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Updating the NEA International FEP List

An Integration Group for the Safety Case (IGSC) Technical Note

Technical Note 1: Identification and Review of Recent Project-specific FEP Lists

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Technical Note 1: Identification and Review of Recent Project specific FEP Lists.

September 2012

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25 September 2012

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1. INTRODUCTION

Background

The Nuclear Energy Agency's (NEA) Integration Group for the Safety Case (IGSC), and its predecessor, the Performance Assessment Advisory Group (PAAG), have carried out activities related to the compilation and use of lists and databases of features, events and processes (FEPs) in safety and performance assessment studies since the early 1990s.

This activity led to the publication of a report (NEA, 2000) and the development of an electronic database that included both an NEA International FEP List (see Appendix A) and eight FEP lists from national assessment studies. With support from a subgroup of IGSC members, the NEA electronic FEP database was subsequently updated to include two additional national project databases and re-issued as Version 2.1 to participating members of the subgroup in 2006.

In view of the maturing of geological disposal programmes towards implementation, and also developments in safety assessment methodologies as well as in the underlying scientific understanding (e.g. concerning thermal, hydraulic, mechanical, and chemical processes) of safety assessments (see for example NEA, 2012), the NEA sent a questionnaire on the use of FEPs in safety assessment studies to IGSC members at the end of 2010. The aims of the questionnaire were (1) to examine the use of FEPs or equivalent concepts in safety assessment studies and (2) to provide a basis for judging the need for any further IGSC activities related to FEP lists, databases or methods. Analysis of the questionnaire responses concluded that:

- The NEA International FEP List has been widely used but many organisations were concerned that it is now out of date and does not reflect more recent experience in safety assessments and their wider or more detailed scope.
- The electronic FEP database (with the attached project databases) has been less widely used, but is regarded as important by those that used it.
- There was strong support for the maintenance and updating of both the NEA International FEP List and the electronic FEP database.

Scope and Objectives of the Project

In light of the questionnaire results, the NEA has decided to support the revision of the NEA International FEP List and the associated database to ensure that they remain useful and relevant to the work of Member States.

It has been agreed that the updated NEA International FEP List should be:

- relevant to all stages of a repository development programme from inception to repository closure;
- relevant to both safety assessors and individual topic experts.

- limited to the post-closure safety of geological disposal facilities. Operational safety is beyond the scope of the current project, as are surface and near-surface disposal facilities (i.e., those on or within 30 m of the surface).
- relevant to all designs of geological disposal facilities.
- relevant to all categories of radioactive waste disposed in geological disposal facilities.
- relevant for the evaluation of radiological and non-radiological impacts of contaminant releases on humans and non-human biota.

A work programme has been developed comprising the following objectives:

- to review recent project-specific FEP lists that are of relevance (Task 1).
- to identify, agree and document the proposed revisions to the NEA International FEP List in light of the review (Task 2).
- to implement the revised NEA International FEP list in a prototype (Version 0) web-based database (Task 3).
- to develop the requirements specification for the Version 1 web-based database (Task 4).

Scope and Structure of this Technical Note

This Technical Note reviews the relevant project-specific FEP lists recently developed (i.e. since 2006) by organisations assessing the post-closure safety of the deep disposal of radioactive waste (Section 2). A country-by-country review is provided that summarises how the FEPs have been used and the structure and content of each FEP list. Relevant information is also summarised on FEP lists and their use from recent publications by the International Atomic Energy Agency (IAEA).

Section 3 provides a summary of how the FEP lists described in Section 2 have been used and structured.

Table 1 summarises the list of organisations contacted and the status of their FEP list or other relevant reports.

Table 1.1: Status of FEP Lists in National Deep Disposal Programmes

Country	Organisation	Updated FEP list or other relevant documents (post-2006)	References
Belgium	ONDRAF/NIRAS	Yes	De Craen *et al.* (2007) Galson Sciences (2007) ONDRAF/NIRAS (2008)
Canada	NWMO	Yes	Quintessa *et al.* (2011)
Czech Republic	NRI	Yes	Vokál *et al*. (2010)
Finland	POSIVA	Yes	Gribi *et al*. (2007) Miller and Marcos (2007) Posiva (2010)
France	ANDRA	No	-
Germany	Various	Yes	Beuth *et al*. (2012a) Beuth *et al*. (2012b) Buhmann *et al.* (2010) Wolf *et al*. (2012a) Wolf *et al*. (2012b)
Hungary	PURAM	No	-
Japan	JAEA	Yes	JAEA and FEPC (2007)
Netherlands	NRG	No	-
Spain	ENRESA	No	-
Sweden	SKB	Yes	SKB (2010, 2011)
Switzerland	Nagra	Yes	Nagra (2008a,b,c, 2010)
UK	NDA/RWMD	No	-
USA	USDoE	Yes	USDOE (2009)

2. RECENTLY APPLIED FEP LISTS

Belgium

Introduction

ONDRAF/NIRAS is developing a disposal concept for high-level radioactive waste (HLW) and is undertaking assessments of the concept's safety. As part of this process, it has developed two lists of FEPs. The first one lists *geosynthesis* events and processes (De Craen *et al*., 2007). This FEP list has been compiled from the knowledge acquired by expert panels comprising topic experts and safety assessors using the results of thirty years of research on the Boom Clay (ONDRAF/NIRAS, 1989, 2001). The second list focuses on the Engineered Barrier System (EBS) and specifically considers the FEPs related to the ONDRAF/NIRAS cement-based engineering design. A formal procedure has been followed to develop this *Supercontainer* EBS FEP list (Galson Sciences, 2006). The original list has been derived from about ten national design-specific FEP lists developed between 1989 and 2002 and screened following selective criteria to retain only the FEPs relevant to the *Supercontainer* design.

Application

The *geosynthesis* list includes FEPs that could potentially affect the disposal system and/or its environment in a positive or detrimental way. The ultimate objective of the *geosynthesis* FEPs is to examine the impact of these FEPs on the reference ("the expected evolution") scenario systematically. FEPs negatively impacting at least one safety function initiate altered scenarios. FEPs might also give rise to alternative calculation cases within the reference scenario if they do not affect any safety function but initiate a different evolution of the repository system. The ambition of the 2007 exercise that resulted in this first preliminary *geosynthesis* FEP list was to perform a first screening of FEPs potentially relevant for safety and in particular to identify those that required further research in order to undertake sound safety assessments. Feedback on the 2007 *geosynthesis* FEP list was thus in the first instance given to the assessment basis groups. A revision of the *geosynthesis* FEP list ready for scenario development is planned.

The *Supercontainer* EBS FEP list was developed for the purpose of a completeness checking. The list was compared with the technical information of the EBS evolution report (ONDRAF/NIRAS, 2008) describing the spatial and temporal evolution of the EBS envisaged by the expert panel (Galson Sciences, 2007). As with the 2007 exercise for the geosynthesis FEPs, this completeness checking was aimed at confirming the issues requiring further work rather than performing a formal verification of the completeness of information.

Structure and Content

Three broad categories of initiating events are considered in the *geosynthesis* FEP list: human induced events; external geodynamic events; and internal geodynamic events (Appendix B). A range of events is considered under each category together with the

event's likelihood (high, medium, low), impact on the long-term safety functions, and the a priori relevance of the impact (Appendix B). The *Supercontainer* EBS FEP list has been organised in six FEP groups (Appendix C). One group comprises features describing the EBS design (D FEPs); the other groups include processes associated with the key drivers for change and evolution within the repository (RCHTP FEPs):

D Design components

R Radiological processes

C Chemical processes

H Hydraulic processes

T Thermal processes

P Physical / mechanical processes

Canada – Assessment of Used Nuclear Fuel

Introduction

NWMO is responsible for designing and implementing Canada's plan for the long-term management of used nuclear fuel. As part of the NWMO work programme, a series of case studies have been undertaken to evaluate the safety of the deep geological repository concept.

The NWMO is currently preparing the 'Fourth Case Study' for a deep geologic repository situated in crystalline rock for submission to the Canadian regulator as part of a pre-project review. The approach taken with respect to FEPs in this study is to start with the existing FEP analysis (for the Third Case Study: Garisto *et al.,* 2004) and implement modifications appropriate to the revised geosphere and scope of work.

Application

Scenarios of interest to the postclosure safety assessment are identified through consideration of the various FEPs that could affect the repository system and its evolution.

- The Category 1 FEPs (External Factors) are used to identify causes or factors outside the repository domain that might cause change. Included in this group are decisions related to repository design, operation and closure since these are outside the temporal boundary of the postclosure behaviour of the repository system.
- The Category 2 FEPs (Repository Factors) are used to identify features and processes occurring within or near the repository site that could affect the thermal, mechanical, chemical, biological or hydraulic conditions. These are important aids in defining the expected evolution of the repository, and they are considered with respect to defining Disruptive Scenarios.
- The Category 3 FEPs (Contaminant Factors) are used to identify factors in the repository and the nearby geosphere and biosphere that are specific to the release and migration of radionuclides and other contaminants, or to the human dose or environmental consequences.

Structure and Content

The FEP list for the Fourth Case Study is given in Appendix D. The format follows the organisation used in NEA (2000) for characterising system level features, events and processes.

Canada – Assessment of Low and Intermediate Level Waste

Introduction

Ontario Power Generation (OPG) has submitted the application to seek Environmental Assessment and licensing approvals to construct a deep geologic repository (DGR) for low and intermediate level radioactive waste at the Bruce nuclear site. The Nuclear Waste Management Organisation (NWMO) has been tasked by OPG with managing the DGR Project and conducting all technical and licensing support activities. To support the licensing application, a post-closure safety assessment was performed to evaluate the long-term safety of the DGR preliminary design (Quintessa *et al.*, 2011a). As part of the work programme undertaken for the post-closure safety assessment, a project-specific FEP list was developed (Quintessa *et al.*, 2011b). This used information specific to the proposed DGR site and design, as well as national and international sources such as Garisto *et al.* (2004), IAEA (2004), Mazurek *et al.* (2003), Nagra (2002), NEA (2000), ONDRAF/NIRAS (2001) and Penfold *et al.* (2002).

Application

The FEP list for low and intermediate level waste was used in a number of ways in the post-closure safety assessment.

- The Category 1 FEPs (i.e. External Factors) were used to identify potential scenarios for consideration in the assessment. These External FEPs provided the system with both its boundary conditions and with FEPs that might cause change in the system. If these External FEPs could significantly affect the system, they were considered to be scenario-generating FEPs, in the sense that whether they occurred or not (or the extent to which they occurred) could define a particular future scenario that should be considered within the assessment.
- The Category 2 FEPs (i.e. Internal Factors) were used to identify whether there were any Internal FEPs that might compromise the isolation and containment functions of the DGR system and thereby impact upon the associated long-term safety arguments so resulting in a Disruptive Scenario.
- The Category 2 FEPs and Category 3 FEPs (i.e. Contaminant Factors) were used to ensure that the conceptual models developed to assess the scenarios included all the potentially relevant Internal FEPs.
- The Category 2 and 3 FEPs were also used as a basis of an audit of the implementation of the conceptual models in the calculation tools used in the assessment.

Structure and Content

The FEP list for low and intermediate level waste is given in Appendix E. Its structure and content is broadly consistent with the NEA International FEP List (reflecting its provenance).

However, there are a number of modifications, the most significant of which are:

- There is no consideration of Category 0 FEPs (i.e. Assessment Basis) since the FEP list was not used in the specification of the assessment context.
- The waste and engineered features reflect the specific waste and design features of the DGR.
- The Category 2 and 3 FEPs have been sub-divided to a greater level of detail.

Czech Republic

Introduction

In September 2010, the Nuclear Research Institute (NRI) Rez published its long-term safety evaluation of a hypothetical deep geological repository for spent nuclear fuel and high-level radioactive waste in the Czech Republic (Vokál *et al.*, 2010). The report took account of international recommendations (e.g. from projects such as "PAMINA" and "MeSA") and safety analyses issued by countries with an advanced development programme for deep geological disposal such as Belgium, Finland, France, Sweden, Switzerland and the USA. The NEA International FEP List was used as the basis of the project-specific FEP list. Expert judgement was used to screen the FEP list so that FEPs that were not relevant to the Czech Republic (for example, the effect of volcanic and magmatic activity, dissolution of salt, etc.) were excluded.

Application

The results of the expert analyses of the FEP list were documented and used for the derivation of the normal/central scenario and alternative scenarios (see Section C2.2.3 of Vokál *et al.*, 2010). The FEPs were also in the formulation of the associated conceptual models (see Section C2.3 of Vokál *et al.*, 2010).

Structure and Content

The NRI FEP list has the same structure and content as the NEA International FEP List given in Appendix A.

Finland

Introduction

Olkiluoto has been selected as the site for the Finnish spent nuclear fuel repository. Posiva is undertaking a series of safety assessment to support its applications for the repository's construction licence and subsequent operating licence. An interim summary report of the safety case was published in 2010 (Posiva, 2010) which noted that Posiva was in the process of compiling its own FEP database and report. FEPs are currently documented in various versions of the Process Report, which is a main report documenting process understanding and the safety relevance of processes in different timeframes.

The latest published version of the Process Report for the KBS-3H concept was produced in 2007 (Gribi *et al.*, 2007), although this report does not contain a standalone FEP list. It recognises that FEPs can be classified into internal processes, initial state and external factors. Internal processes are defined for each component of the repository system (including the geosphere but not the biosphere which is considered in other

reports). Initial state FEPs refer to the initial conditions for the evolution of the repository system. Relevant FEPs occurring outside the system boundary are classified as external factors (e.g. climatic processes and effects, tectonics, seismic activity, future human actions). Initial conditions and external factors are discussed in detail in the Evolution Report for KBS-3H (Smith *et al.*, 2007).

The latest version of the Process Report for the KBS-3V concept is Miller and Marcos (2007). It includes a list of the internal processes considered for the engineered barriers and the geosphere in the context of the Finnish repository design and the Olkiluoto site-specific context. Two key sources were used to identify the relevant FEPs: the NEA International FEP List, and the previous Posiva Process Report (Rasilainen, 2004).

Application

The method used by Posiva for developing scenarios follows a top down approach since most of the scenarios that have to be taken into consideration come from regulatory requirements. This means that the scenarios to be analysed are selected and then the FEP list, complemented with expert judgement, is used to ensure that no FEPs have been omitted from considered in scenario formulation and analysis.

Structure and Content

The KBS-3V Internal FEP List is given in Appendix F. It provides a listing of all of the relevant process thought likely to occur and be significant within the main components of the engineered barriers and within the geosphere. These processes are arranged in the list in terms of the main repository component in which they occur (fuel, canister, buffer, backfill, plugs/seals/grout and geosphere). They have also been categorised as evolution related processes (E) i.e. those that relate to dynamic processes that affect the state of the repository, and migration related processes (M) i.e. those that directly control the migration of radionuclides and other substances.

The list is mapped onto the NEA International FEP List in Table 1.6-1 of Millar and Marcos (2007). Given that the list is only for internal processes affecting the repository and geosphere, it can be seen that it has limited coverage compared with the NEA International FEP List. However, for those FEPs that it does include, it provides more detailed coverage.

Germany

Introduction

In the context of the research project ISIBEL (Buhmann *et al.*, 2010), a FEP list was developed for a generic spent nuclear fuel (SNF)/HLW repository in a salt dome in Northern Germany. Goal of this activity was to implement a general FEP list that is consistent with the NEA FEP database (NEA, 2000) and could be used as a starting point for a FEP list for use in a site specific safety assessment in Germany.

In 2010, the ISIBEL FEP list was used as a basis for the preliminary safety assessment of the Gorleben salt dome (Vorläufige Sicherheitsanalyse Gorleben, VSG). 19 scientists from five German organisations developed the VSG FEP list over a two-year period. It is the first site-specific FEP list for a SNF/HLW repository in a salt dome. The FEPs report is currently only available in German (Wolf *et al.,* 2012a) but an English translation of the FEP names is provided in Appendix G.

Application

The VSG FEP list has been developed to represent the knowledge on the Gorleben site and the concepts to dispose of various kinds of radioactive waste, in particular heat-generating waste (SNF and vitrified HLW) in a transparent and comprehensible way. This includes the definition and description of all FEPs, the identification of relevant FEPs (FEP screening), the indication of important references and open questions.

A very important aspect of the VSG FEP list is its strong linkage with the development of scenarios. The FEP list contains the information required for scenario development.

- Statements on the conditional probability of each FEP - three classes are considered: a) probable; b) less probable; and c) not to consider.
- The influence of the FEPs on containment-providing barriers (containment in a so-called "containing rock zone" being an essential regulatory requirement).
- The dependencies among the relevant FEPs.

The required information is often based on expert judgement. One advantage of the strong linkage of the FEP list and the scenario development is the possibility to document the information base of the expert judgment in the FEP list. Using the categorisation of the FEPs (probability and influence on containment-providing barriers) and the dependencies among the FEPs scenarios can be derived in a systematic approach (Beuth *et al.* 2012a)

Structure and Content

The VSG FEP list is given in Appendix G. More details about the structure are given in Wolf *et al.* (2012b). Its structure is broadly consistent with the NEA International FEP List although there are some issues in the NEA list that are not considered in the VSG FEP list:

- There is no consideration of category 0 FEPs (Assessment Basis) since the FEP list was not used to specify the assessment context.
- FEPs dealing only with the operational phase are not included in the list.
- All FEPs dealing with processes in the biosphere are not elements of the FEP list since an assessment of the biosphere is only possible for today's biosphere conditions. Future conditions and dietary habits are very difficult to predict. According to the current German regulation, the conditions that have to be assumed in the safety assessment are determined by regulatory terms. The NEA Chapters 2.4 (Human behaviour) and 3.3 (Exposure factors) are not considered in the VSG FEP list. In Chapter 2.3 (Surface Environment) only FEPs that have influence on the geosphere are considered.
- Future human actions have to be considered in a safety assessment. According to the German Safety Requirements, reference scenarios for human intrusion have to be considered and, if possible, measures to reduce their likelihood and their consequences have to be implemented when optimising the repository system. This goal, however, is considered subordinate compared to other optimisation goals (radiation protection during the operational phase, long-term safety, operational safety, reliability and quality of long-term containment, safety management, technical and financial feasibility). Since there is no scientific basis for the predictions of these actions, they are not part of the systematic scenario development that is based in VSG on the FEP list. In VSG future human actions, especially human intrusion, are considered in a special report that is independent of the FEP list and the scenario development (Beuth *et al.*, 2012b). The NEA Chapter 1.4 (Future human actions) is not considered in the VSG FEP catalogue.

In common with other more recent FEP lists, the FEPs associated with the waste and engineered features, and the geological environment have been sub-divided to a greater level of detail than in the NEA International FEP List. In some chapters such as the repository issues (Chapter 1.1) FEPs are only added, if they have an effect on the post-closure safety. Since the VSG FEP list contains dependencies among the relevant FEPs, NEA FEPs such as 1.2.10 Hydrological/hydrogeological response to geological changes have not to be considered as separate FEPs.

Japan

Introduction

The Federation of Electric Power Companies in Japan (FEPC) and the Japan Atomic Energy Agency (JAEA) have assessed the safe and optimum geological disposal of TRU-waste[1] in Japan. The results are summarised in the TRU-2 report (JAEA and FEPC, 2007) which had the following aims:

- To summarise the results of collaborative R&D carried out by JAEA and FEPC on the geological disposal of TRU-waste.
- To promote the establishment of a regulatory framework and an implementation body to manage the disposal of TRU-waste.

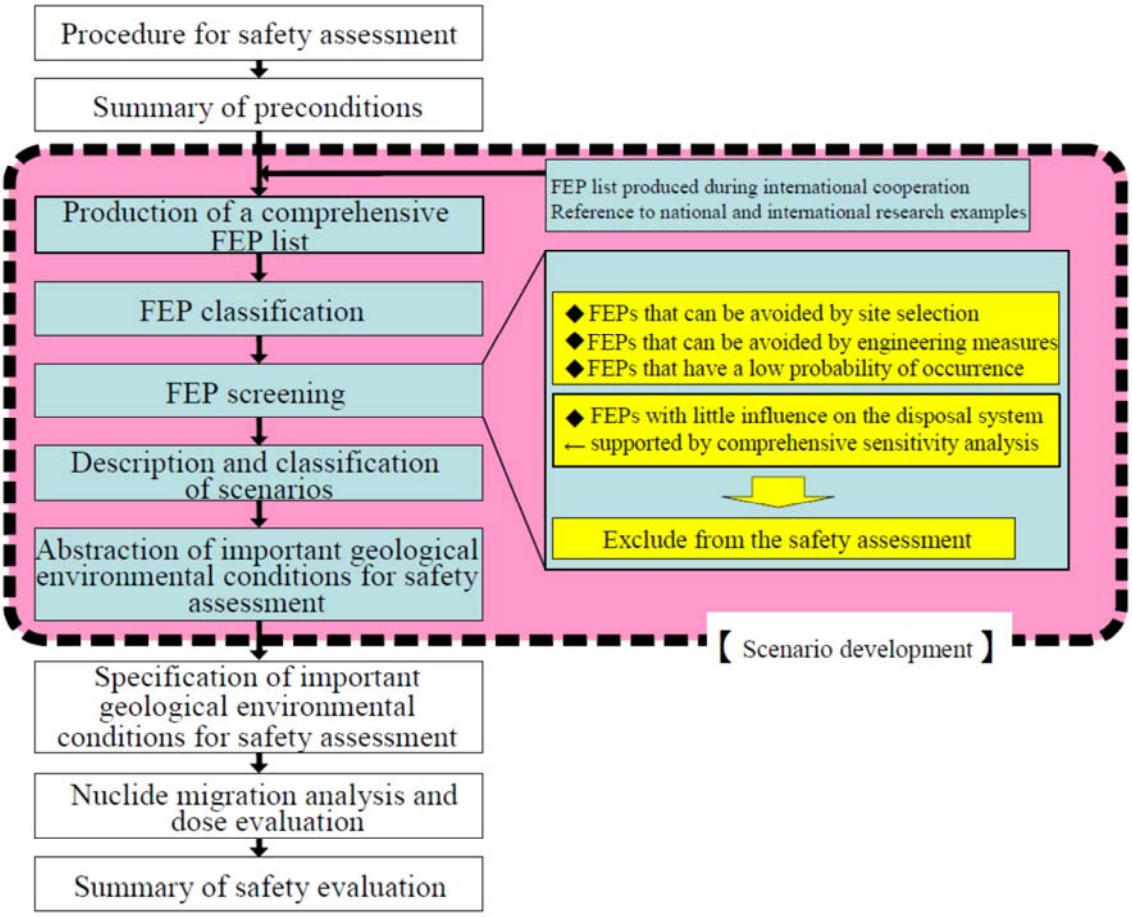
A comprehensive FEP list was developed based on the H12 report (JNC, 2000) and the NEA International FEP List, and by taking into account the specific phenomena relevant to TRU-waste.

