits are over the hard rock
10.13b Sublimation	Transformation of water in solid phase (frost, ice) to gas phase by sublimation in the Quaternary deposits.	This is transport of water, but it is assumed that contaminants are not directly related to this
8.10b Artificial infiltration	Infiltration of water caused by humans, e.g. leakage of municipal water, may affect the water flow and water content in the Quaternary deposits.	The infiltration will normally lead to higher dilution than natural. Not taking this into account thus overestimates the exposure and therefore neglected.
2.10b Dehydration	Transformation of crystal water in minerals in Quaternary deposits to "free" water may affect the water content in the Quaternary deposits.	Under prevailing climate conditions and expected future conditions the water content in the quaternary are probably more affected by variations in percolation and groundwater level changes
11.13a Evaporation/ condensation	Transformation of water in surface waters to gas phase by evaporation.	This is an important process for the water balance, but the effects on local atmosphere is assumed to be negligible compared to air exchange
10.12b Mixing	The magnitude, direction and distribution of the water flow in the Quaternary deposits will affect the mixing of the water and thereby also the composition of the water.	The mixing especially with surface or deep groundwater in deposits is an important process. It is however assumed that it is represented by measured or estimated values
10.7a Settlement	The amount of water in Quaternary deposits affects the settlement of carnivores. Too little or too much water prevents settlement, e.g. worms entering the surface in case of to much water.	The effects as loose or dry soil is assumed to be reflected in species composition and probably of minor importance
10.7b Water uptake	The amount of water in Quaternary deposits affects the water uptake and living conditions for carnivores and thus the type, amount and life-time of carnivores in the area	The uptake of water in deposits is regarded associated with eg. contaminants sorbed to particles (via water composition)
10.6a Settlement	The amount of water in Quaternary deposits affects the settlement of herbivores. Too little or too much water prevents settlement.	The effects as loose or dry soil is assumed to be reflected in species composition and probably of minor importance

Interaction/process in Biosphere matrix	Description	Motivation
10.6b Water uptake	The amount of water in Quaternary deposits affects the water uptake and living conditions for herbivores and thus the type, amount and life-time of herbivores in the area	The uptake of water in deposits is regarded associated with eg. contaminants sorbed to particles
10.4a Settlement	The amount of water in Quaternary deposits affects the settlement of decomposers. Too little or too much water prevents settlement.	Decomposers (esp mushrooms) on land are affected by water content in deposits.
13.15a Mixing	The distribution, magnitude and direction of gas (including air) flow in the different components of the biosphere system affect the concentration of radionuclides and other toxicants in gas phase in the system components.	Important for Carbon-14, Tritium, Iodine and Radon. It is assumed that the mixing is quick in the atmosphere and thus the concentrations are low and thus not important
15.12b Formation of stabile isotopes	Decay of radionuclides to stabile isotopes that affect the composition of the water in the different components of the biosphere system.	Probably too small amounts
15.12c Chemical reactions	Chemical reactions, e.g decomposition of organic toxicants, and all other reactions involving radionuclides and other toxicants in dissolved and in particulate form may affect the composition of the water in the different components of the biosphere system.	Too small amounts of radionuclides to have any important effect.
15.2b Irradiation	Irradiation of the materials in Quaternary deposits by radionuclides in the materials and in the water in Quaternary deposits may affect the mineralogic structure of the materials in Quaternary deposits.	Too small amounts of radionuclides to have any significant effect.
2.12c Sorption/ desorption	The composition and grain size distribution (available surfaces for sorption) of the materials in the Quaternary deposits will affect the extent of sorption of dissolved species and particulates and thus the composition of the water in the Quaternary deposits	This affects the water chemistry. However, it is assumed that there is an equilibrium already established and that there will be no significant changes
3.15c Degradation	Degradation of toxicants by primary producers affects the type and concentration of toxicants in the different parts of the biosphere system.	Only important for toxicants. Not considering this for toxicants is a conservative approach
3.15d Growth	The rate of growth of primary producers affects the concentration of radionuclides and other toxicants in the primary producers.	Presently there is a "growth" of primary producers both on land and in water. Growth can affect the dilution of concentration, if biomass growth is larger than uptake. Not considering this is a conservative approach
5.15c Degradation	Degradation of toxicants by filter feeders affects the type and concentration of toxicants in the different parts of the biosphere system.	Only important for toxicants. If not used probably a conservative estimate
5.15d Growth	The rate of growth of filter feeders affects the concentration of radionuclides and other toxicants in filter feeders.	Could be of importance, but should normally give a dilution in organisms. If it is not treated it is probably a conservative approach.
7.15c Degradation	Degradation of toxicants by carnivores affects the type and concentration of toxicants in the different parts of the biosphere system.	Only important for toxicants

Interaction/process in Biosphere matrix	Description	Motivation
8.15c Degradation	Degradation of toxicants by humans affects the type and concentration of toxicants in the different parts of the biosphere system.	These types of contaminant are not considered
8.15d Growth	The rate of growth of humans and their length of life affects the concentration of radionuclides and other toxicants in humans.	Could be of importance, but is already accounted for in the establishment of dose coefficients and permitted doses
8.15e Human activities	Human activities can affect the concentration of radionuclides and toxicants in the bisospere system e.g. pollution and the operation of nuclear facilities	Uncertain of the importance. Depends on the amount of radionuclides or toxicants released. In this assessment it is assumed that no other releases than from SFR are occuring
13.15b Sorption/desorption	Sorption/desorption of radionuclides and other toxicants in gas phase on particles, pollen and water drops in the atmosphere that affects the distribution of radionuclides and other toxicants and thus the concentration in gas phase, on particles and in water drops.	Of no importance for Carbon-14 and Radon. Could be of importance for Iodine in the aspect of Iodine in water drops that deposits on the surface.
16.14b Insolation	Insolation and other irradiation entering the system influence the temperature in the different part of the system. Remark:The true interaction goes via absorption in the different components	The insolation for temperature change is assumed to be included in temperature statistics. The insolation as a factor affecting photosynthesis is treated directly for primary producers
12.2b Precipitation/ dissolution	The composition of the water in Quaternary deposits will affect precipitation/dissolution reactions and thus the material composition, geometry and porosity of the Quaternary deposits.	The physical structure of deposits is assumed to be a results of this interaction
2.7b Consumption	Consumption of solid material accidentally with the food or by purpose	For pure predators the ingestion of soils and sediments probably is negligible compared to the ingestion of prey. For mixed carnivores, decomposers, herbivores this is handled for the other feeding strategies
2.13b Non-biological decomposition	Physical or chemical degradation of Quaternary deposits leading to gas formation, e.g. sun irradiation and fire	There is probably no effect of this process
2.14b Heat transport	The composition and the grain size distribution of the materials in the Quaternary deposits affects the heat transport in Quaternary deposits and thereby the temperature in the different parts of the biosphere system.	This is an important process for soil temperatures. However, not considered as a process and might be described by temperature statistics and suitable vegetation substrates
2.14c Heat storage	The density and heat properties determines the amount of heat that can be stored in a volume of quaternary deposits	See 2.14b
3.5a Stimulation/ Inhibition	Space competition; food shadowing; + -substrate, -toxin, size Primary producers can stimulate the living conditions for filter feeders by e.g. symbiotic effects and by increasing the surface area available for living. Primary producers can inhibit or restrain the living conditions by e.g competition of place, shadowing effects, content of toxicants.	This not treated as a mechanism, but through the description of the ecosystem and correlation between amcrophytes and filter feeders

Interaction/process in Biosphere matrix	Description	Motivation
3.5b Food supply	Amount of plankton algae and spores. Debris goes via particle content in water composition Type and amount of primary producers affects the type and amount of filter feeders by acting as food supply.	This is important for the amount of matter in the water and thus treated by influencing the amount of POC, which then affects the food supply for filter feeders
3.4a Stimulation/ Inhibition	Quality as food (+ nutrient , - toxins, - mechanical structure). Can also via temperature and water content affect microclimate.	This is not treated as a mechnism, but through the description of the ecosystem
3.7a Stimulation/ Inhibition	+-habitat; -physcial barrier; (feeding carnivorous plants)	The primary producers are important as a habitat structure for other species. But there is no reason to believe that this will change independent from species composition.
3.8a Stimulation/ Inhibition	Species diversity and compostion, shelter, beauty, -aufwuchs	Humans select places to live which are pretty, easy to maintain or give some shelter or view which can be dependent on the amount of primary producers (e.g. forest). Thus the settlement of humans is not random. In the assessment we assume that humans settle anywhere where it is possible.
4.3a Stimulation/ Inhibition	+Mycorriza; -toxins, Mineralisation goes via water composition. Soil structure goes via quaternary deposits.	Decomposers as fungi in symbiosis are important in providing terrestial plant with nutrients. Decomposers can also affect its enviroment with toxins. However, the mycorhiza is inlcuded in the assessment of plants and thus not treated explicitly
4.6a Stimulation/ Inhibition	Food quality (toxins, mushrooms)	The toxic effects of decomposers are assumed to be occassional and thus not affect the population of herbivores.
4.5a Stimulation/ Inhibition	Toxicants, size, mechanical properties (spines…) nutritional value	The characteristics that affect the filter feeders is not evaluated. The effects should limit the food intake. Thus it is considered to just limit food and radionuclide uptake in filter feeders. This is important for the amount of matter in the water and thus treated by influencing the amount of POC, which then affects the food supply for filter feeders.
4.5b Food supply	Amount of food	The transfer of organic matter to filter feeders is not delimited by the food supply in this system. This is important for the amount of matter in the water and thus treated by influencing the amount of POC, which then affects the food supply for filter feeders.
4.7a Stimulation/ Inhibition	Quality as food (+ nutrient ,(- toxins), - mechanical structure e.g shells)	The food quality is assumed to be regraded in the species composition. Thus the species composition estimated from surveys or assumptions reflect the food qualtiy.
4.8a Stimulation/ Inhibition	Quality as food (+ nutrient ,(- toxins), - mechanical structure e.g shells)	The quality and taste of food certainly affects humans as well as toxic decomposers (mushrooms). However, this is assumed to be treated implicitly in food selection by humans of different culture and not by an evaluation of available sources.
4.8b Food supply	Amount and production rate, mushrooms etc	The supply rate of decomposers as food probably will not limit human populations. It is just a tasty supplement in nutrition.

