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Radioactive Waste Management Committee

Updating the NEA International FEP List: An IGSC Technical Note

Technical Note 2: Proposed Revisions to the NEA International FEP List

September 2012

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Updating the NEA International FEP List

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

Technical Note 2: Proposed Revisions to the NEA International FEP List

26 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, chemical, geological, radiological and biological 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- The NEA International FEP List has been widely used but many organisations were concerned that it is now out of date and does not reflect more recent experience in safety assessments and their wider or more detailed scope.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 makes proposals for revisions to the NEA International FEP List in light of the review (documented in Little 2012) of the project-specific FEP lists recently developed (i.e. since 2006) by organisations assessing the safety of the deep disposal of radioactive waste (Section 2). The proposals take into account discussions at a teleconference of the NEA FEPs Task Group in August 2012. Potential uses of the updated FEP list are then discussed in Section 3.

2. PROPOSED REVISIONS TO THE NEA INTERNATIONAL FEP LIST

Background

The NEA International FEP List has the potential to be revised both in terms of its structure and its content. A review of the responses to the NEA questionnaire that was sent to IGSC members on the use of FEPs in safety assessment studies shows that there is a general feeling amongst those organisations that make use of the List that its structure and content would benefit from updating and extending. This conclusion is supported by the findings of the MeSA initiative (NEA, 2012) and the review of recently-developed, project-specific FEP lists (Little 2012). The later shows that, although organisations which use FEP lists have not used radically different FEP list structures to that of the NEA International FEP List, some modifications have been made to the structure and, in particular, the content of the lists.

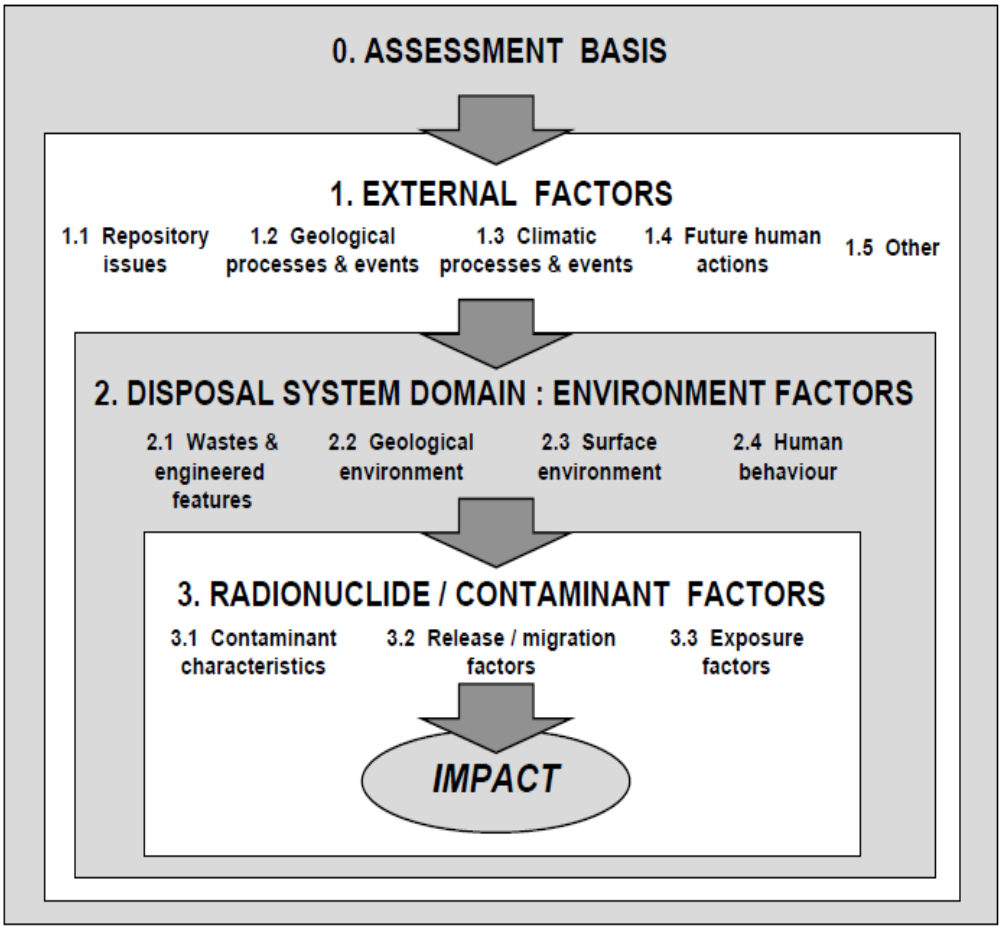
In light of the above, it was suggested that two options could be considered.

- Option 1: keep the existing structure of the NEA International FEP List (see Figure 2.1) but include additional content. See, for example, the NWMO FEP list for low and intermediate level waste (Appendix E of Little 2012) which uses the same structure as the NEA International FEP List but has been extended down to five levels[1] (compared with the three levels of the NEA International FEP List).
- Option 2: modify/extend the structure of the NEA International FEP List and include additional content. As described in Little (2012), many of the more recent FEP lists (e.g. Finland, Japan and Sweden) have used disposal components, such as fuel, canister, buffer, backfill, geosphere and biosphere, to structure their FEP lists rather than just using the external, environment and contaminant factors used in the NEA International FEP List. This has the benefit of allowing greater discretisation of the disposal system and its FEPS at a higher level than was achieved in the NEA International FEP List.

These two options were discussed at a teleconference of the NEA FEPs Task Group in August 2012 and it was decided that Option 2 (i.e. modify/extend the structure of the NEA International FEP List and include additional content) should be followed.

1. Here, "levels" refer to the number of levels to which a particular FEP (e.g. "1. External Factors") has been sub-divided. Sub-dividing the FEP once, produces one or more "Level 2" FEPs (e.g. "1.1 Repository Issues" or "1.2 Geological Factors"; sub-dividing the FEP twice, produces one or more "Level 3" FEP (e.g. "1.1.01 Quality assurance and control" or "1.2.01 Tectonic movement"); etc.

Figure 1. Figure 2.1: Structure of the NEA International FEP List (NEA 2000)



Updated FEPs List

1.

In light of this decision, an updated International FEP List has been developed for review by the NEA FEPs Task Group ahead of the IGSC's October meeting. The updated International FEP List is given in Tables 2.1, 2.2 and 2.3 in increasing level of detail.

- Table 2.1 provides the list sub-divided down to "Level 2".
- Table 2.2 provides the list sub-divided down to "Level 3", i.e. the level of discretisation used in the NEA International FEP List.
- Table 2.3 provides the list sub-divided down to "Level 4", i.e. a greater level of discretisation than used in the NEA International FEP List in order to address the view expressed in the NEA questionnaire that the list needed to be extended.

Table 2.1 shows that the updated list maintains the external factors[2] from the NEA International FEP List but re-structures the environmental and contaminant factors into waste package, repository, geosphere and biosphere factors (consistent with the approach taken by many of the more recent FEP lists). A finer discretisation of the repository into for example buffer, backfill, seals (as has been done in some project-specific FEP lists) is considered to be unnecessary for the purposes of the updated International FEP List which is designed to be generic. In addition, the updated list excludes the assessment basis from its structure since it is now common practice to document the assessment basis separately from the FEP list (see for example NEA, 2012), which has meant that it has been excluded from many of the recently developed FEP lists presented in Little (2012).

Table 2.1: Updated International FEP List Showing FEPs down to Level 2 (bracketed, italicised numbers refer to the FEP Number in the Original NEA International FEP List documented in NEA 2000)

FEP Number and Title	
1.	EXTERNAL FACTORS (*1*)
1.1	Repository Issues (*1.1*)
1.2	Geological Factors (*1.2*)
1.3	Climatic Factors (*1.3*)
1.4	Future Human Actions (*1.4*)
1.5	Other External Factors (*1.5*)
2.	WASTE PACKAGE FACTORS
2.1	Waste Form Characteristics and Properties (*2.1.02*)
2.2	Waste Packaging Characteristics and Properties (*2.1.03*)
2.3	Waste Package Processes (*2.1*)
2.4	Contaminant Release (from waste form) (*3.2*)
2.5	Contaminant Transport (waste package) (*3.2*)
3.	REPOSITORY FACTORS
3.1	Repository Characteristics and Properties (*2.1*)
3.2	Repository Processes (*2.1*)
3.3	Contaminant Transport (repository) (*3.2*)
4.	GEOSPHERE FACTORS
4.1	Geosphere Characteristics and Properties (*2.2*)
4.2	Geosphere Processes (*2.2*)
4.3	Contaminant Transport (geosphere) (*3.2*)
5.	BIOSPHERE FACTORS
5.1	Surface Environment (*2.3*)
5.2	Human Behaviour (*2.4*)
5.3	Contaminant Transport (Biosphere) (*3.2*)
5.4	Exposure Factors (*3.3*)

Table 2.2 shows that 150 FEPs have been sub-divided to "Level 3" compared with 124 FEPs in the NEA International FEP List. Although some new FEPs have been added, most of the additional 26 FEPs result from the division of the "Wastes and Engineered Features" category into two categories "Waste Package Factors" and "Repository Factors" with their own associated FEPs.

2. External Factors are FEPs with causes or origins outside the assessed disposal system. Included in these factors are "Repository Issues", which are related to repository design, operation, closure and post-closure institutional control. They are either outside the temporal bounds of the safety assessment (i.e. occur before the start of the post-closure period) or are repository-related human actions that occur during the post-closure institutional control period.

Table 2.2: Updated International FEP List Showing FEPs down to Level 3 (bracketed, italicised numbers refer to the FEP Number in the Original NEA International FEP List documented in NEA 2000)

FEP Number and Title	
1.	EXTERNAL FACTORS (*1*)
1.1	Repository Issues (*1.1*)
1.1.01	Quality assurance and control (*1.1.08*)
1.1.02	Site investigations (*1.1.01*)
1.1.03	Repository design (*1.1.07*)
1.1.04	Schedule and planning (*1.1.09*)
1.1.05	Construction (*1.1.02*)
1.1.06	Operation (*1.1.03, 1.1.06*)
1.1.07	Closure (*1.1.04*)
1.1.08	Accidents and unplanned events (*1.1.12*)
1.1.09	Repository administrative control (*1.1.10*)
1.1.10	Monitoring (*1.1.11*)
1.1.11	Repository markers (*1.1.05*)
1.2	Geological Factors (*1.2*)
1.2.01	Tectonic movement (*1.2.01*)
1.2.02	Orogeny (*1.2.01*)
1.2.03	Deformation (elastic, plastic or brittle) (*1.2.02*)
1.2.04	Seismicity (*1.2.03*)
1.2.05	Volcanic and magmatic activity (*1.2.04*)
1.2.06	Metamorphism (*1.2.05*)
1.2.07	Hydrothermal activity (*1.2.06*)
1.2.08	Regional erosion and sedimentation (*1.2.07*)
1.2.09	Diagenesis (*1.2.08*)
1.2.10	Pedogenesis
1.2.11	Salt diapirism and dissolution (*1.2.09*)
1.2.12	Hydrological/Hydrogeological response to geological changes (*1.2.10*)
1.2.13	Geomorphological response to geological changes
1.3	Climatic Factors (*1.3*)
1.3.01	Global climate change (*1.3.01*)
1.3.02	Regional and local climate change (*1.3.02*)
1.3.03	Sea level change (*1.3.03*)
1.3.04	Periglacial effects (*1.3.04*)
1.3.05	Local glacial and ice-sheet effects (*1.3.05*)
1.3.06	Warm climate effects (tropical and desert) (*1.3.06*)
1.3.07	Hydrological response to climate change (*1.3.07*)
1.3.08	Ecological response to climate changes (*1.3.08*)
1.3.09	Human response to climate changes (*1.3.09*)
1.3.10	Geomorphological response to climate changes
1.4	Future Human Actions (*1.4*)
1.4.01	Human influences on climate (*1.4.01*)
1.4.02	Social and institutional developments (*1.4.08*)
1.4.03	Technological developments (*1.4.09*)
1.4.04	Knowledge and motivational issues (repository) (*1.4.02*)
1.4.05	Drilling activities (*1.4.04*)
1.4.06	Mining and other underground activities (*1.4.05*)
1.4.07	Un-intrusive site investigation (*1.4.03*)
1.4.08	Surface environment (*1.4.06*)