Application

The TRU-2 FEP list is used in the derivation of the scenarios to be assessed (see Figure 2.1).

1. In Japan 'TRU-waste' broadly equates to long-lived intermediate level waste (ILW) and low level waste (LLW) with significant alpha content.

Figure 2.1: Use of TRU-2 FEPs in Scenario Development (JAEA and FEPC, 2007)



Structure and Content

Following the approach used in the H12 report (JNC, 2000), a matrix approach is used in JAEA and FEPC (2007) to classify the FEPs. The location within the multi-barrier system to which a FEP applies is given in the row and the related phenomenon is given in the columns (see Appendix H).

The following locations are considered:

- Waste.
- Filler.
- Structural framework.
- Bentonite.
- Plug/grout/support/backfill.
- Host rock.

The following phenomena are considered:

- Thermal.
- Hydraulic.

- Mechanical.
- Chemical.
- Radiological.
- Radionuclide migration.
- Phenomena that may potentially disturb the system (i.e. initial defects /natural phenomena/human activities).

Sweden

Introduction

Forsmark has been selected as the site for the Swedish spent nuclear fuel repository using the KBS-3V deep disposal concept. SKB has undertaken a safety assessment (SR-Site) to support its applications for the repository's construction licence (SKB, 2011). The first step of the assessment methodology is the identification of all the factors that need to be included in the analysis. Experience from earlier safety assessments and KBS-3 specific and international databases of relevant FEPs have been used to develop the SR-Site FEP list which is documented in SKB (2010).

Application

The FEP list is used at a number of stages during the assessment process.

- In the development of check lists for process descriptions, initial state descriptions and the handling of external factors.
- In the development of a chart showing how the FEPs are related to the safety function indicators that are used to evaluate the safety of the system.
- In the development of scenarios for assessment by using the FEP chart to help identify uncertain factors that might need to be assessed using additional scenarios.
- In the analysis of FEPs excluded from the assessment.

Structure and Content

The SR-Site FEP catalogue contains FEPs for the following categories.

- Initial state FEPs.
- Processes in fuel, canister, buffer, backfill, tunnel plug, central area, top seal, bottom plate in deposition holes, borehole seals and geosphere.
- Variables in fuel, canister, buffer, backfill, tunnel plug, central area, top seal, bottom plate in deposition holes, borehole seals and geosphere.
- Biosphere FEPs.
- External FEPs.
- Methodology issues.

In total there are 407 FEP records (Appendix I).

Switzerland

Introduction

Important steps in the management of radioactive waste have been implemented in Switzerland and there is wide experience in carrying out the associated activities. These include the handling and packaging of waste, waste characterisation, compiling of inventories, interim storage and the associated transport of waste. In terms of preparing for deep geological disposal, the necessary scientific and technical work is well advanced and the feasibility of implementing geological repositories that provide the required long-term safety has been successfully demonstrated for all wastes arising in Switzerland; these feasibility demonstrations have been approved by the Swiss government (L/ILW repository: 1988; HLW repository: 2006). Currently, the Swiss programme is focussed on site selection. The basis for site selection is the so-called Sectoral Plan for Deep Geological Repositories (SGT), which defines a three-stage site selection process and which was approved by the Swiss government in 2008. As input to Stage 1 of the SGT, Nagra submitted proposals for geological siting areas for the L/ILW repository and the HLW repository to the Swiss Federal Office of Energy (Nagra 2008a,b,c). After a review by the safety authorities and an extensive public consultation process, the Swiss government approved Nagra's proposals in 2011, formally ending Stage 1 of the site selection process. Stage 2 will lead to the selection of at least two sites for each of the L/ILW and the HLW repository. During Stage 3, one site per repository type will be selected; for these, general licence applications will be prepared.

In order to realise the objectives of Stage 2, the state of knowledge of the geological conditions in the proposed siting regions has to be sufficient to perform the provisional safety analyses required for Stage 2 (ENSI, 2010). Therefore, in preparation for Stage 2, the SGT requires Nagra to clarify with the Swiss Federal Nuclear Safety Inspectorate (ENSI), at an early stage, the need for additional investigations aimed at providing input for the provisional safety analyses. For this purpose Nagra developed a technical report (Nagra, 2010), in which the focus was on evaluating the geological information based on processes and parameters (P&Ps) that are relevant for safety and engineering feasibility. These P&Ps can be regarded as a special kind of FEPs. These are discussed below.

Application

The basis to develop the P&Ps was the work documented in the report on safety and engineering feasibility (Nagra, 2008c) prepared for Stage 1 of the SGT. This included the formulation of requirements on geology based on considerations of safety and engineering feasibility. The procedure to define the P&Ps is described in Chapter 3.2 in Nagra (2010). In short, the following steps were applied.

- Definition and consideration of **safety functions and principles** as a starting point (Table J.1, Appendix J).
- Definition and consideration of the **relevant elements of the barrier system** which ensure that the safety functions will work as planned; the elements are chosen in such a way that they conform to the safety functions and principles mentioned above (Table J.1, Appendix J).
- Definition and consideration of **safety-relevant properties** of the elements of the barrier system (Table J.1, Appendix J).
- Definition of the **relevant processes and parameters** (Table J.1, Appendix J).

The P&Ps were then used to evaluate the state of knowledge of the geological conditions in the proposed siting regions, as required by ENSI. In the meantime, ENSI has

reviewed Nagra (2010) and has concluded that the state of knowledge of the geological conditions in the proposed siting regions is sufficient to perform the required provisional safety analyses for Stage 2, if a number of additional requirements formulated in ENSI (2011) are met.

Structure and Content

The description of the P&Ps, and their relationship to:

- the safety functions and principles;
- the relevant elements of the barrier system;
- the safety-relevant properties of the elements of the barrier system;
- the indicators and criteria used in Stage 1(Table J.2, Appendix J, translated from Table 2.4-2 in Nagra 2008a)

is presented in Table J.1, Appendix J (translated from Table A2-1 in Nagra, 2010).

United States of America

Introduction

The United States Department of Energy (USDOE) has developed the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico for the disposal of transuranic (TRU) wastes generated by defence programmes. In May of 1998, the United States Environmental Protection Agency (USEPA) certified that the WIPP would meet the relevant disposal standards, thereby allowing the WIPP to begin waste disposal operations. WIPP needs to be recertified every five years. The USEPA requires the compliance application to:

- Identify all potential processes, events or sequences and combinations of processes and events that may occur during the regulatory time frame and may affect the disposal system.
- Identify the processes, events or sequences and combinations of processes and events included in performance assessments.
- Documents why any identified processes, events or sequences and combinations of processes and events were not included in performance assessment results provided in any compliance application.

As a starting point, the USDOE assembled a list of potentially relevant FEPs from the compilation developed by Stenhouse *et al.* (1993) for the Swedish Nuclear Power Inspectorate (SKI). The compilers of the SKI list eliminated a number of FEPs as irrelevant to the particular disposal concept under consideration in Sweden. These FEPs were reinstated for WIPP, and several FEPs on the SKI list were subdivided to facilitate screening for the WIPP. To ensure comprehensiveness, other FEPs specific to the WIPP were added based on review of key project documents and broad examination of the preliminary WIPP list by both project participants and stakeholders.

Application

Given the regulatory requirement for the use and documentation of FEPs, USDOE's assessment methodology includes a process that compiles a comprehensive list of the FEPs that are potentially relevant to disposal system performance. Those FEPs shown by screening analysis to have the potential to affect performance are represented in

scenarios and quantitative calculations using a system of linked computer models to describe the interaction of the repository with the natural system, both with and without human intrusion.

Structure and Content

The FEP list used in the 2009 Compliance Recertification Application is given in USDOE (2009) and summarised in Appendix K. The list is divided into three categories with a total of 245 FEPs:

- Natural FEPs – those that relate to hydrologic, geologic, and climate conditions that have the potential to affect long-term performance of the WIPP disposal system over the regulatory timeframe.
- Human-induced EPs – those associated with human activities in the past, present and future.
- Waste- and repository-induced FEPs - those that relate specifically to the waste material, waste containers, shaft seals, magnesium oxide (MgO) backfill, panel closures, repository structures, and investigation boreholes. All FEPs related to radionuclide chemistry and radionuclide migration are included in this category. The FEPs related to radionuclide transport resulting from future borehole intersections of the WIPP excavation are defined as waste- and repository-induced FEPs.

The FEPs are also considered within timeframes during which they may occur. Because of the regulatory requirements concerning human activities, two time periods were used when evaluating human-induced EPs. These timeframes were defined as Historical, Current and Near-Future Human Activities (HCN), and Future Human Activities (Future).

International Atomic Energy Agency

The IAEA safety guide on geological disposal facilities for radioactive waste (IAEA 2011) states that it is necessary for the safety case and the supporting assessments to present evidence that the key FEPs are sufficiently well understood to ensure scenarios of possible evolutions are appropriately generated. Systematic examination of FEPs should be used to identify the factors that might influence the safety of the disposal facility and thus aid development of an appropriate safety assessment model. The guide notes that the first step in identifying which of the many phenomena are relevant to the safety assessment should be to establish a checklist such as that developed in NEA (2000). In developing a suitable list of scenarios, the guide notes that events and processes of natural origin, and processes attributable to the waste itself or to features of the disposal facility, should be considered.

3. SUMMARY

Table 3.1 summarises how the ten FEP lists described in Section 2 have been used and structured.

It can be seen that the lists are most commonly used in:

- The identification/development of scenarios (for five of the lists); and/or
- Completeness checking of scenarios, conceptual models and/or their implementation in software tools (also for five of the lists).

In terms of their structure, two of the lists are essentially based on the NEA International FEP List (NEA, 2000), whilst a further two adopt a broadly similar to the NEA International FEP List but contain a more detailed sub-division of certain FEPs (especially relating to internal processes relating the waste and disposal system). The remaining six lists adopt different structures with four adopting a structure in which the waste and repository are discretised at a higher level in the FEP structure than in the NEA International FEP List.

Table 3.1: Summary of FEP Lists Updated Post-2006

Organisation	Updated FEP list	Waste Category	Derivation	Purpose/Use	Structure
ONDRAF/NIRAS	Geosynthesis	HLW	Expert knowledge	Identification of alternative scenarios and calculation cases	Three broad categories of initiating events: human induced events; external geodynamic events; and internal geodynamic events.
	Supercontainer	HLW	Previous design-specific FEP lists	Completeness checking of technical information in EBS evolution report	Six FEP groups: design components; radiological processes; chemical processes; hydraulic processes; thermal processes; physical / mechanical processes.
NWMO	Fourth Case Study	SNF	Third Case Study FEP list (Garisto *et al*. 2004)	Identification of FEPs affecting system evolution and contaminant release/migration/impact	Similar to NEA (2000)
	DGR	LLW/ILW	Review of other FEP lists (e.g. NEA 2000, Garisto *et al*. 2004)	Identification of potential scenarios Completeness checking of conceptual models and their implementation in calculation tools	Broadly similar to NEA (2000) but with: exclusion of Assessment Basis FEPs; inclusion of DGR-specific FEPs; and more detailed sub-division of Category 2 and 3 FEPs,
NRI	Initial Safety Report Study	HLW & SNF	NEA (2000)	Identification of potential scenarios Formulate associated conceptual models	Same as NEA (2000)
POSIVA	To be published	SNF	POSIVA process reports (e.g. Millar and Marcos 2007) and NEA (2000)	Completeness checking that no FEPs have been omitted from considered in scenario formulation and analysis	Repository and geosphere processes arranged in terms of main disposal system components and distinction made between evolution and migration related processes

Organisation	Updated FEP list	Waste Category	Derivation	Purpose/Use	Structure
GRS	VSG	HLW & SNF	ISIBEL FEP list and expert judgement	Identification of potential scenarios	Broadly similar to NEA (2000) but with: exclusion of Assessment Basis, operational, biosphere and human intrusion FEPs; more detailed sub-division of waste, engineered features and geosphere FEPs
JAEA	TRU-2	TRU	H12 FEP (JNC 2000) and NEA (2000)	Identification of potential scenarios	Matrix structure using main disposal system components and key phenomena (thermal, hydraulic, mechanical, chemical, radiological, migration and disturbing)
SKB	SR-Site	SNF	SR-Can (SKB 2006) and NEA (2000)	Development of scenarios Review of safety function indicators	Considers following FEP categories: methodology; external; initial state; fuel; canister; buffer; backfill; tunnel plug; central area, top seal, bottom plate in deposition holes, borehole seals; geosphere; biosphere
Nagra	SGT Stage 2	LLW, ILW & HLW	Consideration of safety functions and principles	Evaluate the state of knowledge of geological conditions in proposed siting regions	Classified on basis of five safety functions and three principles
USDoE	WIPP	TRU	Stenhouse *et al.* (1993)	Meets regulatory requirement for identification of FEPs that: may affect disposal system; and are included in / excluded from assessment	Divided into: natural FEPs, human-induced EPs; and waste- & repository-induced FEPs.

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APPENDIX A: NEA'S INTERNATIONAL FEP LIST (VERSION 1.0)

0 ASSESSMENT BASIS

0.01 Impacts of concern

0.02 Timescales of concern

0.03 Spatial domain of concern

0.04 Repository assumptions

0.05 Future human action assumptions

0.06 Future human behaviour (target group) assumptions

0.07 Dose response assumptions

0.08 Aims of the assessment

0.09 Regulatory requirements and exclusions

0.10 Model and data issues

1 EXTERNAL FACTORS

1.1 REPOSITORY ISSUES

1.1.01 Site investigation

1.1.02 Excavation/construction

1.1.03 Emplacement of wastes and backfilling

1.1.04 Closure and repository sealing

1.1.05 Records and markers, repository

1.1.06 Waste allocation

1.1.07 Repository design

1.1.08 Quality control

1.1.09 Schedule and planning

1.1.10 Administrative control, repository site

1.1.11 Monitoring of repository

1.1.12 Accidents and unplanned events

1.1.13 Retrievability

1.2 GEOLOGICAL PROCESSES AND EFFECTS

1.2.01 Tectonic movements and orogeny

1.2.02 Deformation, elastic, plastic or brittle

1.2.03 Seismicity

1.2.04 Volcanic and magmatic activity

1.2.05 Metamorphism

1.2.06 Hydrothermal activity

1.2.07 Erosion and sedimentation

1.2.08 Diagenesis

1.2.09 Salt diapirism and dissolution

1.2.10 Hydrological/hydrogeological response to geological changes

1.3 CLIMATIC PROCESSES AND EFFECTS

1.3.01 Climate change, global

1.3.02 Climate change, regional and local

1.3.03 Sea level change

1.3.04 Periglacial effects

1.3.05 Glacial and ice sheet effects, local

1.3.06 Warm climate effects (tropical and desert)

1.3.07 Hydrological/hydrogeological response to climate changes

1.3.08 Ecological response to climate changes

1.3.09 Human response to climate changes

1.4 FUTURE HUMAN ACTIONS

1.4.01 Human influences on climate

1.4.02 Motivation and knowledge issues (inadvertent/deliberate human actions)

1.4.03 Un-intrusive site investigation

1.4.04 Drilling activities (human intrusion)

1.4.05 Mining and other underground activities (human intrusion)

1.4.06 Surface environment, human activities

1.4.07 Water management (wells, reservoirs, dams)

1.4.08 Social and institutional developments

1.4.09 Technological developments

1.4.10 Remedial actions

1.4.11 Explosions and crashes

1.5 OTHER

1.5.01 Meteorite impact

1.5.02 Species evolution

1.5.03 Miscellaneous and FEPs of uncertain relevance

2 DISPOSAL SYSTEM DOMAIN: ENVIRONMENTAL FACTORS

2.1 WASTES AND ENGINEERED FEATURES

2.1.01 Inventory, radionuclide and other material

2.1.02 Waste form materials and characteristics

2.1.03 Container materials and characteristics

2.1.04 Buffer/backfill materials and characteristics

2.1.05 Seals, cavern/tunnel/shaft

2.1.06 Other engineered features materials and characteristics

2.1.07 Mechanical processes and conditions (in wastes and EBS)

2.1.08 Hydraulic/hydrogeological processes and conditions (in wastes and EBS)

2.1.09 Chemical/geochemical processes and conditions (in wastes and EBS)

2.1.10 Biological/biochemical processes and conditions (in wastes and EBS)

2.1.11 Thermal processes and conditions (in wastes and EBS)

2.1.12 Gas sources and effects (in wastes and EBS)

2.1.13 Radiation effects (in wastes and EBS)

2.1.14 Nuclear criticality

2.2 GEOLOGICAL ENVIRONMENT

2.2.01 Excavation disturbed zone, host rock

2.2.02 Host rock

2.2.03 Geological units, other

2.2.04 Discontinuities, large scale (in geosphere)

2.2.05 Contaminant transport path characteristics (in geosphere)

2.2.06 Mechanical processes and conditions (in geosphere)

2.2.07 Hydraulic/hydrogeological processes and conditions (in geosphere)

2.2.08 Chemical/geochemical processes and conditions (in geosphere)

2.2.09 Biological/biochemical processes and conditions (in geosphere)

2.2.10 Thermal processes and conditions (in geosphere)

2.2.11 Gas sources and effects (in geosphere)

2.2.12 Undetected features (in geosphere)

2.2.13 Geological resources

2.3 SURFACE ENVIRONMENT

2.3.01 Topography and morphology

2.3.02 Soil and sediment

2.3.03 Aquifers and water-bearing features, near surface

2.3.04 Lakes, rivers, streams and springs

2.3.05 Coastal features

2.3.06 Marine features

2.3.07 Atmosphere

2.3.08 Vegetation

2.3.09 Animal populations

2.3.10 Meteorology

2.3.11 Hydrological regime and water balance (near-surface)

2.3.12 Erosion and deposition

2.3.13 Ecological/biological/microbial systems

2.4 HUMAN BEHAVIOUR

2.4.01 Human characteristics (physiology, metabolism)

2.4.02 Adults, children, infants and other variations

2.4.03 Diet and fluid intake

2.4.04 Habits (non-diet-related behaviour)

2.4.05 Community characteristics

2.4.06 Food and water processing and preparation

2.4.07 Dwellings

2.4.08 Wild and natural land and water use

2.4.09 Rural and agricultural land and water use (incl. fisheries)

2.4.10 Urban and industrial land and water use

2.4.11 Leisure and other uses of environment

3 RADIONUCLIDE/CONTAMINANT FACTORS

3.1 CONTAMINANT CHARACTERISTICS

3.1.01 Radioactive decay and in-growth

3.1.02 Chemical/organic toxin stability

3.1.03 Inorganic solids/solutes

3.1.04 Volatiles and potential for volatility

3.1.05 Organics and potential for organic forms

3.1.06 Noble gases

3.2 CONTAMINANT RELEASE/MIGRATION FACTORS

3.2.01 Dissolution, precipitation and crystallisation, contaminant

3.2.02 Speciation and solubility, contaminant

3.2.03 Sorption/desorption processes, contaminant

3.2.04 Colloids, contaminant interactions and transport with

3.2.05 Chemical/complexing agents, effects on contaminant speciation/transport

3.2.06 Microbial/biological/plant-mediated processes, contaminant

3.2.07 Water-mediated transport of contaminants

3.2.08 Solid-mediated transport of contaminants

3.2.09 Gas-mediated transport of contaminants

3.2.10 Atmospheric transport of contaminants

3.2.11 Animal, plant and microbe mediated transport of contaminants

3.2.12 Human-action-mediated transport of contaminants

3.2.13 Foodchains, uptake of contaminants in

3.3 EXPOSURE FACTORS

3.3.01 Drinking water, foodstuffs and drugs, contaminant concentrations in

3.3.02 Environmental media, contaminant concentrations in

3.3.03 Non-food products, contaminant concentrations in

3.3.04 Exposure modes

3.3.05 Dosimetry

3.3.06 Radiological toxicity/effects

3.3.07 Non-radiological toxicity/effects

3.3.08 Radon and radon daughter exposure

APPENDIX B: ONDARF/NIRAS'S GEOSYNTHESIS EVENTS AND PROCESSES LIST

Initiating event			Likelihood of event < 500 y	< 2.500 y	< 10.000 y	< 1.000.000 y	SF	Description of Impact	Relevance of Impact
HUMAN INDUCED EVENTS*[1]	ABOVE BOOM CLAY	Construction of canals/tunnels	L	M	?	?	D	Dilution capacity of aquifers changes; temporary changes in the groundwater flow distribution in the aquifer during construction of the canal/tunnel.	Low
		Exploitation of mineral resources (e.g. Mol Sand)	H	H	?	?	H D	Reduced overlying rock mass. Temporary changes in groundwater flow distribution.	Low
		Groundwater pumping	H	H	H	H	R2 D	Changes in gradient over BC. Dilution capacity of aquifer changes.	Calculations required
		Geothermal energy Aquifer Thermal Energy Store - ATES	M	M	?	?	R2, R3 D	Changes in gradient through the BC. Possibly changes in geochemistry. Dilution capacity of aquifer changes	Calculations required
	IN	Boom Clay exploitation	L	L	?	?	I1, I2 R2	Perforation of the BC; reduced or absence of overlying rock mass. Changes in gradient over BC.	High
	BENEATH BOOM CLAY	Exploratory drilling	L	M	?	?	I1 R2	Perforation of the BC; possible contact with waste. Creation of preferential pathway; gradient and hydraulic conductivity changes	Low/high*[2]
		CO_2 sequestration or other gas storage	M	M	?	?	I1 R2,R3	Perforation of the BC; possible contact with waste. Changes in gradient through the BC. Possibly changes in geochemistry	Low/high*[2]
		Mining	L	L	?	?	I1, I2 R2, R3	Perforation of the BC. Possibly changing stability. Changes in stress field; changes in gradient through the BC. Possibly changes in geochemistry.	Low/high*[2]
		Groundwater pumping	L	M	M	M	I2 R2 D	Perforation of the BC and aquifers. Changes in gradient over BC. Dilution capacity of aquifer changes.	Low/high*[2] calculations required
		Geothermal energy (from deep geological layers)	M	H	?	?	I1 R2, R3	Perforation of the BC and aquifers. Creation of preferential pathway; gradient and hydraulic conductivity changes. Changes in geochemistry.	Low/high*[2] ?