Interaction/process in Biosphere matrix	Description	Motivation
5.4a Stimulation/ Inhibition	Quality as food (+ nutrient ,(- toxins), - mechanical structure e.g shells). Can also with bioturbation and via water composition, water current and quaternary deposits affect oxygen content and mechanical structure of sediment	Filter feeders can affect the species composition, which is assumed to be estimated by surveys.
5.4b Food supply	Mortality rate gives the supply amount of dead mater, sedimentation, debris production (faeces, pseudofaeces)	The production of faeces and pseudofeaces is substantial for filter feeders and important food sources for decomposers. In this area the filter feeders are scarce and thus insignificant contribution. Is however affected by a more saline environment
5.3a Stimulation/ Inhibition	-space competition ; shadowing; + substrate, reproduction vector ; watertransparency and mineralsiation via watercomposition The type, amount and location of filter feeders can influence the living conditions for primary producers, e.g stimulation by symbiotic effects, algae only living on clams that are acting as substrates. and inhibition by competition of place. Remark: The effect of remineralisation and filtering of particles water transparency goes via the water chemistry.	The competition of space is important, but it is assumed that the species composition is estimated when the competition is in steady state. Thus the process itself is expressed in the estimate of species composition
5.6a Stimulation/ Inhibition	Space competition (eg. Mytilus -. Patella)	Competition about space is assumed to be reflected by species composition
5.6c Feeding	Feeding on zoo plankton, larvae	Feeding is assumed to be low due to the low abundance in todays situation around SFR. Can be affected by higher salinity, but need also higher abundance of rock surfaces. Zoo plankton and larvae are assumed to be contributors to POM in water composition and treated there.
5.7a Stimulation/ Inhibition	Quality as food (+ nutrient , - mechanical structure e.g shells). Can also with +- bioturbation and via water composition, water current and quaternary deposits affect oxygen content and mechanical structure of sediment. +Mechanical degradation of other food items.	The digestibility can affect the carnivores food selection. However, carnivores seem not to be limited by filter feeder availability.
5.7c Feeding	Feeding on larvae, zoo plankton	The feeding on larvae and zoo plankton is assumed to go over the POM content in water composition
5.8a Stimulation/ Inhibition	Aufwuchs; beauty; toxin	The change in human behaviour due to this is assumed to be included in the overall uncertanties of human consumption
6.3a Stimulation/ Inhibition	Selection > competition e.g feeding of epiphytes; +seed dispersal, pollination; trampling. Remark: Mineralisation and soil structure via water composition and deposits	The competition is assumed to be in steady state and reflected by the surveys of species composition and abundance
6.3c Feeding	Feeding grazing, fruit, nectar consumption	The grazing is assumed to be in steady state and reflected by the surveys of species composition and abundance.

Interaction/process in Biosphere matrix	Description	Motivation
6.4a Stimulation/ Inhibition	Quality as food (+ nutrient , - mechanical structure e.g shells). Can also with +- bioturbation and via water composition, water current and quaternary deposits affect oxygen content and mechanical struture of sediment +Mechanical degradation of other food items, +- trampling, +storage (squirrels etc)	The effect of nutritional value of decomposers for herbivores is assumed to be reflected in species composition of decomposers
6.8a Stimulation/ Inhibition	Beauty; toxin; pleasure horse	The preference is assumed to be included in the variability of human behaviour
6.7a Stimulation/ Inhibition	Quality as food (+ nutrient , - mechanical structure e.g shells), +- trampling,	The food quality is assumed to be included in feeding rates
6.5a Stimulation/ Inhibition	Competition space food (plankton) , - toxins	Populations are assumed to be in steady state, thus the species composition reflects the competition.
6.5bFood supply	Amount of herbivorous zoo plankton, gametes. Particle production goes via water composition	Reflected by species composition
7.3a Stimulation/ Inhibition	Trampling; mechanical by nesting woodpecking etc; Remark:mineralisation via water composition; feeding om herbivores via herbivores	The effect is limited and random over a large area and thus not regarded
7.5a Stimulation/ Inhibition	Competition space ; negative selection affects competition between filter feeders	This interaction is assumed to already be established and is reflected by species composition.
7.4a Stimulation/ Inhibition	Quality as food (+ nutrient , - mechanical structure e.g shells). Can also with +- bioturbation and via water composition, water current and quaternary deposits affect oxygen content and mechanical structure of sediment +Mechanical degradation of other food items, +- trampling, +storage (bobcats)	This interaction is assumed to already be established and reflected by species composition.
7.5b Food supply	Amount of gametes	gametes; particle production goes via water composition as particulate matter.
7.5c Feeding	Predation e.g. Flounders, eider	The feeding by carnivores on filter feeders can affect the population of filter feeders, but is assumed to be expressed in species composition.
7.4c Feeding	Feeding of worms, larvae	The feeding by carnivores on decomposers, (eg.worms) can affect the population, but is assumed to be expressed in species composition.
7.6aStimulation/ Inhibition	Selection affects competition between herbivores	The interaction is assumed to be reflected by species composition
7.6c Feeding	Predation Carnivores eating herbivores....	The interaction is assumed to be reflected by species composition
7.8aStimulation/ Inhibition	Food competition: hunting, gaming, disturbance	Not a significant interaction in todays human world
7.8c Feeding	Bears, wolf , crows, gulls, fish on corpses	The consumtion of humans by carnivores is unusal

Interaction/process in Biosphere matrix	Description	Motivation
8.3c Feeding	Feeding of fruits, plants, seeds, roots, medicine, tobacco	Feeding is assumed to be including in habit of utilizig the nature and thus there is no interaction
8.4a Stimulation/ Inhibition	Cultivation by supply of substrate or selection, storages in waste deposits, composts.	Human have an impact in storing and producing garbage etc, but the amount is given by assumption and thus not treated as an interaction
8.4b Food supply	Debris production (faeces, mechanical fragmentation). Mortality rate gives the supply amount of dead maters.	The faeces production is assumed to have only local influence. For that spatial scale the time scale is very long for reutilizing feaces in large quantities.
8.4c Feeding	Feeding of mushrooms, worms and larvae"	The human consumption of detrivores is assumed to be negligible as an impact on them. Moreover this is treated in species composition after impact.
8.4d Dispersal/ Extermination	Dispersal of new populations by cultivation or by accident (eg mushroom farms), gengineering, - extermination of populations by negative selection. Many other ways over chemical composition or toxicants	The human influence can be large, but this is not considered as an interaction because it is assumed to be given by the assessment context.
8.5a Stimulation/ Inhibition	Cultivation, supply of substrate or opposite via over deposits, selection	The human influence is moderate and not used as an interaction because it is assumed to be given by the assessment context
8.5b Food supply	Debris production (faeces, mechanical fragmentation). However, this goes via water composition (particle content)	The human influence can be large in debris production, but this is not used as an interaction because it is assumed to be included in water composition as particle content
8.5c Feeding	Feeding on mussels, oysters etc"	The human consumption of filter feeders is assumed to be negligible as impact on filter feeders. Moreover this is treated in species composition after impact.
8.6c Feeding	Feeding on animals	Feeding on animal has a large impact on population, but is assumed to be fixed by assumption.
8.6d Dispersal/ Extermination	Dispersal of new populations by cultivation (e.g farming) or by accident (eg rabbits), gengineering, - extermination of populations by negative selection (e.g. Vincent)	Included in stimulation
8.7a Stimulation/ Inhibition	Game, - extemination programs, +- cultivation , sancturaries, national parks	The humans have large impact on carnivores, but it is assumed that this is refleted by species composition and assessment context
8.7b Food supply	bears ??	Normally the assumption is that humans not are a food supply for animals
8.7c Feeding	Feeding of fish, birds, etc	Unusual that human feed on carnivorous mammals, but on fish and occassionally lizards. In Sweden fish belong to a normal diet. The impact on fish can be large, but is assumed to be covered by the species composition
8.8a Stimulation/ Inhibition	Competition about space and resources;+ mating fun	Human interact in many ways, but for the future we assume that humans are responsible thinking beeings respecting each other loving each other as much that the poulation is happy and the resources are exploited in a sustainable way.

