OECD

Features, Events and Processes (FEPs) for Geologic Disposal of Radioactive Waste

An International Database

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Radioactive Waste Management

Features, Events and Processes (FEPs) for Geologic Disposal of Radioactive Waste

An International Database

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 27 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

The management of radioactive waste and, in particular, the safety assessment of radioactive waste disposal systems are areas of high priority in the programme of the OECD Nuclear Energy Agency (NEA). The NEA's Radioactive Waste Management Committee (RWMC) and its Performance Assessment Advisory Group (PAAG) and Co-ordinating Group on Site Evaluation and Design of Experiments (SEDE) are committed to promoting information exchange and co-operation among OECD Member countries on subjects related to radioactive waste management strategy, safety assessment of disposal systems, and characterisation of potential disposal sites.

Through international exchanges co-ordinated by the NEA, a general consensus has been reached that:

- the responsibilities of this generation to future generations are better discharged by a strategy of final disposal, and disposal of radioactive wastes in geologic repositories is currently the most favoured option;

- appropriate use of safety assessment methods, coupled with sufficient information from the proposed disposal sites, can provide the technical basis to decide whether specific disposal systems would offer to society a satisfactory level of safety for both current and future generations.

Safety, or performance, assessments involve analysis of the potential release of radionuclides from the disposed waste and subsequent transport to the human environment. An important stage of assessment is the identification and documentation of all the features, events and processes (FEPs) that may be relevant to the long-term safety or performance. This activity provides a basis for the selection of FEPs that should be included in quantitative analyses, and developing the scenarios that should be evaluated.

A Working Group on the identification and selection of scenarios for performance assessment of radioactive waste repositories was set up by PAAG in 1987. The final report of that Group, "Systematic Approaches to Scenario Development", provided a summary of the status of scenario methods and their application up to about 1990. Further discussions at PAAG and RWMC meetings confirmed that scenario development continued to be an area of high priority and particularly suitable for international co-operation. It was suggested that the development of an international database of FEPs would be a valuable follow-up activity and, in 1993, PAAG set up a Working Group to oversee the development of such a database.

This document describes the outcome of the Group's work to develop an "International FEP Database" relevant to the post-closure safety of repositories for solid radioactive waste.

The report is published under the responsibility of the Secretary-General of the OECD. It does not in any way commit the countries of the OECD.

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Swedish Nuclear Power Inspectorate (SKI)
Swedish Nuclear Fuel and Waste Management Company (SKB)

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1. Now part of the Environment Agency for England and Wales.

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Introduction

Key activities in development of a repository safety or performance assessment are the comprehensive identification of the relevant factors, often termed “features, events and processes” (FEPs), and the selection of factors that should be included in quantitative analyses. The processes of identifying, classifying and screening the factors form the first stages of the identification and selection of alternative futures relevant to assessment of repository performance, which is termed scenario development.

A Working Group on the identification and selection of scenarios for repository safety assessment was set up by the Nuclear Energy Agency (NEA) Performance Assessment Advisory Group (PAAG) in 1987. The final report of that Group[2] provided a summary of the status of scenario methods and their application up to about 1990. Further discussions confirmed that scenario development continued to be an area of high priority and particularly suitable for international co-operation. It was suggested that the development of an international database of FEPs would be a valuable follow-up activity and, in 1993, the PAAG set a Working Group to oversee the development of such a database. This report documents the outcome of the Group’s work to develop an “International FEP Database” relevant to the post-closure safety of repositories for solid radioactive waste.

Objectives and Conduct of the Project

The terms of reference for the Working Group set by the PAAG were to:

- determine what FEP information is currently held by member countries;
- decide what kind of information should be included in the international database and at what level of detail;
- define procedures for accessing and maintaining the database to be implemented by the NEA Secretariat.

The Working Group met seven times in the period June 1993 to October 1996. All of the countries represented at the Working Group were engaged in, or were preparing for, performance assessment studies in which the identification of potentially relevant FEPs formed an important part. The

2. NEA, Safety Assessment of Radioactive Waste Repositories: Systematic Approaches to Scenario Development, Report of the NEA Working Group on the Identification and Selection of Scenarios for Performance Assessment of Radioactive Waste Disposal. OECD-NEA, Paris, 1992.

reporting of these national projects at the Working Group meetings, including demonstrations of computer databases used, was valuable and provided the participants with an opportunity to discuss individual experiences and results.

Some of the detailed work of developing the International FEP List and designing the database was carried out by a sub-group which met on three occasions in the period January 1995 to December 1995. An independent consultant carried out work defined by the Working Group, including documenting the Working Group progress and developing the computerised database.

The International FEP Database

The NEA International FEP Database has two main components:

(1) ***The International FEP List*** – a list of factors relevant to the assessment of long-term safety of solid radioactive waste repositories, that attempts to be comprehensive within defined bounds. This forms a master list and classification scheme by which to examine the project-specific database entries. A "glossary" style definition is attached to each International FEP.

(2) ***Project Databases*** – a collection of FEP lists and databases, with references, compiled during various repository safety assessments and scenario development studies. Every FEP of each project database is mapped to one or more of the International FEPs.

Both parts exist as files in an electronic database with simple screening and selection tools, and various screen display and print-out formats. Alternative modes of use are possible and are facilitated by the simple database structure. At present, eight project databases are included. These are published lists or databases made available by members of the Working Group and, together, cover a range of solid waste disposal concepts.

The International FEP List provides:

- a list of FEPs to be considered when determining the scope of a new assessment;
- a list of FEPs against which completed assessments can be audited or reviewed;
- an indication of completeness of an assessment, if it can be demonstrated that all FEPs listed have been considered.

The associated project databases provide a means to:

- interrogate project databases to discover which FEPs are considered in each project and how they are treated;
- compare how different projects have treated the same FEP;
- identify references within each project database for a FEP of interest.

Version 1.0 of the International FEP Database is implemented on Claris FileMaker Pro™, Version 3.0. A suite of menus, supporting information and data display screens have been created to introduce the Database and to encourage the user to explore the International FEP List and project-specific FEPs in a structured way.

The current database is a starting point. It is expected that, in the future, project databases will be added and improvements made to the function of the database.

Conclusions and Recommendations

The primary achievement of the Working Group is the establishment of the International FEP Database. The expected benefits and uses of the International FEP Database will be as:

- an aid to achieving and demonstrating comprehensiveness within an assessment;
- a tool to interrogate individual assessments as well as to assist in comparing assessments.

The database should prove useful within both well-developed and new performance assessment programmes, and will become more valuable as more project databases are added to it.

The discussions and interchange of information among the Working Group has allowed the participants to learn of developments related to FEP identification and scenario development in other projects, and to obtain informal peer review of their own work.

The main recommendations of the Group are as follows:

(1) Performance assessment groups should obtain and examine the International FEP Database to decide how the Database might be used in their own work, or to improve harmonisation or communication between assessment groups.

(2) A User Group should be set up to encourage the use of the Database, to provide a forum for exchange of experiences, to act as a focus for maintenance and development of the Database, and to ensure the quality and consistency of additions to the Database.

(3) A Workshop should be arranged to review developments in scenario methodologies and application in safety assessments since 1992; this should be the basis to prepare an overview of the current status of scenario methods and their application.