	Initiating event	Likelihood of event				SF	Description of Impact	Relevance of Impact
		< 500 y	< 2.500 y	< 10.000 y	< 1.000.000 y			
EXTERNAL GEODYNAMIC EVENTS	Impact of celestial bodies	L	K	L	L	I1, I2 R2 R3 D	Reduced overlying rock mass, changes in stress field Changes in BC pore structure; fracturing and brecciation; creation of preferential pathways; gradient and hydraulic conductivity changes Changes in C geochemistry (heat, fusion, vitrification) Dilution capacity of aquifer changes	High *3
	Climate change: global cooling	L	L	H	H	I1, I2 R2 R3 D	Reduced overlying rock mass due to erosion (eustatic seal level changes, *i.e.* sea level drop; erosion, glacial erosion) Changes in gradient over BC (due to permafrost, ice caps, sea level drop); change in BC pore structure Possible changes in geochemical properties; influx of O_2-rich water Dilution capacity of aquifer changes	High*4
	Climate change: global warming	H	H	H	H	I1, I2 R2 R3 D	Reduced overlying rock mass due to the melting of ice caps and glacial erosion (eustatic sea level changes, *i.e.* sea levels rise); faster weathering due to higher temp. Changes in gradient over BC (drainage of melt water through aquifers,; seal level rise) Changes in BC pore structure (unloading due to melting of ice caps, gradient and hydraulic conductivity changes) Changes in geochemistry Dilution capacity of aquifer changes	High*4

Initiating event			Likelihood of event < 500 y	< 2.500 y	< 10.000 y	< 1.000.000 y	SF	Description of Impact	Relevance of Impact
INTERNAL GEODYNAMIC EVENTES	Tectonics	Earthquake	H	H	H	H	(I2)	Temporary shock wave	Low; except during operational phase
		Faulting	H	H	H	H	I1, I2 R2 D	Possibly vertical displacement of Boom Clay, changes in stress field Creation of preferential pathway; gradient and hydraulic conductivity changes Dilution capacity of aquifer changes	High
		Folding	L	L	L	L	I1, I2	Displacement of Boom Clay, changes in stress field	High
		Uplift	L	M	M	M	I1, I2 R2 D	Isostatic sea level drop, reduced thickness of overlying rock mass due to erosion Changes in BC pore structure and stress field due to unloading; changes in gradient over BC Dilution capacity of aquifer changes	High
		Subsidence	H	H	H	H	I1, I2 R2 D	Isostatic sea level rise; vertical displacement; marine erosion, changes in stress field Changes in gradient over BC Dilution capacity of aquifer changes	?
	Magmatism		L	L	L	L	I1, I2 R2 R3 D	Pushing the waste upwards, cutting through the waste Changes in BC pore structure (gasses, fracture propagation, creation of preferential pathway) Changes in BC geochemistry (heat effect) Dilution capacity of aquifer changes	Low/high*5
	Diapirism		L	L	L	L	I1, I2 R2 D	Changing stability; changes in the stress fielded; pushing the waste upwards, Changes in BC pore structure –fracturing, creation of preferential pathway) Dilution capacity of aquifer changes	High
	Diagenesis		L	L	L	L	I2 R2, R3 D	Chemical changes (changing geochemical conditions) Changes in BC geochemistry; changes in BC pore structure –due to dissolution/precipitation) If diagenesis in aquifers occurs; dilution capacity of aquifer changes	Low
	Geomorphology and oro-hydrography			H	H	?	R2 D	Changes in the river system and in the flow in the overlying aquifer and consequently in the gradient through the BC Dilution capacity of aquifer changes	

*1 More variants on human induced events are possible, all affecting I, R and sometimes D. Climate warming is another result of human activity, but this will be considered with the natural events.

*2 The I-function is affected if the drilling perforates the repository system. If no perforation, only minor or no impact on I. Note that we have some difficulties with the definition of the I-functions, (reduced thickness of BC ≠ resilience of the BC to perforation)

*3 First order meteorite; diameter >600m (impact sufficiently large to pulverise the repository); Second order meteorite; diameter < 600m (fracturing and groundwater entrance in the repository system).

*4 In the Campine Basin probably only permafrost and no ice caps.

*5 The I-function is affected if the magmatic activity perforates the repository system. If no perforation, only minor or no impact on I, however, r can be affected.

Explanation of the considered time frames

<500 y	The period of information conservation and hence exclusion of inadvertent human intrusion
< 2500 y (2000 – 3000 y)	**Thermal phase**; containment of the HLW in an overpack as long as the temperatures around the waste is significantly higher than the ambient temperature and as long as an important thermal gradient is present.
< 10.000 y	**Isolation phase**; period of time during which normally no (or almost no) activity will be released from the system (waste; EBS and host rock)
< 1.000.000 y	**Geological phase**; activity releases from the system to the biosphere are expected to occur, and doses for an individual from the reference group can be calculated

APPENDIX C: ONDARF/NIRAS'S SUPERCONTAINER EBS FEP LIST

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
Disposal system			
D	1	Repository geometry	The overall layout of the repository, including the spacing between waste-containing tunnels and the disposition of connecting tunnels and access shaft. Repository geometry affects the thermal profile, stress regime, and transport routes within the disposal system.
D	2	Overpack – dimensions and properties	The material properties, dimensions and fabrication techniques of the overpack. Overpack properties affect the rate of corrosion, cracking or other failure mechanisms, and the timing of water ingress to the waste.
D	3	Buffer – dimensions and properties	The material properties, dimensions and fabrication techniques of the buffer. Buffer properties affect the thermal, chemical and physical evolution of the buffer and its effectiveness.
D	4	Envelope - dimensions and properties	The material properties, dimensions and fabrication techniques of the envelope (or liner). Envelope properties affect the rate of corrosion, cracking or other failure mechanisms and the timing of water ingress to the buffer.
D	5	Filler - dimensions and properties	The thickness and properties of any material used to fill void space between the buffer and the overpack. Filler properties affect local chemical conditions and, hence, corrosion reactions and transport of radionuclides.
D	6	Backfill / supports - dimensions and properties	The thickness and properties of backfill emplaced between the *Supercontainer* envelope and the tunnel lining. Must also consider the dimensions and properties of supports on which the *Supercontainer* is set. Backfill properties affect the time for host rock porewaters to arrive at the surface of the *Supercontainer* and the importance of this pathway.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
D	7	Tunnel lining – dimensions and properties	The thickness and properties of the lining emplaced immediately against the host rock for structural support. Tunnel lining properties affect the time for host rock porewaters to arrive at the surface of the *Supercontainer* and the importance of this pathway.
D	8	Seals / tunnels – dimensions and properties	Tunnels and shafts connecting the *Supercontainer* storage galleries, and connecting the repository to the surface, including any materials emplaced in the tunnels and shafts. Tunnels provide potential pathways for water ingress and radionuclide transport. The disposition of these tunnels, and the nature of the seals used, will control the importance of this pathway.
D	9	Host-rock EDZ – thickness and properties	That part of the host rock damaged by construction of the repository. The extent of this excavation damage zone (EDZ) along tunnels and shafts will depend on the host rock and construction methods used. EDZ properties affect the rate of repository resaturation and radionuclide transport from the EBS to the host rock.
Radiological processes			
R	1	Inventory / source term	The inventory is the initial amount of various radionuclides in the disposed waste, and the source term is that proportion of the inventory available for transport at any one time. In addition, the content of other materials in the disposed waste could be of interest (e.g., steels, other metals, concrete, hazardous materials). The inventory provides the initial baseline for radionuclide transport through the EBS. The source term depends on various factors such as the rate of waste dissolution and radionuclide solubilities.
R	2	Radioactive decay and ingrowth	The spontaneous disintegration of a nucleus to form one or more different nuclei, with the release of energy in the form of sub-atomic particles (alpha, beta) and/or gamma radiation. Radioactive isotopes are known as radionuclides. Ingrowth is the decay of a parent radionuclide to a daughter nuclide so that the amount of the daughter nuclide increases. These processes define the nature and quantity of radionuclides derived from the initial inventory at any given time after closure.
R	3	Radiolysis	The chemical decomposition of molecules caused by radiation to form hydrogen and other chemical species. Radiolysis of water close to the waste may result in an oxidising environment and may increase gas pressure.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
R	4	Radiation effects / damage	The transfer of radiant energy to neighbouring materials, including the buffer and other components of the EBS. Examples of relevant effects are ionisation, radiolytic decomposition of water, radiation damage to waste matrix or *Supercontainer* materials, and helium gas production due to alpha decay. Radiation may affect the mineralogy and structure of the materials.
R	5	Criticality	A self-sustaining process of nuclear fission in which each neutron released from a fission triggers, on average, at least one other nuclear fission. Nuclear criticality requires a sufficient concentration and localised mass (critical mass) of fissile isotopes (e.g. U-235, Pu-239) and the presence of neutron-moderating materials in a suitable geometry. Includes both in-package criticality owing to the arrival of water and mechanical alterations, and out-of-package criticality as a result of chemical processes such as degradation and accumulation of uranium and/or plutonium as a result of dissolution and segregation. Criticality may affect the thermal profile around the criticality event.
Chemical processes			
C	1	Solubility / solubility limits	A measure of the ability of a particular substance (e.g. radionuclide-bearing solids) to dissolve in a particular solvent (e.g. water), equal to the quantity of substance dissolving in a fixed quantity of solvent to form a saturated solution under specified conditions (e.g. temperature, pressure, pH, redox). The conditions affect the chemical form and speciation of the substance. Thus, different species of the same element may have different solubilities in a particular solution. The concentration of radionuclides in aqueous solution may be limited by the solubility of the waste, or of radionuclide-bearing solids formed by the interaction of the waste and buffer pore fluids.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
C	2	Precipitation / crystallisation / dissolution	Dissolution is a process whereby solid substances dissolve into solution. Precipitation and crystallisation are processes by which solids are formed out of liquids: precipitation occurs when a dissolved substance separates from solution as a fine suspension of solid particles; crystallisation is the process of producing pure crystals of an element, molecule or mineral from a fluid or solution undergoing a cooling process. A change to a more reducing environment away from the waste could cause precipitation of uranium and other redox-sensitive elements that have a lower solubility under reducing conditions. Subsequent dissolution of the precipitated elements may occur if the redox conditions shifts from reducing to oxidising. Other factors that may cause precipitation and dissolution away from the waste are changes in temperature or in the concentration of ions and complexes that affect the speciation of the elements.
C	3	Corrosion – causes / processes	Any process by which a solid, especially a metal, is degraded and changed by a chemical reaction. Includes general corrosion and localised corrosion (pitting, crevice) under both oxic and anoxic conditions. Stress corrosion cracking is considered separately under Physical FEPs.
C	4	Corrosion – chemical effects	The chemical effects on EBS behaviour and pore water chemistry of new products formed as the result of a corrosion reaction on the surface of a solid. Clear identification of corrosion products, including the development of passivating layers, is important in assessing the possible wider effects on EBS performance of corrosion. For example, the formation of magnetite as the overpack corrodes could influence the dissolution rate of the waste and/or the migration of radiolytic oxidants formed near the waste surface, as well as chemical conditions in the buffer porewater. *Supercontainer* envelope corrosion products may affect chemical conditions in the buffer porewater.
C	5	Corrosion – volume effects	The volume effects on EBS behaviour of new products formed as the result of a corrosion reaction on the surface of a solid. Corrosion products have a higher molar volume, even in the most dense state, than the material being corroded. Volume increase of corrosion products may compress the buffer and lead to mechanical stresses in the overpack that in turn may cause an even faster degradation. Alternatively, void space in the waste form may be filled with corrosion products, which may decrease the transport and release of radionuclides from the waste.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
C	6	Corrosion – gases	The production of hydrogen by the anoxic corrosion of metals in the repository, including the *Supercontainer* envelope and overpack, and waste elements. Hydrogen production may influence other near-field processes (e.g. microbial viability, groundwater flow and radionuclide transport) and is a key factor in controlling the near-field chemical environment.
C	7	Mineralogical changes	Hydration, crystallisation and other reactions that cause mineralogical changes in solids. For example, cement evolution reactions will continue after emplacement and may affect the containment properties of the buffer, and other cementitious materials used in the repository (filler, tunnel lining, seals).
C	8	Redox reactions / Eh conditions / Eh changes	Reduction-oxidation (or Redox) reactions are reversible chemical processes usually involving the transfer of electrons, involving a reaction with oxygen (oxidation) to form an oxide and a reaction with hydrogen (reduction) to form a hydride. Eh is a measure of the redox potential, and will vary in time and place within the EBS. Eh conditions are influenced by the natural composition of groundwater and potentially by radiolysis close to the waste. Redox fronts separate regions that may be characterised, in broad terms, as having different redox potentials. Changes in Eh conditions may occur as a result of diffusion processes, or in response to groundwater flow.
C	9	pH conditions / pH changes	pH is the hydrogen potential, a measure of the acidity or alkalinity of a solution equal to the common logarithm of the reciprocal of the concentration of hydrogen ions in moles per cubic decimetre of solution. pH conditions will vary in time and place within the EBS. pH conditions affect many chemical processes and parameters, including solubilities and sorption equilibria. For example, evolution of the cement buffer will lead to changes in pH within the *Supercontainer*.
C	10	Sorption / retardation	Sorption is a general term encompassing processes in which one substance (e.g. part of the EBS) takes up or holds a dissolved species (e.g. radionuclide) by physico-chemical interactions, thereby retarding its transport. For example, radionuclides can interact with the surfaces of open channels within water-conducting features and also on the surfaces of pores accessible by matrix diffusion. Sorption and the extent to which radionuclides are retarded depend on elemental concentrations and on the properties of the solid-water system under consideration. Changes in mineralogy and water chemistry may affect the amount of sorption.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
C	11	Colloid formation and stability	A mixture having particles of one component, with diameters in the nanometre to micrometer size, suspended in a continuous phase of another component; the particles suspended in such a mixture are also called colloids. This FEP includes the occurrence of pseudo-colloids within the EBS. Colloids are present in groundwaters and may also be produced during degradation of the wastes or EBS materials. Colloids may form stable dispersions in porewaters. The formation and stability of colloids depends on their composition and the prevailing chemical conditions.
C	12	Complexation	The formation of aqueous complexes between radionuclides and anthropogenic or naturally occurring chemical agents such as organic materials. Chemical agents may be present in repository materials or otherwise be introduced into the repository, e.g. from spillage of oil, hydraulic fluid, or solvents during repository construction and operation. Organic compounds may also be present in the host rock and be transported by groundwater into the EBS. Complexation of radionuclides with chemical agents in the EBS porewater could affect solubilities and radionuclide speciation, and thus radionuclide migration.
C	13	Microbial / biological / biochemical activity	The modification of chemical speciation or phase change owing to microbial / biological / biochemical activity. Microbes may survive under alkaline conditions and areas of enhanced microbial activity may develop. Metabolites of microbes may form complexes with some radionuclides. Dissolved in the porewater, these metabolites may decrease sorption and increase solubility of the radionuclides concerned. If a high organic load arises, the carbon dioxide produced may affect the properties of the buffer.
C	14	Gas generation	Gas production within the EBS from corrosion and degradation of waste or EBS materials (e.g. H_2), microbial activity (e.g. CO_2, CH_4 and H_2S), and radiation effects (He from alpha decay and H_2 and O_2 from radiolysis). Gas production may change local chemical and hydraulic conditions, and the mechanisms for radionuclide transport (i.e. gas-induced and gas-mediated transport).
C	15	Speciation	The form in which elements occur under particular chemical or environmental conditions, including temperature, pressure, and salinity (ionic strength). Chemical speciation controls the geochemical reactions likely to occur and the consequences for radionuclide mobility.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
C	16	Chemical gradients	Any spatial variation in chemical conditions within the EBS. The existence of chemical gradients within the EBS, induced naturally or resulting from repository material and waste emplacement, may influence the transport of contaminants. Chemical gradients may exist at the interfaces between different repository materials and between repository and geological materials.
C	17	Galvanic coupling / electrochemical effects / electrophoresis / electrochemical gradients	The presence and effects of electrochemical gradients within the waste and/or the EBS. Galvanic coupling refers to the establishment of an electrical current through chemical processes. Electrophoresis is the motion of charged particles in a colloid under the influence of an applied electric field. Electrochemical gradients may be established in the *Supercontainer* owing to the presence of different metals in the *Supercontainer* envelope, overpack and waste. Electrochemical effects may also arise from different local micro-environments (e.g. Eh, pH) on the surface of these metals. Natural currents occurring in the ground, known as "telluric currents", may also create electrochemical gradients. Galvanic coupling and electrochemical gradients may influence corrosion of the *Supercontainer* overpack and envelope and affect the mobility of charged radionuclide species (by electro-osmosis) and particulates (by electrophoresis) in the EBS.
C	18	Chemical interactions and coupled processes	Chemical processes affecting components of the EBS and radionuclide transport that interact in such a way as to accelerate or increase the effect of other processes. For example, corrosion products may affect sorption, or exothermic reactions may result in temperature gradients that affect the movement of redox fronts.
Hydraulic processes			
H	1	Hydraulic properties	The hydraulic properties of the EBS and the EDZ, particularly hydraulic gradient, conductivity, porosity, permeability, and fracture properties. The hydraulic properties will control groundwater flow.
H	2	Advection	The transport of dissolved and solid material by fluid flowing through pores or along fractures and other discontinuities.
H	3	Convection	The process of fluid flow and radionuclide transport arising from thermally-induced differences in fluid density. Convection, driven by temperature differentials within the EBS or the natural system, may affect the pattern of groundwater flow within and around the EBS.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
H	4	Diffusion	The movement of molecules or particles (containing radionuclides) both parallel and transverse to the direction of advection in response to Brownian forces. Also transverse movement of radionuclides that are advected along fractures or connected void spaces into stagnant porewater in the adjacent matrix - termed matrix diffusion. Diffusion occurs in the presence of chemical and thermal gradients, and may affect the transport and spread of dissolved radionuclides.
H	5	Dispersion	The spreading of molecules (e.g. dissolved radionuclides) by means of unresolved velocity variations in a flow field that cannot be described explicitly as advection. Dispersion may affect the transport and spread of radionuclides.
H	6	Density-driven flow	The process of fluid flow caused by spatial variations in fluid density due to chemical processes or salinity gradients. Density variations from chemical processes may arise within the EBS or between the EBS and the surrounding rock. Salinity gradients may exist within the rocks surrounding the EBS.
H	7	Unsaturated flow	The movement of groundwater in response to hydraulic gradients into unsaturated parts of the EBS and surrounding geosphere at repository closure. During resaturation, local groundwater flow directions and rates around the repository may differ from long-term regional patterns of flow. Also, capillarity – a phenomenon associated with surface tension at the surface of a liquid in contact with a solid - could provide a mechanism for water to move through unsaturated zones of the EBS.
H	8	Far-field groundwater flow	The movement of water in the geosphere surrounding the EBS. Changes in patterns of groundwater flow into the EBS from the surrounding geosphere may result in changes in porewater chemistry, and thereby affect many of the Chemical FEPs.
H	9	Colloid transport	The movement of colloids with groundwater. Depending on their size, colloids may be transported at different rates than fully dissolved species. Colloids may retard radionuclide transport by sorption of dissolved radionuclides onto colloids and subsequent filtration or sorption of the colloids by the EBS or natural materials; colloids may also enhance radionuclide transport by sorption of dissolved radionuclides and colloid transport with flowing groundwater through fractured media in channels where velocities are greatest.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
H	10	Particle suspension / transport	Suspensions of (radionuclide-bearing) particles in groundwater flowing rapidly enough to keep the particles from settling out. Particles of radionuclide-bearing material larger than colloids could be transported by suspension in water flowing through the EBS.
H	11	Gas flow and transport	The flow and transport of non-radioactive gases and radioactive gases, and the entrainment of gaseous or volatile radionuclides in gas flow.
H	12	Gas-induced flow and transport	The displacement by gas pressure of porewater containing dissolved radionuclides, or the transport of radionuclides as volatile species with repository-generated gases.
H	13	Natural gas intrusion	The movement of naturally occurring gases into the EBS. Natural gas intrusion could lead to changes in saturation and give rise to gas-induced transport.
H	14	Preferential pathways	Pathways through the EBS or the EDZ through which water or gas can flow more easily than through the bulk matrix (e.g. fracture pathways). Preferential pathways for flow and diffusion may exist or form within the buffer and may affect long-term performance of the *Supercontainer*.
H	15	Alkaline plume	Cementitious (high-pH) leachate from the EBS transported into the surrounding geosphere, forming an alkaline plume with different geochemical characteristics to the surrounding groundwater. Reactions affecting radionuclide transport could occur at the margins of such a plume.
Thermal processes			
T	1	Thermal evolution	The variation in temperature with time and place in the EBS. Temperatures within the EBS will vary as different heat sources (e.g. radioactive decay of waste elements, exothermic reactions, geothermal gradient) vary with time. Thermal evolution may affect mechanical, hydrological and chemical properties and processes - see related FEPs T2, T3 & H3.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
T	2	Thermal effects – physical / mechanical	Differential thermal expansion and other changes in the physical characteristics of EBS components owing to the presence of time-varying thermal gradients within the EBS. These effects could lead to changes in stress and potentially to cracking of EBS components or to the enhancement of pathways through the EDZ. Thermal effects on material properties (e.g. permeability, porosity) could also affect EBS evolution.
T	3	Thermal effects – chemical (including Soret effect)	Changes in the rate of chemical reactions owing to the presence of a time-varying thermal gradient within the EBS. The thermal pulse generated in the EBS by radioactive decay and exothermic reactions may cause rates of near-field processes to change. Processes that may be affected include corrosion, microbial activity, gas production, complex formation, colloid production, radionuclide solubility, sorption processes, and speciation. If sufficiently large thermal gradients exist, diffusion of heavier molecules to cooler regions (Soret effect) could occur.
T	4	Exothermic reactions	Chemical reactions that liberate heat. Exothermic reactions will alter the temperature and thereby affect the properties of the EBS and surrounding materials. Dissipation of heat by conduction and possibly convection will act to limit any overall temperature change. The most significant exothermic reaction in the *Supercontainer* will be cement hydration. Corrosion and waste dissolution reactions may also be exothermic.
T	5	Geothermal effects	Effects associated with the naturally occurring increase in temperature with depth in the geosphere. Groundwater flow into and around the EBS may be influenced by existing geothermal gradients.
Physical / mechanical processes			
P	1	Cracking	The development of cracks in components of the EBS. For example, overpack welds may be subject to "cold cracking" or cementitious materials used in the EBS may be subject to cracking as a result of applied stresses.
P	2	Creep	Slow plastic deformation of solids in response to deviatoric stress. For example, creep may occur in metals used in the *Supercontainer* overpack or envelope, or in the EDZ as a result of stress relief in the host rock arising from tunnel excavation.