Interaction/process in Biosphere matrix	Description	Motivation
7.7aStimulation/ Inhibition	Competition about space and resources;+ mating; physcial disturbance	The competition is assumed to be estimated by species composition and it is assumed that the interactions shows up in species dominance
6.6aStimulation/ Inhibition	Competition about space and resources;+ mating	Populations assumed to be in steady state. That means that competition is expressed in species composition.
5.5a Stimulation/ Inhibition	Competition about space and resources;+ mating; physcial disturbance	The competition is assumed to be optimal and thus no further changes are expected to affect the composition as estimated from field surveys or assumptions
4.4aStimulation/ Inhibition	Competition about space and resources;+ mating; physcial disturbance	The competition is assumed to be optimal and thus no further changes are expected to affect the composition as was estimated from field surveys or assumptions
3.3a Stimulation/ Inhibition	Competition about space and resources and reproduction	The composition of primary producers is assumed to be "optimal" for the ecosystem considered. Thus competition is considered to be established and the result is dependent on external factors, a disturbance (e.g. agriculture), or the system is at its natural "climax" (e.g. forest). This is then identified through the compostion of species registered by surveys (e.g Kautsky et al 1999; Jerling et al 2001) or assumptions (e.g. cerial crops)
5.5b Food supply	Eating each other larvae	The process affecting composition and dominance is assumed to be covered by estimates of species composition.
5.5c Feeding	Eating each other larvae	The process affecting composition and dominance is assumed to be covered by estimates of species composition.
3.11b Retardation/ Acceleration	The type and amount of primary producers in surface waters influences the movement of water. For example the overgrow of a narrow sound. Remark: Alges in particulate form are included in the water composition, the amount of alges influences the water viscosity	This is not considered explicitly. It is assumed that these effects are inlcuded in the uncertainty of water exchange and in the dynamics describing this.
3.11c Uptake/ Excretion	Uptake of surface water by primary producers via roots and cells affects the amount and movement of surface waters. For example water hyacinths take water directly from surface waters.	Surface waters are not significantly affected by plant taking water of the reservoir. This path goes through water in quarternary deposits
3.11d Covering	The amount of primary producers covering the contact area between surface waters and the atmosphere determines the amount of water that can evaporate and thereby the amount of surface waters	This is not addressed explicity. It is assumed to be inluded in the measurements or statistics of runoff
3.12b Particle production and trapping	The existence of primary producers in the surface waters is a source for particle production. The type and amount of primary producers will thus influence the water composition. Particle trapping compare 3.13??	The particle production and trapping by primary producers are not explicitly treated in the assessment. It is assumed that this is included in the estimates of sedimentation rates. For the turbidity and particle content in water the measured values are used instead.
3.13b Particle trapping and production	Primary producers may affect the amount of particles in the gas, e.g. by the deposition of particles on leaves and pine needles, and by the release of pollen.	The effect on gas of dust collection is more dependent on wind direction and strength than on the mechanical obstruction of e.g. vegetation

Interaction/process in Biosphere matrix	Description	Motivation
3.13c Wind retardation	The type, amount and location of primary producers determines the degree of sheltering and influence thereby wind directions and velocities.	The turbulence and changing wind direction is assumed to be more variable than the physical obstruction of vegetation.
3.14b Exotherm/ Endotherm reactions	Biotic processes (e.g. photosyntheses) and abiotic processes (e.g. fires) influence the temperature in the biosphere.	The metabolic heat of vegetation is limited compared to the heat generated due to absorption (95% of the energy) and thus disregarded. Forest fire are only occasional and the effects on temperature are negligible under long-term conditions
3.14c Heat transport	Vegetation can work as an efficient insulator between atmosphere and underlying soil or water	It is not treated explicitly since there is a high variation in air temperature and slope is also affecting e.g.soil temperature
4.14a Radiation	The color and structure of decomposers can affect the radiation balance	Most decomposers are small or in fauna (e.g. worms) and thus not exposed to the surface which can affect radiation balance. If they were at surface they should be outcompeted or in symbiosis with primary producers. Thus there is no or limited effect on radiation balance by decomposers
5.14a Radiation	The color and texture of filter feeders could affect radiation	Of limited importance since radiation of water will be more important
6.14a Radiation	The color and structure of herbivores can affect the radiation balance	Most herbivores are mobile and some are small and thus have specific effect on radiation
7.14a Radiation	The color and structure of carnivores can affect the radiation balance	Most carnivores are very mobile and thus have specific effect on radiation
8.14a Radiation	Humans may affect the radiation balance	Humans are doing the best to change the radiation balance with their activities. However, this is dependent on the assessment context
4.14b Exotherm/ Endotherm reactions	The metabolic heat due to decomposition can increase temperature	The metabolic heat (e.g. compost) due to decomposition is normally a local effect. Normally air temperature and radiation is the dominating factors affecting the temperature. Thus this process is disregarded in the spatial and temporal time frame of assessment
5.14b Exotherm/ Endotherm reactions	The metabolic heat will heat the water surrounding the fitler feeders	Of limited importance since metabolic heat is very small
6.14b Exotherm/ Endotherm reactions	The metabolic heat due to metabolism can increase temperature	The metabolic heat is normally a local effect. Normally air temperature and radiation is the dominating factor affecting the temperature. Thus this process is disregarded in the spatial and temporal time frame of the assessment
7.14b Exotherm/ Endotherm reactions	The metabolic heat due to metabolism can increase temperature	The metabolic heat is normally a local effect. Normally air temperature and radiation is the dominating factor affecting the temperature. Thus this process is disregarded in the spatial and temporal time frame of assessment
8.14b Exotherm/ Endotherm reactions	The metabolic heat	Metabolic heat is assumed to be negligible compared to other sources
4.14c Heat transport	The isolation of decomposers or movement can affect heat transport	The density of decomposers is small compared to the decomposed matter and structure of it. Thus the heat transport propeties of the quaternary deposits is more important.
5.14c Heat transport	A layer of filter feeders could change isolation	Of limited importance since properties of water will be more important
6.14c Heat transport	The isolation of herbivores or movement can affect heat transport	The density of herbivores is small compared to e.g quaternary deposits. Moreover herbivores are mobile and have little effect on isolation.

Interaction/process in Biosphere matrix	Description	Motivation
7.14c Heat transport	The isolation of carnivores or movement can affect heat transport	The density of carnivores is small compared to e.g quaternary deposits. Moreover carnivores are mobile and have little effect on isolation.
8.14c Heat transport	Isolation , greenhosue influence heat trasnprot	The isolation is affected mainly by buildings, which is treated as deposits. It is however assumed that this already is given in the climate situation from assessment context
8.14d Anthropogenic effects	Human activitities such as industrial activities may have a direct influence on the temperature in the biosphere. Treated as an alternative scenario	It is assumed that this already is given in the climate situation from assessmenrt context
4.11a Decomposition	The decomposition of organic material produces water by releasing crystal water and by the production of the degradation products CO2 and H2O.	The contribution from this release will be minor compared to the wet climate conditions in Sweden. Moreover it will not form surface waters, it will then evaporate in dry conditions
4.11b Retardation/ Acceleration	The type and amount of decomposers attached to surfaces in contact with surface waters influence the properties of the surfaces and thereby water movement	The viscosity of surface waters is affected by the amount of eg. micobes. The variation in movement of surface waters and occasional occurence of the viscosity effect assumes that this effect is already encompassed in the variance
4.11c Uptake/ Excretion	Uptake of surface water by decomposers affects the amount and movement of surface waters.	The uptake or excretion of water will normally not affect the amount of surface water where there sustainable surface water. It could however cause ephemeral waterbodies (urine pits), but there lifelength and random placement is disregarded in timescales longer than a day.
4.11d Movement	The existence and movement of decomposers in surface waters may have an influence on the surface water movement	The decomposers are generally small (microbes, fungi, worms, snails) and will probabaly not affect waterbodies larger than some m3 with their movement. This size of waterbodies is assumed anyhow to be homegeneously mixed
5.11a Water pumping	The filter feeders influence actively the water flow by filtrating / pumping the water.	Compared to the turnover of water due to other water movement the effects of filter feeders are negligible.
5.11b Retardation/ Acceleration	The type and amount of filter feeders attached to surfaces in contact with surface waters influence the properties of the surfaces and thereby water movement	Usually of minor importance compared with other factors affecting water flow
5.11c Uptake/ Excretion	Uptake of surface water by filter feeders affect the amount and movement of surface waters.	The exchange of water is small compared to the turbulence
6.11a Movement	The movement of herbivores in surface waters may have an influence on the surface water movement	Normally there are no hippos in the Swedish climate. The water movements induced by herbivores is assumed to be less than normal turnover by e.g. wind stress
6.11b Retardation/ Acceleration	The type and amount of herbivores can by their existence influence the properties of the surface waters and thereby water movement	No known cases of this interaction in Sweden
6.11c Uptake/ Excretion	Consumption of surface water by herbivores affects the amount of surface waters.	Small waterbodies can be affected by consumption by e.g. cows as well as excretion by herbivores. These waterbodies are ephemeral anyhow due to desiccation/flooding and regarded to have statistical minor frequence compared to larger waterbodies

Interaction/process in Biosphere matrix	Description	Motivation
7.11a Movement	The existence and movement of carnivores in surface waters may have an influence on the surface water movement	Crocodiles and shark are not assumed to belong to the Swedish fauna today
7.11b Retardation/ Acceleration	The type and amount of carnivores attached to surfaces in contact with surface waters influence the properties of the surfaces and thereby water movement	No example found that shows this problem
7.11c Uptake/ Excretion	Uptake of surface water by carnivores affects the amount and movement of surface waters.	The water consumption and release by terrestial carnivores is small compared to their prey.
8.11b Retardation/ Acceleration	Human themselves don´t change the retardation/acceleration of water, but through constructions e.g. houses, dams, boats and icebreakers that influence water movement	Humans mainly has small impact on water movement compared with natural sources
8.11d Covering	The use of icebreakers by humans influence the amount of surfaces covered with ice and the free water surfaces and influence thereby amount and surface water movement	Not regarded as important
4.13a Gas uptake and release	Decomposers will for example by uptake of O2 and release of CO2 influence the gas composition. In addition, the decomposition of organic material lead to the production of different kinds of gases (e.g. production of CO2, H20g, H2, CH4, H2S, S2) that influences the amount of gas and the gas composition.	The release and uptake of gas by decomposers will have limited local effect on gas composition, due to high exchange rates of gas in the air by wind and turbulence and is thus regarded as constants in the time perspective of an assessment
4.13b Particle trapping and production	Decomposers may affect the amount of particles in the gas, e.g. by trapping on slimy surfaces and by the production and release of spores	The release and uptake of particles by decomposers will have a limited local effect on gas composition, due to high exchange rates of gas in the air by wind and turbulence and is thus regarded as constants in the time perspective of an assessment
5.12a Uptake/ Excretion	Uptake and excretion by filter feeders will have an influence on the water composition. For example the uptake of O2 and the excretion of CO2 and dissolved organic species.	The procss is important affecting the C02 and O2 content as well as the nutrient level in the water. Here not explicitly treated as a process, but derived from actual water composition measured
5.12b Particle production and trapping	The filtering of surface waters by filter feeders will decrease the amount of small particles in the water. However, by excretion they can be a source for production of larger particles. The type and amount of filter feeders will thus influence the water composition.	The interaction is assumed to be expressed in water composition
6.12a Uptake/ Excretion	Uptake and excretion by herbivores will have an influence on the water composition. For example the uptake of O2 and the excretion of CO2 and dissolved organic species.	In water where the O2 and CO2 dynamics is important, herbivores are situated nearby the producers of O2 and consumer of C02 and thus the effect by herbivores is regarded as insignificant. Excretion of nutrients and other substances in water affect the nutrient turnover. On land the excretion of nutrients can affect small water volumes