1. INTRODUCTION

Background

The Radioactive Waste Management Committee (RWMC) of the OECD Nuclear Energy Agency (NEA) and the International Radioactive Waste Management Advisory Committee of the International Atomic Energy Agency (IAEA) have given a collective opinion on the evaluation of long-term safety of disposal of radioactive wastes, that has been endorsed by the experts for the Community Plan of Action in the Field of Radioactive Waste Management of the Commission of the European Communities (CEC) [NEA 1991]. The committees:

> "Consider that appropriate use of safety assessment methods, coupled with sufficient information from proposed disposal sites, can provide the technical basis to decide whether specific disposal systems would offer to society a satisfactory level of safety for both current and future generations." [NEA 1991, p. 7]

and also note that:

> "... what is expected and sought is a scientific and regulatory process that properly considers those factors that might significantly affect safety ..." [NEA 1991, p. 11]

Thus, key activities in development of a repository safety analysis are the comprehensive identification of the potentially relevant factors, often termed "features, events and processes" (FEPs), and the logical screening and selection of factors that should be included in performance assessment. The processes of identifying, classifying and screening the FEPs is sometimes called FEP analysis. This activity is the first stage of the identification and selection of alternative futures relevant to assessment of radioactive waste repository safety, which is termed scenario development [NEA 1992].

A Working Group on the identification and selection of scenarios for safety assessment of radioactive waste repositories was set up by the NEA Performance Assessment Advisory Group (PAAG) in 1987. The final report of that Group [NEA 1992], provided a summary of the status of scenario methods and their application up to about 1990. Further discussions at PAAG and RWMC meetings confirmed that scenario development continued to be an area of high priority and particularly suitable for international co-operation. It was suggested that the development of an international database of FEPs would be a valuable follow-up activity and, in 1993, the PAAG decided to set up a new Working Group to discuss and oversee the development of such a database.

This document describes the outcome of the Group's work to develop an "International FEP Database" relevant to the post-closure safety of repositories for solid radioactive waste.

Terms of Reference for the Working Group

Following discussions at PAAG and RWMC meetings during 1993, the terms of reference for the Working Group were given as follows.

> As a result of previous performance assessment studies, FEP databases already exist at national and international levels. These existing databases constitute a natural starting point for an international database. The Working Group should:
>
> - determine what FEP information is currently held by member countries;
> - decide what kind of information should be included in the international database and at what level of detail;
> - define procedures for accessing and maintaining the database to be implemented by the Secretariat.
>
> In a second step, the Working Group may analyse the information available in the database and identify, for example, differences resulting from national regulations, traditions, cultures, etc.

Objectives of the Project

At its first meeting (June 1993), the Working Group agreed that the development of an international database of FEPs would be both feasible and beneficial for participants. Although development of a database would involve a substantial effort, much of the work required would be done anyway by individual projects as part of their safety assessments. Once established, the database would provide significant benefits. The Group agreed that an international FEP database might:

- be used directly to assist in the initial stages of performance assessment;
- help in identifying differences (in the overall scope and in the treatment of FEPs) in performance assessments, between countries and between stages of assessment;
- help in demonstrating completeness in the regulatory arena;
- form a basis for peer review and audit of performance assessments.

Experience of using FEP databases was gained within the various national projects during the period of the work and these experiences were discussed by the Group. As a result, ideas on the requirements and possible uses of an international FEP database were refined and developed. Table 1 shows objectives for the NEA FEP Database Project that evolved based on the discussions of the Working Group. These are consistent with the guidance given by the PAAG, see previous section, and were accepted by the PAAG as objectives for the project.

Table 1. **Objectives of the NEA International FEP Database Project as developed by the Working Group**

(1)	To provide a computerised database of FEP names, descriptions and other information being the sum of information provided from individual assessments or scenario/model development projects.
(2)	To provide a list of FEPs – "the International FEP List" – that is comprehensive within defined bounds, and will be a master list by which to examine the various project-specific database entries.
(3)	To provide a brief general description of each FEP of the international list at the level of detail of a glossary.
(4)	To implement a system, consisting of the International FEP List, glossary and project-specific information, on flexible and user-friendly software so that it will be convenient to use in practice and easy to modify the structure of the database in future.

Conduct of the Project

The Working Group met seven times in the period June 1993 to October 1996 for information exchange and discussion. A list of participants in the Working Group is given in Appendix A.

All of the countries represented at the Working Group (Canada, France, Spain, Sweden, Switzerland, the United Kingdom and the United States) were engaged in, or were preparing for, performance assessment studies in which the identification and description of potentially relevant FEPs formed an important part. The reporting of these national projects at the Working Group meetings, including demonstrations of computer databases used, was valuable and provided the participants with an opportunity to discuss the experiences and results.

Some of the more detailed work of developing the International FEP List and designing a database was carried out by a subgroup which met on three occasions in the period January to December 1995. A consultant carried out work on behalf of the Working Group, including preparation of documents and development of a computerised database. A preliminary report of work by the Group was given at the American Nuclear Society International High-Level Radioactive Waste Management Conference [Sumerling 1996].

Scope and Organisation of the Report

The main subject of this report is a description of the "International FEP Database" for radioactive waste disposal assessment studies that has been developed as a result of pooling of experiences of the Working Group participants. The report does not cover the subjects of elicitation of FEPs, or the use of FEP lists or databases in the further activities of model and scenario development. Scenario development has been the subject of a previous NEA Working Group report [NEA 1992], and the PAAG has indicated that this topic may be the subject of a further Working Group study.

Chapter 2 of this report describes the benefits of using formal FEP lists or databases within assessment projects. These benefits have, in part, provided the motivation for this Working Group project. The chapter also includes a summary of key developments in the derivation and use of FEP lists and databases in radioactive waste safety assessment studies, and a survey of published FEP lists and databases.

Chapter 3 describes the International FEP Database which consists of the International FEP List and selected project databases. The design and principles of operation of the Database are described, and the comprehensiveness of the International FEP List is discussed. The derivation of the List is described, classification schemes are discussed, and the International FEP List is presented. The method of including project databases by mapping to the International FEP List is described. Finally, the aims and expected uses of the Database are summarised.

Chapter 3 is supported by Appendices B and C. Appendix B defines the classification scheme that was used in deriving the International List, and also presents the List according to that scheme. Appendix C reproduces the glossary descriptions and comments attached to each International FEP.

Chapter 4 describes the current implementation, possible developments and use of the Database. Appendix D gives information on how to obtain the International FEP Database.

Chapter 5 summarises the achievements, lessons learnt and key recommendations of the Working Group.

2. FEP LISTS AND DATABASES IN NATIONAL PROJECTS

Benefits of FEP Lists and Databases

The identification of the factors, or FEPs, to be considered, is an activity common to all assessments of long-term safety of radioactive wastes. The formality with which this is done and documented may vary considerably between projects. In recent years, however, it has been increasingly recognised that formal documentation of the identification of relevant FEPs, and recording of information related to each FEP, can have several benefits.

Within a project:

- development of a FEP list provides an opportunity for broad discussion amongst the project team and independent experts to identify the relevant FEPs;
- descriptive information and references added against each FEP provides a source of information that can be used during scenario or model development activities;
- a FEP list and database provides a framework to record information about a FEP, whether or not the FEP is included in assessment models and even though its importance may be uncertain;
- the models used in an assessment can be audited against the list of FEPs with a view to ensuring that all important processes are included, or to assist in specifying further model developments or data acquisition.