Category	No	*Supercontainer* EBS FEP Name	FEP Description and FEP Effects
P	3	Corrosion – stress cracking	More rapid corrosion of solids, particularly metals used in the *Supercontainer* overpack or envelope, in areas with high residual stresses, e.g. due to welding. Stress corrosion cracking requires a certain minimum stress level before it can occur, and could affect the physical integrity of EBS components.
P	4	Seismic activity / earthquakes	Relative movements within the Earth, caused by the release of accumulated stress usually along faults or geological interfaces or by volcanic activity. Large earthquakes, vibration from many smaller earthquakes or related seismic events could affect components of the EBS, or cause changes in groundwater flow into and around the repository.
P	5	Faulting / fracturing	To undergo or cause to undergo a relative displacement of rocks along a fault or fracture. Movement on faults or fractures that intercept the repository may cause relative displacement of the components of the EBS. Generation of new faults and reactivation of pre-existing features may change the transport pathways from the EBS to the geosphere.
P	6	Stress changes	Changes in the forces producing deformation or strain (a change in dimensions). The stress field in the EBS will be determined by the regional stress field and by local changes to the stress field caused by excavation, waste emplacement and thermal evolution of the EBS. After re-saturation of the repository, the *Supercontainer* will be subject to hydrostatic pressure. Changes to these stresses could damage components of the EBS.
P	7	Mechanical effects	Mechanical disturbance of components of the EBS. The EBS could be mechanically disturbed by physico-chemical degradation of the buffer, external forces (e.g. tunnel roof or lining collapse, rock creep or faulting in near-field rock), volume increase of corrosion products, and/or the build-up of internal gas pressure. These disturbances could cause processes such as cracking, and movement of the overpack through the buffer.
P	8	Gas explosions	Violent releases of energy caused by chemical reactions between gases (e.g. H_2, CH_4) that collect in the sealed repository. An explosion in the repository could damage the structure of the EBS and enhance or inhibit near-field processes.
P	9	Post-closure activities – effects	Any effects associated with monitoring of the disposal system or other external activities subsequent to closure of the repository.

APPENDIX D: NWMO'S USED NUCLEAR FUEL FEP LIST

1. External Factors		
1.1	**Repository Issues**	
	1.1.01	Site investigation
	1.1.02	Excavation and construction
	1.1.03	Emplacement of wastes and backfill
	1.1.04	Closure and repository sealing
	1.1.05	Repository records and markers
	1.1.06	Waste allocation
	1.1.07	Repository design
	1.1.08	Quality control
	1.1.09	Schedule and planning
	1.1.10	Repository administrative control
	1.1.11	Monitoring
	1.1.12	Accidents and unplanned events
	1.1.13	Retrieval of wastes
1.2	**Geological Processes and Effects**	
	1.2.01	Tectonic movement and orogeny
	1.2.02	Deformation (elastic, plastic or brittle)
	1.2.03	Seismicity (earthquakes)
	1.2.04	Volcanic and magmatic activity
	1.2.05	Metamorphism
	1.2.06	Hydrothermal activity
	1.2.07	Erosion and sedimentation
	1.2.08	Diagenesis
	1.2.09	Salt diapirism and dissolution
	1.2.10	Hydrological response to geological changes
1.3	**Climate Processes and Effects**	
	1.3.01	Global climate change
	1.3.02	Local and regional climate change
	1.3.03	Sea-level change
	1.3.04	Periglacial effects
	1.3.05	Local glacial effects

	1.3.06	Warm climate effects (tropical and desert)
	1.3.07	Hydrological response to climate changes
	1.3.08	Ecological response to climate changes
	1.3.09	Human behavioural response to climate changes
1.4	**Future Human Actions**	
	1.4.01	Human influences on climate
	1.4.02	Deliberate human intrusion
	1.4.03	Non-intrusive site investigations
	1.4.04	Drilling activities (human intrusion)
	1.4.05	Mining (human intrusion)
	1.4.06	Surface environment, human activities
	1.4.07	Water management (wells, reservoirs, dams)
	1.4.08	Social and institutional developments
	1.4.09	Technological developments
	1.4.10	Remedial actions
	1.4.11	Explosions and crashes
1.5	**Other External Factors**	
	1.5.01	Meteorite impact
	1.5.02	Species evolution
	1.5.03	Miscellaneous FEPs

2. REPOSITORY FACTORS			
2.1	Wastes and Engineered Features		
	2.1.01	Waste inventories	
		2.1.01.A	Inventory of radionuclides
		2.1.01.B	Inventory of chemically toxic contaminants
	2.1.02	Waste form materials and characteristics	
		2.1.02.A	Characteristics of used CANDU fuel (UO_2)
		2.1.02.B	Characteristics of Zircaloy cladding
		2.1.02.C	Characteristics of other waste forms
		2.1.02.D	Used fuel dissolution
		2.1.02.E	Zircaloy cladding dissolution
	2.1.03	Container materials and characteristics	
		2.1.03.A	Container design characteristics
		2.1.03.B	Fabrication and installation defects
		2.1.03.C	Stress corrosion cracking
		2.1.03.D	General or uniform corrosion
		2.1.03.E	Mechanical degradation
		2.1.03.F	Localized corrosion
		2.1.03.G	Microbial-induced corrosion

		2.1.03.H	Internal corrosion processes
	2.1.04	Buffer and backfill materials and characteristics	
		2.1.04.A	Repository layout
		2.1.04.B	Buffer characteristics and evolution
		2.1.04.C	Backfill characteristics and evolution
	2.1.05	Seals and grouts (cavern, tunnel, shaft)	
	2.1.06	Other engineered features	
	2.1.07	Mechanical processes and conditions (repository)	
		2.1.07.A	Buffer and backfill swelling
		2.1.07.B	Formation and healing of cracks
		2.1.07.C	Collapse of repository openings
		2.1.07.D	Evolution of stresses in the near-field
		2.1.07.E	Buffer and backfill creep
	2.1.08	Hydrological processes and conditions (repository)	
		2.1.08.A	Desaturation and resaturation of the repository
		2.1.08.B	Groundwater movement
		2.1.08.C	Evolution of hydraulic conditions
		2.1.08.D	Coupled hydraulic processes
	2.1.09	Chemical processes and conditions (repository)	
		2.1.09.A	Water chemistry and evolution (repository)
		2.1.09.B	Hydrothermal alteration
		2.1.09.C	Other chemical processes
	2.1.10	Biological processes and conditions (repository)	
		2.1.10.A	Biological processes (repository)
		2.1.10.B	Complexation by organics (repository materials)
		2.1.10.C	Biological effects on groundwater movement
	2.1.11	Thermal processes and conditions (repository)	
		2.1.11.A	Thermal conduction and convection
		2.1.11.B	Coupled heat transfer processes
	2.1.12	Gas sources and effects (repository)	
	2.1.13	Radiation effects (repository)	
		2.1.13.A	Radiation effects - wasteform
		2.1.13.B	Radiation effects - container
		2.1.13.C	Radiation effects - sealing materials
	2.1.14	Nuclear criticality	
2.2	Geological Environment		
	2.2.01	Excavation disturbed zone	
	2.2.02	Host rock	
	2.2.03	Other geological units	
	2.2.04	Discontinuities and lineaments (geosphere)	
	2.2.05	Contaminant transport path characteristics (geosphere)	

		2.2.05.A	Advection and dispersion
		2.2.05.B	Diffusion
		2.2.05.C	Matrix diffusion
	2.2.06	Mechanical processes and conditions (geosphere)	
	2.2.07	Hydrological processes and conditions (geosphere)	
	2.2.08	Chemical processes and conditions (geosphere)	
	2.2.09	Biological processes and conditions (geosphere)	
	2.2.10	Thermal processes and conditions (geosphere)	
	2.2.11	Gas sources and effects (geosphere)	
	2.2.12	Undetected features (geosphere)	
	2.2.13	Geological resources	
2.3	Surface Environment		
	2.3.01	Topography and morphology	
	2.3.02	Soil and sediment	
		2.3.02.A	Surface soils
		2.3.02.B	Overburden
		2.3.02.C	Aquatic sediments
	2.3.03	Near surface aquifers	
	2.3.04	Surface water bodies	
		2.3.04.A	Wetlands
		2.3.04.B	Lakes and rivers
		2.3.04.C	Springs and discharge zones
	2.3.05	Coastal features	
	2.3.06	Marine features	
	2.3.07	Atmosphere	
	2.3.08	Vegetation	
	2.3.09	Animal populations	
	2.3.10	Meteorology	
	2.3.11	Hydrological regime and water balance	
	2.3.12	Erosion and deposition	
	2.3.13	Ecological systems	
2.4	Human Behaviour		
	2.4.01	Human characteristics (physiology, metabolism)	
	2.4.02	Age, gender and ethnicity	
	2.4.03	Diet and liquid intake	
		2.4.03.A	Farming diet
		2.4.03.B	Hunter/gatherer diet
		2.4.03.C	Other diets
	2.4.04	Habits (excluding diet)	
	2.4.05	Community characteristics	

		2.4.05.A	Community type
		2.4.05.B	Community location
		2.4.05.C	Water source
	2.4.06	Food and water processing and preparation	
	2.4.07	Dwellings	
	2.4.08	Wild and natural land and water use	
	2.4.09	Rural and agricultural land and water use	
	2.4.10	Urban and industrial land and water use	
	2.4.11	Leisure and other uses of the environment	
3. CONTAMINANT FACTORS			
3.1	Contaminant Characteristics		
	3.1.01	Radioactive decay and ingrowth	
	3.1.02	Chemical and organic toxin stability	
	3.1.03	Inorganic solids and solutes	
	3.1.04	Volatiles and potential for volatility	
	3.1.05	Organics and potential for organic forms	
	3.1.06	Noble gases	
3.2	Contaminant Release and Migration Factors		
	3.2.01	Dissolution, precipitation and crystallisation (contaminant)	
		3.2.01.A	Dissolution and precipitation (repository)
		3.2.01.B	Dissolution and precipitation (geosphere)
		3.2.01.C	Dissolution and precipitation (biosphere)
	3.2.02	Speciation and solubility (contaminant)	
		3.2.02.A	Speciation and solubility (repository)
		3.2.02.B	Speciation and solubility (geosphere)
		3.2.02.C	Speciation and solubility (biosphere)
	3.2.03	Sorption and desorption (contaminant)	
		3.2.03.A	Sorption/desorption (repository)
		3.2.03.B	Sorption/desorption (geosphere)
		3.2.03.C	Sorption/desorption (biosphere)
	3.2.04	Colloid interactions and transport (contaminant)	
	3.2.05.	Complexing agent effects (contaminant)	
	3.2.06.	Biologically mediated processes, excluding transport (contaminant)	
	3.2.07.	Water-mediated transport of contaminants	
		3.2.07.A	Water-mediated effects (repository)
		3.2.07.B	Water-mediated effects (geosphere)
		3.2.07.C	Water-mediated effects (biosphere)
		3.2.07.D	Coupled solute transport processes
	3.2.08	Solid-mediated transport of contaminants	
	3.2.09	Gas-mediated transport of contaminants	
	3.2.10	Atmospheric transport of contaminants	

	3.2.11	Biological-mediated transport of contaminants	
	3.2.12	Human action mediated transport of contaminants	
	3.2.13	Foodchains and uptake of contaminants	
3.3	Exposure Factors		
	3.3.01.	Contaminated drinking water, foodstuffs and drugs	
	3.3.02	Contaminated environmental media	
	3.3.03	Other contaminated materials	
	3.3.04	Exposure modes	
		3.3.04.A	Exposure of humans
		3.3.04.B	Exposure of biota other than humans
	3.3.05	Dosimetry	
	3.3.06	Radiological toxicity effects	
	3.3.07	Chemical toxicity effects	
	3.3.08	Radon and radon daughter exposure	

APPENDIX E: NWMO'S LOW AND INTERMEDIATE LEVEL WASTE FEP LIST

Category	FEP	FEP
1. EXTERNAL FACTORS		
1.1	Repository Factors	
	1.1.01	Site investigations
	1.1.02	Design of repository
	1.1.03	Schedule and planning
	1.1.04	Construction
	1.1.05	Operation
	1.1.06	Waste allocation
	1.1.07	Repository closure
	1.1.08	Quality assurance
	1.1.09	Repository administrative control
	1.1.10	Accidents and unplanned events
	1.1.11	Retrieval
	1.1.12	Repository records and markers
	1.1.13	Monitoring
1.2	Geological Processes and Effects	
	1.2.01	Tectonic movement
	1.2.02	Orogeny
	1.2.03	Seismicity
	1.2.04	Volcanic and magmatic activity
	1.2.05	Metamorphism
	1.2.06	Hydrothermal activity
	1.2.07	Denudation and deposition (large-scale)
	1.2.08	Diagenesis
	1.2.09	Pedogenesis
	1.2.10	Salt diapirism and dissolution
	1.2.11	Hydrological response to geological changes
	1.2.12	Geomorphologic response to geological changes
	1.2.13	Deformation (elastic, plastic or brittle)
1.3	Climate Processes and Effects	
	1.3.01	Global climate change

Category	FEP	FEP	
	1.3.02	Regional and local climate change	
	1.3.03	Sea-level change	
	1.3.04	Periglacial effects	
	1.3.05	Local glacial and ice-sheet effects	
	1.3.06	Warm climate effects (tropical and desert)	
	1.3.07	Hydrological response to climate changes	
	1.3.08	Ecological response to climate changes	
	1.3.09	Human behavioural response to climate changes	
	1.3.10	Geomorphologic response to climate changes	
1.4	Future Human Actions		
	1.4.01	Human influences on climate	
	1.4.02	Social and institutional developments	
	1.4.03	Knowledge and motivational issues (repository)	
	1.4.04	Drilling activities	
	1.4.05	Mining and other underground activities	
	1.4.06	Un-intrusive site investigation	
	1.4.07	Surface excavations	
	1.4.08	Site development	
	1.4.09	Archaeology	
	1.4.10	Water management (groundwater and surface water)	
	1.4.11	Explosions and crashes	
	1.4.12	Pollution	
	1.4.13	Remedial actions	
	1.4.14	Technological developments	
	1.4.15	Deliberate human intrusion	
1.5	Other External Factors		
	1.5.01	Impact of meteorites and human space debris	
	1.5.02	Evolution of biota	
2. INTERNAL FACTORS			
2.1	Waste, Waste Form & Engineered Components		
	2.1.01	Waste inventory	
		2.1.01.01	Radionuclide content
		2.1.01.02	Chemical content
	2.1.02	Waste-form characteristics	
		2.1.02.01	Metallic wastes
		2.1.02.02	Organic wastes
		2.1.02.03	Non-metallic, inorganic wastes

Category	FEP	FEP	
	2.1.03	Waste-packaging characteristics	
		2.1.03.01	Containers
		2.1.03.02	Overpacks
	2.1.04	Emplacement room, access tunnel and shaft & services area characteristics	
		2.1.04.01	Roofs and walls
		2.1.04.02	Floors
		2.1.04.03	Rock bolts
		2.1.04.04	Room and closure walls
		2.1.04.05	Backfill
	2.1.05	Shaft characteristics	
		2.1.05.01	Lining
		2.1.05.02	Backfill
		2.1.05.03	Plugs
		2.1.05.04	Rock bolts
	2.1.06	Mechanical processes and conditions (in wastes, emplacement rooms, tunnels and shafts)	
		2.1.06.01	Packaging collapse
			A Steel failure
			B Concrete failure
		2.1.06.02	Material volume changes
			A Concrete shrinkage/expansion
			B Bentonite swelling
			C Corrosion products
		2.1.06.03	Emplacement room/tunnel collapse
		2.1.06.04	Container movement
		2.1.06.05	Fracture formation
		2.1.06.06	Stress-corrosion cracking
		2.1.06.07	Gas explosion
		2.1.06.08	Influence of climate change
	2.1.07	Hydraulic/hydrogeological processes and conditions (in wastes, emplacement rooms, tunnels and shafts)	
		2.1.07.01	Resaturation/desaturation
		2.1.07.02	Water flow
		2.1.07.03	Gas-mediated water flow
		2.1.07.04	Failure of drainage system
		2.1.07.05	Fracturing of repository components due to hydraulic pressure
		2.1.07.06	Coupled hydraulic processes including temperature, chemical or electrical gradients

Category	FEP	FEP	
		2.1.07.07	Influence of climate change
	2.1.08	Chemical/geochemical processes and conditions (in wastes, emplacement rooms, tunnels and shafts)	
		2.1.08.01	pH conditions
		2.1.08.02	Redox conditions
		2.1.08.03	Chloride and sulphate concentrations
		2.1.08.04	Corrosion
			A General
			B Localized
			C Galvanic
		2.1.08.05	Polymer degradation
		2.1.08.06	Mineralisation
			A Leaching
			B Chloride attack
			C Sulphate attack
			D Carbonation
			E Illitization
		2.1.08.07	Precipitation reactions
		2.1.08.08	Chelating agent effects
		2.1.08.09	Colloid formation
		2.1.08.10	Osmotic effects
		2.1.08.11	Chemical concentration gradients
		2.1.08.12	Influence of climate change
	2.1.09	Biological/biochemical processes and conditions (in wastes, emplacement rooms, tunnels and shafts)	
		2.1.09.01	Microbial growth and poisoning
		2.1.09.02	Microbially/biologically mediated processes
		2.1.09.03	Microbial/biological effects on evolution of redox (Eh) and acidity/alkalinity (pH).
		2.1.09.04	Influence of climate change
	2.1.10	Thermal processes and conditions (in wastes, emplacement rooms, tunnels and shafts)	
		2.1.10.01	Radiogenic, chemical and biological heat production from the waste packages
		2.1.10.02	Heat production from engineered features
		2.1.10.03	Temperature evolution
		2.1.10.04	Temperature dependence of processes,
			A Mechanical
			B Hydraulic