FEP Number and Title	
1.4.09	Water management (groundwater and surface water) (*1.4.07*)
1.4.10	Explosions and crashes (*1.4.11*)
1.4.11	Remedial actions (*1.4.10*)
1.4.12	Deliberate human intrusion (*1.4.02*)
1.5	Other External Factors (*1.5*)
1.5.01	Meteorites and human space debris (*1.5.01*)
1.5.02	Evolution of biota (*1.5.02*)
2.	WASTE PACKAGE FACTORS
2.1	Waste Form Characteristics and Properties (*2.1.02*)
2.1.01	Waste state
2.1.02	Waste type
2.1.03	Waste conditioning matrix (*2.1.02*)
2.1.04	Contaminant inventory (*2.1.01*)
2.1.05	Waste form properties
2.2	Waste Packaging Characteristics and Properties
2.2.01	Containers (*2.1.03*)
2.2.02	Overpacks
2.3	Waste Package Processes (*2.1*)
2.3.01	Thermal processes (waste package) (*2.1.11*)
2.3.02	Hydraulic processes (waste package) (*2.1.08*)
2.3.03	Mechanical processes (waste package) (*2.1.07*)
2.3.04	Chemical processes (waste package) (*2.1.09*)
2.3.05	Biological processes (waste package) (*2.1.10*)
2.3.06	Radiological processes (waste package) (*2.1.13*)
2.3.07	Gas generation (waste package) (*2.1.12*)
2.4	Contaminant Release (from waste form) (*3.2*)
2.4.01	Liquid-mediated release (*3.2.07*)
2.4.02	Gas-mediated release (*3.2.09*)
2.4.03	Solid-mediated release (*3.2.08*)
2.4.04	Human-action-mediated release (*3.2.12*)
2.5	Contaminant Transport (waste package) (*3.2*)
2.5.01	Transport pathways (waste package)
2.5.02	Water-mediated transport (waste package) (*3.2.07*)
2.5.03	Gas-mediated transport (waste package) (*3.2.09*)
3.	REPOSITORY FACTORS
3.1	Repository Characteristics and Properties (*2.1*)
3.1.01	Design (*1.1.07*)
3.1.02	Buffer/backfill (*2.1.04*)
3.1.03	Room/tunnel seals (*2.1.05*)
3.1.04	Shaft/ramp seals (*2.1.05*)
3.1.05	Other engineered features (*2.1.06*)
3.1.06	Excavation damaged and disturbed zones (*2.2.01*)
3.2	Repository Processes (*2.1*)
3.2.01	Thermal processes (repository) (*2.1.11*)
3.2.02	Hydraulic processes (repository) (*2.1.08*)
3.2.03	Mechanical processes (repository) (*2.1.07*)
3.2.04	Chemical processes (repository) (*2.1.09*)
3.2.05	Biological processes (repository) (*2.1.10*)
3.2.06	Radiological processes (repository) (*2.1.13*)
3.2.07	Gas generation (repository) (*2.1.12*)

FEP Number and Title	
3.3	Contaminant Transport (repository) (*3.2*)
3.3.01	Transport pathways (repository)
3.3.02	Water-mediated transport (repository) (*3.2.07*)
3.3.03	Gas-mediated transport (repository) (*3.2.09*)
3.3.04	Solid-mediated transport (repository) (*3.2.08*)
3.3.05	Human-action-mediated transport (repository) (*3.2.12*)
4.	GEOSPHERE FACTORS
4.1	Geosphere Characteristics and Properties (*2.2*)
4.1.01	Stratigraphy (*2.2.03*)
4.1.02	Host rock lithology (*2.2.02*)
4.1.03	Large-scale discontinuities (*2.2.04*)
4.1.04	Geological resources (*2.2.13*)
4.1.05	Undetected features (*2.2.12*)
4.1.06	Current geothermal state (*2.2.10*)
4.1.07	Current hydraulic state (*2.2.07*)
4.1.08	Current stress state (*2.2.06*)
4.1.09	Current geochemical state (*2.2.08*)
4.1.10	Current biological state (*2.2.09*)
4.1.11	Current gas state (*2.2.11*)
4.2	Geosphere Processes (*2.2*)
4.2.01	Thermal processes (geosphere) (*2.2.10*)
4.2.02	Hydraulic processes (geosphere) (*2.2.07*)
4.2.03	Mechanical processes (geosphere) (*2.2.06*)
4.2.04	Geochemical processes (geosphere) (*2.2.08*)
4.2.05	Biological processes (geosphere) (*2.2.09*)
4.2.06	Radiological processes (geosphere)
4.2.07	Gas processes (geosphere) (*2.2.11*)
4.3	Contaminant Transport (geosphere) (*3.2*)
4.3.01	Transport pathways (geosphere) (*2.2.05*)
4.3.02	Water-mediated transport (geosphere) (*3.2.07*)
4.3.03	Gas-mediated transport (geosphere) (*3.2.09*)
4.3.04	Solid-mediated transport (geosphere) (*3.2.08*)
4.3.05	Human-action-mediated transport (geosphere) (*3.2.12*)
5.	BIOSPHERE FACTORS
5.1	Surface Environment (*2.3*)
5.1.01	Topography and morphology (*2.3.01*)
5.1.02	Biomes
5.1.03	Soil and sediment (*2.3.02*)
5.1.04	Near-surface aquifers and water-bearing features (*2.3.03*)
5.1.05	Terrestrial surface water bodies (*2.3.04*)
5.1.06	Coastal features (*2.3.05*)
5.1.07	Marine features (*2.3.06*)
5.1.08	Atmosphere (*2.3.07*)
5.1.09	Vegetation (*2.3.08*)
5.1.10	Animals (*2.3.09*)
5.1.11	Climate and weather (*2.3.10*)
5.1.12	Hydrological regime and water balance (near-surface) (*2.3.11*)
5.1.13	Erosion and deposition (*2.3.12*)
5.1.14	Ecological/biological/microbial systems (*2.3.13*)
5.2	Human Behaviour (*2.4*)
5.2.01	Human characteristics (physiology, metabolism) (*2.4.01*)

FEP Number and Title	
5.2.02	Age, gender and ethnicity (*2.4.02*)
5.2.03	Diet and fluid intake (*2.4.03*)
5.2.04	Habits (excluding diet) (*2.4.04*)
5.2.05	Community characteristics (*2.4.05*)
5.2.06	Food preparation and water processing (*2.4.06*)
5.2.07	Dwellings (*2.4.07*)
5.2.08	Natural / semi-natural land and water use (*2.4.08*)
5.2.09	Rural / agricultural land and water use (*2.4.09*)
5.2.10	Urban / industrial land and water use (*2.4.10*)
5.2.11	Leisure and other uses of the environment (*2.4.11*)
5.3	Contaminant Transport (Biosphere) (*3.2*)
5.3.01	Water-mediated transport (biosphere) (*3.2.07*)
5.3.02	Gas-mediated transport (biosphere) (*3.2.09*)
5.3.03	Solid-mediated transport (biosphere) (*3.2.08*)
5.3.04	Human-action-mediated transport (biosphere) (*3.2.12*)
5.3.05	Atmospheric transport and deposition (*3.2.10*)
5.3.06	Biologically-mediated transport (*3.2.06*, *3.2.11*)
5.3.07	Foodchains and uptake of contaminants (*3.2.13*)
5.4	Exposure Factors (*3.3*)
5.4.01	Contaminated drinking water and food (*3.3.01*)
5.4.02	Contaminated non-food products (*3.3.03*)
5.4.03	Other contaminated environmental media (*3.3.02*)
5.4.04	Exposure modes (*3.3.04*)
5.4.05	Dosimetry and biokinetics (*3.3.05*)
5.4.06	Radiological toxicity/effects (*3.3.06*)
5.4.07	Chemical toxicity/effects (*3.3.07*)
5.4.08	Radon and radon daughter exposure (*3.3.08*)

Table 2.3 provides the complete updated FEP list together with explanation of the modifications and additions from the NEA International FEP List. All the FEPs from the NEA International FEP List have been included in the updated FEP with the exception of the "Assessment Basis" FEPs (as discussed above), FEP 1.1.13 (Retrievability), FEP 1.5.03 (Miscellaneous and FEPs of uncertain relevance) and FEP 3.1.02 (Chemical/organic toxin stability).

FEP 1.1.13 was "related to any special design, emplacement, operational or administrative measures that might be applied or considered in order to enable or ease retrieval of wastes" (NEA 2000). Rather than having a specific FEP for such measures, it is considered that they can be included within the existing FEPs relating to design, emplacement, operation or administration.

FEP 1.5.03 was provided for "FEPs that cannot be mapped anywhere else on the International FEP List" and "FEPs which have been identified but no connection made to possible effects on repository performance" (NEA, 2000) and was intended to allow project-specific FEPs that could not be mapped onto another FEP in the NEA International FEP List to be mapped onto this FEP. It is considered that the greater discretisation of the updated FEP list has partly removed the need for this FEP. In addition, it is expected that the new software[3], in which the updated NEA International FEP List and project-specific FEP lists are proposed to be implemented, will allow users to flag up any project-specific

3. A full requirements specification for Version 1 of this software will be developed during late 2012 and early 2013.

FEPs that are not included in the updated NEA International FEP List. It is expected that a search facility will allow all such FEPs to be identified and, if considered appropriate, the then current NEA International FEP List could be updated to include these FEPs. Such a software feature will remove the need for a "miscellaneous" FEP in the updated NEA International FEP List.

FEP 3.1.02 concerns "FEPs related to chemical stability of chemotoxic species" (NEA 2000). It is considered that such FEPs will be covered by other FEPs in the updated list such as those relating to thermal, chemical and biological processes in the waste package, repository and geosphere and so there is no need for a specific FEP relating to chemical stability of chemotoxic species.

Table 2.3 shows that 180 FEPs have been sub-divided to "Level 4". In some cases these "Level 4" FEPs are in fact "Level 3" FEPs in the NEA International FEP List – the restructuring of the FEP list has simply resulted in them being moved down from "Level 3" to "Level 4". However in the majority of cases (shown in red), they are FEPs that do not explicitly appear in the NEA International FEP List since that list was not sub-divided beyond "Level 3" FEPs. They have been taken from the more detailed FEP lists reviewed in Little (2012). It is considered that this increased level of detail has not resulted in the updated International FEP List becoming too detailed and has ensured that a suitable balance between generality and detail has been maintained.

Table 1.

Table 2.3: Updated International FEP List Showing FEPs down to Level 4

Number	Name	Description
1	EXTERNAL FACTORS	FEPs related to external factors.
1.1	Repository Issues	Decisions on designs and waste allocation, and also events related to site investigation, operations and closure. "Repository Issues" is a sub-category in the International FEP List and is divided into individual FEPs.
1.1.1	Quality assurance and control	Quality assurance and control procedures and tests during the design, construction and operation of the repository, as well as the manufacture of the waste forms, containers and engineered features.
1.1.2	Site investigations	FEP related to the investigations that are carried out at a potential repository site in order to characterise the site both prior to repository excavation and during construction and operation.
1.1.3	Repository design	The design of the repository including both the safety concept, i.e. the general features of design and their safety functions, and the more detailed engineering specification for excavation, construction and operation.
1.1.4	Schedule and planning	The sequence of events and activities occurring during repository excavation, construction, waste emplacement and sealing.
1.1.5	Construction	The excavation of shafts, tunnels, waste emplacement galleries, silos etc. of a repository, the stabilisation of these openings and installation/assembly of structural elements.
1.1.6	Operation	The operation of the repository including the placing of wastes (usually in containers) at their final position within the repository and placing of any buffer and backfill materials. Also includes FEPs related to the choices on allocation of wastes to the repository, including waste type(s) and amount(s).
1.1.7	Closure	The cessation of waste emplacement operations at a site and the backfilling and sealing of access tunnels and shafts.
1.1.8	Accidents and unplanned events	Accidents and unplanned events during excavation, construction, waste emplacement and closure which might have an impact on long-term performance or safety.
1.1.9	Repository administrative control	Measures to control events at or around the repository site both during the operational period and after closure.
1.1.10	Monitoring	Monitoring that is carried out during operations or following closure of sections of, or the total, repository. This includes monitoring for operational safety and also monitoring of parameters related to the long-term safety and performance.

Number	Name	Description
1.1.11	Repository markers	The retention of records of the content and nature of a repository after closure and also the placing of permanent markers at or near the site.
1.2	Geological Factors	Processes arising from the wider geological setting and long-term processes. “Geological Factors” is a sub-category in the International FEP List and is divided into individual FEPs.
1.2.1	Tectonic movement	The movement of the lithosphere (the Earth’s outermost layer) due to the underlying movements of the crustal plates. These movements give rise to large-scale processes such as continental drift, mountain building (orogeny), crustal deformation, faulting, folding and subduction.
1.2.2	Orogeny	The formation of mountains (orogeny), the potential for orogeny and its effects on the performance of the repository.
1.2.3	Deformation (elastic, plastic, or brittle)	The physical deformation of geological structures in response to geological forces. This includes faulting, fracturing, extrusion and compression of rocks.
1.2.4	Seismicity	The release of accumulated geologic stress via rapid relative movements within the Earth’s crust usually along existing faults or geological interfaces. The accompanying release of energy may result in ground movement and/or rupture, e.g. earthquakes.
1.2.5	Volcanic and magmatic activity	Magma is molten, mobile rock material, generated below the Earth’s crust, which gives rise to igneous rocks when solidified. Magmatic activity occurs when there is intrusion of magma into the crust. A volcano is a vent or fissure in the Earth’s surface through which molten or part-molten materials (lava) may flow, and ash and hot gases be expelled.
1.2.6	Metamorphism	The processes by which rocks are changed by the action of heat (T>200 C) and pressure at great depths (usually several kilometres) beneath the Earth’s surface or in the vicinity of magmatic activity.
1.2.7	Hydrothermal activity	FEPs associated with high temperature groundwaters, including processes such as density-driven groundwater flow and hydrothermal alteration of minerals in the rocks through which the high temperature groundwater flows.
1.2.8	Regional erosion and sedimentation	FEPs related the large scale (geological) removal and accumulation of rocks and sediments, with associated changes in topography and geological/hydrogeological conditions of the repository host rock.