Interaction/process in Biosphere matrix	Description	Motivation
6.12b Particle production and trapping	The eventual filtering of surface waters by herbivores will decrease the amount of small particles in the water. However, by excretion they can be a source for production of larger particles. The type and amount of herbivores will thus influence the water composition.	This interaction affects the particle content in water, but it is refelected in estimates and measurements of particle content.
7.12a Uptake/ Excretion	Uptake and excretion by carnivores will have an influence on the water composition. For example the uptake of O2 and the excretion of CO2 and dissolved organic species.	In water where the O2 and CO2 dynamics is important. However, carnivores contribute far less than decomposers. Excretion of nutrients and other substances in water affect the nutrient turnover. On land the excretion of nutrients can affect small water volumes.
7.12b Particle production and trapping	The eventual filtering of surface waters by carnivores will decrease the amount of small particles in the water. However, by excretion they can be a source for production of larger particles. The type and amount of carnivores will thus influence the water composition.	This is interaction affect the particle content in water, but is reflected in estimates and measurements.
6.13a Gas uptake and release	Herbivores will for example by respiration (uptake of O2 and release of CO2) influence the gas composition.	The effect is local and due to high turn over of atmosphere regarded as insignificant
6.13b Particle trapping and production	Herbivores may affect the amount of particles in the gas, e.g. by trapping on slimy surfaces or furs and by the release of e.g. hair	The effect is local and due to high turn over of atmosphere regarded as insignificant
7.13a Gas uptake and release	Carnivores will for example by respiration (uptake of O2 and release of CO2) influence the gas composition.	The effect is local and due to high turn over of atmosphere regarded as insignificant
7.13b Particle trapping and production	Carnivores may affect the amount of particles in the gas, e.g. by trapping on slimy surfaces or furs	The effect is local and due to high turn over of atmosphere regarded as insignificant
8.12b Filtering	Humans may affect the composition of surface waters by filtering	Human filter water which will affect e.g. drinking water. This will if anything probably reduce the contaminants. Although the filter equipment needs to be taken care of. It is assumed that this is neglible.
8.12c Pollution	Humans may affect the water composition by releasing pollutants (chemical toxicants and radionuclides not included)	Humans certainly affect the water composition by pollution, but it is assumed that this already is reflected in water composition
8.13a Gas uptake and release	Humans can for example by respiration (uptake of O2 and release of CO2) influence the air composition.	The release is assumed to be included already in atmosphere compostion
8.13c Wind	Humans can by their behaviour have an influence on wind velocities and fields, for example by the use of airplanes, helicopters, cars, fans, etc. In addition, man made structures such as buildings can redistribute wind velocities and field.	The influence on mass transport is regarded as insignificant compared to natural causes for wind
8.13d Pollution	Humans may affect the gas composition in the surrounding air and atmosphere by their behaviour and by industrial activities releasing pollutants (chemical toxicants and radionuclides not included)	Assumed to already be taken into account by the composition of the air

Interaction/process in Biosphere matrix	Description	Motivation
8.16b Emigration	Humans moving from site	Human moving from the area will get a lower exposure than people living at the site, thus it is conservative not to account for this
10.12c Density effect	The water pressure affects the density of the water in the Quaternary deposits and thereby the water composition.	Assumed to have a minor influence in the normally thin deposits in the SFR area
11.12b Density effect	The water pressure affects the density of the water and thereby the water composition.	Not regarded because the water is shallow (less than 80 m) in this area. Probably of minor importance due to the low compressibility of water.
10.14b Heat storage	The water content as well as the magnitude, direction and distribution of water flow in the Quaternary deposits affect the heat storage capacity and thus the temperature in the Quaternary deposits	This can affect surface temperature especially in winter. However, assumed that these effects will be reflected in species composition and therefore not specifically taken into account
11.1e Ice load	Changes in thickness of the ice sheet due to seasonal variations and during periods of glaciation and deglaciation will affect the mechanical stress in the rock. (GEO17.14b)	Normal seasonal variations. Negligible effects. No glaciation will take place within the time period considered
11.4a Settlement	Decomposers on land live mainly in quarternary deposit. In water they are everywhere mainly as bacteria Remark: Live mainly in Quaternary deposits	Decomposers on land are more dependent on water in quaternary deposits and vegetation structure, which is affected by surface water. Thus they are correlated to vegetation. In water they are abundant everywhere and treated then as estimated species abundance
11.3b Relocation	The magnitude and direction of surface water flow affects the extent of relocation of primary producers and thus the location. In addition, ice sraping can cause relocation.	This is an important process along the shoreline above and under water. It is however reflected in species composition in this area
11.4b Relocation	The flow of surface water cause detachment of decomposers and dispersal of decomposer to other places	Decomposers are either living in quaternary deposit and not directly affected byt this process or they live in water and are assumed to be reflected by species composition and a homogeneous distribution in water.
11.5b Relocation	Currents and water level changes detaches filter feeders from their substrate.	The estimated composition of species is assumed to reflect the variations in the water level and current conditions
11.6b Relocation	Currents and waterlevel changes can detach small herbivores	Assumed to be reflected in species composition
11.7b Relocation	Surface waters could move carnivores	They are moving as plankton, but that is reflected in species composition for plankton. Detachment is of minor importance because most carnivores are mobile.
11.8b Relocation	The water level changes or current relocate humans	This process can be avoided by human behaviour
11.4c Water uptake	Decomposers on land and water need water to their metabolism	The assumption is that there is sufficient of water for metabolism and contaminants transported with water are addressed in radionuclide transport.
11.5c Water uptake	Filter feeders need water for metabolism and as a carrier of organic matter and oxygen	Assumed that there is sufficient of water for established filter feeders. Uptake of organic matter is derived from water composition
11.7c Water uptake	Carnivores need water for metabolism	Quantitatively not so high compared to their prey

Interaction/process in Biosphere matrix	Description	Motivation
11.13b Sublimation	Transformation of water in solid phase (frost, ice) to gas phase by sublimation.	The effects on local atmosphere is assumed to be negligible compared to air exchange
11.13c Erosion	The release of water droplets by sea spray or snow by snowdrifts influences the composition of gas.	The effects on local atmosphere is assumed to be negligible compared to air exchange
11.14a Radiation	The size of the surface water area affects the extent of radiation and thereby the temperature in the surface waters	This is an important interaction for he temperature in diffrent compartments. However, the interaction is assumed to be expressed in available data on temperatures.
11.14b Exotherm/ Endotherm reactions	Exothermic/ endothermic reactions would impact temperature in surface waters	No exothermic or endothermic reactions of significance are identified
11.14c Heat transport	The magnitude, direction and distribution of water flow in the surface waters affect the heat transport in the biosphere system and thus the temperature in the system components.	The heat transport between compartments in surface waters is small compared to the heat transport through convection.
11.14e Light reflection	The wave form of the surface waters affects light reflection and thereby the temperature in the surface waters	The measured temperatures in water are a long term integrater of the high variation in waves and light reflection. Thus it is assumed that the water temperature reflects this process
12.2c Erosion / weathering	The composition of water in Quaternary deposits and surface waters influences the erosion/weathering of Quaternary deposits. For example the extent of blasting is influenced by the particle content in the waters.	The composition will affect the deposits but the movement of water will be higher and it is assumed that the effect of composition is included in the interaction with water movement
12.4b Stimulation/ Inhibition	The water composition (e.g. trace elements, nutrients, toxicants, etc.,) in Quaternary deposits (and surface waters) will affect the stimulation/inhibition of production of decomposers.	The stimulation and inhibition is assumed to be reflected in the species composition
12.6b Stimulation/ Inhibition	The water composition (e.g. trace elements, toxicants, etc.) in Quaternary deposits and surface waters will affect the stimulation/inhibition of production of herbivores and thereby affecting the amount of herbivores living both in water and on land.	Herbivores get their major supply of nutrient elements through their food and thus the growth effects are assumed to be reflected by food and not in settlement
12.7b Stimulation/ Inhibition	The water composition (e.g. trace elements, toxicants, etc.,) in Quaternary deposits and surface waters will affect the stimulation/inhibition of production of carnivores and thereby affecting the amount of carnivores living both in water and on land.	Carnivores get their major supply of nutrient elements through their food and thus the growth effects are assumed to be reflected by food and not in settlement
12.8a Settlement	The water composition (e.g. salinity, trace elements, toxicants, etc.,) in Quaternary deposits and surface waters affects the settlement of humans.	Humans are not in a very large extent affected by water composition
12.13b Dissolution/ Degassing	The amount of dissolved gases in surface waters and waters in Quaternary deposits will affect the degree of dissolution/degassing and thereby the composition of gas and atmosphere.	The gas exchange with the atmosphere is an important process. However, the local atmosphere will not be affected to a large extent because of the wind exhanges. The neglection of this will make a conservative estimate for contaminants (e.g 14CO2)