Both within a project and for external audiences (e.g. the public or regulators):

- the extent of the project FEP database indicates of the range of FEPs that have been given at least qualitative consideration, and
- clear descriptions of each FEP, their relevance and importance, and how each FEP is treated (e.g. in quantitative analyses), generates confidence in the logic and thoroughness of the assessment.

A project FEP database becomes especially valuable as iterative assessments are carried out for a given concept or site. The information contained in the database can provide an organic record of a given phase of assessment and should provide a basis for subsequent phases. In some countries, the use of such databases has been extended so that they include graphical tools for scenario or conceptual model development, or project management information.

Experiences with FEP Lists and Databases

In the early 1980s, the IAEA reproduced a list of about 60 phenomena potentially relevant to release scenarios for waste repositories [IAEA 1981, 1983]. This was presented as a "suggested checklist of phenomena" and has been cited as the starting point for scenario development activities in a number of repository safety studies. The IAEA reports do not state the origin of the list, but the list is similar to that reproduced in Koplik et al. [1982] and Burkholder [1980] which were developed in the USA.

Also during the 1980s in the USA, Sandia National Laboratories (SNL) was developing the well-known scenario development methodology on behalf of the US Nuclear Regulatory Commission [Cranwell et al. 1982]. Cranwell et al. [1982] and related reports present a list of 30 "potentially disruptive events and processes" that have been the basis for preliminary scenario development studies for the assessment of the disposal of transuranic wastes in bedded salt at the WIPP[3] site [Guzowski 1990]. In Europe, a list of 25 "primary events" was used as a starting point for a probabilistic assessment of radioactive waste disposal in clay based on a fault-tree methodology [d'Alessandro and Bonne 1981], and lists of processes and events relevant to the disposal of high-level waste in crystalline basement and short-lived intermediate-level wastes in marl were presented in the Swiss Project Gewähr reports [Nagra 1985 a, b]. In the Project Gewähr reports, tables were included to indicate, for each process or event, the time period of importance and the treatment or effect in the assessment model chain.

All of the above lists comprised events and processes that were mainly scenario initiating (e.g. potentially disruptive) phenomena, or phenomena that would lead to changes in the disposal system or the pathways for radionuclide release and migration. In the late 1980s, however, the Swedish Nuclear Fuel and Waste Management Company (SKB) and Nuclear Power Inspectorate (SKI) carried out a Joint Scenario Development Exercise which was distinct in several respects [Andersson (ed.) 1989].

(a) Lists of features, events and processes (the term "FEP" was introduced) were derived by four groups of experts working semi-independently. The groups included experts from the Swedish national waste management programme, from other countries, and from broader scientific disciplines; previous lists had been derived mainly through in-house expertise.

(b) Efforts were made to record ***all*** potentially relevant FEPs, not just scenario initiating or potentially disruptive phenomena.

(c) For each FEP a "memo comment" was written which recorded information on the process, its effects, references to the process and whether the FEP could be omitted (screened-out) from quantitative analysis. The information was compiled in an electronic database created by dBASE III Plus.

The list focused on the performance of the engineered barriers and geosphere for a repository for spent fuel in Swedish bedrock; a separate, smaller group undertook elicitation of FEPs related to the biosphere.

In the late 1980s and early 1990s, Atomic Energy of Canada Limited (AECL) was preparing a catalogue of factors for use in scenario development for post-closure assessment of the Canadian

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3. USDOE Waste Isolation Pilot Plant, near Carlsbad, New Mexico.

nuclear fuel waste disposal concept [Stephens and Goodwin 1989] and, in the United Kingdom, both UK Nirex Ltd. [Billington et al, 1989] and the UK Department of Environment [Thorne 1992] were developing FEP lists in relation to assessment of low- and intermediate-level waste disposal. The AECL catalogue of factors comprised a large number of FEPs (over 250) and supplied descriptions for each, plus classification codes, e.g. indicating the recommended treatment [Goodwin et al. 1994]. In the UK DoE study [Thorne 1992], the elicitation of the FEP list was carried out by a group of 12 experts with a broad range of relevant scientific expertise. The process of eliciting and refining the list, which was done over several meetings and by correspondence, is recorded in detail. Work on scenario methodology for UK Nirex Ltd. was the basis of the example compilation of FEPs that appears in the NEA Scenario Working Group report [NEA 1992, pp. 24-25].

More recently, developments have been made in formal methods of FEP manipulation and analysis, compilation of extensive FEP catalogues and the use of computer databases.

- The Rock Engineering System (RES) matrix method of Hudson [1992] has been examined in the context of repository scenario development studies in Sweden [Eng et al. 1994; Skagius et al. 1995], Finland [Vieno et al. 1994], the United Kingdom [Hudson 1995] and in the international BIOMOVS study [BIOMOVS II 1994]. The method assists in identifying FEPs and checking for comprehensiveness of a FEP list.

- In Sweden, SKI has developed a method based on “process influence diagrams” that illustrate graphically the interactions between a large number of FEPs [Chapman et al. 1995]. The graphics, and also text information about the individual FEPs and interactions, are managed using a commercially available software package. This tool provides a method of managing information on FEPs and also a basis for development of assessment models.

- In Switzerland, comprehensive FEP catalogues have been developed for the assessment of vitrified high-level waste in crystalline basement rock [Nagra 1994a]. A feature of this work is that the FEP database and scenario analysis is expected to provide a method of active management and development of a safety case [Sumerling et al. 1993]. This is done through the mapping of FEPs to models and the identification of “reserve FEPs” and “open questions”, i.e. FEPs that are not treated in the current assessment models but may be mobilised or require consideration in future phases of assessment.

- A method of identifying scenarios in terms of “independent initiating events” has been developed and applied during the CEC EVEREST project [Cadelli et al. 1996]. In this method initiating events are identified from a FEP list and the scenarios that result as a consequence are described [Raimbault et al. 1992].

- The US Department of Energy has developed a comprehensive list of FEPs for the WIPP facility [USDOE 1996]. FEPs are eliminated from quantitative treatment by detailed screening arguments. Scenarios are formed based on the set of remaining FEPs. Detailed descriptions are provided of how these FEPs are incorporated in the performance assessment system model.

- In the UK, a computer program has been developed to facilitate scenario analysis and conceptual model formulation [Kelly and Billington 1997]. The program implements a systematic methodology based on the use of “Directed Diagrams” that are similar to fault-tree structures. It is used to record technical information, expert views and decisions from meetings and, thus, build up an audit trail for an assessment.

Survey of Project FEP Databases

A large number of FEP lists, catalogues and databases have been developed in OECD countries. These encompass a range of radioactive waste types, repository designs and geological environments. The sizes of the lists etc. vary, as do the content and level of detail of entries.

Table 2 summarises information on published FEP lists, catalogues and databases from OECD countries and international organisations. The table has been compiled from the knowledge of the Working Group and is not intended to be complete. Where several FEP lists or databases are known from a single country, preference is given to more recently published lists or databases containing detailed FEP descriptions.