Number	Name	Description
1.2.9	Diagenesis	The processes by which deposited sediments at or near the Earth's surface are formed into rocks by compaction, cementation and crystallisation, i.e. under conditions of temperature and pressure normal to the upper few kilometres of the earth's crust.
1.2.10	Pedogenesis	The process by which soil is formed. Pedogenesis depends upon climactic conditions as well as on mineral and biological processes and topography.
1.2.11	Salt diapirism and dissolution	The large scale evolution of salt formations. Diapirism is the lateral or vertical intrusion or upwelling of either buoyant or non-buoyant rock, into overlying strata (the overburden) from a source layer. Dissolution of the salt may occur where the evolving salt formation is in contact with groundwaters with salt content below saturation.
1.2.12	Hydrological/Hydrogeological response to geological changes	FEPs arising from large-scale geological changes that affect regional and local groundwater flow and pressures. These could include changes of hydrological boundary conditions due to effects of erosion on topography, and changes of hydraulic properties of geological units due to changes in rock stress or fault movements.
1.2.13	Geomorphological response to geological changes	FEPs arising from geomorphological responses to geological changes that cause changes to surface landforms on a regional and local scale. Geomorphology relates to the evolution of a landscape due to geological events as well as climatic, hydrologic, and biologic conditions.
1.3	Climatic Factors	Processes related to global climate change and consequent regional effects. "Climatic Factors" is a sub-category in the International FEP List and is divided into individual FEPs.
1.3.1	Global climate change	The possible future, and evidence for past, long term change of global climate. This is distinct from resulting changes that may occur at specific locations according to their regional setting and also climate fluctuations, c.f. FEP 1.3.2.
1.3.2	Regional and local climate change	The possible future changes, and evidence for past changes, of climate at a repository site. This is likely to occur in response to global climate change, but the changes will be specific to situation, and may include shorter term fluctuations, c.f. FEP 1.3.1.
1.3.3	Sea level change	Changes in sea level which may occur as a result of global (eustatic) change and regional geological change, e.g. isostatic movements.
1.3.4	Periglacial effects	The physical processes and associated landforms in cold but ice-sheet-free environments.

Number	Name	Description
1.3.5	Local glacial and ice-sheet effects	The effects of glaciers and ice sheets within the region of a repository, e.g. changes in the geomorphology, erosion, meltwater and hydraulic effects. This is distinct from the effect of large ice masses on global and regional climate, c.f. FEPs 1.3.1, 1.3.2.
1.3.6	Warm climate effects (tropical and desert)	Effects of warm tropical and desert climates, including seasonal effects, and meteorological and geomorphological effects specific to these climates.
1.3.7	Hydrological response to climate change	Changes in hydrology and hydrogeology, e.g. recharge, sediment load and seasonality, in response to climate change in a region.
1.3.8	Ecological response to climate change	Changes in ecology, e.g. vegetation, plant and animal populations, in response to climate change in a region.
1.3.9	Human response to climate change	Changes in human behaviour, e.g. habits, diet, size of communities, in response to climate change in a region.
1.3.10	Geomorphological response to climate changes	Geomorphological responses to climate changes that cause changes to surface landforms on a regional and local scale, e.g. the generation of periglacial landforms. Geomorphology relates to the evolution of a landscape due to geological events as well as climatic, hydrologic, and biologic conditions.
1.4	Future Human Actions	Human actions and regional practices, in the post-closure period, that can potentially affect the performance of the engineered and/or geological barriers, e.g. intrusive actions, but not the passive behaviour and habits of the local population, c.f. 5.2. “Future Human Actions” is a sub-category in the International FEP List and is divided into individual FEPs.
1.4.1	Human influences on climate	Human activities that could affect the change of climate either globally or in a region. Original image: IPCC website
1.4.2	Social and institutional developments	Changes in social patterns and degree of local government, planning and regulation.
1.4.3	Technological developments	Future developments in human technology and changes in the capacity and motivation to implement technologies. This may include retrograde developments, e.g. loss of capacity to implement a technology.
1.4.4	Knowledge and motivational issues (repository)	The degree of knowledge of the existence, location and/or nature of the repository.
1.4.5	Drilling activities	Any type of drilling activity in the vicinity of the repository. These may be taken with or without knowledge of the repository (see FEP 1.4.4).

Number	Name	Description
1.4.6	Mining and other underground activities	Any type of mining or excavation activity carried out in the vicinity of the repository. These may be taken with or without knowledge of the repository (see FEP 1.4.4).
1.4.7	Unintrusive site investigation	Airborne, geophysical or other surface-based investigation of a repository site after repository closure.
1.4.8	Surface Environment	Human activities that may be carried out in the surface environment that can potentially affect the performance of the engineered and/or geological barriers, or the exposure pathways, excepting those FEPs related to water management which are at FEP 1.4.9.
1.4.9	Water management (groundwater and surface water)	Groundwater and surface water management including water extraction, reservoirs, dams, and river management.
1.4.10	Explosions and crashes	Deliberate or accidental explosions and crashes such as might have some impact on a closed repository, e.g. underground nuclear testing, aircraft crash on the site, acts of war.
1.4.11	Remedial Actions	Actions that might be taken following repository closure to remedy problems with a waste repository that, either, was not performing to the standards required, had been disrupted by some natural event or process, or had been inadvertently or deliberately damaged by human actions.
1.4.12	Deliberate human intrusion	Reasons for and nature and consequences of deliberate intrusion into a repository after closure with complete or incomplete knowledge.
1.5	Other External Factors	A “catch-all” for any external factor not accommodated in 1.1 to 1.4, e.g. meteorite impact. “Other External Factors” is a sub-category in the International FEP List and is divided into individual FEPs.
1.5.1	Meteorites and human space debris	The possibility of a large meteorite or human space debris impact occurring at or close to the repository site and related consequences. The impact could cause phenomena such as the creation of a crater, activation, creation and sealing of faults, and physical and chemical changes in rock.
1.5.2	Evolution of biota	The biological evolution of humans, other animal or plant species, by both natural selection and selective breeding/culturing.
2	WASTE PACKAGE FACTORS	FEPs related to waste packages (i.e. waste forms and any packaging).
2.1	Waste Form Characteristics and Properties	FEPs related to the physical, chemical, biological characteristics of the waste form at the time of emplacement in the repository.

Number	Name	Description
2.1.1	Waste State	The physical state of the waste form following any conditioning prior to emplacement in the repository.
2.1.1.1	Solid	Wastes which are disposed in the solid state. Includes wastes that have been solidified through conditioning.
2.1.1.2	Liquid	Wastes which are disposed in the liquid state. Limits on the acceptance of such wastes for disposal in a repository are usually set.
2.1.1.3	Gas	Wastes which are disposed in the gaseous state. Limits on the acceptance of such wastes for disposal in a repository are usually set.
2.1.2	Waste Type	The physical, chemical and biological characteristics of the waste prior to any treatment and/or conditioning prior to packaging and emplacement in the repository.
2.1.2.1	Metallic wastes	The characteristics of metallic wastes that may be disposed in the repository.
2.1.2.2	Organic wastes	The characteristics of organic wastes that may be disposed in the repository.
2.1.2.3	Non-metallic, inorganic wastes	The characteristics of non-metallic, inorganic wastes that may be disposed in the repository.
2.1.3	Waste conditioning matrix	The physical, chemical, biological characteristics of the waste conditioning matrix/matrices at the time of emplacement in the repository.
2.1.4	Contaminant inventory	The content in the repository of radioactive and non-radioactive contaminants disposed in the repository.
2.1.4.1	Radionuclide content	The masses of radioactive isotopes (radionuclides) of all elements in the various waste forms disposed in the repository.
2.1.4.2	Chemical content	The masses of non-radioactive species in the various waste forms disposed in the repository.
2.1.5	Waste form properties	The physical, chemical and biological characteristics and properties of the waste forms at the time of emplacement in the repository.
2.2	Waste Packaging Characteristics and Properties	The physical, chemical and biological characteristics and properties of the waste packages at the time of emplacement in the repository.
2.2.1	Containers	The physical, chemical, biological characteristics of the container at the time of emplacement in the repository.

Number	Name	Description
2.2.2	Overpacks	The physical, chemical, biological characteristics of any overpack at the time of emplacement in the repository. An overpack is a container that is used to secure or shield one or more inner containers.
2.3	Waste Package Processes	Processes within the waste packages. The focus is on processes occurring after waste package emplacement in the repository. “Wastes Package Processes” is a sub-category in the International FEP List and is divided into individual FEPs.
2.3.1	Thermal processes (waste package)	FEPs related to the thermal processes that affect the waste packages (i.e. waste form and containers). This includes the effects of heat on waste packages from the engineered materials in the repository and the surrounding geology.
2.3.1.1	Radiogenic heat production and transfer	Heat production and transfer from radioactive decay of the radionuclides in the waste packages. Heat generation from radiation attenuation is a function of the decay rate and the composition of the waste. The composition of the waste package controls its thermal conductivity.
2.3.1.2	Chemical heat production and transfer	Heat production and transfer from chemical processes affecting the waste packages.
2.3.1.3	Biological heat production and transfer	Heat production and transfer related to biological sources affecting the waste packages.
2.3.1.4	Impact of thermal processes on other processes (waste package)	FEPs relating to thermal processes coupled with other processes. Couplings of thermal processes with hydraulic, mechanical and chemical processes, as well as biological and radiological processes, will affect the evolution of the waste package. One potential consequence is the failure of the waste package.
2.3.2	Hydraulic processes (waste package)	FEPs related to the hydraulic processes that affect the waste packages. This includes the effects of hydraulic influences on waste packages by the engineered materials in the repository and the surrounding geology.
2.3.2.1	Resaturation/desaturation (waste package)	The resaturation or desaturation of the waste package will be controlled by the hydraulic conditions in the repository and the surrounding geosphere.
2.3.2.2	Thermal effects (waste package)	The evolution of the waste package’s temperature over time can influence the hydraulic conditions affecting the waste package.
2.3.2.3	Gas effects (waste package)	The generation and migration of gases in the waste packages can affect the hydraulic conditions in the waste package.

Number	Name	Description
2.3.2.4	Impact of hydraulic processes on other processes (waste package)	FEPs relating to hydraulic processes coupled with other processes. Couplings of hydraulic processes with thermal, mechanical and chemical processes, as well as biological and radiological processes, will affect the evolution of the waste package. One potential consequence is the failure of the waste package.
2.3.3	Mechanical processes (waste package)	FEPs related to the mechanical processes that affect the waste packages. This includes the effects of hydraulic and mechanical loads imposed on waste packages by the engineered materials in the repository and the surrounding geology.
2.3.3.1	Package deformation	Large loads and pressures imposed on the waste package due to both internal and external sources can cause package deformation. The nature of these loads and their potential for causing deformation is, to some extent, dependent on whether the canister is intact or has been breached.
2.3.3.2	Material volume changes (waste package)	The effects of volume changes in materials used in the waste package (e.g. the shrinkage/expansion of concrete, the corrosion of metals and the swelling of bentonite).
2.3.3.3	Package movement	The movement of the waste package in the repository. Movement could result from mechanical stresses on the waste package caused by, for example, package deformation or mass redistribution in the repository. It could also result from seismic events (see FEP 1.2.04).
2.3.3.4	Stress corrosion cracking	A potential failure mechanism for metallic containers, involving the uptake of hydrogen gas and formation of metal hydrides. Stress corrosion cracking, or hydride embrittlement and cracking, may mechanically weaken the container and promote subsequent failure or other corrosion mechanisms.
2.3.3.5	Gas explosion (waste package)	Some gases produced from the corrosion and degradation of waste packages might be flammable or might form an explosive mixture; for instance, hydrogen and methane could mix with oxygen and explode to damage the waste package. A gas explosion can only occur if a flammable gas mixture forms and there is a source of ignition or the gas mixture has the capability to auto-ignite.
2.3.3.6	Impact of mechanical processes on other processes (waste package)	FEPs relating to mechanical processes coupled with other processes. Couplings of mechanical processes with thermal, hydraulic and chemical processes, as well as biological and radiological processes, will affect the evolution of the waste package. One potential consequence is the failure of the waste package.