Interaction/process in Biosphere matrix	Description	Motivation
12.14a Exotherm/ Endotherm reactions	The reaction between substances in water in quaternary deposits and surface waters can require heat or release heat	This process is assumed to be negligible in the normal case since the substances are already dissolved in water. Other heat producing processes are of higher importance
12.14c Light reflection/ scattering	The presence of snow or other particles at the surface will influence the degree of light reflection and the amount of particles in the waters will influence the degree of scattering and thus the temperature in surface waters.	When this occurs the temperature of the water will anyhow be low and much lower is not possible due to convection of water
12.14d Adiabatic compression	Water with higher density will by gravitational forces sink and the water will be compressed when the pressure increases. The compression leads to the release of heat and thus a temperature increase.	This adiatbatic compression occurs at high pressures not obtainable in this area
13.2b Deposition	The amount of particles in the atmosphere and the wind velocity will affect the amount of deposited particles and thereby the amount, geometry and composition of Quaternary deposits.	The transport of fine material is limited in this region and thus also the deposition
13.2c Oxidation	The humidity of gas atmosphere and the content of oxidants, e.g. O2, will affect the oxidation of minerals in quaternary deposits and thereby the composition. In addition, fires will oxidise organic materials in quaternary deposits and thereby change the composition.	It is assumed that this process has already occured
13.3a Settlement	The deposition of spores, seeds and pollen is influenced by wind velocities and wind fields and affects thereby the settlement of primary producers.	This is an important dispersal process, but it is assumed that the species composition is instantaneous and reflected by the estimated composition
13.3b Stimulation/ Inhibition	The atmospheric conditions influence the living conditions and thus the productivity of primary producers, e.g. humidity, CO2 and toxicants. In addition, the deposition of particles leading to shadowing and the shadowing effects by clouds are included here.	It is assumed that this is reflected by species composition and that these processes varies largely over time
13.3c Relocation	The magnitude of the wind velocities and the distribution of the wind field affects the extent of relocation of primary producers and thus the location.	Likewise to settlement it is assumed that species composition reflects this condition. In the current climate it is not regarded as important in this area compared to the action of water
13.3d Deposition/ Removal	The magnitude of the wind velocities and the distribution of the wind field determines the deposition or removal of particulates, but also the removal of parts of primary producers and thus the living conditions.	See 13.3c
13.4a Settlement	Dispersal can be mediated by wind	The dispersal eg spores is assumed to be reflected by the species composition
13.4b Stimulation/ Inhibition	The atmospheric conditions influence the living conditions and thus the productivity of "species" e.g. humidity, O2 and toxicants.	The atmospheric condition affects the organism, but it is assumed that this is already reflected by species composition.
13.4c Relocation	See 13.4a	Se 13.4a
13.4d Deposition/ Removal	See 13.4a	Se 13.4a

Interaction/process in Biosphere matrix	Description	Motivation
13.8a Settlement	Humans might select place to setltle depending on wind	Not assumed to be important in this assessment
13.7a Settlement	Carnivores select areas depending on e.g. wind	The atmospheric changes have a short time constant and is assumed to vary randomly and thus the response is assumed to be random and with low quantitative importance
13.6a Settlement	Herbivores could avoid sheltered areas (e.g reindeers) or the opposite	The atmospheríc changes have a short time constant and is assumed to vary randomly and thus the response is assumed to be random and with low quantitative importance
13.8b Stimulation/ Inhibition	The atmospheric conditions influence the living conditions and thus the productivity of "species" e.g. humidity, O2 and toxicants.	Not assumed to be important in this assessment
13.7b Stimulation/ Inhibition	The atmospheric conditions influence the living conditions and thus the productivity of "species" e.g. humidity, O2 and toxicants.	The atmospheric changes have a short time constant and is assumed to vary randomly and thus the response is assumed to be random and with low quantitative importance
13.6b Stimulation/ Inhibition	The atmospheric conditions influence the living conditions and thus the productivity of "species" e.g. humidity, O2 and toxicants.	see 13.6a
13.8c Relocation	see 13.8a	Not assumed to be important in this assessment since humans are very mobile
13.7c Relocation	see 13.7a	The atmospheric changes have a short time constant and is assumed to vary randomly and thus the response is assumed to be random and with low quantitative importance
13.6c Relocation	see 13.6a	see 13.6a
13.8d Deposition/ Removal	see 13.8a	Not assumed to be important in this assessment since humans are very mobile
13.7d Deposition/ Removal	see 13.7a	The atmospheric changes have a short time constant and is assumed to vary randomly and thus the response is assumed to be random and with low quantitative importance
13.6d Deposition/ Removal	see 13.6a	see 13.6a
13.10c Sublimation	The transformation of water in solid phase (frost, ice) to gas phase by sublimation in the Quaternary deposits is influenced by the gas and atmospheric pressure.	Not regarded as a quantitatively important process compared with the others
13.11e Sublimation	The degree of transformation of water in solid phase (frost, ice) to gas phase by sublimation is influenced by the atmospheric pressure.	Not regarded as quantitatively important compared with other processes.
13.12b Deposition	Dry and wet deposition may affect the water composition.	The primary source of contamination is assumed to be through the ground. Thus secondary deposition does not provide higher levels
13.12c Evaporation/ Condensation	The degree of evaporation of water and the degree of condensation of humidity in the gas /atmosphere will by concentration and dilution, respectively, influence the water composition.	The water balance is included in interaction with surface water. The primary source of contamination is assumed to be through the ground. Thus secondary deposition does not provide higher levels

Interaction/process in Biosphere matrix	Description	Motivation
13.12d Dissolution/ Degassing	The chemical composition of gas and atmosphere will by dissolution of gas in waters influence the water composition. In addtion, the degree of degassing is influenced by the gas and atmosperic pressure.	The diffusion between water and atmosphere is regarded to be of quantitatively low importance. Neglecting it gives a conservative estimate
13.15c Photochemical reactions	Photochemical reaction can produce toxicants	There are no such toxicants identified and thus the process is neglected
14.3b Stimulation/ Inhibition	The temperature affects the productivity and water turnover of plant and algae	The temperature is an important factor regulating the processes. However, when estimating the annual net primary production the summer temperature has less effect than light and respiration.
14.4a Settlement	The temperature will affect the settlement of decomposers	The estimated species distribution is assumed to reflect the temperature dependence on settlement
14.5a Settlement	The temperature affects the settlement of filter feeders	The water temperature affects the settlement and spawning of e.g. blue mussels. However, it is assumed that this is reflected in the estimated species distribution.
14.6a Settlement	The temperature affects the settlement of herbivores	The estimated species distribution is assumed to reflect the temperature dependence on settlement
14.7a Settlement	The temperature affect the settlement of Carnivores	The estimated species distribution is assumed to reflect the temperature dependence on settlement
14.8a Settlement	Humans settle, build houses or prefer to stay where temperatures are nice	It is assumed that humans do the worst to get exposed, thus even settle in hostile environments
14.8b Stimulation/ Inhibition	Humans are stimulated / inhibited dependent on temperature	It is assumed that humans do the worst to get exposed, and they are able to alter its enviroment to make it more stimulating
14.11a Phase transitions	Freezing and evaporation of surface waters as a result of changes in temperature will affect water movement and amounts of water and ice.Temperature affects the aggregation state of water (gas, ice and water)	It is an important process, which however is included in most annual averages in the normal climate scenario. In a cooler climate this interaction is important
13.14b Exotherm/ Endotherm reactions	Change in temperature due to exothermic/endothermic reactions	The heat contribution due to exotherm/endotherm reactions is assumed to be of quantitatively small importance for heat transport compared with e.g. change in heat transport due to wind
13.14c Heat transport	Heat transport by gas/atmosphere	The heat transport with the atmosphere is rapid and assumed to be reflected by temperature measurements
13.14d Heat storage	Heat storage in gas/atmosphere that affects temperature	The heat storage in gas is limited compared to heat storage in soil and water and thus neglected
13.14e Adiabatic temperature change	Changes in gas pressure that affects temperature	Tha adiabatic temperature changes are assumed to be reflected by temperature measurements. The build up of mountains is unlikely in this time period with small changes in adiabatic processes
13.14f Phase changes	Heat generation/consumption due to phase changes will affect the temperature. Of importance in transpiration of primary producers.	The temperature changes due to phase transition is assumed to be reflected by temperature and not treated explicilty.