Table 2. **Published FEP lists, catalogues and databases from OECD countries and international organisations**

Country /organisation	**Project/disposal concept**	**Contents and format of FEP list/database**	**Reference**
Belgium SCK·CEN	Assessment of radioactive waste disposal in the Boom clay at the Mol Site.	~130 FEPs classified according to cause based on the list appearing in NEA [1992]. Descriptions are added plus comments on the relevance to, or treatment in respect of, assessment of waste disposal at the Mol site.	Bronders et al. 1994
Canada AECL	Assessment of a reference disposal system consisting of spent CANDU fuel in durable containers in deposition holes in the floor of caverns in a granite pluton based on characteristics of the AECL Underground Research Laboratory at the Whiteshell site.	~280 factors classified as • vault; • geosphere; • biosphere. Coding to indicate, for example, component affected, mechanism, recommended treatment. Each factor has a description, and most have further information on the judged importance of the factor for the specific assessment study.	Goodwin et al. 1994
Canada AECL	Analysis of safety issues for the preliminary safety analysis report on the Intrusion Resistant Underground Structure (IRUS) for near-surface disposal of wastes.	~150 issues each with a description of the issue, response (evaluation), related issues and priority for safety assessment. These are selected from a preliminary list of ~350 issues.	Stephens et al. 1997
CEC ANDRA/IPSN/ SCK·CEN/GRS/ ECN	Scenario selection in the framework of the CEC EVEREST Project.	10 "Independent Initiating Events" (IIE) are considered leading to the identification of scenarios for repositories in alternative geological environments: 7 in clay, 5 in granite, 7 in salt.	Raimbault et al. 1992
France ANDRA	Assessment of deep disposal options.	At the time of the Working Group, a FEP database was under development at ANDRA	unpublished
IAEA	Generic check list of phenomena potentially relevant to release scenarios for waste repositories.	~60 phenomena classified as: • natural processes and events, • human activities, • waste and repository effects. Phenomenon names only.	IAEA 1981 & IAEA 1983
IAEA BIOMOVS II	International BIOsphere Model Validation Study – Phase II	A structured classification scheme for FEPs related to the biosphere. ~140 FEPs with descriptions, comments and codes indicating their treatment in biosphere models.	BIOMOVS II 1996

Table 2 (cont'd). **Published FEP lists, catalogues and databases from OECD countries and international organisations**

Country /organisation	**Project/disposal concept**	**Contents and format of FEP list/database**	**Reference**
NEA Scenario WG	Example compilation of features, events and processes for a deep geological repository (in hard rock).	~130 phenomena classified according to cause: • natural phenomena; • human activities; • waste and repository effects. with further subdivision into 13 subcategories. FEP names only.	NEA 1992
NEA Future Human Actions WG	List of "scenario-building elements for development of future human action scenarios".	~60 elements classified as: • subsurface activities; • surface activities. No descriptions, but references to discussion or analysis of FEPs in assessment studies are included.	NEA 1995
Netherlands ECN/RIVM/ RGD	Assessment of radioactive waste disposal in the salt formations in the Netherlands.	~130 FEPs classified according to cause based on the list appearing in NEA [1992]. Descriptions are added based on work in Belgium, plus comments on the relevance to, or treatment in respect of, assessment of waste disposal in salt formations.	Prij (ed.) 1993
Spain	Assessment of nuclear fuel waste in a deep repository in crystalline rock.	~120 factors related to near-field and geosphere, classified according to cause and the element affected. Descriptions, references and qualitative estimates of time frame, importance and probability are included (in Spanish).	ENRESA 1995
Sweden SKB/SKI	Joint SKB/SKI scenario development for assessment of spent fuel in copper canisters in Swedish bedrock.	~160 FEPs related to near-field and geosphere, classified according to the element of the disposal system affected. Descriptions of process and effects included, plus references, and codes indicating potential treatment in assessments.	Andersson (ed.) 1989
Sweden SKB	Identification of important issues affecting the long-term function of the geological barrier of an underground repository for spent nuclear fuel.	~150 interactions between the main features of the geological barrier, and between the geological barrier and adjacent system parts (buffer, biosphere) including judgements on their importance.	Skagius et al. 1995

Table 2 (cont'd). **Published FEP lists, catalogues and databases from OECD countries and international organisations**

Country /organisation	**Project/disposal concept**	**Contents and format of FEP list/database**	**Reference**
Sweden SKI	SITE-94 assessment of spent fuel in copper canisters in Swedish bedrock based on the Äspö site.	~165 FEPs in the "Reference Case and Central Scenario" (names only) plus note of very much larger number of influences between FEPs with short descriptions.	Chapman et al. 1995
Switzerland Nagra	Kristallin-I assessment of vitrified high-level waste disposal in the crystalline basement of Northern Switzerland.	~240 FEPs classified according to main safety-relevant features of the disposal system plus external influences. Descriptions plus comments on the treatment in the safety assessment are included in a supporting report.	Nagra 1994a Sumerling et al. 1998
Switzerland Nagra	Assessment of disposal of low and short-lived intermediate wastes in concrete lined caverns in marl at Wellenberg.	~50 summary FEPs classified according to model domain or external influences (in German).	Nagra 1994b
United Kingdom DoE/HMIP	Dry Run 3 assessment of hypothetical disposal of low- and intermediate-level waste in clay strata at Harwell.	~300 FEPs classified as near field, geosphere, biosphere or short-circuit pathway. No FEP descriptions, but method of derivation/development of the FEP list is documented.	Thorne 1992
United Kingdom HMIP	Assessment of UK Nirex Ltd. proposed disposal of intermediate-level waste in volcanic rock at Sellafield.	~80 FEPs classified as near field, geosphere, climatology, biosphere or short-circuit pathway. FEP descriptions and discussions of the relevance of each process.	Miller and Chapman 1993
United Kingdom UK Nirex Ltd.	Assessment of proposed disposal of intermediate-level waste in volcanic rock at Sellafield.	At the time of the Working Group, a FEP database was under development at Nirex.	unpublished
United States SNL for USNRC	Development of methodology for risk assessment of geological disposal of radioactive wastes.	~30 "potentially disruptive events and processes" classed as: • natural; • human-induced; • waste and repository-induced. Phenomenon names only.	Cranwell et al. 1982
United States USDOE	WIPP Project – assessment of disposal of transuranic waste in bedded salt in south-eastern New Mexico	~240 FEPs classified as • natural; • waste- and repository-induced; • human-initiated. Detailed FEP descriptions and comments on screening out of FEPs.	USDOE 1996 (Appendix SCR)

3. THE INTERNATIONAL FEP DATABASE

Design and Principles of Operation

The NEA International FEP Database has two main components:

(1) **The International FEP List** – a list of factors or FEPs relevant to the assessment of long-term safety of solid radioactive waste repositories, that attempts to be comprehensive at a given level of detail and within defined bounds. The list forms a master list and classification scheme by which to examine the project-specific database entries. A "glossary" style definition is attached to each FEP; this defines the scope and indicates the range of project-specific FEPs that might be mapped to each International FEP.

(2) **Project Databases** – a collection of FEP lists, FEP descriptions and references, compiled during repository safety assessments and scenario development studies. Every FEP of each project database is mapped to one or more of the International FEPs. The information given within each project varies but, typically, includes descriptions of each FEP in the context of the disposal system considered and comments on the importance and representation of FEPs in assessment models.