Number	Name	Description
2.3.4	Chemical processes (waste package)	FEPs related to the chemical/geochemical processes that affect the waste packages. This includes the effects of chemical/geochemical influences on waste packages by the engineered materials in the repository and the surrounding geology.
2.3.4.1	pH conditions (waste package)	The temporal evolution of the waste package's pH depends on a number of factors, including the pH of the surrounding water, the water flow rate through the waste package and the characteristics of the waste form.
2.3.4.2	Redox conditions (waste package)	The temporal evolution of the waste package's Eh depends on a number of factors, including the Eh conditions of the surrounding water and the consumption rate of any available oxygen. Oxygen-deficient (anaerobic) conditions promote the formation of lower, and often less soluble, oxidation states of elements, promotes relatively slow corrosion and microbial processes, and minimises the rate of gas generation.
2.3.4.3	Perturbing species' concentrations (waste package)	The presence of certain species, such as chloride and sulphate, can affect the evolution of the waste package, for example through promoting the corrosion of metals (high chloride concentrations) and the degradation of cement (high sulphate concentrations). Sources of such species can include the waste forms and inflowing water.
2.3.4.4	Corrosion (waste package)	Corrosion of the waste package can be generalised (or uniform), local, or galvanic. All metals are subject to uniform corrosion at rates that are dependent on the chemical and physical (and possibly biological) environment, while localised formation of cavities in a metal surface is caused by non-uniform corrosion. Galvanic corrosion occurs when two different metals are in electric contact.
2.3.4.5	Polymer degradation	Degradation of plastics or other polymers in the waste package can lead to gas generation, or the degradation of a polymeric packaging material may lead to a loss of containment.
2.3.4.6	Dissolution (waste package)	Dissolution is the process by which molecules of a solid dissolve into solution. The chemical environment of the waste package (e.g. pH and Eh) is likely to evolve over time, and these changes could lead to the evolution of species dissolution.
2.3.4.7	Mineralisation (waste package)	Mineralisation in the waste package includes processes such as leaching, carbonation, illitisation, and chloride and sulphate attack. These processes will affect the rate of species migration out of the waste package.

Number	Name	Description
2.3.4.8	Precipitation reactions (waste package)	The precipitation of an element from the aqueous phase to the solid phase can be affected by chemical conditions in the waste package (particularly pH, Eh and the concentration of complexing ions). The mass of precipitates could increase until dissolution of the waste form ceases, after which the mass would decrease as the precipitate itself dissolves.
2.3.4.9	Chelating agent effects (waste package)	Chelating agents are organic compounds, usually carboxylic acids that have a number of locations in each molecule which can complex with a single metal atom. The resulting complexes are usually highly stable, a factor that can increase significantly the solubilities of certain elements. Sources can include organic wastes and inflowing water.
2.3.4.10	Colloid formation (waste package)	Colloids are very fine particles (with diameters typically less than 10 μm) that can affect the transport of contaminants. Particles of clay minerals, silica, iron oxy-hydroxides, other minerals, organic and bio-organic macromolecules may form the colloid phase. Sources can include materials in the waste package itself (e.g. cementitious materials, organic wastes), repository materials (e.g. bentonite and cementitious materials) and inflowing water.
2.3.4.11	Chemical concentration gradients (waste package)	Chemical concentration gradients in the waste package could be caused by various factors such as temperature changes, radiolysis, different electrochemical potentials between various materials, and the ingress of saline water. Possible effects include altered dissolution rates of the waste matrices and dissolution and precipitation of chemical compounds with subsequent opening or plugging of pores.
2.3.4.12	Impact of chemical processes on other processes (waste package)	FEPs relating to chemical processes coupled with other processes. Couplings of chemical processes with thermal, hydraulic and mechanical processes, as well as biological and radiological processes, will affect the evolution of the waste package.
2.3.5	Biological processes (waste package)	FEPs related to the biological/biochemical processes that affect the waste packages. This includes the effects of biological/biochemical influences on waste packages by the engineered materials in the repository and the surrounding geology.
2.3.5.1	Microbial growth and poisoning (waste package)	Microbes can be present in the waste packages, especially those containing organic waste. Growth requires the presence of suitable nutrients, such as cellulosic wastes, simple organic molecules containing oxygen, nitrogen and/or sulphur, and small amounts of putrescible materials. Poisoning of microbial processes can occur due to temperatures in excess of about 70ºC, changing the pH to a value at which the microbial population ceases to function, and high heavy metals concentrations. However, extremophiles can survive and thrive outside the range at which most microbes flourish.

Number	Name	Description
2.3.5.2	Microbially/biologically mediated processes (waste package)	Microbiological/biological processes can affect the form or related properties of the waste form. For example, microbial processes can lead to the formation of acidic and oxidising species that can participate in corrosion of the metals and generation of reducing conditions. Bacteria and microbes may also result in the generation of gases (see FEP 2.3.7.2), and anaerobic bacteria may form biofilms on or around the waste package.
2.3.5.3	Impact of biological processes on other processes (waste package)	FEPs relating to biological processes coupled with other processes. Couplings of biological processes with thermal, hydraulic, mechanical and chemical processes, as well as radiological processes, will affect the evolution of the waste package.
2.3.6	Radiological processes (waste package)	FEPs related to the effects of radiation emitted from the wastes in the waste packages, and the overall radiogenic evolution of the waste packages with time.
2.3.6.1	Radioactive decay and ingrowth (waste package)	Radioactive decay results in the reduction in the activity of the radionuclides in the waste package. Where a parent radionuclide decays to a daughter radionuclide, this causes the ingrowth of daughter in the waste package.
2.3.6.2	Radiolysis (waste package)	Waste packages may contain a mixture of water vapour, air, and argon. This humid air will be subject to radiation inside the waste package. The actual composition and amount of the radiolysis products that will be formed is controlled by the radiation dose rate and by the composition and amount of the air and water vapour mixture contained in the waste package (see FEP 2.3.7.4).
2.3.6.3	Helium production	Helium production from alpha decay of waste.
2.3.6.4	Radiation attenuation (waste package)	The rate of radiation attenuation is controlled in part by the design of the waste package. Much of the radiation from the waste will be attenuated by the waste form, and radiation attenuation can generate thermal energy (see FEP 2.3.1.1).
2.3.6.5	Radiation damage (waste package)	Radiation damage from fission and alpha decay may affect waste packaging materials, influencing their chemical stability
2.3.6.6	Impact of radiological processes on other processes (waste package)	FEPs relating to radiological processes coupled with other processes. For example, radiolysis within a waste package may lead to mechanical stresses and radioactive decay can result in heat generation. Helium and other gas production could lead to gas-induced failure of the waste package.
2.3.7	Gas generation (waste package)	FEPs within and around the waste packages resulting in the generation of gases and their subsequent effects on the repository system.

Number	Name	Description
2.3.7.1	Metal corrosion (waste package)	Metals (e.g. iron, carbon steel, aluminium) present in the waste packages will corrode resulting in hydrogen gas generation if the conditions are anaerobic.
2.3.7.2	Organic degradation (waste package)	Organic materials present in the waste package will be subject to chemical and biological degradation resulting in the generation of gases such as carbon dioxide and methane.
2.3.7.3	Radon production (waste package)	Radon will be produced from the decay of any Ra-226 in the waste.
2.3.7.4	Radiolysis (waste package)	Radiolysis (i.e. the dissociation of molecules by nuclear radiation) of water within a waste package can produce molecular species such as hydrogen, oxygen, and hydrogen peroxide which can impact the chemical conditions in the waste package and the wider repository (see FEP 2.3.6.2).
2.3.7.5	Volatilisation (waste package)	Volatile compounds can be formed due to chemical and biochemical processes occurring in the waste package (e.g. degradation of organic materials). The rate of volatilisation is controlled by changes in pressure, temperature and concentration in the waste package
2.3.7.6	Gas dissolution (waste package)	Gases can dissolve in water in the waste package. Dissolution is controlled by changes in pressure, temperature and concentration.
2.3.7.7	Gas-induced failure	The pressure resulting from gases generated in a sealed waste package might be sufficient to cause the waste package to fail.
2.3.7.8	Impact of gas generation on other processes (waste package)	Gas generation may influence other processes; for example, gas generation in a waste form may expedite the mechanical failure of a waste package from crevice corrosion.
2.4	Contaminant Release (from waste form)	The processes that directly affect the release of radiotoxic and chemotoxic species from the waste form once the waste package has been emplaced in the repository. “Contaminant Release (from waste form)” is a sub-category in the International FEP List and is divided into individual FEPs.
2.4.1	Liquid-mediated release	FEPs related to release of radiotoxic and chemotoxic species into water in the aqueous phase from the waste form.
2.4.1.1	Liquid wastes	Release from waste packages in liquid form of radiotoxic and chemotoxic species in liquid wastes.

Number	Name	Description
2.4.1.2	Dissolution (waste form)	On contact with water, a waste form may alter and dissolve. For some waste forms (e.g. glass), this process can be very slow and result in the slow congruent release of radiotoxic and chemotoxic species contained within the waste form.
2.4.1.3	Diffusion (waste form)	Aqueous diffusion of radiotoxic and chemotoxic species from the waste form. For example, on contact with water, radiotoxic and chemotoxic species in a waste form may dissolve and diffuse into the water. This process is controlled by the chemical environment and by the waste form composition and structure.
2.4.1.4	Speciation and solubility (waste form)	Chemical speciation and solubility processes affecting the release of radiotoxic and chemotoxic species from a waste form under repository conditions. Speciation and solubility are affected by factors such as temperature, pressure, pH and redox conditions.
2.4.1.5	Sorption and desorption (waste form)	Sorption/desorption processes affecting the release of radiotoxic and chemotoxic species from a waste form under repository conditions. Sorption describes the physico-chemical interaction of dissolved species with a solid phase. Desorption is the opposite effect.
2.4.1.6	Complexation (waste form)	The impact of complexing agents on the release of radiotoxic and chemotoxic species from a waste form under repository conditions. Such agents can be in the waste and/or waste package and other repository materials (e.g. as additives to cements and grouts).
2.4.1.7	Colloids	The release of radiotoxic and chemotoxic species from a waste form due to transport of colloids and interaction of radiotoxic and chemotoxic species with colloids from a waste form under repository conditions. Sources can include materials in the waste package itself (e.g. cementitious materials, organic wastes) and inflowing water.
2.4.2	Gas-mediated release	FEPs related to release of radiotoxic and chemotoxic species in gas or vapour phase or as fine particulate or aerosol in gas or vapour.
2.4.2.1	Gaseous wastes	Release from waste packages in gas form of radiotoxic and chemotoxic species in gas wastes (e.g. Kr isotopes)
2.4.2.2	Radon production (waste form)	Release of radon gas from decay of Ra-226 in waste form.
2.4.2.3	Volatilisation (waste form)	Release of contaminants from waste form due to volatilisation resulting from chemical or biochemical reactions, e.g. C-14 incorporated into carbon dioxide or methane, I-129 forming iodine gas or methyl iodide, and tritium (H-3) incorporated into hydrogen gas or water vapour.

Number	Name	Description
2.4.2.4	Radiolysis (waste form)	Free hydrogen and oxygen gas generated from radiolysis in the waste form can affect the degradation of the waste form and the release of contaminants (e.g. tritium (H-3) incorporated into hydrogen gas).
2.4.3	Solid-mediated release	The release of radiotoxic and chemotoxic species in solid phase. This might result from processes such as the glacial/fluvial erosion of the repository or volcanic activity affecting the repository.
2.4.4	Human-action-mediated release	The release of radiotoxic and chemotoxic species as a direct result of human actions, e.g. due to drilling into or excavation of the waste form.
2.5	Contaminant Transport (waste package)	The processes that directly affect the migration of contaminant through the waste package once they have been released from the waste form. “Contaminant Transport” is a sub-category in the International FEP List and is divided into individual FEPs.
2.5.1	Transport pathways (waste package)	The possible transport pathways for contaminants through the waste package once they have been released from the waste form. Liquid-mediated transport processes could include advection, convection, dispersion, molecular or matrix diffusion, or multiphase transport. Gas-mediated processes and solid-mediated transport processes should also be considered.
2.5.2	Water-mediated transport (waste package)	FEPs related to transport of radiotoxic and chemotoxic species from waste packages in water in the aqueous phase.
2.5.2.1	Advection (waste package)	Advection is a process in which dissolved species are transported by the flow of the water through the waste package. The rate of advection will vary depending on hydraulic conditions in the repository and the integrity of the waste package.
2.5.2.2	Dispersion (waste package)	Dispersion is the spread in the spatial distribution of contaminants with time because of differential rates of advective or convective transport through the waste package.
2.5.2.3	Molecular diffusion (waste package)	Molecular diffusion of radiotoxic and chemotoxic species through the waste package. Diffusive transport is driven by thermal, concentration, or chemical potential gradients and can be in any direction relative to any advective water flow.