Interaction/process in Biosphere matrix	Description	Motivation
14.12c Mixing	The temperature influences the diffusion	The mixing process due to water movement is assumed to be much larger than the molecular diffusion
14.13b Phase transitions	Temperature affects the aggregation state of water (gas, ice and water) Remark: To get precipitation condensation kernels are required	The temperature effect on gas is an important driving mechanism for the phase transitions in the atmosphere. The external influences are assumed to be larger than the local effect
14.15a Kinetics and chemical equlibria	The temperature affects kinetics and chemical equilibria and thus the concentration of radionuclides and toxicants in the system components	The seasonal temperature variation encompasses the natural extremes for kinetics and chemical equilibria of radionuclides. Thus it is assumed that the annual average includes this variation
16.8b Immigration	The degree of immigration of humans to the studied area influences e.g living conditions and human behaviour.	It is assumed that human behaviour is predefined to give highest doses. Thus immigration will reduce the doses and is disregarded
16.13b Photochemical reactions	Photochemical reactions close to the surface will affect the gas composition e.g. ozon formation, smog formation and reactions in exhaust gases.	Assumed to be a non site-specific effect. If important then included in transfer factors
2.8c Material supply	The quarternay deposits can be used as construction material (e.g. sand, gravel, stones, clay),	It is assumed that the external radiation from this material is low since the concentration from the repository is low. Thus it is not regarded in the safety analysis
4.6b Food supply	Food supply (mushrooms)	Decomposers as fungi (mushrooms), but also as conditioners of plant material are food supply for herbivores. They are however not considered as limiting and thus the supply doesn`t affect the herbivore population.
4.8d Material supply	Material supply Penecilin, yeast	Some decomposers could be regarded as material supply for e.g. medicine. When they are used for this purpose it is assumed that also a quality check will ensure that it is non-contaminated matter.
5.8d Material supply	Pearls; shells; corals;	The supply of filter feeder is usually not a limiting factor for humans, and it is assumed that the external radiation from these objects are limited
7.8d Resource	Resource souvenirs, bone, zoo, dog , cat	The effect as external radiation from the these things is of minor importance
8.3d Dispersal/ Extermination	Dispersal of new populations by cultivation or by accident (eg farming planting), gengineering, -extermination of populations by negative selection, many other ways over chemical composition or toxicants	Dispersal is assumed to be including in habit of utilizig the nature and thus there is no interaction
8.5d Dispersal/ Extermination	Dispersal of new populations by cultivation (e.g farming) or by accident (eg Dreissena spp), gengineering, -extermination of populations by negative selection (Anodonta..) , many other ways over chemical composition or toxicants	The human influence is moderate and not used as an interaction because it is assumed to be given by the assessment context
8.7d Dispersal/ Extermination	Dispersal of new populations by cultivation or by accident (e.g. mink, dog. cat) , gengineering, -extermination of populations by negative selection e.g. wolf, falcon, many other ways over chemical composition or toxicants	The impact can be large, but is assumed to be covered by the species composition

Interaction/process in Biosphere matrix	Description	Motivation
8.7e Material use	Horns , teeth, stuffed birds	Has an impact on population, but is assumed to be reflected in species composition
4.4b Food supply	Eating each other. Decomposers e.g. eat microbes, or fungi can be a food source to e.g.worms.	The supply of organic or "conditioned "matter by decomposers is not considered explicitly. Is assumed to be contained in amount of organic matter in water, soil or sediments.
4.4c Feeding	Eating each other. Decomposers as e.g. worm can eat microbes or fungi.	The consumption of decomposers by decomposers is not considered explicitly. Is assumed to be contained in consumption of organic matter in water, soil or sediments.
1.8b Settlement - Living and building	Mineral resources and supply of water influence the location of human settlements as well as a stable ground. The sources for supply of water will also have an influence on the use of water e.g. showering and/or bathing	In this area there are no resources of importance. Water usage is determined also by the supply and quality of water from other sources such as quaternary deposits and surface waters. The area will be protected for some hundred years. Human activities caused by the existence of the repository are treated as separate scenarios.
2.15b Dissolution	Dissolution of natural radionuclides and toxicants included in minerals in quaternary deposits.	Not important compared to sorption/desorption.
12.15c Sedimentation	Aggregation of particles and sedimentation of these. Is influenced by the ionic strength and the particle size	An important process for sedimentation. However, the estimated sedimentation rates include these effects
2.3c Deposition on land	Deposition of sediments on e.g. plants and trees will influence their location. The degree of deposition on primary producers is influenced by the location and the properties of Quaternary deposits. Examples are shading or putting high load on the primary producers.	This effect is of larger importance on land than in water because of the longer times for recolonisation (>1 year). The probability of large relocation is however small. Humans can cause relocation on land e.g. by ploughing. This is assessed for annual plants and more treated as soil turnover and thus not treated in a normal scenario
1.2b Changes in rock surface location	Repository induced changes in rock surface location (eg collapse of caverns). The initiating event is eg cavern collapse that affects the stress conditions in the surrounding rock. These changes in stress may result in cave in of surrounding rock. (GEO14.17). Other examples could be neotectonic movements (Ref Mörner)	The thickness of Quarternary deposits is between 4-14 m [Sigurdsson, 1997]. If caverns collapse or neotektonics occur the impact has to be in the order of several meters to influence the surface location. Therefore other processes affecting relocation of Quarternary deposits are more important for the topography
10.2c Pingo formation	Temperature changes leading to freezing of the water and expansion of the ice and/or freeze and thaw in Quaternary deposits may result in the formation of pingos thereby changing the topography, e.g. formation of hills in bog lands.	Not relevant for the base scenario. Could possibly be important in case of permafrost, but it is not known if the conditions in the SFR area are such that pingos will develop. Furthermore it is assessed that formation of pingos is of negligible importance for the performance of SFR.
14.2b Thermal expansion/contraction	The change in geometry due to temperature and phase transitions eg,. water freezing	The changes of geometry are minor compared to other causes of changes in geometry e.g. erosion etc
2.13c Wind field changes	The topography results in increases and decreases in the windflow and influences thereby the distribution of the wind velocities and directions.	The wind field is affected by topography, but the process is fast and therefore not relevant in the time-scale of interest in the assessment
2.13d Air pressure	The topography determines the air pressure at the surface.	The expected height distribution is too small for this to be of importance

Appendix F: Repository, Geosphere and Biosphere matrices

A colour coding is used to display the priorities in the interaction matrices. In cases where one interaction box contains more than one interaction, the interaction with the highest priority determines the colour of the interaction box. The definition of the priorities used in the evaluation of the matrices is given in the table below. In the following figures the prioritised interaction matrices for the Repository, Geosphere and Biosphere are given.

Definition of priorities used in the matrices

Priority		**Description**
No	Colour	
4	Pink	**Important interaction only in the water saturation phase – part of the Performance Assessment.** It can influence other parts of the process system included in this matrix, or other parts of the repository system not included in this matrix.
3	Red	**Important interaction - part of the Performance Assessment.** Could also influence other parts of the process system, (defined in this matrix), or other parts of the repository system. The interaction can be either a prerequisite for the PA or handled by assumptions or modelling efforts in the PA.
2	Yellow	**Interaction present – probably part of the Performance Assessment.** Limited or uncertain influence directly or via this interaction on other parts of the process system, or other parts of the repository system. However, this interaction can be in main focus in other matrices.
1	Green	**Interaction present - do not have to be considered in the Performance Assessment.** Negligible influence on other parts of the process system, (defined in this matrix) and other parts of the repository system.
0	White	**No identified interactions**