Category	FEP	FEP	
			C Chemical
			D Biological
		2.1.10.05	Influence of climate change
	2.1.11	Gas sources (in wastes, emplacement rooms, tunnels and shafts)	
		2.1.11.01	Radioactive decay
		2.1.11.02	Metal corrosion
		2.1.11.03	Organic waste degradation
		2.1.11.04	Cement degradation
		2.1.11.05	Asphalt degradation
	2.1.12	Radiation effects (in wastes, emplacement rooms, tunnels and shafts)	
	2.1.13	Effects of extraneous materials	
	2.1.14	Nuclear criticality	
2.2	Geological Environment		
	2.2.01	Stratigraphy	
	2.2.02	Host rock lithology	
	2.2.03	Disturbed zone (in geosphere)	
		2.2.03.01	Emplacement rooms and tunnels
		2.2.03.02	Shafts
	2.2.04	Large-scale discontinuities (in geosphere)	
		2.2.04.01	Faults and shear zones
		2.2.04.02	Fractures and joints
		2.2.04.03	Dykes
	2.2.05	Mechanical processes and conditions (in geosphere)	
		2.2.05.01	Geomechanical properties
		2.2.05.02	Current stress regime
		2.2.05.03	Future stress regime
	2.2.06	Hydraulic/hydrogeological processes and conditions (in geosphere)	
		2.2.06.01	Hydraulic properties
		2.2.06.02	Current hydraulic potentials and gradients
		2.2.06.03	Future hydraulic potentials and gradients
	2.2.07	Chemical/geochemical processes and conditions (in geosphere)	
		2.2.07.01	Mineralogical properties
		2.2.07.02	Geochemical properties
		2.2.07.03	Effects of engineered barriers
		2.2.07.04	Effects of climate change
	2.2.08	Biological/biochemical processes and conditions (in geosphere)	
	2.2.09	Thermal processes and conditions (in geosphere)	

Category	FEP	FEP	
		2.2.09.01	Thermal properties
		2.2.09.02	Effects of waste and repository materials
		2.2.09.03	Effects of climate change
	2.2.10	Gas processes and effects (in geosphere)	
		2.2.10.01	Gas sources (excluding waste and repository materials)
		2.2.10.02	Gas migration
		2.2.10.03	Gas dissolution
		2.2.10.04	Gas-induced fracturing
	2.2.11	Geological resources (in geosphere)	
	2.2.12	Undetected features (in geosphere)	
2.3	Surface Environment		
	2.3.01	Topography and morphology	
	2.3.02	Biomes	
	2.3.03	Soil and sediment	
		2.3.03.01	Surface soils
		2.3.03.02	Overburden
		2.3.03.03	Aquatic sediments
	2.3.04	Near-surface aquifers and water-bearing features	
	2.3.05	Terrestrial surface-water bodies	
		2.3.05.01	Wetlands
		2.3.05.02	Lakes and rivers
		2.3.05.03	Springs and discharge zones
	2.3.06	Coastal features	
	2.3.07	Marine features	
	2.3.08	Atmosphere	
	2.3.09	Vegetation	
	2.3.10	Animal populations	
	2.3.11	Climate and weather	
	2.3.12	Hydrological regime and water balance (near-surface)	
	2.3.13	Erosion and deposition	
	2.3.14	Ecological/biological/microbial systems	
	2.3.15	Biotic intrusion	
2.4	Human Behaviour		
	2.4.01	Human characteristics (physiology, metabolism)	
	2.4.02	Age, gender and ethnicity	
	2.4.03	Diet and liquid intake	
		2.4.03.01	Farming diet

Category	FEP	FEP	
		2.4.03.02	Hunter/gatherer diet
		2.4.03.03	Other diets
	2.4.04	Habits (non-diet-related behaviour)	
	2.4.05	Community characteristics	
		2.4.05.01	Community type
		2.4.05.02	Community location
		2.4.05.03	Water source
	2.4.06	Food preparation and water processing	
	2.4.07	Dwellings	
	2.4.08	Natural/semi-natural land and water use	
	2.4.09	Rural and agricultural land and water use	
	2.4.10	Urban and industrial land and water use	
	2.4.11	Leisure and other uses of environment	
3. CONTAMINANT FACTORS			
3.1	Contaminant Characteristics		
	3.1.01	Radioactive decay and in-growth	
	3.1.02	Organics and potential for organic forms	
	3.1.03	Chemical/organic toxin stability	
	3.1.04	Inorganic solids/solutes	
	3.1.05	Volatiles and potential for volatility	
	3.1.06	Noble gases	
3.2	Contaminant Release and Migration Factors		
	3.2.01	Contaminant release pathways	
	3.2.02	Water-mediated migration of contaminants	
		3.2.02.01	Water-mediated effects (repository)
			A Advection
			B Molecular diffusion
			C Dispersion
		3.2.02.02	Water-mediated effects (geosphere)
			A Advection
			B Molecular diffusion
			C Dispersion
			D Matrix diffusion
		3.2.02.03	Water-mediated effects (biosphere)
			A Groundwater discharge to biosphere
			B Infiltration
			C Capillary rise

Category	FEP	FEP	
			D Transport by surface run-off
			E Transport by interflow
			F Transport in surface-water bodies
		3.2.02.04	Multiphase transport processes
	3.2.03	Solid-mediated migration of contaminants	
	3.2.04	Gas-mediated migration of contaminants	
	3.2.05	Atmospheric migration of contaminants	
	3.2.06	Microbially/biologically-mediated processes, effects on contaminant release and migration	
	3.2.07	Animal-, plant- and microbe-mediated migration of contaminants	
	3.2.08	Human-action-mediated migration of contaminants	
	3.2.09	Colloid-mediated migration of contaminants	
	3.2.10	Dissolution, precipitation and mineralization	
		3.2.10.01	Dissolution and Precipitation (repository)
		3.2.10.02	Dissolution and Precipitation (geosphere)
		3.2.10.03	Dissolution and Precipitation (biosphere)
		3.2.10.04	Change in mineralization
	3.2.11	Speciation and solubility (contaminant)	
		3.2.11.01	Speciation and solubility (solubility limitation, repository)
		3.2.11.02	Speciation and solubility (solubility limitation, geosphere)
		3.2.11.03	Speciation and solubility (solubility limitation, biosphere)
		3.2.11.04	Solubility changes caused by chemical interaction between waste and pore water
		3.2.11.05	Solubility changes caused by change in temperature
		3.2.11.06	Species equilibrium change caused by change in temperature
	3.2.12	Sorption and desorption (contaminant)	
		3.2.12.01	Sorption and desorption (repository)
		3.2.12.02	Sorption and desorption (geosphere)
		3.2.12.03	Sorption and desorption (biosphere)
		3.2.12.04	Chemical reactions caused by adsorption or desorption
		3.2.12.05	Anion exclusion effects
		3.2.12.06	Sorption change caused by change in temperature
	3.2.13	Complexing agent effects (contaminant)	
		3.2.13.01	Organics
		3.2.13.02	Inorganic ligands
		3.2.13.03	Microbes

Category	FEP	FEP	
	3.2.14	Food chains and uptake of contaminants	
3.3	Exposure Factors		
	3.3.01	Contaminant concentrations in drinking water, foodstuffs and drugs	
	3.3.02	Contaminant concentrations in non-food products	
	3.3.03	Contaminant concentrations in other environmental media	
	3.3.04	Exposure modes	
		3.3.04.01	Exposure of humans
		3.3.04.02	Exposure of biota other than humans
	3.3.05	Dosimetry and biokinetics	
		3.3.05.01	Dosimetry and biokinetics for humans
		3.3.05.02	Dosimetry and biokinetics for biota other than humans
	3.3.06	Radiological toxicity/effects	
		3.3.06.01	Radiological toxicity/effects for humans
		3.3.06.02	Radiological toxicity/effects for biota other than humans
	3.3.07	Chemical toxicity/effects	
		3.3.07.01	Chemical toxicity/effects for humans
		3.3.07.02	Chemical toxicity/effects for biota other than humans
	3.3.08	Radon and radon daughter exposure	

APPENDIX F: POSIVA'S KBS-3V INTERNAL FEP LIST

Chapter 3: Fuel/cavity in canister

3.2.1 Radioactive decay and in-growth (E)

3.2.2 Radiogenic heat generation and heat transfer (E)

3.2.3 Structural alteration of the fuel pellets and fuel cladding (E)

3.2.4 Radiolytic acid production (E)

3.2.5 Radiolysis of the groundwater (E)

3.2.6 Corrosion of the fuel assembly (E)

3.2.7 Dissolution of the fuel matrix (E)

3.2.8 Dissolution of the gap inventory (E)

3.2.9 Production of helium gas (E)

3.3.1 Diffusion in fuel pellet (M)

3.3.2 Radionuclide release from the fuel - radionuclide solubility (M)

3.3.3 Water and gas transport (M)

3.3.4 Radionuclide transport - advection and diffusion (M)

3.3.5 Colloidal transport (M)

Chapter 4: Cast iron insert and copper over pack (canister)

4.2.1 Radiation attenuation by canister metal (E)

4.2.2 Heat transfer in canister metal (E)

4.2.3 Deformation of cast iron insert (E)

4.2.4 Deformation of copper overpack (E)

4.2.5 Thermal expansion of the canister (E)

4.2.6 Deformation from internal corrosion products (E)

4.2.7 Corrosion of cast iron insert (E)

4.2.8 Corrosion of copper overpack (E)

4.2.9 Deposition of salts on canister surface (E)

4.3.1 Radionuclide retardation by iron corrosion products (M)

Chapter 5: Bentonite buffer

5.2.1 Heat transfer (E)

5.2.2 Water uptake (E)

5.2.3 Piping and erosion, including chemical erosion (E)

5.2.4 Swelling/mass redistribution (E)

5.2.5 Radiolysis of porewater (E)
5.2.6 Montmorillonite transformation (E)
5.2.7 Alteration of accessory minerals and impurities (E)
5.2.8 Microbial activity (E)
5.3.1 Advection – Diffusion (M)
5.3.2 Gas transport (M)
5.3.3 Colloid formation and transport (M)
5.3.4 Sorption (including ionic-exchange) (M)
5.3.5 Osmosis/Donnan equilibrium (M)
5.3.6 Speciation of radionuclides (M)
5.3.7 Precipitation and co-precipitation (M)
Chapter 6: Backfill
6.2.1 Heat transfer (E)
6.2.2 Freezing (E)
6.2.3 Water uptake (E)
6.2.4 Piping and erosion, including chemical erosion (E)
6.2.5 Swelling/mass redistribution (E)
6.2.5 Radiolysis of porewater (E)
6.2.6 Alteration of accessory minerals and impurities (E)
6.2.7 Microbial activity (E)
Chapter 7: Plugs, seals, grout
7.2.1 Heat transfer (E)
7.2.2 Freezing (E)
7.2.3 Degradation of cementitious materials due to radiation and thermal effects (E)
7.2.4 Degradation of cementitious materials due to reactions with groundwater (E)
7.3.1 Diffusion (M)
7.3.2 Sorption (M)
7.3.3 Colloid formation (M)
Chapter 8: Geosphere
8.2.1 Heat transfer (E)
8.2.2 Freezing and permafrost (E)
8.2.3 Stress redistribution due to excavation (E)
8.2.4 Reactivation-displacements along existing fractures (E)
8.2.5 Spalling of rock (E)
8.2.6 Rock creep (E)
8.2.7 Erosion and sedimentation in fractures (E)
8.2.8 Rock-water interaction (E)

8.2.9 Methane hydrate formation (E)

8.2.10 Salt exclusion (E)

8.2.11 Microbial populations and processes (E)

8.3.1 Radionuclide solubility, sorption and precipitation (M)

8.3.2 Groundwater flow (advection) (M)

8.3.3 Dispersion (M)

8.3.4 Matrix diffusion (M)

8.3.5 Two-phase flow (M)

8.3.6 Colloidal transport (M)

APPENDIX G: VSG FEP LIST

FEP Number	FEP Name
1.1.12.01	Unplanned events during operational phase
1.1.12.02	Sticking of canisters
1.2.01.01	Tectonic movements
1.2.01.02	Orogeny
1.2.01.03	Sinking of earth crust
1.2.01.04	Lifting of earth crust
1.2.02.01	Crustal deformation
1.2.02.02	Graben formation
1.2.03.01	Seismicity
1.2.04.01	Magmatic activity
1.2.05.01	Metamorphism
1.2.06.01	Hydrothermal activity
1.2.07.01	Erosion
1.2.07.02	Sedimentation
1.2.08.01	Diagenesis
1.2.09.01	Salt diapirism
1.2.09.02	Subrosion
1.3.01.01	Global climate change
1.3.03.01	Transgression and regression
1.3.04.01	Permafrost
1.3.04.02	Cryogenic joints
1.3.05.01	Continental ice sheet close to site
1.3.05.02	Continental ice sheet above site
1.3.05.03	Subglacial tunnel valleys
1.5.01.01	Meteorite impact
1.5.03.01	Pathways in exploration drillings
2.1.01.01	Inventory: Radionuclides
2.1.01.02	Inventory: Metal compounds
2.1.01.03	Inventory: Organic compounds
2.1.01.04	Inventory: Other compounds
2.1.02.01	Waste form materials
2.1.03.01	Spent fuel containers
2.1.03.02	Other disposal containers
2.1.03.03	Loss of integrity of a spent fuel container
2.1.03.04	Failure of other container

2.1.04.01	Backfill materials
2.1.05.01	Sealing materials
2.1.05.02	Shaft seals
2.1.05.03	Drift seals
2.1.05.04	Alteration of shaft and drift seals
2.1.05.05	Other seals
2.1.06.01	Technical installations and their characteristics
2.1.06.02	Borehole tubing
2.1.07.01	Convergence
2.1.07.02	Fluid pressure
2.1.07.03	Compaction of crushed salt
2.1.07.04	Non thermally–induced volume change of materials
2.1.07.05	Early loss of tightness of a shaft seal
2.1.07.06	Early loss of tightness of a drift seal
2.1.07.07	Displacement of the shaft seals
2.1.07.08	Failure of drift plug
2.1.07.09	Failure of borehole tubing
2.1.08.01	Porosity
2.1.08.02	Permeability
2.1.08.03	Brines in mine excavations
2.1.08.04	Channeling in crushed salt
2.1.08.05	Channeling in sealing components
2.1.08.06	Brine intrusion into mine excavations
2.1.08.07	Flow processes in mine excavations
2.1.08.08	Swelling of bentonite
2.1.09.01	Geochemical regime in the repository
2.1.09.02	Dissolution and precipitation
2.1.09.03	Corrosion of metal
2.1.09.04	Corrosion of spent fuel
2.1.09.05	Corrosion of glass
2.1.09.06	Corrosion of cement- or sorel-based materials
2.1.09.07	Corrosion of graphite waste and uranium enrichment tails
2.1.09.08	Hydrogen induced embrittlement
2.1.10.01	Degradation of organic compounds
2.1.10.02	Microbial processes in the repository and the salt rock
2.1.11.01	Heat production
2.1.11.02	Thermal expansion or contraction
2.1.11.03	Vaporisation of water
2.1.12.01	Gas production
2.1.12.02	Gases in mine workings
2.1.12.03	Gas entry pressure
2.1.12.04	Ignitable gas mixtures
2.1.13.01	Radiation-induced activation
2.1.13.02	Radiation-induced embrittlement

2.1.13.03	Radiolysis
2.1.14.01	Nuclear criticality
2.2.01.01	Excavation disturbed zone
2.2.02.01	Host rock
2.2.02.02	Faults and joints in the host rock
2.2.03.01	Overburden and adjoining rock
2.2.04.01	Faults and joints in the overburden
2.2.06.01	Change and redistribution of stress
2.2.06.02	Self compaction
2.2.07.01	Fluid occurrences in the host rock
2.2.07.02	Hydrocarbon occurrences in the host rock
2.2.07.03	Groundwater flow in the overburden and adjoining rock
2.2.07.04	Gas flow in the overburden and adjoining rock
2.2.08.01	Hydrochemical regime in the overburden and adjoining rock
2.2.09.01	Microbial processes in the overburden and adjoining rock
2.2.10.01	Thermally-induced lifting of the overburden and adjoining rock
2.2.10.02	Thermomigration
2.2.10.03	Thermal degradation of carnallite
2.2.10.04	Melting of salt rock
2.2.10.05	Thermochemical sulfate reduction
2.2.11.01	Pressure-induced fluid infiltration into the salt rock
2.3.01.01	Geomorphology
2.3.04.01	Surface waters
3.1.01.01	Radioactive decay
3.2.01.01	Mobilisation of radionuclides
3.2.03.01	Sorption and desorption
3.2.04.01	Colloids
3.2.05.01	Complexing agents
3.2.07.01	Water-mediated transport of radionuclides
3.2.07.02	Advection
3.2.07.03	Mechanical dispersion
3.2.07.04	Diffusion
3.2.07.05	Matrix diffusion
3.2.07.06	Other transport processes
3.2.08.01	Lifting or sinking of containers
3.2.09.01	Gas-mediated transport of radionuclides

1.