Number	Name	Description
2.5.2.4	Dissolution, precipitation, and mineralisation (waste package)	The dissolution, precipitation and crystallisation of radiotoxic and chemotoxic species in waste packages under repository conditions. Dissolution is the process by which constituents of a solid dissolve into solution. Precipitation occurs when chemical species in solution react to produce a solid that does not remain in solution. Mineralisation is the process of producing pure crystals of an element, molecule or mineral from a fluid or solution undergoing a cooling process.
2.5.2.5	Speciation and solubility (waste package)	Chemical speciation and solubility of radiotoxic and chemotoxic species in waste packages under repository conditions. Speciation and solubility are affected by factors such as temperature, pressure, pH and redox conditions. Different species of the same element may have different solubilities in a particular solution.
2.5.2.6	Sorption and desorption (waste package)	Sorption/desorption processes affecting the migration of radiotoxic and chemotoxic species through the waste packages under repository conditions. Sorption describes the physico-chemical interaction of dissolved species with a solid phase. Desorption is the opposite effect.
2.5.2.7	Complexation (waste package)	The impact of complexing agents on the transport of radiotoxic and chemotoxic species through waste packages under repository conditions. Such agents can be in the waste and/or waste package and other repository materials (e.g. as additives to cements and grouts).
2.5.2.8	Colloid transport (waste package)	The transport of colloids and interaction of radiotoxic and chemotoxic species with colloids migrating through waste packages under repository conditions. Colloids may influence contaminant transport in a variety of ways: retarding transport by sorption of aqueous radionuclide species and subsequent filtration; or, enhancing transport by sorption and transport with flowing groundwater. Sources can include materials in the waste package itself (e.g. cementitious materials, organic wastes) and inflowing water.
2.5.3	Gas-mediated transport (waste package)	Transport of radiotoxic and chemotoxic species in gas or vapour phase or as fine particulate or aerosol in gas or vapour through the waste packages.
3	REPOSITORY FACTORS	FEPs related to the repository (including the excavation damaged and disturbed zones but excluding the waste packages (see FEP 2: Waste Package Factors).
3.1	Repository Characteristics and Properties	Features and properties of the repository at the time of closure (including the excavation damaged and disturbed zones but excluding waste packages). “Repository Characteristics and Properties” is a sub-category in the International FEP List and is divided into individual FEPs.
3.1.1	Design	The design and layout of the repository and its various engineered features and associated seals at the time of repository closure.

Number	Name	Description
3.1.2	Buffer/backfill	The physical, chemical and biological characteristics of the buffer and/or backfill at the time of waste emplacement in the repository.
3.1.3	Room/tunnel seals	The physical, chemical and biological characteristics of the seals in the waste emplacement rooms/tunnel at the time of sealing.
3.1.4	Shaft/ramp seals	The physical, chemical and biological characteristics of the shaft/ramp seals at the time of sealing.
3.1.5	Other engineered features	The physical, chemical and biological characteristics of the engineered features (other than packages, buffer/backfill, and seals) at the time of waste emplacement in the repository. Such features can include rock bolts, shotcrete, tunnel liners, silo walls, any services and equipment not removed before closure.
3.1.6	Excavation damaged and disturbed zones	The zone of rock around caverns, tunnels, shafts or other underground openings that may be mechanically disturbed during excavation. The extent of damage will decrease within increasing distance from the excavation and there will be transition from the excavation damaged zone to the excavation disturbed zone to the undisturbed host rock.
3.2	Repository Processes	Processes within the repository (including the excavation damaged and disturbed zones but excluding waste packages). The primary focus is on processes occurring after repository closure but some consideration is required of processes pre-closure. “Repository Processes” is a sub-category in the International FEP List and is divided into individual FEPs.
3.2.1	Thermal processes (repository)	FEPs related to the thermal processes that affect the seals and other engineered repository features. This includes the effects of heat on seals and repository components from the waste packages and surrounding geology.
3.2.1.1	Thermal conduction and convection	Heat transfer due to gradients in temperature caused by heat conduction or convective flow - the overall thermal evolution of the repository with time.
3.2.1.2	Impact of thermal processes on other processes (repository)	Thermal processes coupled with hydraulic, mechanical and chemical processes, as well as biological and radiological processes. The behaviour of any buffer/backfill and the achievement of its safety functions can depend on the time and rate at which these processes occur.
3.2.2	Hydraulic processes (repository)	FEPs related to the hydraulic/hydrogeological processes that affect the seals and other engineered repository features, and the overall hydraulic/hydrogeological evolution of repository with time. This includes the effects of hydraulic/hydrogeological influences on the repository components by the waste packages and surrounding geology.

Number	Name	Description
3.2.2.1	Resaturation/desaturation (repository)	The establishment of unsaturated conditions near the repository during the excavation and operation phases, and their return to saturated conditions. The timing of desaturation/resaturation will be affected by a variety of factors, including the characteristics of the host rock, the performance of the repository seals, and the evolution of pressure and temperature in the repository.
3.2.2.2	Piping/hydraulic erosion	The hydraulic erosion of the buffer or backfill. Water may flow into the repository, e.g. through intersecting hydraulically active fractures. If the rate of inflow exceeds the rate of uptake by the buffer/backfill, then active flow channels or 'pipes' may develop in the buffer/backfill. Continuing flow through these pipes could result in progressive erosion of the buffer which, over time, may result in a reduction in the density of the buffer/backfill that could compromise its barrier functions.
3.2.2.3	Impact of hydraulic processes on other processes (repository)	Hydraulic processes coupled with thermal, mechanical and chemical processes, as well as biological and radiological processes. The behaviour of the seals and the achievement of their safety functions will depend on the time and rate at which these processes occur.
3.2.3	Mechanical processes (repository)	FEPs related to the mechanical processes that affect the seals and other engineered repository features, and the overall mechanical evolution of repository with time. This includes the effects of hydraulic and mechanical loads imposed on repository components by the waste packages and surrounding geology.
3.2.3.1	Material volume changes (repository)	The effects of buffer and backfill swelling, as well as volume changes in other repository materials (e.g. the shrinkage/expansion of concrete, the corrosion of rock bolts).
3.2.3.2	Creep	The plastic movement of buffer and backfill material under an imposed load. The buffer and backfill materials can creep or move as a result of imposed loads such as the weight of the waste packages or lithostatic pressure from the host rock.
3.2.3.3	Collapse of openings	The collapse of tunnels and boreholes, including cave-ins, roof settling, and rock bursts. Potential effects include damage to the waste packages, buffer, backfill and other seals, and changes to water flow conditions in the repository and surrounding geosphere.
3.2.3.4	Gas explosion (repository)	Some gases produced from the corrosion and degradation of waste packages and engineered repository features might be flammable or might form an explosive mixture; for instance, hydrogen and methane could mix with oxygen and explode to damage the repository and its seals. A gas explosion can only occur if a flammable gas mixture forms and there is a source of ignition or the gas mixture has the capability to auto-ignite.

Number	Name	Description
3.2.3.5	Impact of mechanical process on other processes (repository)	FEPs relating to mechanical processes coupled with other processes. Couplings of mechanical processes with thermal, hydraulic and chemical processes, as well as biological and radiological processes, will affect the evolution of the repository. For example, the swelling of bentonite sealing can limit the resaturation of the repository.
3.2.4	Chemical processes (repository)	FEPs related to the chemical/geochemical processes that affect the seals and other engineered repository features, and the overall chemical/geochemical evolution of the repository with time. This includes the effects of chemical/geochemical influences on repository components by the waste packages and surrounding geology.
3.2.4.1	pH conditions (repository)	The temporal evolution of pH within the repository. Repository water composition, including its pH, is important in determining the solubility of certain elements. It depends on a number of factors, including the pH of the water in the host geology, the water flow rate through the repository and the characteristics of the repository seals and other engineered features.
3.2.4.2	Redox conditions (repository)	The temporal evolution of the repository's Eh depends on a number of factors, including the Eh of the water in the host geology, the water flow rate through the repository and the consumption rate of any available oxygen.
3.2.4.3	Perturbing species' concentrations (repository)	The presence of certain species, such as chloride, sulphate and potassium, can affect the evolution of the repository and its seals, for example through promoting the corrosion of metals (high chloride concentrations), the degradation of cement (high sulphate concentrations) and the illitisation of bentonite (high potassium concentrations). Sources of such species can include the waste forms and inflowing water.
3.2.4.4	Corrosion (repository)	Corrosion of repository metals (e.g. rock bolts) can be generalised (or uniform), local, or galvanic. All metals are subject to uniform corrosion at rates that are dependent on the chemical and physical (and possibly biological) environment, while localised formation of cavities in a metal surface is caused by non-uniform corrosion. Galvanic corrosion occurs when two different metals are in electric contact.
3.2.4.5	Dissolution (repository)	Dissolution processes, including their evolution in time, affecting repository materials. Changes to the chemical environment of the repository (e.g. changes to pH and Eh) could lead to evolution of the dissolution rate of repository materials (e.g. dissolution of cements).
3.2.4.6	Mineralisation (repository)	Mineralisation in repository materials, including leaching, carbonation, illitisation, and chloride and sulphate attack. If fractures in the repository walls are mineralised, the accessibility of the rock matrix may be reduced.

Number	Name	Description
3.2.4.7	Precipitation reactions (repository)	Precipitation processes, including their evolution in time, affecting repository materials. Precipitation can occur in the buffer and backfill or elsewhere in the repository if there is an abrupt change in the chemical environment
3.2.4.8	Chelating agent effects (repository)	Chelating agents in the repository can form very stable species, a factor that can increase significantly the solubilities of certain elements. Sources can include organic wastes and inflowing water.
3.2.4.9	Colloid formation (repository)	Colloids are very fine particles that can affect the transport of contaminants. Particles of clay minerals, silica, iron oxy-hydroxides, other minerals, organic and bio-organic macromolecules may form the colloid phase. Sources can include materials in the waste package (e.g. cementitious materials, organic wastes), repository materials (e.g. bentonite and cementitious materials) and inflowing water.
3.2.4.10	Chemical concentration gradients (repository)	Chemical concentration gradients in the repository could be caused by heterogeneities in the spatial distribution of waste packages and repository materials. The formation of chemical concentration gradients may lead to the dissolution and precipitation of chemical compounds with subsequent opening or plugging of flow paths.
3.2.4.11	Impact of chemical processes on other processes (repository)	Chemical processes coupled with other processes. Couplings of chemical processes with thermal, hydraulic and mechanical processes, as well as biological and radiological processes, will affect the evolution of the repository. For example, chemical precipitation of minerals can limit the flow of water through repository seals.
3.2.5	Biological processes (repository)	FEPs related to the biological/biochemical processes that affect the seals and other engineered repository features, and the overall biological/biochemical evolution of the repository with time. This includes the effects of biological/biochemical influences on repository components by the waste packages and surrounding geology.
3.2.5.1	Microbial growth and poisoning (repository)	A wide range of microbes can be introduced into the repository during its construction and operation. Growth requires the presence of suitable nutrients, such as cellulosic wastes, simple organic molecules containing oxygen, nitrogen and/or sulphur, and small amounts of putrescible materials. Poisoning of microbial processes can occur but extremophiles can survive and thrive outside the range at which most microbes flourish (see FEP 2.3.5.2).
3.2.5.2	Microbially/biologically mediated processes (repository)	Microbial processes can lead to the formation of acidic and oxidising species that can participate in corrosion of the metals and promotion of reducing conditions in the repository. Bacteria may also result in the conversion of gases (e.g. carbon dioxide and hydrogen into methane – methanogenesis), and restrict the movement of water through the generation of biofilms of repository surfaces.

Number	Name	Description
3.2.5.3	Impact of biological processes on other processes (repository)	FEPs relating to biological processes coupled with other processes. Couplings of biological processes with thermal, hydraulic, mechanical and chemical processes, as well as radiological processes, will affect the evolution of the repository. For example, methanogenesis will reduce repository gas pressures which can affect repository resaturation.
3.2.6	Radiological processes (repository)	FEPs related to the effects of radiation emitted from the wastes on the seals and other repository engineered features.
3.2.6.1	Radioactive decay and ingrowth (repository)	Radioactive decay and ingrowth will affect any radionuclides released from the waste packages into the repository.
3.2.6.2	Radiolysis (repository)	Radiolysis of any water in the repository environment immediate adjacent to the waste packages (especially for high-level waste and spent fuel) can produce species such as free hydrogen and oxygen which can impact the chemical conditions in the repository (e.g. the redox potential) (see FEP 3.2.7.4).
3.2.6.3	Radiation attenuation (repository)	Radiation attenuation in the buffer and backfill adjacent to the waste package. The rate of radiation attenuation is controlled in part by the design of the waste package. Radiation from the waste package can affect heat transfer, thermal expansion, resaturation and water radiolysis in the buffer and backfill.
3.2.6.4	Radiation damage (repository)	Radiation damage from fission and alpha decay in the buffer and/or backfill adjacent to the waste package. This could detrimentally affect the properties of the sealing materials.
3.2.6.5	Criticality	The possibility and effects of spontaneous nuclear fission chain reactions within the repository. Criticality requires a sufficient concentration and localised mass (critical mass) of fissile isotopes (e.g. U-235, Pu-239) and also presence of neutron moderating materials in a suitable geometry; a chain reaction is liable to be damped by the presence of neutron absorbing isotopes (e.g. Pu-240).
3.2.6.6	Impact of radiological processes on other processes (repository)	FEPs relating to radiological processes coupled with other processes. For example, the effects of radiolysis of the water in the sealing materials could potentially affect the water chemistry, i.e., the effective electrochemical potential (Eh) and pH, and result in chemical changes to the bentonite materials in the sealing materials.
3.2.7	Gas generation (repository)	FEPs within and around the seals and engineered repository features resulting in the generation of gases and their subsequent effects on the repository system (excludes gas generation from waste packages – see FEP 2.3.7).