The Repository matrix

Waste/ cement a) Recrystallis.	NONE	NONE	Expans./contract.	Expans./contract.	NONE	NONE	NONE	NONE	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Diffusion e) Sorption f) Colloid filtering	a) Water flow b) Capillary suct.	a) Corrosion b) Degrad.organic c) Gas flow	a) Cement hydration b) Heat conduction c) Exothermic reactions	Expans./contract.	Microbial activity	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Diffusion e) Sorption f) Colloid filtering	NONE	NONE
NONE	**Waste/ bitumen**	NONE	NONE	Expans./contract.	NONE	NONE	NONE	NONE	a) Dissol./precip. b) Degrad.organic c) Diffusion d) Sorption e) Colloid filtering	a) Water flow b) Capillary suct.	a) Degrad.organic b) Gas flow	a) Heat conduction b) Exothermic reactions	Expans./contract.	Microbial activity	a) Dissol./precip. b) Degrad.organic c) Diffusion d) Sorption e) Colloid filtering	NONE	NONE
NONE	NONE	**Waste/non-solidified**	Expans./contract.	Expans./contract.	NONE	NONE	NONE	NONE	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Diffusion e) Sorption f) Colloid filtering	a) Water flow b) Capillary suct.	a) Corrosion b) Degrad.organic c) Gas flow	a) Heat conduction b) Exothermic reactions	Expans./contract.	Microbial activity	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Diffusion e) Sorption f) Colloid filtering	NONE	NONE
Expans./contract.	NONE	Expans./contract.	**Concrete packaging** a) Recrystallis.	NONE	Expans./contract.	NONE	NONE	Expans./contract.	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Diffusion e) Sorption f) Colloid filtering g) Erosion	a) Water flow b) Capillary suct.	a) Corrosion b) Degrad.organic c) Gas flow	a) Cement hydration b) Heat conduction	Expans./contract.	Microbial activity	a) Diffusion b) Sorption c) Colloid filtering	NONE	NONE
Expans./contract.	Expans./contract.	Expans./contract.	NONE	**Steel packaging**	Expans./contract.	NONE	NONE	Expans./contract.	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Diffusion e) Sorption f) Colloid filtering g) Erosion	a) Water flow b) Capillary suct.	a) Corrosion b) Degrad.organic c) Gas flow	Heat conduction	Expans./contract.	Microbial activity	a) Diffusion b) Sorption c) Colloid filtering	NONE	NONE
NONE	NONE	NONE	Expans./contract.	Expans./contract.	**Concrete backfill** a) Recrystallis.	Expans./contract.	NONE	Expans./contract.	a) Dissol./precip. b) Degrad.organic c) Diffusion d) Sorption e) Colloid filtering f) Erosion	a) Water flow b) Capillary suct.	a) Degrad.organic b) Gas flow	a) Cement hydration b) Heat conduction	Expans./contract.	Microbial activity	a) Diffusion b) Sorption c) Colloid filtering	NONE	NONE
NONE	NONE	NONE	NONE	NONE	Expans./contract.	**Concrete structures** a) Recrystallis.	a) Expans/ contraction b) Bentonite expansion	Expans./contract.	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Diffusion e) Sorption f) Colloid filtering g) Erosion	a) Water flow b) Capillary suct.	a) Corrosion b) Degrad.organic c) Gas flow	a) Cement hydration b) Heat conduction	Expans./contract.	Microbial activity	a) Diffusion b) Sorption c) Colloid filtering	NONE	NONE
NONE	NONE	NONE	NONE	NONE	NONE	Bentonite expansion	**Bentonite barriers**	Bentonite expansion	a) Dissol./precip. b) Degrad.organic c) Diffusion d) Sorpt/ion-exch. e) Colloid filtering f) Colloid formation	a) Water flow b) Capillary suct.	a) Degrad.organic b) Gas flow	a) Heat conduction b) Exothermic reactions	Expans./contract.	Microbial activity	a) Diffusion b) Sorption/ion-exch. c) Colloid filtering	NONE	a) Bent. expans. b) Erosion
NONE	NONE	NONE	Expans./contract.	Expans./contract.	Expans./contract.	Expans./contract.	a) Expans./ contraction b) Bentonite expansion	**Vaults and backfill**	a) Dissol./precip. b) Degrad.organic c) Diffusion d) Sorption e) Colloid filtering f) Erosion	a) Water flow b) Capillary suct.	a) Degrad.organic b) Gas flow	a) Heat conduction b) Exothermic reactions	Expans./contract.	Microbial activity	a) Diffusion b) Sorption c) Colloid filtering	NONE	NONE
a) Dissol./precip. b) Corrosion c) Degrad.organic d) Water uptake	a) Dissol./precip. b) Degrad.organic c) Water uptake	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Water uptake	a) Dissol./precip. b) Corrosion c) Degrad.organic	a) Dissol./precip. b) Corrosion c) Degrad.organic	a) Dissol./precip. b) Degrad.organic	a) Dissol./precip. b) Corrosion c) Degrad.organic	a) Dissol./precip. b) Degrad.organic c) Ion-exchange d) Water uptake e) Expans/dispers f) Montmorillonite transformation	a) Dissol./precip. b) Degrad.organic	**Water composition** a) Colloid formation/stability	a) Water flow b) Convection c) Osmosis	a) Gas dissol./ degassing b) Chem. react. c) Corrosion d) Degrad.organic	Heat transport	NONE	Microbial activity	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Diffusion e) Sorption f) Colloid trsp	Mass flow	Mass flow
a) Dissol./precip. b) Corrosion c) Degrad.organic d) Water uptake	a) Dissol./precip. b) Degrad.organic d) Water uptake	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Water uptake e) Redistribution	a) Dissol./precip. b) Corrosion c) Degrad.organic e) Erosion	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Erosion	a) Dissol./precip. b) Degrad.organic c) Erosion	a) Dissol./precip. b) Corrosion c) Degrad.organic d) Erosion	a) Dissol./precip. b) Degrad.organic c) Ion-exchange d) Water uptake e) Erosion	a) Dissol./precip. b) Degrad.organic c) Erosion d) Redistribution (subsidence)	a) Advection and mixing b) Chem. equilibr c) Erosion	**Hydrology**	a) Saturation b) Diss./degass. c) Two phase flow d) Expansion/ contraction	Heat advection	Water pressure interaction	Advection	a) Advection b) Dispersion c) Gas dissol./ degassing	a) Mass flow b) Disch./rech and pressure c) Biomass flow d) Contamin.trsp	a) Mass flow b) Disch./rech and pressure c) Biomass flow d) Contamin.trsp
NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	a) Gas dissolution /degassing b) Colloid trsp	a) Saturation b) Two phase flow	**Gas**	a) Heat advection b) Heat conduction	Gas pressure interaction	a) Micr. activity b) Advection-gas	a) Advection-gas b) Colloid trsp	Gas transport	Gas transport
a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Expansion/ contraction	a) Kinetics and equlibria b) Prop. changes c) Diffusion	Phase changes	a) Exp./contract. b) Convection	**Temperature**	Thermal stress interaction	Microbial activity	a) Kinetics and equlibria b) Diffusion c) Soret effect	Heat transport	Heat transport
Cracking	Cracking	Redistribution	Cracking	Deformation	Cracking	a) Cracking b) Redistribution	Redistribution (subsidence)	Redistribution (subsidence)	NONE	Water pressure interaction	NONE	NONE	**Stress conditions**	NONE	NONE	Stress and strain changes	Stress and strain changes
Microbial growth	Microbial growth	Microbial growth	Microbial growth	Microbial growth	Microbial growth	Microbial growth	Microbial growth	Microbial growth	Microbial activity	NONE	Microbial activity	Microbial activity	NONE	**Biological state**	a) Microbial trsp b) Methylation/ transformation	Biomass flow	Biomass flow
Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	a) Radiolysis b) Radionuclide decay c) Degradation	NONE	a) Radiolysis b) Degradation	Heat from decay	NONE	Irradiation (mutation)	**Radionuclides and toxicants** a) Radionuclide decay	Contaminant transport	Contaminant transport
NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	Mass flow	Rech./disch. and pressure	Gas transport	Heat transport	Stress and strain changes	Biomass flow	Contaminant transport	**Tunnels (B.C.)**	NONE
NONE	NONE	NONE	NONE	Rock fall out	NONE	Rock fallout	a) Bent. expans. b) Erosion c) Rock creep	a) Rock fallout b) Rock creep	Mass flow	Rech./disch. and pressure	Gas transport	Heat transport	Stress and strain changes	Biomass flow	Contaminant transport	NONE	**Repository rock (B.C.)**

The Geosphere matrix

SILO (B.C.)	NONE	NONE	NONE	NONE	NONE	NONE	Bentonite expansion	NONE	a) Mass flow b) Erosion	Disch/recharge and pressure	Gas transport	Heat transport	Stress and strain changes	Biomass flow	Contaminant transport	NONE	NONE
NONE	**BMA (B.C.)**	NONE	NONE	NONE	NONE	NONE	NONE	NONE	Mass flow	Disch/recharge and pressure	Gas transport	Heat transport	Stress and strain changes	Biomass flow	Contaminant transport	NONE	NONE
NONE	NONE	**BTF (B.C.)**	NONE	NONE	NONE	NONE	NONE	NONE	Mass flow	Disch/recharge and pressure	Gas transport	Heat transport	Stress and strain changes	Biomass flow	Contaminant transport	NONE	NONE
NONE	NONE	NONE	**BLA (B.C.)**	NONE	NONE	NONE	NONE	NONE	Mass flow	Disch/recharge and pressure	Gas transport	Heat transport	Stress and strain changes	Biomass flow	Contaminant transport	NONE	NONE
NONE	NONE	NONE	NONE	**Tunnel/ borehole/ backfill**	Bentonite expansion	NONE	Bentonite expansion	Bentonite expansion	a) Dissol./precip. b) Corrosion c) Diffusion d) Sorption e) Colloid filtering f) Erosion g) Degr. of organics	a) Water flow b) Capillary suct.	a) Gas flow b) Corrosion c) Microbial activity	Heat conduction	Stress and strain changes	Microbial activity	a) Sorption b) Diffusion	NONE	NONE
NONE	NONE	NONE	NONE	a) Redistribution b) Bentonite exp.	**Plugs** a) Recrystallis.	NONE	Bentonite expansion	NONE	a) Diss/prec. Concr. b) Diss/prec. Bent. c) Diffusion d) Sorption/ion-exch e) Corrosion f) Colloid filtering g) Colloid formation	a) Water flow b) Capillary suct.	a) Gas flow b) Corrosion c) Microbial activity	Heat conduction	a) Bentonite expansion b) Stress and strain changes	Microbial activity	a) Sorption b) Diffusion	NONE	NONE
NONE	NONE	NONE	NONE	NONE	NONE	**Repository rock - rock matrix**	NONE	NONE	a) Dissol./precip. b) Diffusion c) Sorption	Capillary suction	a) Microbial activity b) Radon gener.	Heat conduction	Deformation	Microbial activity	a) Matrix diffusion b) Sorption	NONE	NONE
Bentonite expansion	NONE	NONE	NONE	Bentonite expansion	Bentonite expansion	NONE	**Repository rock - fracture system**	NONE	a) Dissol./prec. b) Diffusion c) Sorption d) Colloid filtering e) Erosion	a) Water flow b) Capillary suct.	a) Gas flow b) Microbial activity c) Radon gener.	Heat conduction	Deformation	Microbial activity	a) Matrix diff. b) Sorption c) Diffusion	NONE	NONE
NONE	NONE	NONE	NONE	Bentonite expansion	NONE	NONE	NONE	**Rock - rock matrix and fracture systems**	a) Dissol./prec. b) Diffusion c) Sorption d) Colloid filtering e) Erosion	Water flow	a) Gas flow b) Microbial activity c) Radon gen.	Heat conduction	Deformation	Microbial activity	a) Matrix diff. b) Sorption c) Diffusion	Erosion/ weathering	NONE
Mass flow	Mass flow	Mass flow	Mass flow	a) Diss./precip. b) Corrosion c) Ionic strength effects	a) Diss./precip. b) Corrosion c) Ion-exchange d) Water uptake e) Expans/dispers	Dissolution/ precipitation	Dissolution/ precipitation	Dissolution/ precipitation	**Water composition** a) Colloid formation/stability	a) Convection b) Water flow c) Osmosis	a) Gas dissol./ degassing b) Chemical reactions	Heat conduction	NONE	Microbial activity	a) Diffusion b) Sorption c) Prec./diss. d) Colloid trsp	Mass flow	Mass exchange
a) Mass flow b) Rech/disch and pressure c) Erosion d) Biomass flow e) Contamin.trsp	a) Mass flow b) Rech./disch and pressure c) Biomass flow d) Contamin.trsp	a) Mass flow b) Rech./disch and pressure c) Biomass flow d) Contamin.trsp	a) Mass flow b) Rech./disch and pressure c) Biomass flow d) Contamin.trsp	a) Diss./precip. b) Corrosion c) Redistribution	a) Diss./precip. b) Corrosion c) Erosion d) Water uptake	Diss./precip.	a) Diss./precip. b) Erosion	a) Diss./precip. b) Erosion	a) Advection and mixing b) Chemical equilibria c) Erosion	**Hydrology**	a) Saturation b) Diss./degass. c) Two phase flow d) Expansion/ contraction	Heat advection	Water pressure interaction	Advection	a) Advection b) Dispersion c) Gas dissol./ degassing	a) Mass flow b) Disch./rech and pressure c) Biomass flow d) Contamin trsp	a) Mass exchange b) Disch./rech and pressure c) Biomass exch.
Gas transport	Gas transport	Gas transport	Gas transport	NONE	NONE	NONE	NONE	NONE	a) Gas dissol./ degassing b) Colloid trsp	a) Saturation b) Two phase flow	**Gas**	a) Heat adv. b) Heat cond.	Gas pressure interaction	a) Biological activity b) Advection-gas	a) Advection-gas b) Colloid trsp	Gas transport	Gas exchange
Heat transport	Heat transport	Heat transport	Heat transport	a) Kinetics and equilibria b) Expansion/ contraction	a) Kinetics and equilibria b) Expansion/ contraction	a) Kinetics and equilibria b) Expansion/ contraction	a) Kinetics and equilibria b) Expansion/ contraction	a) Kinetics and equilibria b) Expansion/ contraction	a) Kinetics and equilibria b) Property changes c) Diffusion	Phase changes	a) Expansion/ contraction b) Convection	**Temperature**	Thermal stress interaction	Microbial activity	a) Kinetics and equilibria b) Diffusion c) Soret effect	Heat transport	Heat exchange
a) Stress/strain changes b) Rock fallout c) Rock creep	a) Stress/strain changes b) Rock fallout c) Rock creep	a) Stress/strain changes b) Rock fallout c) Rock creep	a) Stress/strain changes b) Rock fallout c) Rock creep	a) Rock creep b) Stress redist. c) Rock fall out	a) Cracking b) Rock creep	Stress redistribution	Stress redistribution	Stress redistribution	NONE	Water pressure interaction	NONE	NONE	**Stress conditions**	NONE	NONE	Change in rock surface location	Stress and strain changes
Biomass flow	Biomass flow	Biomass flow	Biomass flow	Microbial growth	Microbial growth	Microbial growth	Microbial growth	Microbial growth	Microbial activity	NONE	Microbial activity	Microbial activity	NONE	**Biological state**	a) Microbial trsp b) Methylation/ transformation	Biomass exchange	Biomass exchange
Contaminant transport	Contaminant transport	Contaminant transport	Contaminant transport	Irradiation	Irradiation	Irradiation	a) Irradiation b) Precipitation	Irradiation	a) Radiolysis b) Radionuclide decay c) Degradation	NONE	a) Radiolysis b) Degradation	Heat from decay	NONE	Irradiation (mutation)	**Radionuclides and toxicants** a) Radionuclide decay	Contaminant transport	NONE
NONE	NONE	NONE	NONE	Root penetration	Root penetration	NONE	NONE	a) Consolid. b) Root penetr. c) Erosion/ weath.	Mass flow	a) Rech./disch and wells b) Press. change	Gas transport	Heat transport	a) Mechan. load b) Ice load	a) Root penetr. b) Intrusion c) Biomass exchange	Contaminant transport	**Biosphere (B.C.)**	NONE
NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	Mass exchange	Rech./disch and pressure	Gas exchange	Heat exchange	Stress and strain changes	Biomass exchange	NONE	NONE	**External rock (B.C.)**