APPENDIX H: TRU-2 FEP LIST

	Waste	Filler	Structural framework	Buffer material	Plug and grout/Support/Backfill (Secondary device)	Host rock
Thermal Phenomena/ Characteristics	WT-01 Waste packages's thermophysical properties WT-02 Waste package's temperature WT-03 Waste package's thermal expansion WT-04 Production of radioactive decay heat	MT-01 Filling materials' thermophysical properties MT-02 Filling materials' temperature MT-03 Filling materials' thermal expansion MT-04 Heating by absorption of γ-rays from the waste package MT-05 Heating by hydration	ST-01 Structural framework's thermophysical properties ST-02 Structural framework's temperature ST-03 Structural framework's thermal expansion ST-04 Heating by absorption of γ-rays from the waste package ST-05 Heating by hydration	BT-01 Buffer materials' thermophysical properties BT-02 Buffer materials' temperature BT-03 Buffer materials' thermal expansion	XT-01 Secondary devices' thermophysical properties XT-02 Secondary devices' temperature XT-03 Secondary devices' thermal expansion XT-04 Heating by hydration	RT-01 Host rocks' thermophysical properties RT-02 Host rocks' temperature RT-03 Host rocks' thermal expansion
Hydraulic Phenomena/ Characteristics	WH-01 Waste package's hydraulic characteristics WH-02 Waste package's saturation WH-03 Groundwater flow in waste package	MH-01 Filling materials' hydraulic characteristics MH-02 Filling materials' saturation MH-03 Groundwater flow in filling material	SH-01 Structural framework's hydraulic characteristics SH-02 Structural framework's saturation SH-03 Groundwater flow in structural framework	BH-01 Buffer materials' hydraulic characteristics BH-02 Buffer materials' saturation BH-03 Groundwater flow in buffer material	XH-01 Secondary devices' hydraulic characteristics XH-02 Secondary devices' saturation XH-03 Groundwater flow in secondary devices	RH-01 Host rocks' thermophysical properties RH-02 Host rocks' saturation RH-03 Groundwater flow in host rocks
Mechanical Phenomena/ Characteristics	WM-01 Waste package's mechanical properties WM-02 Waste package's stress WM-03 Swelling of solid asphalt WM-04 Deformation of solid asphalt WM-05 Release from solid asphalt WM-06 Fracturing of solid asphalt WM-07 Waste package movement/settling WM-08 Corrosion expansion of metal waste WM-09 Damage to external container WM-10 Corrosion expansion of external container	MM-01 Filling materials' mechanical properties MM-02 Filling materials' stress/deformation MM-04 Fracturing of filling material	SM-01 Structural framework's mechanical properties SM-02 Structural framework's stress/deformation SM-04 Fracturing of structural framework SM-05 Structural framework's movement/settling SM-06 Corrosion expansion of reinforcing steel	BM-01 Buffer materials' mechanical properties BM-02 Buffer materials' stress/deformation BM-03 Swelling of buffer material BM-05 Release from buffer material	XM-01 Secondary devices' mechanical properties XM-02 Secondary devices' stress/ deformation XM-03 Swelling of secondary devices XM-05 Release from secondary devices XM-06 Fracturing of secondary devices XM-07 Corrosion expansion of rock bolts	RM-01 Host rocks' mechanical properties RM-02 Host rocks' stress RM-03 Host rocks' creep
Chemical Phenomena/ Characteristics	WC-01 Waste package's chemical characteristics WC-02 Solute transport in waste packages WC-03 Waste package-groundwater reaction WC-04 Chemical alteration of waste packages (except corrosion) WC-05 Corrosion of waste package WC-06 Effect of organics in waste packages WC-07 Effect of microbes in waste packages WC-08 Effect of colloids in waste packages WC-09 Effect of nitrate in waste packages WC-10 Effect of sulphate in waste packages WC-11 Effect of gas production in waste packages WC-12 Effect of salt accumulation in waste packages	MC-01 Filling materials' chemical characteristics MC-02 Solute transport in filling materials MC-03 Filling materials'-groundwater reaction MC-04 Chemical alteration of filling materials MC-05 Effect of organics in filling materials MC-06 Effect of microbes in filling materials MC-07 Effect of colloids in filling materials MC-08 Effect of nitrate in filling materials MC-09 Effect of sulphate in filling materials MC-10 Effect of gas production in filling materials MC-11 Effect of salt accumulation in filling materials	SC-01 Structural framework's chemical characteristics SC-02 Solute transport in structural framework SC-03 Structural framework-groundater reaction SC-04 Chemical alteration of structural framework SC-05 Effect of organics SC-06 Effect of microbes SC-07 Effect of colloids SC-08 Effect of nitrate SC-09 Effect of sulphate SC-10 Effect of gas production in structural framework SC-11 Effect of salt production in structural framework	BC-01 Buffer materials' chemical characteristics BC-02 Solute transport in buffer materials BC-03 Buffer materials-groundwater reaction BC-04 Chemical alteration of buffer materials BC-05 Effect of organics in buffer materials BC-06 Effect of microbes in buffer materials BC-07 Effect of colloids in buffer materials BC-08 Effect of nitrate in buffer materials BC-09 Effect of sulphate in buffer materials BC-10 Effect of gas production in buffer materials BC-11 Effect of salt accumulation in buffer materials	XC-01 Secondary devices' chemical characteristics XC-02 Solute transport in secondary devices XC-03 Secondary devices-groundwater reaction XC-04 Chemical alteration of secondary devices XC-05 Effect of organics XC-06 Effect of microbes XC-07 Effect of colloids XC-08 Effect of nitrate XC-09 Effect of sulphate XC-10 Effect of gas production in secondary devices	RC-01 Host rocks' chemical characteristics RC-02 Solute transport in host rocks RC-03 Host rocks'-groundwater reaction RC-04 Chemical alteration of host rocks RC-05 Effect of organics in host rocks RC-06 Effect of microbes in host rocks RC-07 Effect of colloids in host rocks RC-08 Effect of nitrate in host rocks RC-09 Effect of sulphate in host rocks RC-10 Effect of gas production in host rocks
Radiological Phenomena/ Characteristics	WR-01 Radionuclide decay/production in the waste package WR-02 Radiolysis of waste package's porewater WR-03 Radiation damage of waste package	MR-01 Radionuclide decay/production in the filling materials MR-02 Radiolysis of the filling materials' porewater MR-03 Radiation damage of filling materials	SR-01 Radionuclide decay/production in the structural framework SR-02 Radiolysis of the structural framwork's porewater SR-03 Radiation damage of structural framework	BR-01 Radionuclide decay/production in buffer materials BR-02 Radiolysis of buffer materials' porewater BR-03 Radiation damage of buffer materials	XR-01 Radionuclide decay/production in secondary devices XR-02 Radiolysis of secondary devices' porewater XR-03 Radiation damage of secondary devices	RR-01 Radionuclide decay/production in host rocks RR-02 Radiolysis of host rocks' porewater RR-03 Radiation damage of host rocks
Nuclide migration Phenomena/ Characteristics	WN-01 Characteristics of mass transport in waste packages WN-02 Nuclide release from porous matrix WN-03 Nuclide release from impermeable matrix WN-04 Nuclide release from the exterior surfaces of waste packages WN-05 Nuclide sorption WN-06 Nuclide precipitation/dissolution WN-07 Nuclide release in colloidal form WN-08 Nuclide release in gaseous form WN-09 Variation in nuclides in form of nitrates	MN-01 Characteristics of mass transport in the filling materials MN-02 Nuclide advection/dispersion MN-03 Nuclide diffusion MN-04 Nuclide sorption MN-05 Nuclide precipitation/dissolution MN-06 Nuclide migration in colloid form MN-07 Nuclide migration in gaseous form MN-08 Variation in nuclides in form of nitrates	SN-01 Characteristics of mass transport in the structural framework SN-02 Nuclide advection/dispersion SN-03 Nuclide diffusion SN-04 Nuclide sorption SN-05 Nuclide precipitation/dissolution SN-06 Nuclide migration in colloid form SN-07 Nuclide migration in gaseous form SN-08 Variation in nuclides in form of nitrates	BN-01 Characteristics of mass transport in the buffer material BN-02 Nuclide advection/dispersion BN-03 Nuclide diffusion BN-04 Nuclide sorption BN-05 Nuclide precipitation/dissolution BN-06 Nuclide migration in colloid form BN-07 Nuclide migration in gaseous form BN-08 Variation in nuclides in form of nitrates	XN-01 Characteristics of mass transport in the secondary devices XN-02 Nuclide advection/dispersion XN-03 Nuclide diffusion XN-04 Nuclide sorption XN-05 Nuclide precipitation/dissolution XN-06 Nuclide migration in colloid form XN-07 Nuclide migration in gaseous form XN-08 Variation in nuclides in form of nitrates	RN-01 Characteristics of mass transport in the host rock RN-02 Nuclide advection/dispersion RN-03 Nuclide diffusion RN-04 Nuclide sorption RN-05 Nuclide precipitation/dissolution RN-06 Nuclide migration in colloid form RN-07 Nuclide migration in gaseous form RN-08 Variation in nuclides in form of nitrates RN-09 Criticality
Phenomena that may potentially disturb the system	WQ-01 Production/manufacturing faults in waste packages	MQ-01 Production/manufacturing faults in filling material	SQ-01 Production/manufacturing faults in structural framework	BQ-01 Production/manufacturing faults in buffer material	XQ-01 Production/manufacturing faults in secondary devices	RQ-01 Failure of boring and tunnel Seals due to deterioration
	NP-01 Earthquake/Active faulting NP-02 Volcanism/Magmatic activity NP-03 Uplift/Subsidence NP-04 Climate/Sealevel change NP-05 Meteorite impact					
	HA-01 Boring (Investigation, exploration, underground applications, public works etc) HA-02 Geological environment (Human activities) HA-03 Drilling/mining/other underground activities (Human intrusion) HA-04 Water well drilling/sampling HA-05 Water management (Water storage/dam)					

APPENDIX I: SR-SITE FEP LIST

Initial State FEPs

FEP ID	FEP name	Description
ISGen01	Major mishaps/accidents/ sabotage	Major mishaps/accidents like fire, explosions, earthquakes and flooding in encapsulation plant, during transport and repository operation. Possible decontamination following severe mishap.
		Ditto sabotage (chemical, physical etc), improper management.
ISGen02	Effects of phased operation	Phased operation mainly affects the geosphere and the subsequent development of the entire repository. The hydrological state of the bedrock is perturbed as soon as repository excavation starts (a smaller perturbation even occurs earlier during site investigations). Different parts of the repository, completed at different times, will be exposed to different hydrological conditions, affecting e.g. the saturation of the buffer and backfill. Possible upconing of saline water could also vary between different parts of repository due to phased operation. Other factors to consider are the effects of blasting and underground traffic on completed parts of the repository. All these issues are part of the expected evolution of the repository, but are not automatically captured in the system of processes describing the repository evolution over time or by the initial state descriptions. As they need to be adequately included in the discussion of the repository evolution, they are propagated to the analysis of the reference evolution.
ISGen03	Incomplete closure	Concerns the effects of an unsealed, abandoned repository.
ISGen04	Monitoring activities	Implications of monitoring activities, including underground monitoring boreholes, on long-term safety.
ISC01	Mishaps – canister	Concerns mishandling and breakage of a canister during manufacturing, sealing, transport and deposition. Random defects are considered, despite quality control in manufacturing and sealing.
		A number of defects may be related by a common cause, despite quality control in manufacturing and sealing.
ISC02	Design deviations – canister	Welding or material defects (geometry, material composition), e.g. loss of ductility due to impurities in the copper material or bad manufacturing methods or "cold cracks" due to bad manufacturing methods. Random defects despite quality control in manufacturing and sealing.
		A number of defects may be related by a common cause, despite quality control in manufacturing and sealing.
ISBu01	Mishaps – buffer	Faulty or deviating buffer emplacement caused by e.g. difficulties due to inflow, problems with remote control handling, etc leading to e.g. inhomogeneous buffer and/or reduced density.
ISBu02	Design deviations – buffer	Deviations in buffer properties despite quality control.
ISBfT01	Mishaps – backfill in tunnels	Faulty or deviating backfill emplacement due to e.g. difficulties due to inflow, etc leading to e.g. inhomogeneous backfill.
ISBfT02	Design deviations – backfill in tunnels	Deviations in backfill properties despite quality control.
ISBP01	Mishaps – bottom plate in deposition holes	Faulty or deviating emplacement of bottom plate in deposition holes.
ISBP02	Design deviations – bottom plate in deposition holes	Deviations in structural material (concrete bottom plate) properties despite quality control.
ISPg01	Mishaps – plugs	Faulty or deviating emplacement of plugs.
ISPg02	Design deviations – plugs	Deviations in plug properties despite quality control.
ISCA01	Mishaps – central area	Faulty or deviating backfill emplacement in central area due to e.g. difficulties due to inflow, etc leading to e.g. inhomogeneous backfill.
ISCA02	Design deviations – central area	Deviations in central area backfill properties despite quality control.
ISTS01	Mishaps/Design deviations – top seal	Faulty or deviating top seal emplacement leading to e.g. inhomogeneity and deviations in top seal properties despite quality control.
ISBhS01	Mishaps/Design deviations – borehole seals	Faulty or deviating emplacement of borehole seals and deviations in properties despite quality control.

Process FEPs: Fuel

SR-Site FEP ID	SR-Site FEP name
F01	Radioactive decay
F02	Radiation attenuation/heat generation
F03	Induced fission (criticality)
F04	Heat transport
F05	Water and gas transport in canister cavity, boiling/condensation
F06	Mechanical cladding failure
F07	Structural evolution of fuel matrix
F08	Advection and diffusion
F09	Residual gas radiolysis/ acid formation
F10	Water radiolysis
F11	Metal corrosion
F12	Fuel dissolution
F13	Dissolution of gap inventory
F14	Speciation of radionuclides, colloid formation
F15	Helium production
F16	Chemical alteration of the fuel matrix
F17	Radionuclide transport

Process FEPs: Canister

SR-Site FEP ID	SR-Site FEP name
C01	Radiation attenuation/ heat generation
C02	Heat transport
C03	Deformation of cast iron insert
C04	Deformation of copper canister from external pressure
C05	Thermal expansion (both cast iron insert and copper canister)
C06	Copper deformation from internal corrosion products
C07	Radiation effects
C08	Corrosion of cast iron insert
C09	Galvanic corrosion
C10	Stress corrosion cracking of cast iron insert
C11	Corrosion of copper canister
C12	Stress corrosion cracking of the copper canister
C13	Earth currents – stray current corrosion
C14	Deposition of salts on canister surface
C15	Radionuclide transport

Process FEPs: Buffer

SR-Site FEP ID	SR-Site FEP name
Bu01	Radiation attenuation/ heat generation
Bu02	Heat transport
Bu03	Freezing
Bu04	Water uptake and transport for unsaturated conditions
Bu05	Water transport for saturated conditions
Bu06	Gas transport/dissolution
Bu07	Piping/erosion
Bu08	Swelling/mass redistribution
Bu09	Liquefaction
Bu10	Advective transport of species
Bu11	Diffusive transport of species
Bu12	Sorption (including exchange of major ions)
Bu13	Alterations of impurities
Bu14	Aqueous speciation and reactions
Bu15	Osmosis
Bu16	Montmorillonite transformation
Bu17	Iron-bentonite interaction
Bu18	Montmorillonite colloid release
Bu19	Radiation-induced transformations
Bu20	Radiolysis of porewater
Bu21	Microbial processes
Bu22	Cementation
Bu23	Colloid transport
Bu24	Speciation of radionuclides
Bu25	Transport of radionuclides in the water phase
Bu26	Transport of radionuclides in a gas phase

Process FEPs: Backfill

SR-Site FEP ID	SR-Site FEP name
BfT01	Heat transport
BfT02	Freezing
BfT03	Water uptake and transport for unsaturated conditions
BfT04	Water transport for saturated conditions
BfT05	Gas transport/dissolution
BfT06	Piping/erosion
BfT07	Swelling/mass redistribution
BfT08	Liquefaction
BfT09	Advective transport of species
BfT10	Diffusive transport of species
BfT11	Sorption (including exchange of major ions)
BfT12	Alterations of backfill impurities
BfT13	Aqueous speciation and reactions
BfT14	Osmosis
BfT15	Montmorillonite transformation
BfT16	Backfill colloid release
BfT17	Radiation-induced transformations
BfT18	Microbial processes
BfT19	Colloid formation and transport
BfT20	Speciation of radionuclides
BfT21	Transport of radionuclides in the water phase
BfT22	Transport of radionuclides by a gas phase

Process FEPs: Tunnel Plugs, Ventral Area, Top Seal, Bottom Plate in Disposition Holes and Borehole Seals

SR-Site FEP ID	SR-Site FEP name
BP01, Pg01, CA01, TS01, BhS01	Heat transport
BP02, Pg02, CA02, TS02, BhS02	Freezing
BP03, Pg03, CA03, TS03, BhS03	Water uptake and transport under unsaturated conditions
BP04, Pg04, CA04, TS04, BhS04	Water transport under saturated conditions
BP05, Pg05, CA05, TS05, BhS05	Gas transport/dissolution
BP06, Pg06, CA06, TS06, BhS06	Piping/erosion
BP07, Pg07, CA07, TS07, BhS07	Swelling/mass redistribution
Pg08, CA08, TS08, BhS08	Liquefaction
BP08, Pg09, CA09, TS09, BhS09	Advective transport of species
BP09, Pg10, CA10, TS10, BhS10	Diffusive transport of species
BP10, Pg11, TS11, BhS11	Sorption (including exchange of major ions)
CA11	Sorption
CA12	Alteration of central area backfill
BP11, Pg12, TS12, BhS12	Alteration of concrete
CA15	Alteration of concrete components
BP12, Pg13, CA13, TS13, BhS13	Aqueous speciation and reactions
BP13, BhS14	Copper corrosion
BhS15	Alterations of impurities in bentonite
Pg14, CA14, BhS16	Osmosis
Pg15, BhS17	Montmorillonite transformation
Pg16, BhS18	Montmorillonite colloid release
TS14	Colloid release
TS15	Steel corrosion
CA16	Corrosion of steel components
BP14, Pg17, CA17, TS16, BhS19	Microbial processes
BP15, Pg18, CA18, TS17, BhS21	Speciation of radionuclides
BP16, Pg19, CA19, TS18, BhS22	Transport of radionuclides in the water phase

Process FEPs: Geosphere

SR-Site FEP ID	SR-Site FEP name
Ge01	Heat transport
Ge02	Freezing
Ge03	Groundwater flow
Ge04	Gas flow/dissolution
Ge05	Displacements in intact rock
Ge06	Reactivation – Displacement along existing discontinuities
Ge07	Fracturing
Ge08	Creep
Ge09	Surface weathering and erosion
Ge10	Erosion/sedimentation in fractures
Ge11	Advective transport/mixing of dissolved species
Ge12	Diffusive transport of dissolved species in fractures and rock matrix
Ge13	Speciation and sorption
Ge14	Reactions groundwater/rock matrix
Ge15	Dissolution/precipitation of fracture-filling minerals
Ge16	Microbial processes
Ge17	Degradation of grout
Ge18	Colloidal processes
Ge19	Formation/dissolution/reaction of gaseous species
Ge20	Methane hydrate formation
Ge21	Salt exclusion
Ge22	Radiation effects (rock and grout)
Ge23	Earth currents
Ge24	Transport of radionuclides in the water phase
Ge25	Transport of radionuclides in the gas phase

Variable FEPs: Fuel

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarF01	Radiation intensity	Intensity of alpha, beta, gamma and neutron radiation as a function of time and space in the fuel assembly.
VarF02	Temperature	Temperature as a function of time and space in the fuel assembly.
VarF03	Hydrovariables (pressure and flow)	Flows, volumes and pressures of water and gas as a function of time and space in the cavities in the fuel and the canister.
VarF04	Fuel geometry	Geometric dimensions of all components of the fuel assembly, such as fuel pellets and Zircaloy cladding. Also includes the detailed geometry, including cracking, of the fuel pellets.
VarF05	Mechanical stresses	Mechanical stresses as a function of time and space in the fuel assembly.
VarF06	Radionuclide inventory	Occurrence of radionuclides as a function of time and space in the different parts of the fuel assembly. The distribution of the radionuclides in the pellets between matrix and surface is also described here.
VarF07	Material composition	The materials of which the different components in the fuel assembly are composed, excluding radionuclides.
VarF08	Water composition	Composition of water (including any radionuclides and dissolved gases) in the fuel and canister cavities.
VarF09	Gas composition	Composition of gas (including any radionuclides) in the fuel and canister cavities.

Variable FEPs: Canister

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarC01	Radiation intensity	Intensity of gamma and neutron radiation as a function of time and space in the cast iron insert and copper canister.
VarC02	Temperature	Temperature as a function of time and space in the cast iron insert and copper canister.
VarC03	Canister geometry	Geometric dimensions of all components of the cast iron insert and copper canister.
VarC04	Material composition	The detailed chemical composition of the materials used for the cast iron insert and copper canister. This also includes cast iron and copper corrosion products.
VarC05	Mechanical stresses	Mechanical stresses as a function of time and space in the cast iron insert and copper canister.

Variable FEPs: Buffer

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarBu01	Radiation intensity	Intensity of (α-, β-), γ- and neutron radiation as a function of time and space in buffer.
VarBu02	Temperature	Temperature as a function of time and space in buffer.
VarBu03	Water content	Water content as a function of time and space in buffer.
VarBu04	Gas content	Gas contents (including any radionuclides) as a function of time and space in buffer.
VarBu05	Hydrovariables (pressure and flow)	Flows and pressures of water and gas as a function of time and space in buffer.
VarBu06	Buffer geometry	Geometric dimensions for buffer. An example is description of interfaces (on the inside towards the canister and on the outside towards the geosphere).
VarBu07	Pore geometry	Pore geometry as a function of time and space in buffer. The porosity, i.e. the fraction of the volume that is not occupied by solid material, is often given.
VarBu08	Stress state	Stress conditions as a function of time and space in buffer.
VarBu09	Bentonite composition	Chemical composition of the bentonite (including any radionuclides) in time and space in buffer, levels of impurities in time and space in buffer.
VarBu10	Montmorillonite composition	The mean molecular structure of montmorillonite including the type of charge compensating cations.
VarBu11	Porewater composition	Composition of the porewater (including any radionuclides and dissolved gases) in time and space in the buffer.
VarBu12	Structural and stray materials	Chemical composition and quantity of any stray materials accidently left in the buffer. At this stage, no structural materials are defined for this component.

Variable FEPs: Backfill

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarBfT01	Temperature	Temperature as a function of time and space in deposition tunnels.
VarBfT02	Water content	Water content as a function of time and space in deposition tunnels.
VarBfT03	Gas content	Gas content (including any radionuclides) as a function of time and space in deposition tunnels.
VarBfT04	Hydrovariables (pressure and flow)	Flows and pressures of water and gas as a function of time and space in deposition tunnels.
VarBfT05	Backfill geometry	Geometric dimensions for backfill. A description of e.g. interfaces towards buffer and towards the geosphere.
VarBfT06	Backfill pore geometry	Pore geometry as a function of time and space in backfill. The porosity, i.e. the fraction of the volume that is not occupied by solid material, is often given.
VarBfT07	Stress state	Stress state as a function of time and space in backfill.
VarBfT08	Backfill materials – composition and content	Total chemical composition and content of the backfill material (including any radionuclides) in time and space.
VarBfT09	Backfill porewater composition	Composition of the porewater (including any radionuclides and dissolved gases) in time and space in backfill.
VarBfT10	Structural and stray materials	Chemical composition and quantity of structural materials (rock bolts, filling material in boreholes for grouting, nets etc) and stray materials in deposition tunnels.

Variable FEPs: Bottom Plate

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarBP01	Temperature	Temperature as a function of time and space in the bottom plate.
VarBP02	Bottom plate water content	Water content as a function of time and space in the bottom plate.
VarBP03	Bottom plate gas content	Gas content as a function of time and space in the bottom plate.
VarBP04	Hydrovariables (pressure and flow)	Flows and pressures of water and gas as a function of time and space in the bottom plate.
VarBP05	Bottom plate geometry	Geometric dimensions of the bottom plate.
VarBP06	Bottom plate pore geometry	Pore geometry as a function of time and space in the plate components. The porosity, i.e. the fraction of the volume that is not occupied by solid material, is often given.
VarBP07	Stress state	Stress conditions as a function of time and space in the bottom plate.
VarBP08	Bottom plate materials – composition and content	Composition of the concrete plate and the copper plate.
VarBP09	Bottom plate porewater composition	Composition of the porewater in time and space in the bottom plate.
VarBP10	Structural and stray materials	(undefined) The structural materials in the bottom plate are already included in the "Bottom plate materials – composition and content" variable – stray materials are assumed to be of no concern since no long-term performance is expected from the bottom plate.

Variable FEPs: Plugs

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarPg01	Temperature	Temperature as a function of time and space in the plug.
VarPg02	Water content	Water content as a function of time and space in the plug.
VarPg03	Gas content	Gas content as a function of time and space in the components.
VarPg04	Hydrovariables (pressure and flow)	Flows and pressures of water and gas as a function of time and space in the plug.
VarPg05	Plug geometry	Geometric dimensions of the plug.
VarPg06	Plug pore geometry	Pore geometry as a function of time and space in the components. The porosity, i.e. the fraction of the volume that is not occupied by solid material, is often given.
VarPg07	Stress state	Stress conditions as a function of time and space in the plug.
VarPg08	Plug materials – composition and content	Composition of the concrete plug, the concrete beams, the bentonite, the drainage and the filter material in space and time.
VarPg09	Plug porewater composition	Composition of the porewater in time and space in the plug.
VarPg10	Structural and stray materials	(undefined) The structural materials in the plug are already included in the "Plug materials – composition and content" variable – stray materials are assumed to be of no concern since no long-term performance is expected from the plug.