Number	Name	Description
3.2.7.1	Metal corrosion (repository)	Metals utilised in the repository construction (e.g. rock bolts, ventilation ducts and rails) that are not removed at closure will corrode resulting in hydrogen gas generation if the conditions are anaerobic.
3.2.7.2	Organic degradation (repository)	Organic materials and compounds contained within the repository (excluding any organics contained the waste packages) that are prone to chemical and biological degradation. Might include oils not removed at the time of repository closure.
3.2.7.3	Radon production (repository)	The production of radon gas in the repository from the decay naturally occurring Ra-226.
3.2.7.4	Radiolysis (repository)	Radiolysis of any water in the repository environment immediately adjacent to the waste packages (especially for high-level waste and spent fuel) can produce gaseous species such as free hydrogen and oxygen which can impact the chemical conditions in the repository (e.g. the redox potential) (see FEP 3.2.6.2).
3.2.7.5	Volatilisation (repository)	Volatile compounds can be formed due to chemical and biochemical processes occurring in the repository. The rate of volatilisation is controlled by changes in pressure, temperature and concentration in the repository.
3.2.7.6	Gas dissolution (repository)	Gases can dissolve in repository water and be transported out of the repository as dissolved species. Dissolution is controlled by changes in pressure, temperature and concentration in the repository.
3.2.7.7	Gas-induced dilation (repository)	Under certain conditions, the repository gas pressure might become sufficiently high to cause physical damage to the repository seals and allow the movement of gas as a discrete phase within stress- or pressure-induced microscopic porosity in the seals.
3.2.7.8	Impact of gas generation on other processes (repository)	Gas generation may influence other processes. For example, when a gas phase is formed in a water saturated repository system, water will be expelled from it. If gas generation from a repository is such that substantial pressure build-up occurs, intermittent gas flow can occur.
3.3	Contaminant Transport (repository)	The processes that directly affect the migration of radionuclides in the repository once they have been released from the waste packages. “Contaminant Transport (repository)” is a sub-category in the International FEP List and is divided into individual FEPs.
3.3.1	Transport pathways (repository)	Possible contaminant transport pathways from the waste packages through the repository and its various features into the surrounding geosphere.

Number	Name	Description
3.3.2	Water-mediated transport (repository)	FEPs related to transport of radiotoxic and chemotoxic species in repository water in the aqueous phase.
3.3.2.1	Advection (repository)	Advection is a process in which dissolved species are transported by the flow of water through the repository. The rate of advection will vary depending on hydraulic conditions in the repository and geosphere and the integrity of the repository seals.
3.3.2.2	Dispersion (repository)	Variations in water velocity and pathways cause dispersion, i.e. the spatial spreading of contaminants from advective transport. Dispersion can occur in the direction of flow (longitudinal dispersion) and perpendicular to the direction of flow (transverse dispersion).
3.3.2.3	Molecular diffusion (repository)	Molecular diffusion can occur in moving or stagnant repository water. Diffusive transport is driven by thermal, concentration, or chemical potential gradients and can be in any direction relative to any advective water flow. Diffusion can be the most important transport mechanisms in situations where repository water flow is very slow.
3.3.2.4	Dissolution, precipitation, and mineralisation (repository)	The dissolution, precipitation and crystallisation of radiotoxic and chemotoxic species in the repository under prevailing repository conditions. Dissolution is the process by which constituents of a solid dissolve into solution. Precipitation occurs when chemical species in solution react to produce a solid that does not remain in solution. Mineralisation is the process of producing pure crystals of an element, molecule or mineral from a fluid or solution undergoing a cooling process.
3.3.2.5	Speciation and solubility (repository)	Chemical speciation and solubility of radiotoxic and chemotoxic species in the repository under prevailing repository conditions. Speciation and solubility are affected by factors such as temperature, pressure, pH and redox conditions.
3.3.2.6	Sorption and desorption (repository)	Sorption/desorption processes affecting the migration of radiotoxic and chemotoxic species through the repository under prevailing repository conditions. Sorption describes the physico-chemical interaction of dissolved species with a solid phase. Desorption is the opposite effect.
3.3.2.7	Complexation (repository)	The impact of complexing agents on the transport of radiotoxic and chemotoxic species through the repository under prevailing repository conditions. Such agents can be in the waste package and other repository materials (e.g. as additives to cements and grouts).

Number	Name	Description
3.3.2.8	Colloid transport (repository)	The transport of colloids and interaction of radiotoxic and chemotoxic species with colloids migrating through the repository under prevailing repository conditions. Colloids may influence contaminant transport in a variety of ways: retarding transport by sorption of aqueous radionuclide species and subsequent filtration; or, enhancing transport by sorption and transport with flowing water. Sources can include materials in the waste package (e.g. organic wastes), the repository (e.g. cementitious materials) and inflowing water.
3.3.3	Gas-mediated transport (repository)	Transport of radiotoxic and chemotoxic species in gas or vapour phase or as fine particulate or aerosol in gas or vapour through the repository.
3.3.4	Solid-mediated transport (repository)	Transport of radiotoxic and chemotoxic species in solid phase from the repository. This might result from processes such as the glacial/fluvial erosion of the repository or volcanic activity affecting the repository.
3.3.5	Human-action-mediated transport (repository)	Transport of radiotoxic and chemotoxic species from the repository as a direct result of human actions, e.g. due to drilling into or excavation of the repository.
4	GEOSPHERE FACTORS	FEPs related to the geosphere.
4.1	Geosphere Characteristics and Properties	The features and properties within the geosphere prior to repository construction and waste emplacement. "Geosphere Characteristics and Properties" is a sub-category in the International FEP List and is divided into individual FEPs.
4.1.1	Stratigraphy	The succession of different rock types that form the geosphere (other than the host rock – see FEP 4.1.2) . Typically rocks are divided into geological units with similar properties and characteristics. Relevant properties and characteristics of units include: spatial extent, thermal and hydraulic conductivity, fracture frequency and connectivity, compressive and shear strength, porosity, tortuosity, thickness, structure, groundwater composition and salinity, mineral composition and pore water pressure. The inhomogeneity and uncertainty of these properties is also part of their characterisation.
4.1.2	Host rock lithology	The properties and characteristics of the rock in which the repository is sited (excluding the rock that may be mechanically disturbed by the excavation).
4.1.3	Large-scale discontinuities	The properties and characteristics of discontinuities in and between the host rock and geological units, including faults, shear zones, intrusive dykes and interfaces between different rock types.

Number	Name	Description
4.1.4	Geological resources	Natural resources within the geosphere, particularly those that might encourage investigation or excavation at or near the repository site (e.g. oil, gas, solid minerals, water and geothermal resources).
4.1.5	Undetected features	Natural or man-made features within the geology that may not be detected during the site investigation (e.g. fracture zones, faults, brine pockets, old mine workings and boreholes).
4.1.6	Current geothermal state	The thermal processes that affect the host rock and other rock units prior to construction of the repository and the resulting thermal conditions. Consideration needs to be given to the sources of geological heat, the distribution of heat by conduction and transport (convection) in fluids, and the resulting thermal field or gradient.
4.1.7	Current hydraulic state	The hydraulic and hydrogeological processes that affect the host rock and other rock units prior to construction of the repository and the resulting hydraulic conditions. Consideration needs to be given to movement of water through the geological units and the factors that control the movement including recharge and discharge zones, groundwater flow systems, density effects due to salinity gradients or temperature gradients.
4.1.8	Current stress state	The mechanical processes that affect the host rock and other rock units prior to construction of the repository and the resulting stress conditions. Consideration needs to be given to loading and uploading events such as ice sheet advance and retreat that will have affected the site.
4.1.9	Current geochemical state	The chemical and geochemical processes that affect the host rock and other rock units prior to construction of the repository and the resulting geochemical conditions. Consideration needs to be given to factors such as speciation, solubility, complexants, redox conditions, rock mineral composition and weathering processes, salinity and chemical gradients.
4.1.10	Current biological state	The biological and biochemical processes that affect the host rock and other rock units prior to construction of the repository and the resulting biological conditions. Information should be provided on current microbe populations.
4.1.11	Current gas state	Natural gas sources within the geosphere and their effect of on the geosphere, including the transport of bulk gases. Gas movement in the geosphere will be determined by many factors including the rate of production, gas permeability and solubility, and the hydrostatic pressure conditions.

Number	Name	Description
4.2	Geosphere Processes	The processes in pre-emplacement state and as modified by the presence of the repository and other long-term changes. “Geosphere Processes” is a sub-category in the International FEP List and is divided into individual FEPs.
4.2.1	Thermal processes (geosphere)	FEPs related to the thermal processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. temperature, due to the excavation, construction and long-term presence of the repository.
4.2.1.1	Thermal effects of repository (geosphere)	Thermal energy generated from the waste form will be transferred through the waste package and repository and into the geosphere. Some heat can also be transferred from the repository backfill (e.g. curing of cement) to the geosphere.
4.2.1.2	Thermal effects of climate change (geosphere)	The primary cause of climate change is likely to be glacial/inter-glacial cycling that might result in ice sheet advance/retreat over the site which will affect the thermal profile in the geosphere.
4.2.1.3	Other processes affecting future thermal conditions in geosphere	Processes other than those related to the repository and climate change that might affect the thermal evolution of the host rock and other rock units. Examples include volcanic and magmatic activity (see FEP 1.2.5) and hydrothermal activity (see FEP 1.2.7).
4.2.2	Hydraulic processes (geosphere)	FEPs related to the hydraulic and hydrogeological processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. hydraulic head, due to the excavation, construction and long-term presence of the repository.
4.2.2.1	Hydraulic effects of repository (geosphere)	The short and long-term hydraulic effects of the repository on the geosphere. Effects include the potential dewatering of the rock immediately surrounding the repository during the operational phase and the modification of groundwater flow directions.
4.2.2.2	Hydraulic effects of climate change (geosphere)	The primary cause of climate change is likely to be glacial/inter-glacial cycling that might result in ice sheet advance/retreat over the site. This will impact on groundwater recharge and hydraulic gradients.
4.2.2.3	Other processes affecting future hydraulic conditions in the geosphere	Processes other than those related to the repository and climate change that might affect the hydraulic evolution of the host rock and other rock units. Examples include seismicity (see FEP 1.2.4), regional erosion and sedimentation (see FEP 1.2.7) and water management (see FEP 1.4.9). Such events may change flow pathways, permeabilities, head distributions.

Number	Name	Description
4.2.3	Mechanical processes (geosphere)	FEPs related to the mechanical processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. rock stress, due to the excavation, construction and long-term presence of the repository
4.2.3.1	Mechanical effects of repository (geosphere)	The effects on in situ stresses that the presence of the repository has on the host rock and other rock units.
4.2.3.2	Mechanical effects of climate change (geosphere)	The primary cause of climate change is likely to be glacial/inter-glacial cycling that might result in ice sheet advance/retreat over the site which will affect the in situ stresses in the geosphere.
4.2.3.3	Other processes affecting future stress conditions in geosphere	Processes other than those related to the repository and climate change that might affect the evolution of stress conditions in the host rock and other rock units. Examples include tectonic movement (see FEP 1.2.1), orogeny (see FEP 1.2.2), deformation (see FEP 1.2.3), seismicity (see FEP 1.2.4), regional erosion and sedimentation (see FEP 1.2.7), drilling activities (see FEP 1.4.5) and mining and other underground activities (see FEP 1.4.6).
4.2.4	Geochemical processes (geosphere)	FEPs related to the chemical and geochemical processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. Eh, pH, due to the excavation, construction and long-term presence of the repository.
4.2.4.1	Geochemical effects of repository (geosphere)	Geochemical effects resulting from the materials used in the repository for waste encapsulation, backfilling and structural purposes. These effects may impact the performance of the geosphere by potentially changing factors such as sorption, groundwater flow, and matrix diffusion behaviour.
4.2.4.2	Geochemical effects of climate change (geosphere)	The primary cause of climate change is likely to be glacial/inter-glacial cycling that might result in ice sheet advance/retreat over the site. This will impact on groundwater recharge which will introduce meltwater with different compositional and thermal properties into the geosphere and modify the geochemical conditions, at least in the upper parts of the geosphere.
4.2.4.3	Other processes affecting future geochemical conditions in geosphere	Processes other than those related to the repository and climate change that might affect the geochemical evolution of the host rock and other rock units. Examples include hydrothermal activity (see FEP 1.2.7), drilling activities (see FEP 1.4.5) and mining and other underground activities (see FEP 1.4.6).