The Biosphere matrix

GEOSPHERE (B.C.)	a)Erosion/weath. b)Change in rock surface location	NONE	NONE	NONE	NONE	NONE	a)Material supply b)Settlement		Discharge/ recharge	Discharge/ recharge	Mass flux	Gas transport	Heat transport	Contaminant transport	NONE
a) Mech. load b) Consolidation	**Quaternary deposits** a)Relocation	a)Settlement b)Deposition	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption c)Material supply		a) Water transport b) Dehydration	a)Water transport b)Wave formation	a)Resuspension b)Leaching c)Sorpt./desorpt.	a)Resuspension b)Non-biol decomp c)Wind field changes d)Air pressure	a)Radiation b)Heat transport c)Heat storage	a)Sorption/desorpt. b)Dissolution	Export
Root penetration a) Rock b) Tunnels c) Biological	Root growth	**Primary producers** a)Stimul./Inhib.	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib.	a)Stimul./Inhib. b)Food supply d)Material supply		Root uptake	a)Interception b)Retard./Accel. c)Uptake/Excret. d)Covering	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod c)Wind retard.	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export detached outflow of plankton
Potential intrusion	a)Decomposition b)Bioturbation	a)Stimul./Inhib.	**Decomposers** a)Stimul/Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply d)Material supply		Decomposition	a)Decomposition b)Retard./Accel. c)Uptake/Excret. d)Movement	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export
Potential intrusion	Bioturbation	a)Stimul/Inhib. c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	**Filter feeders** a)Stimul/Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply d)Material supply		NONE	a)Water-pumping b)Retard./Accel. c)Uptake/Excret.	a)Uptake./Excret. b)Particle prod	NONE	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export detachment spawn
Potential intrusion	Bioturbation	a)Stimul./Inhib. c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply	**Herbivores** a)Stimul/Inhib.	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply d)Resource		NONE	a)Movement b)Retard./Accel. c)Uptake/Excret.	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export
Potential intrusion	Bioturbation	a)Stimul./Inhib.	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. c)Feeding	**Carnivores** a)Stimul/Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding d)Resource		NONE	a)Movement b)Retard./Accel. c)Uptake/Excret.	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export swimming running
NONE	Disturbance (dredging, digging)	a)Stimul./Inhib. c)Feeding d)Dispersal/ Extermination	a)Stimul./Inhib. b)Food supply c)Feeding d)Dispersal/ Extermination	a)Stimul./Inhib. c)Feeding d)Dispersal/ Extermination	a)Stimul./Inhib. c)Feeding d)Dispersal/ Extermination	a)Stimul./Inhib. b)Food supply c)Feeding d)Dispersal/ Extermination e)Material use	**Humans** a)Stimul/Inhib.		a)Water extraction b)Artific.infiltr.	a)Movement b)Retard./Accel. c)Uptake/Excret. d)Covering	a)Excretion b)Filtering c)Pollution	a)Gas uptake/rel b)Part. trap/prod c)Pollution d)Wind retard/acc.	a)Radiation b)Exo/Endo react. c)Heat transp. d)Antropogen eff	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	a)Export of energy b)Emigration?
								NONE (former topography)							
a) Rech./disch. b) Press. change c) Mass flux d) Erosion/weath.	a)Erosion b)Water content change	a) Settlement b) Water uptake	a) Settlement b) Water uptake	NONE	a) Settlement b) Water uptake	a) Settlement b) Water uptake	a) Settlement b) Water use		**Water in quarternary deposits**	Discharge (recharge)	a) Erosion b) Mixing c) Dens. effects	a)Evapo./Cond. b)Sublimation	a)Heat transp. b)Heat storage	Mixing	Export
a) Rech./disch. b) Press. change c) Mass flux d) Erosion/weath. e) Ice-load	Erosion (icescoring)	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water use		Recharge (discharge)	**Surface water**	a) Mixing b)Dens. effects	a)Evapo./Cond. b)Sublimation c)Erosion (seaspray/snowdrift)	a)Radiation b)Exo/Endo react. c)Heat transp. d)Heat storage e)Light reflection	Mixing	Export/import
a) Mass flux b)Erosion/weath.	a) Sedimentation b) Precip./dissol. c) Erosion/weath.	a)Settlement b)Stimul./Inhib. c)Light attenu.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.		Water transport	Water transport	**Water composition**	a)Spray/Snowdrift b)Dissol./Degas.	a)Exo/Endo react. b)Light absorb. c)Light reflect./scatt. d)Adiab. compr.	a) Sorpt./desorpt. b) Dissol./precip. c) Sedimentation	Export
Gas transport	a)Erosion b)Deposition c)Oxidation	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.	NONE	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.		a)Water transport b)Evapo./cond. c)Sublimation	a)Water transport b)Evapo./Cond. c)Precipitation d)Wind stress e)Sublimation	a)Precipitation b)Deposition c)Evapo./Cond. d)Dissol./Degas.	**Gas** -------------- **Atmosphere**	a)Radiation b)Exo/Endo react. c)Heat transp. d)Heat storage e)Adiab.temp.change f)Phase changes	a)Mixing b)Sorpt./desorpt. c)Photochem. reactions	Export
a)Heat transport b)Erosion/weath.	a)Weathering b)Thermal expans/contr	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.		Phase transitions	a)Phase transitions b)Convection	a)Kinetics & chem equil. b)Property changes c)Mixing	a)Pressure change b)Phase transitions	**Temperature**	a)Kinetics & chem equil. b)Phase transitions	Export of heat
Contaminant transport	a) Surface dep./uptake b) Irradiation	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure		NONE	NONE	a) Radiolysis b) Stab. isotopes c) Chem. react.	Phase transition	Heat from decay	**Radionuclides and toxicants** a) Decay	Export
NONE	a) Import b) Land rise	a) Import b) Insolation	Import	Import	Import	Import	a)Import of energy b)Immigration		Import	a) Sea level changes b) Sea currents	Import	a)Import b)Photochem-reactions	a) Import of heat b) Insolation	External load of contaminants	**External conditions (B.C.)**