Both parts exist as files in an electronic database with simple screening and selection tools, and various screen display and print-out formats. The system thus fulfils the project objectives set out in Table 1.

The basic mode in which the database has been designed to operate, illustrated in Figure 1, is as follows:

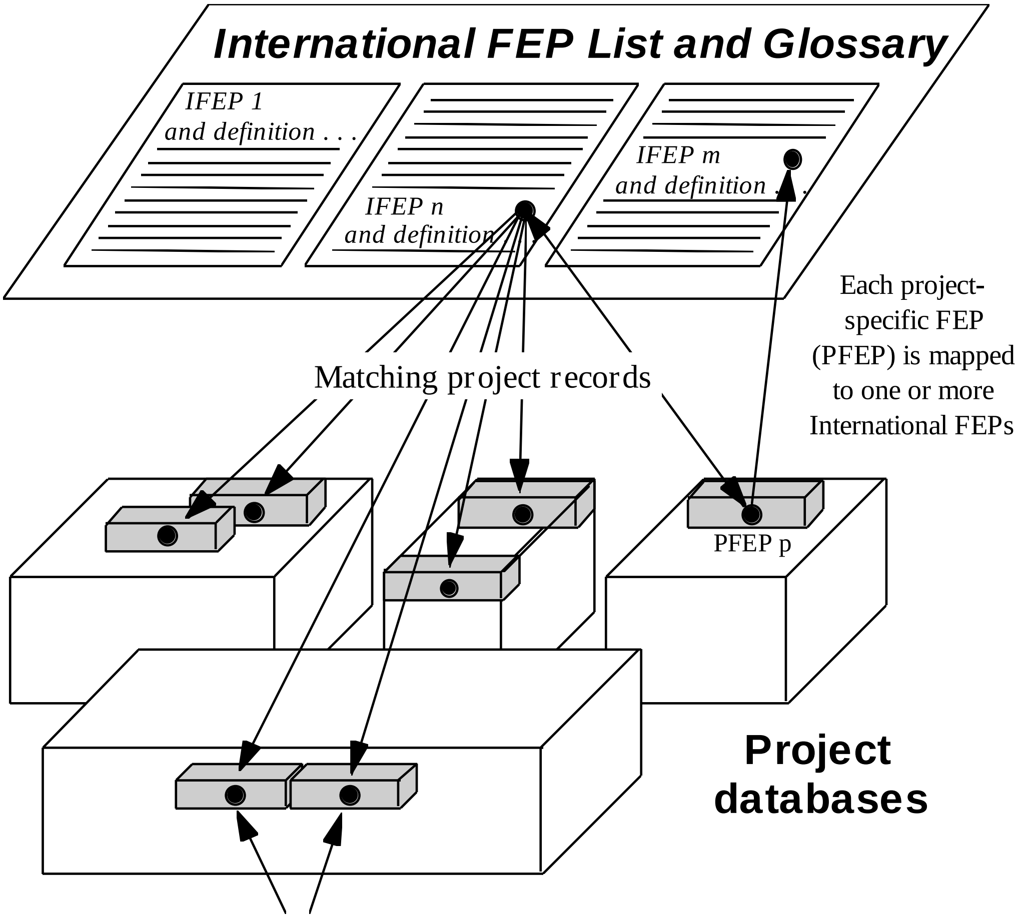
(a) Select an international FEP that most closely matches an enquirer's interest; a FEP can be selected by a search on FEP names and glossary definitions, or by examination of the International FEP List.

(b) Look up project-specific FEPs that have been mapped to that International FEP, and the associated literature references.

Alternative modes of use are possible and are facilitated by the simple database structure. For example, a user may examine, or perform word searches on, the project-specific FEP records or references directly, without using the International FEP List.

The current database is a starting point. It is expected that, in the future, project databases will be added and improvements made to the function of the database.

Figure 1. **The International FEP List as a key to FEP descriptions and literature references held in project databases**



Comprehensiveness of the International FEP List

Safety assessment of any facility cannot be expected to include an evaluation of all FEPs that might possibly affect the condition and safety of the facility over its life time. This is especially true for a radioactive waste disposal facility where the time period of interest may extend to hundreds of thousand of years into the future. It can be expected that reasonable efforts are made to identify those FEPs that might be significant to long-term safety, and logical procedures are used to evaluate these FEPs and to decide which should be included in quantitative safety or performance analyses.

The claim to "comprehensiveness" of the International FEP List is important to its use, see last section of Chapter 3. It is impossible to demonstrate comprehensiveness or completeness, in the sense that it is impossible to exhaustively identify all possible FEPs and interactions within a complex and evolving system. It is possible, however, to list a range of broadly-defined FEPs that might be relevant to consider in safety assessments. This is the aim of the International FEP List: to be comprehensive in a broad sense rather than in a detailed sense. The International FEP List should be comprehensive enough:

- to define a broad range of FEPs that might be relevant to safety assessment;
- to relate the information in the different project databases in a consistent and useful way.

Scope

The scope of the International FEP List must be bounded, for example, by:

- the limits for discussion and analysis within post-closure safety assessments, e.g. operational and worker safety are not included;

- the limits of what has been considered in previous post-closure safety assessments, e.g. disposal concepts very different of those considered to date are not included.

In addition, at a more-detailed level, the scope of the List will be limited by the current understanding within the waste disposal assessment community of the types of FEPs that could be relevant.

Table 3 provides an indication of the intended scope and applicability of the International FEP List at present. It is not the intention, however, to “turn away” project databases that may be submitted in future because they do not meet the current definition of scope. If a project database is submitted that contains information that is potentially useful to other safety assessment projects but falls outside the scope of the current List, then the List will be extended to include additional general factors or FEPs.

Level of Detail

The level of detail that should be included in the International FEP List depends on the intended uses of the List. A compromise must be struck between the competing requirements of comprehensiveness and the use of the List as a prompt. A list that is too general will not be useful. On the other hand, a list that descends to a too-detailed level risks leading the analyst; in addition, the list will tend to become incomplete as it becomes more difficult to be comprehensive at more detailed levels.

Typically, a FEP at the level “container materials and characteristics” is appropriate, because most disposal systems for solid radioactive waste employ containers or packages of some sort. FEPs referring to specific materials or container types are not appropriate. These FEPs may be found in the project-specific entries that are mapped to the International FEP. The analyst using the Database must be responsible for deciding whether the information in the project-specific entries is relevant to the particular disposal system that they are considering.

The Working Group thought that, as a guide, the International List should contain a total of about 100 FEPs, and not more that about 200 FEPs. The larger the List, the finer the classification and allocation of project-specific FEPs that can be achieved, but the List becomes harder to use. The List is designed to be short enough that a user can become generally familiar with it and will not inadvertently overlook a FEP on the List.