Number	Name	Description
4.2.5	Biological processes (geosphere)	FEPs related to the biological and biochemical processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. microbe populations, due to the excavation, construction and long-term presence of the repository.
4.2.5.1	Biological effects of repository (geosphere)	Microbes can be natural to the geosphere, or can be introduced with repository materials. The presence of the repository may change the conditions in the geosphere around the repository, which will affect the microbial species in the geosphere around the repository (e.g. provide a source of nutrients).
4.2.5.2	Biological effects of climate change (geosphere)	The primary cause of climate change is likely to be glacial/inter-glacial cycling that might result in ice sheet advance/retreat over the site. This will impact on thermal, hydraulic and geochemical conditions in the geosphere which in turn will affect the microbial species.
4.2.5.3	Other processes affecting future biological conditions in geosphere	Processes other than those related to the repository and climate change that might affect the biological evolution of the host rock and other rock units. Examples include hydrothermal activity (see FEP 1.2.7), drilling activities (see FEP 1.4.5) and mining and other underground activities (see FEP 1.4.6).
4.2.6	Radiological processes (geosphere)	Any possible effects of radiation emitted from the wastes on the host rock immediately surrounding repository, such as radiolysis and radiation attenuation.
4.2.7	Gas processes (geosphere)	FEPs related to natural gas sources and production of gas within the geosphere and also the effect of natural and repository produced gas on the geosphere, including the transport of bulk gases and the overall evolution of conditions with time.
4.2.7.1	Gas sources (geosphere)	Sources of non-repository derived gases in the geosphere such as methane (derived from the degradation of organics in the rocks) and gases stored by humans.
4.2.7.2	Radon production (geosphere)	The production of radon gas in the geosphere from the decay of naturally occurring Ra-226.
4.2.7.3	Volatilisation (geosphere)	Volatile compounds can be formed due to chemical and biochemical processes occurring in the geosphere. The rate of volatilisation is controlled by changes in pressure, temperature and concentration in the geosphere.
4.2.7.4	Gas dissolution (geosphere)	Gases can dissolve in groundwater and be transported through the geosphere as dissolved species. Dissolution is controlled by changes in pressure, temperature and concentration in the geosphere.

Number	Name	Description
4.2.7.5	Gas-induced dilation (geosphere)	Under certain conditions, the repository gas pressure might become sufficiently high to cause physical damage to the host rock and allow the movement of gas as a discrete phase within stress- or pressure-induced microscopic porosity in the rock.
4.3	Contaminant Transport (geosphere)	The processes that directly affect the migration and/or release of radionuclides in the geosphere. “Contaminant Transport (geosphere)” is a sub-category in the International FEP List and is divided into individual FEPs
4.3.1	Transport pathways (geosphere)	The properties and characteristics of discontinuities and features within the host rock and other geological units that are expected to be the main paths for contaminant transport through the geosphere, as they may evolve both before and after repository closure.
4.3.2	Water-mediated transport (geosphere)	FEPs related to transport of radiotoxic and chemotoxic species in groundwater and within the geosphere in the aqueous phase.
4.3.2.1	Advection (geosphere)	Advection is a process in which dissolved species are transported by the flow of water through the repository. The rate of advection will vary depending on hydraulic conditions in the geosphere and repository.
4.3.2.2	Dispersion (geosphere)	Variations in water velocity and pathways cause dispersion, i.e. the spatial spreading of contaminants from advective transport. Dispersion can occur in the direction of flow (longitudinal dispersion) and perpendicular to the direction of flow (transverse dispersion).
4.3.2.3	Molecular diffusion (geosphere)	Molecular diffusion can occur in moving or stagnant water. Diffusive transport is driven by thermal, concentration, or chemical potential gradients and can be in any direction relative to any advective groundwater flow. Diffusion can be the most important transport mechanisms in situations where groundwater flow in the geosphere is very slow.
4.3.2.4	Matrix diffusion	This process occurs in a flowing fracture where contaminants may move laterally out of the fracture and into an intricate network of interconnected microfractures and micropores within the rock by molecular diffusion.
4.3.2.5	Dissolution, precipitation, and mineralisation (geosphere)	The dissolution, precipitation and mineralisation of radiotoxic and chemotoxic species in the geosphere under prevailing geosphere conditions. Dissolution is the process by which constituents of a solid dissolve into solution. Precipitation occurs when chemical species in solution react to produce a solid that does not remain in solution. Mineralisation is the process of producing pure crystals of an element, molecule or mineral from a fluid or solution undergoing a cooling process.

Number	Name	Description
4.3.2.6	Speciation and solubility (geosphere)	Chemical speciation and solubility of radiotoxic and chemotoxic species in the geosphere under prevailing geosphere conditions. Speciation and solubility are affected by factors such as temperature, pressure, pH and redox conditions.
4.3.2.7	Sorption and desorption (geosphere)	Sorption/desorption processes affecting the migration of radiotoxic and chemotoxic species in the geosphere under prevailing geosphere conditions. Sorption describes the physico-chemical interaction of dissolved species with a solid phase. Desorption is the opposite effect.
4.3.2.8	Complexation (geosphere)	The impact of complexing agents on the transport of radiotoxic and chemotoxic species through the geosphere under prevailing geosphere conditions. Such agents can be in the waste package and other repository materials (e.g. as additives to cements and grouts).
4.3.2.9	Colloid transport (geosphere)	The transport of colloids and interaction of radiotoxic and chemotoxic species with colloids migrating through the geosphere under prevailing geosphere conditions. Colloids may influence contaminant transport in a variety of ways: retarding transport by sorption of aqueous radionuclide species and subsequent filtration; or, enhancing transport by sorption and transport with flowing groundwater. Sources can include materials in the waste package (e.g. organic wastes), the repository (e.g. cementitious materials) and the geosphere (e.g. naturally occurring organics).
4.3.3	Gas-mediated transport (geosphere)	Transport of radiotoxic and chemotoxic species in gas or vapour phase or as fine particulate or aerosol in gas or vapour through the geosphere.
4.3.4	Solid-mediated transport (geosphere)	Transport of radiotoxic and chemotoxic species in solid phase in the geosphere, for example large-scale glacial/fluvial erosion and volcanic activity.
4.3.5	Human-action-mediated transport (geosphere)	Transport of radiotoxic and chemotoxic species in the geosphere as a direct result of human actions, e.g. due to drilling into or excavation of the geosphere.
5	BIOSPHERE FACTORS	FEPs related to the biosphere.
5.1	Surface Environment	The features and processes within the surface environment and their potential future evolution, including near-surface aquifers and unconsolidated sediments but excluding human activities and behaviour, see FEPs 1.4 and 5.2. “Surface Environment” is a sub-category in the International FEP List and is divided into individual FEPs.
5.1.1	Topography and morphology	The relief and shape of the surface environment and its potential evolution with time. Topography defines surface water flows, the location of groundwater recharge and discharge locations, and the magnitude of hydraulic heads that drive local and regional groundwater flows.

Number	Name	Description
5.1.2	Biomes	A biome is a mixed community of plants and animals (a biotic community) occupying a major geographical area on a continental scale. Each biome is characterised by similarity of vegetation structure or physiognomy rather than by similarity of species composition, and is usually related to climate. Within a particular biome, the plants and animals are regarded as being well adapted to each other and to broadly similar environmental conditions, especially climate.
5.1.3	Soil and sediment	FEPs related to the characteristics of the soils and sediments that overlie the rock of the geosphere and their potential evolution with time.
5.1.3.1	Surface soils	The soils and sediments that are at or near the terrestrial surface. The soil type, such as loam, sand, clay and organic, can be roughly characterised by parameters such as particle-size distribution and organic matter content. These will have different physical and chemical properties, different land management properties, and different contaminant transport properties. Microbial populations (or their absence) are an important component of soils and sediments.
5.1.3.2	Overburden	The unconsolidated rock, clay, sand and soils that overly the rock of the geosphere, but not including the surface soils. The overburden will change in time. These changes will be driven by natural weathering processes in the same way that soils evolve. Human activities such as dredging and excavation can also affect the overburden.
5.1.3.3	Aquatic sediments	Aquatic sediments are found at the bottom of surface water bodies and are generally composed of fine-grained sand, clays, and organic material. They are subject to wave action and currents and can be eroded and reformed relatively easily.
5.1.4	Near-surface aquifers and water-bearing features	Aquifers and water-bearing features within a few tens of metres of the land surface and their potential evolution with time.
5.1.5	Terrestrial surface water bodies	FEPs related to the characteristics of terrestrial surface water bodies and their potential evolution with time.
5.1.5.1	Wetlands	Land areas where the water table is at or near the surface. Wetlands (including marshes, fens and peat bogs) may be underlain by, or lead to formation of, thick deposits of organic material (e.g., peat) and may be discharge areas for deep groundwaters. Wetlands may also be drained to provide agricultural land and mined for peat which is then used as a fuel or soil supplement.

Number	Name	Description
5.1.5.2	Lakes and rivers	Surface water bodies that are large enough to persist for many years. Surface water bodies will evolve through a number of processes such as gradual infill, meandering and braiding. Climate change bringing about the evolution of surface water bodies should also be considered.
5.1.5.3	Spring and discharge zones	Locations where the water table intersects the surface, allowing groundwaters to flow out onto the surface. Discharge zones are often low-lying areas such as at the margin or bottoms of lakes and wetlands (bogs and marshes). Springs may also be found at various elevations depending on factors such as the lithology and stratigraphy of the geosphere and the location of outcropping geological units.
5.1.6	Coastal features	The characteristics of coasts and the near shore, and their potential evolution with time. Coastal features include headlands, bays, beaches, spits, cliffs and estuaries. The processes operating on these features, e.g. active erosion, deposition, longshore transport, determine the development of the coastal system.
5.1.7	Marine features	The characteristics of seas and oceans, including the sea bed, and their potential evolution with time. Marine features include oceans, ocean trenches, shallow seas, and inland seas. Processes operating on these features such as erosion, deposition, thermal stratification and salinity gradients, determine the development of the marine system.
5.1.8	Atmosphere	The characteristics of the atmosphere, including capacity for transport, and their potential evolution with time. Relevant processes include physical transport of gases, aerosols and dust in the atmosphere and chemical and photochemical reactions.
5.1.9	Vegetation	The characteristics of terrestrial and aquatic vegetation both as individual plants and in mass, and their potential evolution with time.
5.1.10	Animals	The characteristics of the terrestrial and aquatic animals both as individual animals and as populations, and their potential evolution with time.
5.1.11	Climate and weather	The characteristics of weather and climate, and their potential evolution with time. They are characterised by precipitation, temperature, pressure and wind speed and direction. Their variability should be considered so that extremes such as drought, flooding, storms and snow melt are identified.
5.1.12	Hydrological regime and water balance (near-surface)	The near-surface hydrology at a catchment scale and soil water balance, and their potential evolution with time. Includes movement of water and sediments and consideration of extremes such as drought, flooding, storms and snow melt.

Number	Name	Description
5.1.13	Erosion and deposition	The erosional and depositional processes that operate in the surface environment, and their potential evolution with time. Relevant processes may include, fluvial and glacial erosion and deposition, denudation, aeolian erosion and deposition. These processes will be controlled by factors such as the climate, vegetation, topography and geomorphology
5.1.14	Ecological/biological/microbial systems	The relations between populations of animals, plants and microbes and their potential evolution with time.
5.2	Human Behaviour	The habits and characteristics of the individuals or populations, e.g. critical groups, to whom exposures are calculated. “Human Behaviour” is a sub-category in the International FEP List and is divided into individual FEPs.
5.2.1	Human characteristics (physiology, metabolism)	Characteristics, i.e. physiology and metabolism, of individual humans. Physiology refers to body and organ form and function. Metabolism refers to the chemical and biochemical reactions that occur within an organism in connection with the production and use of energy.
5.2.2	Age, gender, and ethnicity	Considerations of variability, in individual humans, of physiology, metabolism and habits. Susceptibility to radioactive and chemically toxic materials varies with age, sex and reproductive status. In addition, children and infants, although similar to adults, often have characteristic differences (e.g. respiratory rates, food types, ingestion of soil) that may lead to different exposure characteristics.
5.2.3	Diet and fluid intake	FEPs related to intake of food and water by individual humans and the compositions and origin of intake.
5.2.3.1	Farming diet	The food and water intake characteristics of persons living a farming lifestyle. For instance, the community’s food intake may have a high proportion of plant food grown on local (and potentially contaminated) soil, as well as domesticated animals and fish. Water would come from wells or surface water bodies. The type of farming household can vary from self-sufficient to an "industrial" or monoculture operation.
5.2.3.2	Hunter/gatherer diet	The food and water ingested by persons living a hunter/gatherer lifestyle. Typically, the community’s food intake would have a high proportion of fish and wild game, with little agriculture, water would come from springs or other surface water bodies, and a high percentage of their time may be spent outdoors.
5.2.3.3	Other diets	Other diets that cannot be adequately represented by a farming household diet or a hunter/gatherer diet.