Variable FEPs: Central Area

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarCA01	Temperature	Temperature as a function of time and space in the component.
VarCA02	Water content	Water content as a function of time and space in the component.
VarCA03	Gas content	Gas content as a function of time and space in the component.
VarCA04	Hydrovariables (pressure and flow)	Flows and pressures of water and gas as a function of time and space in the component.
VarCA05	Central area geometry	Geometric dimensions of the component.
VarCA06	Central area pore geometry	Pore geometry as a function of time and space in the component. The porosity, i.e. the fraction of the volume that is not occupied by solid material, is often given.
VarCA07	Stress state	Stress conditions as a function of time and space in the component.
VarCA08	Central area materials – composition and content	Composition of the crushed rock in time and space in the component.
VarCA09	Central area porewater composition	Composition of the porewater in time and space in the component.
VarCA10	Structural and stray materials	Composition and quantity of construction, reinforcements and stray materials in the component as a function of time and space.

Variable FEPs: Top Seal

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarTS01	Temperature	Temperature as a function of time and space in the component.
VarTS02	Water content	Water content as a function of time and space in the component.
VarTS03	Gas content	Gas content as a function of time and space in the component.
VarTS04	Hydrovariables (pressure and flow)	Flows and pressures of water and gas as a function of time and space in the component.
VarTS05	Top seal geometry	Geometric dimensions of the component.
VarTS06	Top seal pore geometry	Pore geometry as a function of time and space in the components. The porosity, i.e. the fraction of the volume that is not occupied by solid material, is often given.
VarTS07	Stress state	Stress conditions as a function of time and space in the component.
VarTS08	Top seal materials – composition and content	Composition of the crushed rock in time and space in the component.
VarTS09	Top seal porewater composition	Composition of the porewater in time and space in the component.
VarTS10	Structural and stray materials	Composition and quantity of construction, reinforcements and stray materials in the component as a function of time and space.

Variable FEPs: Borehole Seals

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarBhS01	Temperature	Temperature as a function of time and space in the components.
VarBhS02	Water content	Water content as a function of time and space in the components.
VarBhS03	Gas content	Gas content as a function of time and space in the components.
VarBhS04	Hydrovariables (pressure and flow)	Flows and pressures of water and gas as a function of time and space in the component.
VarBhS05	Borehole geometry	Geometric dimensions of the components.
VarBhS06	Pore geometry	Pore geometry as a function of time and space in the component. The porosity, i.e. the fraction of the volume that is not occupied by solid material, is often given.
VarBhS07	Stress state	Stress conditions as a function of time and space in the component.
VarBhS08	Sealing materials – composition and content	Composition of the bentonite and the concrete in time and space in the component.
VarBhS09	Porewater composition	Composition of the porewater in time and space in the component.
VarBhS10	Structural and stray materials	Composition and quantity of construction, reinforcements and stray materials in the components as a function of time and space. This includes the copper tube, the till, rock cylinders and the anchor materials.

Variable FEPs: Geosphere

SR-Site FEP ID	SR-Site FEP name	SR-Site definition
VarGe01	Temperature	Temperature in the bedrock as a function of time and space.
VarGe02	Groundwater flow	Groundwater flow as a function of time and space in the geosphere's fracture system.
VarGe03	Groundwater pressure	Groundwater pressure as a function of time and space in the geosphere's fracture system.
VarGe04	Gas phase flow	Gas phase flow as a function of time and space in the geosphere's fracture system.
VarGe05	Repository geometry	Geometric description of deposition holes, tunnels, ramps, boreholes etc; i.e. of all excavated volumes.
VarGe06	Fracture geometry	All cavities, from fracture zones to micropores in the matrix. Also included here is the excavation-disturbed zone (EDZ) and any other geometric changes in the fracture structure induced by construction.
VarGe07	Rock stresses	Rock stresses as a function of time and space.
VarGe08	Matrix minerals	Chemical composition of the rock matrix as a function of (time and) space, i.e. a description of the various minerals that occur and their extent.
VarGe09	Fracture minerals	Chemical composition of the fracture minerals as a function of time and space, i.e. a description of the various fracture-filling minerals that occur. Also the amount and composition of these fracture-filling minerals.
VarGe10	Groundwater composition	Chemical composition of the groundwater as a function of time and space, i.e. concentrations of relevant components in the groundwater. This variable also includes quantities such as Eh and pH, as well as any radionuclides and dissolved gases.
VarGe11	Gas composition	Chemical composition of gases, including any radionuclides and naturally occurring gases, in geosphere cavities.
VarGe12	Structural and stray materials	Chemical composition and quantities of grouts and other structural and stray materials injected/located in fractures in the rock and left there at repository closure.
VarGe13	Saturation	Degree of water saturation of the geosphere

Biosphere Process FEPs

SR-Site FEP ID	SR-Site FEP name
Bio01	Bioturbation
Bio02	Consumption
Bio03	Death
Bio04	Decomposition
Bio05	Excretion
Bio06	Food supply
Bio07	Growth
Bio08	Habitat supply
Bio09	Intrusion
Bio10	Material supply
Bio11	Movement
Bio12	Particle release/trapping
Bio13	Primary production
Bio14	Stimulation/inhibition
Bio15	Uptake
Bio16	Anthropogenic release
Bio17	Material use
Bio18	Species introduction/extermination
Bio19	Water use
Bio20	Change of pressure
Bio21	Consolidation
Bio22	Element supply
Bio23	Loading
Bio24	Phase transitions
Bio25	Physical properties change
Bio26	Reactions
Bio27	Sorption/desorption
Bio28	Water supply
Bio29	Weathering
Bio30	Wind stress
Bio31	Acceleration
Bio32	Convection
Bio33	Covering
Bio34	Deposition
Bio35	Export
Bio36	Import
Bio37	Interception
Bio38	Relocation
Bio39	Resuspension
Bio40	Saturation
Bio41	Decay
Bio42	Exposure
Bio43	Heat storage
Bio44	Irradiation
Bio45	Light-related processes
Bio46	Radiolysis
Bio47	Radionuclide release
Bio48	Change in rock surface location
Bio49	Sea level change
Bio50	Terrestrialisation
Bio51	Thresholding

Biosphere Component FEPs

SR-Site FEP ID	SR-Site FEP name
CompBio01	Geosphere[1]
CompBio02	Regolith
CompBio03	Primary producers
CompBio04	Decomposers
CompBio05	Filter feeders
CompBio06	Herbivores
CompBio07	Carnivores
CompBio08	Humans
CompBio09	Water in regolith
CompBio10	Surface water
CompBio11	Water composition
CompBio12	Gas and local atmosphere
CompBio13	Temperature
CompBio14	Radionuclides
CompBio15	External conditions[1]

External FEPs: Climate

SR-Site FEP ID	SR-Site FEP name
Cli01	Climate system – Components of the climate system
Cli02	Climate system – Climate forcing
Cli03	Climate system – Climate dynamics
Cli04	Climate system – Climate in Sweden and Forsmark
Cli05	Climate related issues – Development of permafrost
Cli06	Climate related issues – Ice-sheet dynamics
Cli07	Climate related issues – Ice–sheet hydrology
Cli08	Climate related issues – Glacial isostatic adjustment
Cli09	Climate related issues – Shoreline migration
Cli10	Climate related issues – End-glacial faulting
Cli11	Climate related issues – Denudation

External FEPs: Geology

SR-Site FEP ID	SR-Site FEP name
LSGe01	Mechanical evolution of the Shield
LSGe02	Earthquakes

External FEPs: Future Human Actions

SR-Site FEP ID	SR-Site FEP name
FHA01	General considerations
FHA02	Societal analysis, considered societal aspects
FHA03	Technical analysis, general aspects
FHA04	Technical analysis, actions with thermal impact and purpose
FHA05	Technical analysis, actions with hydraulic impact and purpose
FHA06	Technical analysis, actions with mechanical impact and purpose
FHA07	Technical analysis, actions with chemical impact and purpose

External FEPs: Other

SR-Site FEP ID	SR-Site FEP name
Oth01	Meteorite impact

Site-specific Factors

SR-Site FEP ID	SR-Site FEP name
SiteFact02	Construction of nearby rock facilities
SiteFact03	Nearby nuclear power plant
SiteFact04	Mine excavation

Methodological Issues

SR-Site FEP ID	SR-Site FEP name
Meth01	Assessment basis
Meth02	Assessment methodology

APPENDIX J: NAGRA'S PROCESSES AND PARAMETERS

Table J.1: Derivation of Relevant Processes and Parameters from the Safety Functions and Principles

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-relevant properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
I S1 Physical separation of waste from the human environment ("isolation") S2 Ensuring the necessary long-term stability of the barrier system	B1 Configuration of storage chambers deep underground	E1 Physical separation of waste from the human environment E2 Protecting the repository from processes and events on the Earth's surface during the period under consideration (e.g. erosion)	Uplift, large-scale erosion and glacial erosion (reduction in the rock coverage, but without exposing the storage chambers within the period under consideration[1)]): ***Depth below ground level with respect to denudation*** (PG-1) ***Glacially over-deepened valleys*** (PG-2) ***Development of regional erosion basis over time (PG-4)*** Climate change and long-term geomorphological changes in the Earth's surface: ***Changes in the local topography over time with respect to long-term geological developments*** (PG-28, levelling) ***Climate change with respect to long-term geological developments*** (PG-30, different phases in climate change)	'Depth below ground level with respect to surface erosion' 'Depth below rock surface with respect to glacial erosion' 'Large-scale erosion during the period under consideration'	2.2 Erosion

1) The period under consideration was defined as part of the safety studies in SGT Stage 1. This amounted to 100 000 years for the L/ILW

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
I S1 Physical separation of waste from the human environment ("isolation") S2 Ensuring the necessary long-term stability of the barrier system	B2 Geological situation	E3 Stability of the site and rock properties E4 Protection from inadmissible erosion	Neotectonic activity and rock behaviour over long periods; differential movements of the rock mass (shearing, reactivation of fractures and fault zones), rare geological events (volcanism, fracture formation due to major earthquakes, etc), self-sealing, formation of new water pathways due to karstification: *Geodynamic and neotectonic activity* (PI-2, Frequency and properties of reactivatable fault zones, extension of fault zones in the lateral and vertical direction, seismicity) *Volcanic activity* (PI-3) *Self-sealing capacity* (PI-6) ***Position and properties of rocks prone to karstification within the host rock (***PG-12)	'Geodynamic and neotectonic model concepts' 'Seismicity' 'Rare geological events (volcanism)' 'Self-sealing capacity' 'Potential to form new water pathways (karstification)'	2.1 Stability of the site and rock properties

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
I S1 Physical separation of waste from the human environment ("isolation") S2 Ensuring the necessary long-term stability of the barrier system	B2 Geological situation	E3 Stability of the site and rock properties E4 Protection from inadmissible erosion	Uplift, large-scale erosion and glacial erosion (reduction in the rock coverage, but without exposing the storage chambers within the period under consideration): ***Depth below ground level with respect to denudation*** (PG-1) ***Glacially over-deepened valleys*** (PG-2) ***Development of regional erosion basis over time*** (PG-4) Climate change and long-term geomorphological changes in the Earth's surface: ***Changes in the local topography over time with respect to long-term geological developments*** (PG-28, levelling) ***Climate change with respect to long-term geological developments*** (PG-30, different phases in climate change)	'Depth below ground level with respect to surface erosion' 'Depth below rock surface with respect to glacial erosion' 'Large-scale erosion during the period under consideration'	2.2 Erosion

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
I S1 Physical separation of waste from the human environment ("isolation") S2 Ensuring the necessary long-term stability of the barrier system	B2 Geological situation	E5 Low probability of human penetration thanks to absence of foreseeable resource conflicts	Resource conflicts; impairment of the barrier system (damage to formations, drilling into storage chambers[2]): *Use of the rock as a raw material (*PI-1) *Resource conflicts with respect to raw material deposits beneath the host rock (*PG-32) *Resource conflicts with respect to raw material deposits above the host rock* [3] *(PG-33)* ***Resource conflicts with respect to mineral and thermal springs (***PB-10) *Resource conflicts with respect to geothermal sources (PG-34)*	'Resource deposits within the host rock' 'Resource deposits beneath the host rock' 'Resource deposits above the host rock' 'Mineral and thermal springs' 'Geothermal sources'	2.4 Resource conflicts
II S3 Radionuclide containment ("containment")	B3 Final storage containers B4 Additional engineered barriers	E6 Corrosion resistance	Corrosion of final storage containers (steel, alternative materials): ***pH*** (PG-16) ***Redox conditions (***PG-17) ***Salinity (***PG-18) **Canister lifetime SF/HLW** (PT-1)	'Redox conditions' 'Salinity' 'pH'	1.3 Geochemical conditions

2) According to the ENSI specifications, human penetration into a deep geological repository can be ruled out in the quantitative safety analysis in Stage 2. However, resource conflicts should be taken into account in the qualitative assessment of sites and the possibility of human penetration into a deep geological repository is still considered in subsequent analyses.

3) The possibility of rock quarrying may lead to changes in the overlying formations and stress field and may in extreme cases lead to rock decompaction. This was not taken into consideration in the test calculations.

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
II S3 Radionuclide containment ("containment")	B3 Final storage containers B4 Additional engineered barriers	E7 Geometric conditions (lateral extension and thickness or space available in consideration of the deep location and geological elements defining the boundaries of the siting region) E8 Geomechanical conditions	Spatial extent of the host rock: ***Depth below ground level with respect to engineering feasibility (***PB-1) ***Depth below ground level with respect to denudation*** (PG-1) ***Glacially over-deepened valleys*** (PG-2) ***Depth below ground level with respect to rock decompaction*** (PG-3) ***Thickness*** (PG-5) ***Geological elements defining the boundaries of the siting region*** (PB-2) ***Geological elements determining the configuration of the repository*** (PB-3) ***Space available underground*** (PB-4) Geomechanical loads on the final storage containers due to ground stresses and neotectonic activity / differential movements in the vicinity of the deep repository (effects minimised by avoiding geological elements defining the boundaries of the siting region): ***Depth below ground level with respect to engineering feasibility*** (PB-1) ***In-situ rock stresses*** (PB-6) **Canister lifetime SF/HLW** (PT-1)	'Thickness' 'Space available underground' 'Depth below ground level with respect to engineering feasibility' 'Depth below ground level with respect to surface erosion' 'Depth below ground level with respect to rock decompaction' 'Depth below rock surface with respect to glacial erosion'	1.1 Spatial extent

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
II S3 Radionuclide containment ("containment")	B3 Final storage containers B4 Additional engineered barriers	E7 Geometric conditions (lateral extension and thickness or space available in consideration of the deep location and geological elements defining the boundaries of the siting region) E8 Geomechanical conditions	Accelerated degradation of technical barriers due to uplift/erosion (rock decompaction, but no denudation of the storage chambers within the period under consideration): ***Depth below ground level with respect to denudation*** (PG-1) ***Glacially over-deepened valleys*** (PG-2) ***Development of regional erosion basis over time*** (PG-4) ***Changes in the local topography over time with respect to long-term geological developments*** (PG-28, levelling) ***Climate change with respect to long-term geological developments*** (PG-30, different phases in climate change) **Canister lifetime SF/HLW** (PT-1)	'Depth below ground level with respect to surface erosion' 'Depth below rock surface with respect to glacial erosion' 'Large-scale erosion during the period under consideration'	2.2 Erosion
			Resource conflicts; impairment of the barrier system (damage to formations, drilling into storage chambers): *Use of the rock as a raw material* (PI-1) *Resource conflicts with respect to raw material deposits beneath the host rock* (PG-32) *Resource conflicts with respect to raw material deposits above the host rock* (PG-33) ***Resource conflicts with respect to mineral and thermal springs*** (PB-10) *Resource conflicts with respect to geothermal sources* (PG-34)	'Resource deposits within the host rock' 'Resource deposits beneath the host rock' 'Resource deposits above the host rock' 'Mineral and thermal springs' 'Geothermal sources'	2.4 Resource conflicts

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
II S3 Radionuclide containment ("containment")	B3 Final storage containers B4 Additional engineered barriers	E7 Geometric conditions (lateral extension and thickness or space available in consideration of the deep location and geological elements defining the boundaries of the siting regions) E8 Geomechanical conditions	Technical feasibility (construction, operation, monitoring, sealing, waste recovery): ***Depth below ground level with respect to engineering feasibility*** (PB-1) ***Rock strength and deformation properties of the host rock*** (PB-7) ***In-situ rock stresses*** (PB-6)	'Depth below ground level with respect to engineering feasibility' 'Rock strength and deformation properties'	4.1 Rock mechanical properties and conditions
III S4 Delayed release of radionuclides ("delayed release")	B5 Waste matrix	E9 Corrosion resistance (Eh, pH), particularly after container failure	Corrosion of the waste matrix and cladding (corrosion rates): ***pH*** (PG-16) ***Redox conditions*** (PG-17) ***Salinity*** (PG-18) **Dissolution rate for fuel matrix and cladding** (PT-2)	'Redox conditions' 'Salinity' 'pH'	1.3 Geochemical conditions
		E10 Stability of the waste matrix thanks to low water flow	Corrosion of the waste matrix and cladding (corrosion rates): ***Depth below ground level with respect to rock decompaction*** (PG-3) ***Large-scale hydraulic conductivity*** (PG-6) ***Impact of decompaction on hydraulic conductivity (***PG-7) ***Hydraulic gradient*** (PG-8)	'Hydraulic conductivity' 'Depth below ground level with respect to rock decompaction'	1.2 Hydraulic barrier efficiency

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
IV S5 Radionuclide retention in the near field and in the geosphere ("retention") S6 Low release rates	B3 Final storage containers	E11 Retention by damaged containers (corrosion products)	Radionuclide sorption by container corrosion products (sorption coefficient): ***pH*** (PG-16) ***Redox conditions*** (PG-17) ***Salinity*** (PG-18) **Sorption coefficients in the near field** (PT-4)	'Redox conditions' 'Salinity' 'pH'	1.3 Geochemical conditions
	B6 Backfill B7 Backfill & sealing	E12 Stability of backfill and sealing materials (low water flow in the host rock, geochemical conditions) E13 Retention thanks to favourable transport properties (low water flow in the host rock, solubility limitation, sorption, diffusion, colloid filter)	Changes in the backfill and sealing materials over time (in particular chemical degradation due to mineral dissolution/conversion/precipitation): **Transport-relevant properties at the interface between SF/HLW emplacement tunnels/host rock** (PT-6, hydraulic conductivity, sorption and diffusion coefficients) ***Depth below ground level with respect to rock decompaction*** (PG-3) **Advection or diffusion in the near field** (PT-5) ***Large-scale hydraulic conductivity*** (PG-6) ***Impact of decompaction on hydraulic conductivity*** (PG-7) ***Hydraulic gradient*** (PG-8)	'Hydraulic conductivity' 'Depth below ground level with respect to rock decompaction'	1.2 Hydraulic barrier efficiency

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
IV S5 Radionuclide retention in the near field and in the geosphere ("retention") S6 Low release rates	B6 Backfill B7 Backfill & sealing	E12 Stability of backfill and sealing materials (low water flow in the host rock, geochemical conditions) E13 Retention thanks to favourable transport properties (low water flow in the host rock, solubility limitation, sorption, diffusion, colloid filter)	Radionuclide retention in backfill and sealing materials due to solubility limitation, sorption, diffusion-dominated transport and colloid filtration: ***pH*** (PG-16) ***Redox conditions*** (PG-17) ***Salinity*** (PG-18) **Solubility limits in the near field SF/HLW/ILW** (PT-3) **Sorption coefficients in the near field** (PT-4, in consideration of degradation) **Advection and diffusion in the near field** (PT-5)	'Redox conditions' 'Salinity' 'pH'	1.3 Geochemical conditions

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
IV S5 Radionuclide retention in the near field and in the geosphere ("retention") S6 Low release rates	B8 Host rock (HR) or effective containment zone (ECZ)	E14 Retention (sorption, influenced by mineralogy, Eh, pH, salinity, microbial processes; influence of colloids)	Radionuclide retention in the host rock or effective containment zone due to sorption and colloid filtration: ***Mineralogy*** (PG-15) ***pH*** (PG-16) ***Redox conditions*** (PG-17) ***Salinity*** (PG-18) ***Microbial processes*** (PG-19) ***Colloid filtration*** (PG-20) ***Sorption coefficients for HR/ECZ*** (PG-21, in consideration of geochemical conditions)	'Mineralogy' 'pH' 'Redox conditions' 'Salinity' 'Microbial processes' 'Colloids'	1.3 Geochemical conditions