Table 3. **The current scope and applicability of the NEA International FEP List** [a]

Included	Excluded
Assessment applicability	
• post-closure safety assessment	• operational safety assessment • conventional environmental impact assessment, e.g. noise, ecological and social impacts. • economic assessment • technical design assessment
Physical applicability	
• solid radioactive wastes (spent fuel, high-level, transuranic, intermediate- and low-level wastes) • deep geological disposal[b] facilities - deep mine and cavern disposal - deep boreholes • near-surface disposal[b] facilities - engineered facilities - shallow-land burial	• disposal in conventional landfill facilities • liquid and gaseous effluents • mixed solid wastes • in-situ solidified liquid wastes • liquid waste injection • monitored retrievable storage • sub-seabed disposal • sea dumping
Content – FEPs related to:	
• assessment basis/assumptions • repository/engineered environment • geological environment • surface environment (aspects relevant to repository performance and safety) • human actions (affecting repository performance and safety) • radionuclide (and other contaminant) release, migration and exposure processes	• political/policy environment • future technological and sociological developments • radiation health effects • release, migration and exposure processes specific to other toxins

Notes

a. In the future, the scope of the International List may be extended to match the scope of project databases submitted for inclusion.

b. Disposal here means deposition without intention to retrieve, although retrieval may not be ruled out.

Derivation of the International FEP List

Several methods could be used to arrive at a generic FEP list:

(a) examination of, and distillation from, existing detailed lists of FEPs considered in assessment projects;

(b) top-level-down elicitation, for example, starting from comprehensive classification schemes;

(c) brainstorming, i.e. freely-structured identification of FEPs by groups of relevant experts.

An example of approach (a) is provided in Stenhouse et al. [1993]. This describes the integration of over 1000 FEPs from 9 different lists. In this case, the integrated list was derived to assist in the audit of an assessment of a specific site and disposal concept, and was screened with this in mind. Pre-agreed FEP screening arguments were an important requirement in developing the FEP list, and a classification scheme was used to sort the large number of FEPs before compounding them into a single list.

A subgroup of the Working Group examined the Stenhouse et al. report and carried out partial tests of various methods of developing a FEP list. It was concluded that method (c), above, is unsatisfactory on its own; it is liable to lead to an incomplete or uneven list and is time consuming to carry out. Method (a) has the advantage that it can be relatively objectively performed but relies on having a good classification scheme to sort and allocate the input FEPs; it is also necessary to supplement the list with FEPs that are not included on any of the input lists. Method (b) is conceptually attractive since it addresses the problem of "comprehensiveness" directly, but is difficult to begin and alternative comprehensive classification schemes could be chosen.

In the event, working over several meetings, the subgroup employed a hybrid procedure, consisting of the following stages:

(a) reclassification of an existing FEP list[4], according to an alternative classification scheme in order to generalise the list. Initially, this resulted in an increase in the number of FEPs since each FEP could be assigned to more than one class. The FEPs in each class were then examined and compounded, and duplication removed.

(b) refinement and extension of the classification scheme, and refinement and generalisation of the FEP names within each class. The classification scheme that was adopted is discussed in next section.

(c) trial mapping of project FEP databases to the prototype list. This led to identification of omissions from the prototype list and also helped to guide the style of naming FEPs within the list so that mapping could be satisfactorily achieved. The inclusion of project databases, and mapping of project-specific FEPs, is discussed in the section "Inclusion of Project Databases".

(d) the name of each FEP was checked for consistency of style within the overall list and to assist in alphabetical ordering.

This procedure led to the International FEP List described in the section "Inclusion of Project Databases".

Classification Schemes

The advantage of an electronic database is that FEPs can be readily re-organised according to different keywords or criteria. In forming the list, however, it is helpful to have a structure or categories so that the completeness (of categories and within categories) can be assessed, and equivalent levels of detail guided, e.g. similar numbers of FEPs might be found in each category.

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4. The list appearing in the NEA Scenario Working Group report [NEA 1992] was chosen, as this list has been used as the starting point for scenario development in several countries.

Various categories have been suggested for classification of FEPs in order to help assess and develop comprehensiveness, see NEA [1992]. Some of these would not be suitable for use as classifiers in the International List, e.g. timescale, probability and consequence, since they prejudge the analysis. Examination of various project databases indicates that FEP lists are usually classified either on cause, on field of effect, or on a combination of these two, e.g.

- by cause – i.e. natural processes and events, human activities, waste and repository effects [IAEA 1981; Cranwell et al. 1982; NEA 1992];

- by model field of effect – i.e. near field (or vault), geosphere, biosphere [Thorne 1992[5]; Goodwin et al. 1994];

- by physical field of effect and external causative factors – e.g. waste, canister, backfill, near field rock, repository/far field, geology, near surface and human actions [Andersson (ed.) 1989], and glass, canister, bentonite, hydrogeological path (sub-divided), biosphere, geological processes and events, climatic processes and events, human activities [Nagra 1994a].

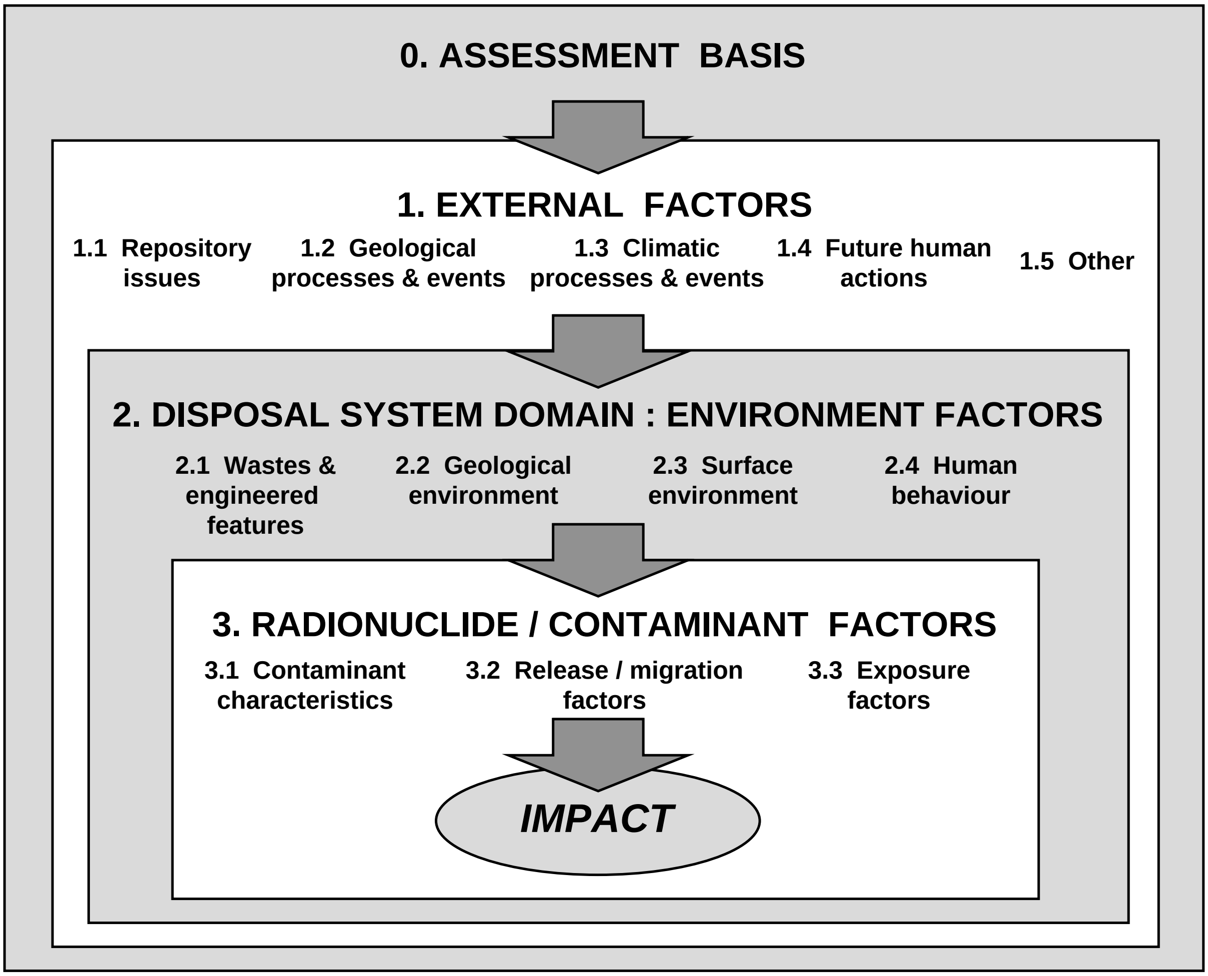
There is a danger of leading future analyses by classification. Schemes based too closely on features that are important in specific disposal systems should be avoided, and schemes based on model domains may be criticised, since they assume an approach to modelling. Past practice will, however, influence the structure of analyses in future, and the International List will be most useful if, by its classification, it assists the process of locating FEPs. The Working Group agreed that a final presentation of the International FEP List should be made in alphabetical order, but that a classification scheme was necessary to assist in devising the List and could provide some evidence for comprehensiveness of the List.