Number	Name	Description
5.2.4	Habits (excluding diet)	Non-diet related behaviour of individual humans, including time spent in various environments, pursuit of activities and uses of materials. Habits will be influenced by agricultural practices and human factors such as culture, religion, economics and technology. Smoking, ploughing, fishing, and swimming are examples of behaviour that might give rise to particular modes of exposure to environmental contaminants.
5.2.5	Community characteristics	FEPs related to characteristics, behaviour and lifestyle of groups of humans that might be considered as target groups in an assessment.
5.2.5.1	Community type	The general nature and size of the community, and in particular their degree of self-sufficiency. Some characteristics may have the potential for unique exposure pathways; for instance ploughing of contaminated agricultural land may be an important inhalation and external exposure pathway.
5.2.5.2	Community location	The location of the community relative to areas which might be contaminated by the effects of the repository.
5.2.5.3	Water source	The origin of water used by the critical group for domestic purposes, including drinking, and to meet irrigation demands. The source(s) could be contaminated to different degrees, with factors such as volume of diluting water, sedimentation and sorption affecting contaminant concentrations in the water.
5.2.6	Food preparation and water processing	Treatment of food stuffs and water between raw origin and consumption. Once a crop is harvested or an animal slaughtered it may be subject to a variety of storage, processing and preparation activities prior to human or livestock consumption.
5.2.7	Dwellings	Houses or other structures or shelter in which humans spend time. Materials used in their construction, the nature of their construction and their location are important factors.
5.2.8	Natural/semi-natural land and water use	Use of natural or semi-natural tracts of land and water such as forest, bush and lakes. Special foodstuffs and resources may be gathered from natural land and water.
5.2.9	Rural/agricultural land and water use	Use of permanently or sporadically agriculturally managed land and managed fisheries. An important set of processes are those related to agricultural practices, their effects on land form, hydrology and natural ecology, and also their impact in determining uptake through food chains and other exposure paths

Number	Name	Description
5.2.10	Urban/industrial land and water use	Urban and industrial developments, including transport, and their effects on hydrology and potential contaminant pathways. Significant areas of land may be devoted to urban and industrial activities. Water resources may be diverted over considerable distances to serve urban and/or industrial requirements.
5.2.11	Leisure and other uses of the environment	Leisure activities, the effects on the surface environment and implications for contaminant exposure pathways. Significant areas of land, water, and coastal areas may be devoted to leisure activities, e.g. water bodies for recreational uses, mountains/wilderness areas for hiking and camping activities.
5.3	Contaminant Transport (Biosphere)	The processes that directly affect the release and/or migration of radionuclides in the biosphere. “Contaminant Transport (Biosphere)” is a sub-category in the International FEP List and is divided into individual FEPs.
5.3.1	Water-mediated transport (biosphere)	FEPs related to transport of radiotoxic and chemotoxic species in near-surface groundwater and surface water in aqueous phase and as sediments in surface water bodies.
5.3.1.1	Groundwater discharge to biosphere	Discharge of radiotoxic and chemotoxic species in the groundwater into surface water bodies and soils.
5.3.1.2	Transport associated with surface soil and overburden	Transport of radiotoxic and chemotoxic species in water through in the surface soil and overburden. Contaminant transport by advection, diffusion and dispersion in soil pore water would be affected by characteristics such as soil texture, mineralogy and porewater pH and composition. Contaminants may also move through the soil profile via processes such as infiltration and interflow, and across the soil via surface runoff.
5.3.1.3	Transport associated with surface water bodies	Transport of radiotoxic and chemotoxic species in surface water bodies such as rivers, lakes and seas. Transport with the surface water bodies can be in the aqueous phase or as sediment.
5.3.1.4	Dissolution and precipitation (biosphere)	The dissolution and precipitation of radiotoxic and chemotoxic species in the biosphere under prevailing environmental conditions. Dissolution is the process by which constituents of a solid dissolve into solution. Precipitation occurs when chemical species in solution react to produce a solid that does not remain in solution.
5.3.1.5	Speciation and solubility (biosphere)	Chemical speciation and solubility of radiotoxic and chemotoxic species in the biosphere under prevailing environmental conditions. Speciation and solubility are affected by factors such as temperature, pressure, pH and redox conditions.

Number	Name	Description
5.3.1.6	Sorption and desorption (biosphere)	Sorption/desorption of radiotoxic and chemotoxic species in the biosphere under prevailing environmental conditions. Sorption describes the physico-chemical interaction of dissolved species with a solid phase. Desorption is the opposite effect.
5.3.1.7	Complexation (biosphere)	The impact of complexing agents on the transport of radiotoxic and chemotoxic species through the biosphere under prevailing environmental conditions. Such agents can be found throughout the biosphere.
5.3.1.8	Colloid transport (biosphere)	The transport of colloids and interaction of radiotoxic and chemotoxic species with colloids migrating through the biosphere under prevailing environmental conditions.
5.3.2	Gas-mediated transport (biosphere)	FEPs related to transport of radiotoxic and chemotoxic species in gas or vapour phase or as fine particulate or aerosol in gas or vapour through the biosphere.
5.3.2.1	Gas discharge to biosphere	Release of radionuclides and chemical contaminants in the gas or vapour phase, or as fine particulate or aerosols suspended in gas or vapour to the biosphere.
5.3.2.2	Radon production (biosphere)	The production of radon gas in the biosphere from the decay of repository-derived Ra-226.
5.3.2.3	Volatilisation from soil/water	Volatile compounds can be formed due to chemical and biochemical processes occurring in the biosphere. The rate of volatilisation is controlled by changes in pressure, temperature and concentration in the biosphere
5.3.3	Solid-mediated transport (biosphere)	Transport of radiotoxic and chemotoxic species in solid phase in the biosphere, for example glacial/fluvial erosion, landslide, and solifluction.
5.3.4	Human-action-mediated transport (biosphere)	Transport of radiotoxic and chemotoxic species in the biosphere as a direct result of human actions, e.g. dredging of contaminated sediments from lakes, rivers and estuaries and placing them on land, and ploughing of soils.
5.3.5	Atmospheric transport and deposition	Transport of radiotoxic and chemotoxic species in the air as gas, vapour, fine particulate or aerosol. Radionuclides may enter the atmosphere from the surface environment as a result of a variety of processes including transpiration, suspension of radioactive dusts and particulates or as aerosols.
5.3.6	Biologically-mediated transport	The modification of speciation or phase change due to microbial/biological/plant activity in the biosphere and the transport of radiotoxic and chemotoxic species as a result of animal, plant and microbial activity (e.g. burrowing, deep rooted plants) in the biosphere.

Number	Name	Description
5.3.7	Foodchains and uptake of contaminants	Incorporation of radiotoxic and chemotoxic species into plant or animal species that are part of the possible eventual food chain to humans. Plants may become contaminated either as a result of direct deposition of radionuclides onto their surfaces or indirectly as a result of uptake from contaminated soils or water via the roots. Animals may become contaminated with radionuclides as a result of ingesting contaminated plants, or directly as a result of ingesting contaminated soils, sediments and water sources, or via inhalation of contaminated particulates, aerosols or gases.
5.4	Exposure Factors	Processes and conditions that directly affect the dose to members of the critical group, from given concentrations of contaminants in environmental media. “Exposure Factors” is a sub-category in the International FEP List and is divided into individual FEPs.
5.4.1	Contaminated drinking water and food	The presence of radiotoxic and chemotoxic species in drinking water, foodstuffs or drugs that may be consumed by human. Contaminants may be incorporated into the food chain through contaminated soil, water and air.
5.4.2	Contaminated non-food products	The presence of radiotoxic and chemotoxic species in human manufactured materials or environmental materials that have special uses, e.g. clothing, building materials, peat.
5.4.3	Other contaminated environmental media	The presence of radiotoxic and chemotoxic species in environmental media other than drinking water, foodstuffs or drugs, i.e. soil, water, sediment and air.
5.4.4	Exposure modes	FEPs related to the exposure of man (or other organisms) to radiotoxic and chemotoxic species.
5.4.4.1	Exposure of humans	Exposure modes affecting humans. The important internal and external exposure modes affecting humans are ingestion, absorption, inhalation, and external exposure.
5.4.4.2	Exposure of biota other than humans	Exposure modes affecting biota other than humans. Biota can be divided into two broad groups: domesticated and cultivated species, and wild and indigenous species. The exposure pathway would be similar to those for humans: inhalation, ingestion, external contamination, and radiation. However, the relative importance of these pathways would likely be quite different from humans and also between species.
5.4.5	Dosimetry and biokinetics	FEPs related to the dependence between radiation or chemotoxic effect and amount and distribution of radiation or chemical agent in organs of the body.

Number	Name	Description
5.4.5.1	Dosimetry and biokinetics for humans	The dependence between radiation and chemical toxicity effect and the amount of radiation or chemical agent in human organs, tissues, and body. Doses depend on factors that include form of exposure, metabolism of the radioelement, residence time in the tissue or organ, energy and type of radioactive emissions of the radionuclide, and the age of the human at exposure and the lifetime commitment to the exposure.
5.4.5.2	Dosimetry and biokinetics for biota other than humans	The dependence between radiation or chemical toxicity effect and the amount of radiation or chemical agent in the organs, tissues or the whole body. Dose factors will be the same as those for humans, but different species will have different dosimetry.
5.4.6	Radiological toxicity/effects	FEPs related to the effect of radiation on man or other organisms.
5.4.6.1	Radiological toxicity/effects for humans	The effects of radiation on humans. Radiation effects can be classified in several different ways: somatic or genetic and stochastic or non-stochastic. Radiation exposure can have a wide variety of effects depending upon the exposure levels.
5.4.6.2	Radiological toxicity/effects for biota other than humans	The effects of radiation on organisms other than humans. The radiation effect classifications are the same as those for humans. If the effects are widespread throughout a population of some biota, there could also be consequential effects, such as disruption of food webs or ecosystems.
5.4.7	Chemical toxicity/effects	FEPs related to the effects of chemotoxic species on man or other organisms.
5.4.7.1	Chemical toxicity/effects for humans	The effects of chemically toxic species on humans. Chemical toxicity can involve a wide range of effects, including teratogenic, mutagenic, and carcinogenic effects. Another issue of concern is synergistic effects or the combined effects of two or more radiotoxic or chemotoxic species on humans.
5.4.7.2	Chemical toxicity/effects for biota other than humans	The effects of chemically toxic species on organisms, including plants. Chemical toxicity has the same range of effects on biota as it does on humans, although toxicity may alter between species.
5.4.8	Radon and radon daughter exposure	Exposure to radon and radon daughters from repository derived Ra-226. The principal mode of exposure to humans and animals is inhalation of radon daughters attached to dust particles.

3. PROPOSED USES OF THE UPDATED NEA INTERNATIONAL FEP LIST

A FEP list can be used for various purposes at different stages of the development of a repository programme. As the programme matures, the role of the FEP list can be expected to change. Typically at the early stage, FEPs analysis and identification is a key activity when developing concepts and so the FEP list can play a key role in the identification and development of scenarios and conceptual models. However, as NEA (2012) notes, as the programme advances and the understanding of relevant thermal, hydraulic, mechanical, chemical, geological, radiological and biological processes evolves, the knowledge to be managed and documented can go beyond the capacity of simple FEP records. Additional mechanisms might need to be used for documentation, for example extensive process reports (e.g. SKB 2010a-c). In such programmes, the more general NEA International FEP List can become a tool mainly used for completeness checking for scenarios and models.

In light of the above, it is envisaged that the updated NEA International FEP List will be used as:

- The starting point for the development of a project-specific FEP list for programmes that are in the early stages of repository planning. The project-specific FEP list can then be used in the post-closure safety assessment of the repository, e.g. for the the identification and development of scenarios and/or conceptual models. This use would represent a knowledge transfer from more to less advanced programmes.
- An audit tool to check the completeness of scenarios, conceptual models and/or their implementation in software tools. Such an audit tool could be used by either the assessor or the reviewer of the assessment.
- An audit tool to check the completeness of any project-specific FEP list that has been developed independently from the updated International FEP List.

Additionally, if the electronic database containing the updated NEA International FEP List (and any project-specific FEP lists) is updated regularly, it can become a database of updated references on particular fields and topics, as is the case with the FEPCAT database (NEA 2003). This new feature will be specifically interesting for the topic experts who might contribute much more to the regular update and the maintenance of the database than before when the database was a product oriented to safety assessment. Furthermore, if the database also includes project-specific FEP lists and links to any associated process reports, the database could be used to identify how a given FEP from the updated NEA International FEP List has been treated in a specific assessment, and vice-versa. It will also allow the identification of any project-specific FEPs that are not included in the updated NEA International FEP List, and vice-versa.

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