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
IV S5 Radionuclide retention in the near field and in the geosphere ("retention") S6 Low release rates	B8 Host rock (HR) or effective containment zone (ECZ)	E15 Transport properties (low water flow, prevailing transport processes (advection, diffusion), type and length of release pathways)	Radionuclide transport due to advection/diffusion in the host rock or effective containment zone: ***Large-scale hydraulic conductivity*** *(*PG-6) ***Impact of decompaction on hydraulic conductivity*** *(PG-7)* ***Depth below ground level with respect to rock decompaction*** (PG-3) ***Hydraulic gradient*** (PG-8) ***Porosity*** (PG-10) ***Diffusion coefficients for HR/ECZ*** (PG-22, in consideration of accessible porosity) *Independent evidence of long-term isolation* (PI-4)	'Hydraulic conductivity' 'Depth below ground level with respect to rock decompaction' 'Multi-aquifer structure' 'Independent evidence of long-term isolation'	1.2 Hydraulic barrier efficiency

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
IV S5 Radionuclide retention in the near field and in the geosphere ("retention") S6 Low release rates	B8 Host rock or effective containment zone	E15 Transport properties (low water flow, prevailing transport processes (advection, diffusion), type and length of release pathways)	Radionuclide transport due to advection/diffusion in preferential release pathways and matrix diffusion in the adjacent rock matrix: ***Type of transport pathways*** *(PG-9, equivalent porous medium vs.* fracture network, channelling, matrix diffusion) ***Porosity*** (PG-10) ***Sedimentary architectural elements*** (PG-11) ***Length of transport pathways*** (PG-13, incl. lateral transport pathway elements) ***Transmissivity of fracture zones*** (PG-14) in consideration of the clay content or self-sealing capacity) *Self-sealing capacity* (PI-6)	'Type of transport pathways and structure of pore space' 'Homogeneity of the rock structure' 'Length of release pathways' 'Transmissivity of preferential release pathways' 'Self-sealing capacity'	1.4 Release pathways

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
IV S5 Radionuclide retention in the near field and in the geosphere ("retention") S6 Low release rates	B8 Host rock or effective containment zone	E16 Spatial extent of host rock or effective containment zone	Technical feasibility, influenced by lateral extension, thickness and the space available underground (in consideration of the deep location and geological elements defining the boundaries of the siting region): ***Depth below ground level with respect to engineering feasibility*** (PB-1) ***Depth below ground level with respect to denudation*** (PG-1) ***Glacially over-deepened valleys*** (PG-2) ***Depth below ground level with respect to rock decompaction*** (PG-3) ***Thickness*** (PG-5) ***Geological elements defining the boundaries of the siting region*** (PB-2) ***Geological elements determining the configuration of the repository*** (PB-3) ***Space available underground*** (PB-4)	'Thickness' 'Space available underground' 'Depth below ground level with respect to engineering feasibility' 'Depth below ground level with respect to surface erosion' 'Depth below ground level with respect to rock decompaction' 'Depth below rock surface with respect to glacial erosion'	1.1 Spatial extent

Safety function (S), principle (P)	Relevant elements of the barrier system (B)	Safety-related properties (E)	**Relevant processes and parameters** in context and explanations	Indicators for qualitative assessment	Criteria assigned as per SGT
IV S5 Radionuclide retention in the near field and in the geosphere ("retention") S6 Low release rates	B8 Host rock or effective containment zone	E17 Minor repository-induced effects (no short-circuits, minimal adverse impact on the barrier effect of the host rock or effective containment zone)	Repository-induced effects on radionuclide transport: Formation of a disturbed zone in the vicinity of underground excavations, chemical interactions (especially pH plumes), gas formation / transport and gas-induced radionuclide transport, thermal processes (in consideration of self-sealing capacity in each case): ***Excavation disturbed zone in the vicinity of underground excavations*** (PG-23) ***Effects of pH plume on the host rock*** (PG-24) ***Behaviour of the host rock with respect to gas*** (PG-25) ***Behaviour of the host rock with respect to temperature*** (PG-26) ***In-situ temperature*** (PB-5) *Self-sealing capacity* (PI-6)	'Excavation disturbed zone in the vicinity of underground excavations' 'Chemical interactions' 'Behaviour of the host rock with respect to gas' 'Behaviour of the host rock with respect to temperature' 'Self-sealing capacity'	2.3 Repository-induced effects

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
V P1 Reliable construction of the deep geological repository: Reliable implementation Reliable sealing of the repository Safety during operation	B8 Host rock or effective containment zone	E18 Flexibility / reserves (spatial extent in consideration of uncertainties with regard to geological elements defining the boundaries of the siting region and fracture zones determining the configuration of the repository)	Technical feasibility, influenced by lateral extension, thickness and the space available underground (in consideration of the deep location and geological elements defining the boundaries of the siting region): ***Depth below ground level with respect to engineering feasibility*** (PB-1) ***Depth below ground level with respect to denudation*** (PG-1) ***Glacially over-deepened valleys*** (PG-2) ***Depth below ground level with respect to rock decompaction*** (PG-3) ***Thickness*** (PG-5) ***Geological elements defining the boundaries of the siting region*** (PB-2) ***Geological elements determining the configuration of the repository*** (PB-3) ***Space available underground*** (PB-4) **Layout of storage chambers** (PT-7)	'Thickness' 'Space available underground' 'Depth below ground level with respect to engineering feasibility' 'Depth below ground level with respect to surface erosion' 'Depth below ground level with respect to rock decompaction' 'Depth below rock surface with respect to glacial erosion'	1.1 Spatial extent

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
V P1 Reliable construction of the deep geological repository: Reliable implementation Reliable sealing of the repository Safety during operation	B8 Host rock or effective containment zone B7 Backfill & sealing	E19 Geotechnical properties	Technical feasibility of the deep geological repository (construction, operation, monitoring, sealing, waste recovery): ***Depth below ground level with respect to engineering feasibility*** (PB-1) ***Rock strength and deformation properties of the host rock*** (PB-7) ***In-situ rock stresses*** (PB-6) **Layout of storage chambers** (PT-7)	'Depth below ground level with respect to engineering feasibility' 'Rock strength and deformation properties'	4.1 Rock mechanical properties and conditions
	B2 Geological situation	E20 Geotechnical and hydrogeological conditions	Technical feasibility of underground access (construction, operation, monitoring, sealing, waste recovery): ***Geotechnical and hydrogeological conditions in overlying rock formations*** (PB-8) ***Natural gas in the host rock*** (PB-9) **Surface situation** (PB-11)	'Geotechnical and hydrogeological conditions in overlying rock formations' 'Natural gas (in the host rock)'	4.2 Underground access and water drainage

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
VI P2 Reliability of geological information: Characterisability Explorability Predictability of long-term changes	B8 Host rock or effective containment zone	E21Reliability of geological information (rock properties)	Reliability of geological information on rock properties: *Variability in rock properties* (PI-5, especially more permeable preferential release pathways) *Experience* (with comparable rocks, PI-7) ***Geological elements defining the boundaries of the siting region*** (PB-2) ***Geological elements determining the configuration of the repository*** (PB-3)	'Variability of rock properties with respect to their characterisability' 'Experience'	3.1 Rock characterisability
	B2 Geological situation	E22 Reliability of geological information (spatial aspects)	Reliability of geological information on spatial aspects: Regional fault patterns / deposition conditions / small areas of fragmentation *Exploration conditions deep underground* (PI-8) *Surface exploration conditions (*PI-9, topography, deep location of seismic markers, surface usage, coupling conditions) **Relevant exfiltration pathways** (PG-27)	'Continuity of potentially interesting rock formations' 'Exploration conditions deep underground' 'Surface exploration conditions'	3.2 Explorability of spatial conditions

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
VI P2 Reliability of geological information: Characterisability Explorability Predictability of long-term changes	B2 Geological situation B8 Host rock or effective containment zone	E23 Reliability of geological information (time aspects)	Reliability of geological information on long-term changes (including biosphere): ***Development of regional erosion basis over time*** (PG-4) *Geodynamic and neotectonic activity* (PI-2, frequency and properties of reactivatable fault zones, extension of fault zones in the lateral and vertical direction, seismicity) *Independent evidence of long-term isolation* (PI-4, containment of old pore water, stay times for deep groundwater, existence of tracer profiles) ***Climate change with respect to long-term geological changes*** (PG-30, different phases in climate change) **Relevant exfiltration pathways** (PG-27) **Changes in the local topography over time with respect to biosphere modelling** (PG-29, geomorphology types) **Climate change with respect to estimating water flows during biosphere modelling** (PG-31, various climate alternatives, especially a warm, dry climate and an ice-age climate)	'Geodynamic and neotectonic model concepts' 'Seismicity' 'Independent evidence of long-term isolation'	3.3 Predictability of long-term changes

Safety function (S), principle (P)	**Relevant elements of the barrier system (B)**	**Safety-related properties (E)**	**Relevant processes and parameters** in context and explanations	**Indicators for qualitative assessment**	**Criteria assigned as per SGT**
VII P3 Repository-induced effects are reduced as much as deemed reasonably possible and with reasonable expense by structural and/or operational means. [4)]	B2 Geological situation B8 Host rock or effective containment zone	E17 Minor repository-induced effects (no short-circuits, minimal adverse impact on the barrier effect of the host rock or effective containment zone)	Repository-induced effects on radionuclide transport: Formation of a disturbed zone in the vicinity of underground excavations, chemical interactions (especially pH plumes), gas formation / transport and gas-induced radionuclide transport, thermal processes (in consideration of self-sealing capacity in each case): ***Excavation disturbed zone in the vicinity of underground excavations*** (PG-23) ***Effects of pH plume on the host rock*** (PG-24) ***Behaviour of the host rock with respect to gas*** (PG-25) ***Behaviour of the host rock with respect to temperature*** (PG-26) ***In-situ temperature*** (PB-5) *Self-sealing capacity* (PI-6)	'Excavation disturbed zone in the vicinity of underground excavations' 'Chemical interactions' 'Behaviour of the host rock with respect to gas' 'Behaviour of the host rock with respect to temperature' 'Self-sealing capacity'	2.3 Repository-induced effects

4) This principle was established in Table 5.3-1 in Nagra (2008d) in the context of Criterion 2.3 "Repository-induced effects", but is not listed as an independent principle.

Table J.2: List of Indicators used in the Procedure for Narrowing down the Geological Siting Possibilities

SGT criteria	Indicators used	MR	IR	AS
1.1 Spatial extent	***Depth below ground level with respect to engineering feasibility***	×	×	×
	Depth below ground level with respect to rock decompaction	×	×	×
	***Depth below ground level* with respect to surface erosion**	×		×
	Depth below rock surface with respect to glacial erosion	×	×	×
	Thickness	×	×	×
	Distance from regional fault zones	×		
	Lateral extension	×		×
	Space available underground		×	×
1.2 Hydraulic barrier efficiency	***Hydraulic conductivity***	×	×	×
	Multi-aquifer structure			×
1.3 Geochemical conditions	Mineralogy			×
	pH			×
	Redox conditions	×		×
	Salinity			×
	Microbial processes			×
	Colloids			×
1.4 Release pathways	Type of transport pathways and structure of pore space			×
	Homogeneity of the rock structure		(×)	×
	Length of release pathways			×
	Transmissivity of preferential release pathways	×		×
	Clay content	×		
	Self-sealing capacity			×

SGT criteria	Indicators used	MR	IR	AS
2.1 Stability of the site and rock properties	**Geodynamic and neotectonic model concepts**	×		×
	Seismicity			×
	Model concepts for geochemical processes[1)]			×
	Rare geological events (volcanism)	×		×
	Potential to form new water pathways (karstification)	×		×
2.2 Erosion	**Large-scale erosion in the period under consideration**	×		×
2.3 Repository-induced effects	Excavation-disturbed zone in the vicinity of underground excavations			×
	Chemical interactions			×
	Behaviour of the host rock with respect to gas			×
	Behaviour of the host rock with respect to temperature			(×)
2.4 Resource conflicts	**Resource deposits within the host rock**	×		×
	Resource deposits beneath the host rock	×		×
	Resource deposits above the host rock			×
	Mineral and thermal springs	×		×
	Geothermal sources			×
3.1 Rock characterisability	*Diffusely damaged zones*		×	
	Variability of rock properties with respect to characterisability		×	×
	Experience			×
3.2 Explorability of spatial conditions	**Regional fault patterns and deposition conditions**	×		×
	Continuity of potentially interesting rock formations			×
	Exploration conditions deep underground			×
	Surface exploration conditions	×		×
3.3 Predictability of long-term changes	*Tectonic regime (zones conceptually to be avoided)*		×	
	Independent evidence of long-term isolation			×
4.1 Rock mechanical properties and conditions	**Rock strength and deformation properties**	×		×
4.2 Underground access and water drainage	Geotechnical and hydrogeological conditions in overlying rock formations			×
	Natural gas (in the host rock)	×		×

1) Only used for description.

APPENDIX K: WIPP FEP LIST

EPA FEP I.D.[a,b,c]	FEP Name
N1	Stratigraphy
N2	Brine Reservoirs
N3	Changes in Regional Stress
N4	Regional Tectonics
N5	Regional Uplift and Subsidence
N6	Salt Deformation
N7	Diapirism
N8	Formation of Fractures
N9	Changes in Fracture Properties
N10	Formation of New Faults
N11	Fault Movement
N12	Seismic Activity
N13	Volcanic Activity
N14	Magmatic Activity
N15	Metamorphic Activity
N16	Shallow Dissolution

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-Induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
N18	Deep Dissolution
N20	Breccia Pipes
N21	Collapse Breccias
N22	Fracture Infills
N23	Saturated Groundwater Flow
N24	Unsaturated Groundwater Flow
N25	Fracture Flow
N27	Effects of Preferential Pathways
N26	Density effects on Groundwater Flow
N28	Thermal effects on Groundwater Flow
N29	Saline Intrusion [Hydrogeological Effects]
N30	Freshwater Intrusion [Hydrogeological effects]
N31	Hydrological Response to Earthquakes
N32	Natural Gas Intrusion
N33	Groundwater Geochemistry
N34	Saline Intrusion (Geochemical Effects)
N38	Effects of Dissolution
N35	Freshwater Intrusion (Geochemical Effects)
N36	Changes in Groundwater Eh
N37	Changes in Groundwater pH
N39	Physiography
N40	Impact of a Large Meteorite
N41	Mechanical Weathering
N42	Chemical Weathering
N43	Aeolian Erosion

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-Induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
N44	Fluvial Erosion
N45	Mass Wasting [Erosion]
N46	Aeolian Deposition
N47	Fluvial Deposition
N48	Lacustrine Deposition
N49	Mass Wasting [Deposition]
N50	Soil Development
N51	Stream and River Flow
N52	Surface Water Bodies
N53	Groundwater Discharge
N54	Groundwater Recharge
N55	Infiltration
N56	Changes in Groundwater Recharge and Discharge
N57	Lake Formation
N58	River Flooding
N59	Precipitation (e.g. Rainfall)
N60	Temperature
N61	Climate Change
N62	Glaciation
N63	Permafrost
N64	Seas and Oceans
N65	Estuaries
N66	Coastal Erosion
N67	Marine Sediment Transport and Deposition
N68	Sea Level Changes
N69	Plants
N70	Animals
N71	Microbes
N72	Natural Ecological Development

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-Induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
H1	Oil and Gas Exploration
H2	Potash Exploration
H4	Oil and Gas Exploitation
H8	Other Resources
H9	Enhanced Oil and Gas Recovery
H3	Water Resources Exploration
H5	Groundwater Exploitation
H6	Archaeological Investigations
H7	Geothermal
H10	Liquid Waste Disposal
H11	Hydrocarbon Storage
H12	Deliberate Drilling Intrusion
H13	Conventional Underground Potash Mining
H14	Other Resources (mining for)
H15	Tunneling
H16	Construction of Underground Facilities (for Example Storage, Disposal, Accommodation)
H17	Archaeological Excavations
H18	Deliberate Mining Intrusion

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-Induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
H19	Explosions for Resource Recovery
H20	Underground Nuclear Device Testing
H21	Drilling Fluid Flow
H22	Drilling Fluid Loss
H23	Blowouts
H24	Drilling-Induced Geochemical Changes
H25	Oil and Gas Extraction
H26	Groundwater Extraction
H27	Liquid Waste Disposal–OB
H28	Enhanced Oil and Gas Production–OB
H29	Hydrocarbon Storage–OB

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
H60	Liquid Waste Disposal–IB
H61	Enhanced Oil and Gas Production–IB
H62	Hydrocarbon Storage–IB
H30	Fluid-injection Induced Geochemical Changes
H31	Natural Borehole Fluid Flow
H32	Waste-Induced Borehole Flow
H34	Borehole-Induced Solution and Subsidence
H35	Borehole-Induced Mineralization
H36	Borehole-Induced Geochemical Changes
H37	Changes in Groundwater Flow Due to Mining
H38	Changes in Geochemistry Due to Mining

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
H39	Changes in Groundwater Flow Due to Explosions
H40	Land Use Changes
H41	Surface Disruptions
H42	Damming of Streams or Rivers
H43	Reservoirs
H44	Irrigation
H45	Lake Usage
H46	Altered Soil or Surface Water Chemistry by Human Activities
H47	Greenhouse Gas Effects
H48	Acid Rain
H49	Damage to the Ozone Layer
H50	Coastal Water Use
H51	Sea water Use
H52	Estuarine Water Use
H53	Arable Farming
H54	Ranching
H55	Fish Farming
H56	Demographic Change and Urban Development
H57	Loss of Records
H58	Solution Mining for Potash
H59	Solution Mining for Other Resources
W1	Disposal Geometry
W2	Waste Inventory
W3	Heterogeneity of Waste Forms
W4	Container Form
W5	Container Material Inventory
W6	Shaft Seal Geometry
W7	Shaft Seal Physical Properties
W109	Panel Closure Geometry
W110	Panel Closure Physical Properties
W8	Shaft Seal Chemical Composition
W111	Panel Closure Chemical Composition

[a] N = Natural FEP
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[c] W = Waste- and Repository-induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
W9	Backfill Physical Properties
W10	Backfill Chemical Composition
W11	Post-Closure Monitoring
W12	Radionuclide Decay and In-Growth
W13	Heat from Radioactive Decay
W14	Nuclear Criticality: Heat
W15	Radiological Effects on Waste
W16	Radiological Effects on Containers
W17	Radiological Effects on Shaft Seals
W112	Radionuclide Effects on Panel Closures
W18	Disturbed Rock Zone (DRZ)
W19	Excavation-Induced Changes in Stress
W20	Salt Creep
W21	Changes in the Stress Field
W22	Roof Falls
W23	Subsidence
W24	Large Scale Rock Fracturing
W25	Disruption Due to Gas Effects
W26	Pressurization
W27	Gas Explosions
W28	Nuclear Explosions
W29	Thermal Effects on Material Properties
W30	Thermally-Induced Stress Changes
W31	Differing Thermal Expansion of Repository Components
W72	Exothermic Reactions
W73	Concrete Hydration
W32	Consolidation of Waste
W36	Consolidation of Shaft Seals
W37	Mechanical Degradation of Shaft Seals
W39	Underground Boreholes
W113	Consolidation of Panel Closures
W114	Mechanical Degradation of Panel Closures
W33	Movement of Containers
W34	Container Integrity

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
W35	Mechanical Effects of Backfill
W40	Brine Inflow
W41	Wicking
W42	Fluid Flow Due to Gas Production
W43	Convection
W44	Degradation of Organic Material
W45	Effects of Temperature on Microbial Gas Generation
W48	Effects of Biofilms on Microbial Gas Generation
W46	Effects of Pressure on Microbial Gas Generation
W47	Effects of Radiation on Microbial Gas Generation
W49	Gases from Metal Corrosion
W51	Chemical Effects of Corrosion
W50	Galvanic Coupling (Within the Repository)
W52	Radiolysis of Brine
W53	Radiolysis of Cellulose
W54	Helium Gas Production
W55	Radioactive Gases

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
W56	Speciation
W57	Kinetics of Speciation
W58	Dissolution of Waste
W59	Precipitation of Secondary Minerals
W60	Kinetics of Precipitation and Dissolution
W61	Actinide Sorption
W62	Kinetics of Sorption
W63	Changes in Sorptive Surfaces
W64	Effects of Metal Corrosion
W66	Reduction-Oxidation Kinetics
W65	Reduction-Oxidation Fronts
W67	Localized Reducing Zones
W68	Organic Complexation
W69	Organic Ligands
W71	Kinetics of Organic Complexation
W70	Humic and Fulvic Acids

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
W74	Chemical Degradation of Shaft Seals
W76	Microbial Growth on Concrete
W115	Chemical Degradation of Panel Closures
W75	Chemical Degradation of Backfill
W77	Solute Transport
W78	Colloid Transport
W79	Colloid Formation and Stability
W80	Colloid Filtration
W81	Colloid Sorption
W82	Suspensions of Particles
W83	Rinse
W84	Cuttings
W85	Cavings
W86	Spallings
W87	Microbial Transport
W88	Biofilms
W89	Transport of Radioactive Gases
W90	Advection
W91	Diffusion
W92	Matrix Diffusion
W93	Soret Effect
W94	Electrochemical Effects
W95	Galvanic Coupling (Outside the Repository)
W96	Electrophoresis

[a] N = Natural FEP
[b] H = Human-induced EP
[c] W = Waste- and Repository-induced FEP

EPA FEP I.D.[a,b,c]	FEP Name
W97	Chemical Gradients
W98	Osmotic Processes
W99	Alpha Recoil
W100	Enhanced Diffusion
W101	Plant Uptake
W102	Animal Uptake
W103	Accumulation in Soils
W104	Ingestion
W105	Inhalation
W106	Irradiation
W107	Dermal Sorption
W108	Injection

[a] N = Natural FEP
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