Several classification schemes were discussed by the Working Group and trial exercises using different classification schemes were carried out by a subgroup. Figure 2 illustrates the scheme that was adopted for the classification of the International FEP List for the purposes of deriving a list. This scheme is developed from the overall system affecting repository performance illustrated in respect of environmental simulation methods in NEA [1992].

The rationale underlying the scheme is as follows. The purpose of identification of, and collation of information on, FEPs is to construct a model of the disposal system and processes relevant to long-term radiological safety. The purpose of a safety assessment model is to estimate release and migration of contaminants and consequent human exposures. At its centre, therefore, the scheme includes processes related to contaminant release, migration and exposures. It is also necessary to consider the features of the disposal system (wastes, engineered and natural barriers and human behaviour) and events and processes which may cause the system to evolve. Beyond this, there are processes and events originating outside the disposal system but which act upon it.

5. Thorne 1992 also includes “short-circuit pathway” as a class.

Figure 2. **Illustration of the classification scheme used in deriving the International FEP List**



The rationale for choice of the scheme layers is described in the main text. In general, interactions between FEPs tend to occur within each layer, or shell, and in the inward direction, but not in the outward direction. The definition of layers and categories within each layer is given in Appendix B.

This leads to a three-layer categorisation based on:

- Disposal System Domain: Radionuclide/Contaminant Factors;
- Disposal System Domain: Environmental Factors;
- External Factors.

Assessment models are not expected to predict exactly how the environment or radiological impacts will actually evolve in the far future. Rather, they are designed to produce estimates of quantities required by regulatory guidance or for comparison with other design targets. In deciding the scope of an analysis, the analyst thinks not only of physical factors that might be relevant but also the regulatory guidance and aims of the analysis. These may constrain the extent to which some FEPs are considered or the way in which they are treated in the analysis, e.g. regulatory time periods and the use of critical groups as representative of future human populations at risk. Therefore, a fourth layer is added:

- Assessment Basis

This leads to the structure illustrated in Figure 2. To assist in its practical use, definitions were developed for each layer and category of the scheme; these are given in Table B.1 of Appendix B.

The scheme is intended to guide the allocation of FEP descriptions. It is clear, however, that a FEP allocated to any particular category may have consequences for FEPs within other categories.

The International FEP List and Glossary

Table 4 shows the International FEP List that has been developed by the Working Group. This consists of 134 International FEPs (IFEPs) presented here in alphabetical order.

Alphabetical order is chosen so that the list is as neutral as possible. To make the list more accessible in this order, IFEPs names are arranged so that the most important word (or words) are brought to the beginning of the name, e.g. "Administrative control, repository site" rather than "Repository site administrative control". A unique code number is attached to each IFEP which relates to the classification scheme that has been used in deriving the List, see previous section. The International List is presented in an order based on the classification scheme in Table B.2 of Appendix B.

To make the list applicable to a wide range of waste disposal concepts, many of the IFEPs have rather general names. The scope of each IFEP is defined within a glossary which the user should also examine. Each glossary entry consists of two parts:

- a FEP definition, which defines the scope of the IFEP in a general way and may include a technical definition if necessary;

- comments, which give more specific remarks on processes or issues that might be discussed under this IFEP name.

The glossary entries have been developed to be consistent with the IAEA Radioactive Waste Management Glossary [IAEA 1993]. The Glossary is reproduced in Appendix C.

The International FEP List is a result of iterative development, working from pre-existing lists and classification schemes, and taking account of experience of mapping project databases to the List, see the section "Inclusion of Project Databases". It is intended that the List should remain relatively stable, since any changes imply re-examination of the mapping of project-specific FEPs to the List, see last section of Chapter 3. Minor changes are to be expected, however, e.g. if a new project database is included that has FEPs of a type not previously considered. The IFEP glossary may also be developed.

Table 4. **The International FEP List (Version 1.0) in alphabetical order**

Accidents and unplanned events	1.1.12
Administrative control, repository site	1.1.10
Adults, children, infants and other variations	2.4.02
Aims of the assessment	0.08
Animal, plant and microbe mediated transport of contaminants	3.2.11
Animal populations	2.3.09
Aquifers and water-bearing features, near surface	2.3.03
Atmosphere	2.3.07
Atmospheric transport of contaminants	3.2.10
Biological/biochemical processes and conditions (in geosphere)	2.2.09
Biological/biochemical processes and conditions (in wastes and EBS)	2.1.10
Buffer/backfill materials and characteristics	2.1.04
Chemical/complexing agents, effects on contaminant speciation/transport	3.2.05
Chemical/geochemical processes and conditions (in geosphere)	2.2.08
Chemical/geochemical processes and conditions (in wastes and EBS)	2.1.09
Chemical/organic toxin stability	3.1.02
Climate change, global	1.3.01
Climate change, regional and local	1.3.02
Closure and repository sealing	1.1.04
Coastal features	2.3.05
Colloids, contaminant interactions and transport with	3.2.04
Community characteristics	2.4.05
Container materials and characteristics	2.1.03
Contaminant transport path characteristics (in geosphere)	2.2.05
Deformation, elastic, plastic or brittle	1.2.02
Diagenesis	1.2.08
Diet and fluid intake	2.4.03
Discontinuities, large scale (in geosphere)	2.2.04
Dissolution, precipitation and crystallisation, contaminant	3.2.01
Dose response assumptions	0.07
Dosimetry	3.3.05
Drilling activities (human intrusion)	1.4.04
Drinking water, foodstuffs and drugs, contaminant concentrations in	3.3.01
Dwellings	2.4.07
Ecological response to climate changes	1.3.08
Ecological/biological/microbial systems	2.3.13
Emplacement of wastes and backfilling	1.1.03
Environmental media, contaminant concentrations in	3.3.02
Erosion and deposition	2.3.12
Erosion and sedimentation	1.2.07

Table 4 (cont'd). **The International FEP List (Version 1.0) in alphabetical order**

Excavation disturbed zone, host rock	2.2.01
Excavation/construction	1.1.02
Explosions and crashes	1.4.11
Exposure modes	3.3.04
Food and water processing and preparation	2.4.06
Foodchains, uptake of contaminants in	3.2.13
Future human action assumptions	0.05
Future human behaviour (target group) assumptions	0.06
Gas sources and effects (in geosphere)	2.2.11
Gas sources and effects (in wastes and EBS)	2.1.12
Gas-mediated transport of contaminants	3.2.09
Geological resources	2.2.13
Geological units, other	2.2.03
Glacial and ice sheet effects, local	1.3.05
Habits (non-diet-related behaviour)	2.4.04
Host rock	2.2.02
Human characteristics (physiology, metabolism)	2.4.01
Human influences on climate	1.4.01
Human response to climate changes	1.3.09
Human-action-mediated transport of contaminants	3.2.12
Hydraulic/hydrogeological processes and conditions (in geosphere)	2.2.07
Hydraulic/hydrogeological processes and conditions (in wastes and EBS)	2.1.08
Hydrological regime and water balance (near-surface)	2.3.11
Hydrological/hydrogeological response to climate changes	1.3.07
Hydrological/hydrogeological response to geological changes	1.2.10
Hydrothermal activity	1.2.06
Impacts of concern	0.01
Inorganic solids/solutes	3.1.03
Inventory, radionuclide and other material	2.1.01
Lakes, rivers, streams and springs	2.3.04
Leisure and other uses of environment	2.4.11
Marine features	2.3.06
Mechanical processes and conditions (in geosphere)	2.2.06
Mechanical processes and conditions (in wastes and EBS)	2.1.07
Metamorphism	1.2.05
Meteorite impact	1.5.01
Meteorology	2.3.10
Microbial/biological/plant-mediated processes, contaminant	3.2.06
Mining and other underground activities (human intrusion)	1.4.05
Miscellaneous and FEPs of uncertain relevance	1.5.03

Table 4 (cont'd). **The International FEP List (Version 1.0) in alphabetical order**

Model and data issues	0.10
Monitoring of repository	1.1.11
Motivation and knowledge issues (inadvertent/deliberate human actions)	1.4.02
Noble gases	3.1.06
Non-food products, contaminant concentrations in	3.3.03
Non-radiological toxicity/effects	3.3.07
Nuclear criticality	2.1.14
Organics and potential for organic forms	3.1.05
Other engineered features materials and characteristics	2.1.06
Periglacial effects	1.3.04
Quality control	1.1.08
Radiation effects (in wastes and EBS)	2.1.13
Radioactive decay and in-growth	3.1.01
Radiological toxicity/effects	3.3.06
Radon and radon daughter exposure	3.3.08
Records and markers, repository	1.1.05
Regulatory requirements and exclusions	0.09
Remedial actions	1.4.10
Repository assumptions	0.04
Repository design	1.1.07
Retrievability	1.1.13
Rural and agricultural land and water use (incl. fisheries)	2.4.09
Salt diapirism and dissolution	1.2.09
Schedule and planning	1.1.09
Sea level change	1.3.03
Seals, cavern/tunnel/shaft	2.1.05
Seismicity	1.2.03
Site investigation	1.1.01
Social and institutional developments	1.4.08
Soil and sediment	2.3.02
Solid-mediated transport of contaminants	3.2.08
Sorption/desorption processes, contaminant	3.2.03
Spatial domain of concern	0.03
Speciation and solubility, contaminant	3.2.02
Species evolution	1.5.02
Surface environment, human activities	1.4.06
Technological developments	1.4.09
Tectonic movements and orogeny	1.2.01
Thermal processes and conditions (in geosphere)	2.2.10
Thermal processes and conditions (in wastes and EBS)	2.1.11

Table 4 (cont'd). **The International FEP List (Version 1.0) in alphabetical order**

Timescales of concern	0.02
Topography and morphology	2.3.01
Un-intrusive site investigation	1.4.03
Undetected features (in geosphere)	2.2.12
Urban and industrial land and water use	2.4.10
Vegetation	2.3.08
Volatiles and potential for volatility	3.1.04
Volcanic and magmatic activity	1.2.04
Warm climate effects (tropical and desert)	1.3.06
Waste allocation	1.1.06
Waste form materials and characteristics	2.1.02
Water management (wells, reservoirs, dams)	1.4.07
Water-mediated transport of contaminants	3.2.07
Wild and natural land and water use	2.4.08

Inclusion of Project Databases

A prime function of the International FEP Database is to provide a collation of FEP information from performance assessments and scenario development studies. The International FEP List, discussed in the preceding sections, provides the framework to relate and access the information contained in project FEP databases. Table 2 indicates that there is already a large number of such databases with varying levels of information included.

Included projects

In Version 1.0 of the International FEP Database, eight project FEP databases are included. These are all published lists or databases, made available by members of the Working Group. Together, they cover a range of solid waste disposal concepts. Three project databases were mapped to International FEP List during the iterative process of developing the List:

- the AECL database of FEPs, termed factors, related to the Canadian concept of disposal of nuclear fuel waste in plutonic rock of the Canadian Shield [Goodwin et al. 1994];
- the joint SKI/SKB database of FEPs related to the Swedish KBS-3 concept of disposal of spent fuel in Swedish bedrock [Andersson (ed.) 1989];
- the example compilation of FEPs (names only) relevant to deep geological repositories that appears in the NEA Scenario Working Group report [NEA 1992].

For these databases, the mapping was carried out by a subgroup of the Working Group. Since that time, a further five databases have been included. In these cases, the mapping has been done by individual members of the Working Group:

- the Nagra database of FEPs related to the Kristallin-I assessment of disposal of vitrified high-level waste in crystalline basement rock of Northern Switzerland [Nagra 1994a];
- the HMIP database of FEPs related to the assessment of UK Nirex proposed disposal of intermediate-level waste in volcanic rock near to the Sellafield site [Miller and Chapman 1993];
- the USDOE database of FEPs related to the assessment of disposal of transuranic waste in bedded salt at the WIPP site [USDOE 1996];
- the SKI database of FEPs related to the SITE-94 assessment of disposal of spent fuel in a hypothetical deep repository in basement rock at the Äspö site [SKI 1996];
- the AECL database of FEPs, termed issues, related to the preliminary safety assessment of the near-surface Intrusion Resistant Underground Structure (IRUS) at the Chalk River site [Stephens et al. 1997].

Information on the scope, derivation and content of each of these databases is included in the electronic database. Typically, each project-specific FEP record consists of:

- a FEP name,
- a code number identifier,
- a description of the FEP, which in several of the project databases is sub-divided into a general description and comments specific to the project, and
- in some cases, project-specific codes that indicate the treatment or judgements made on the FEP.

Figure 3 illustrates a typical FEP record, in this case from the AECL nuclear fuel waste disposal database.

Figure 3. **Example of a project FEP record, in this case from the AECL database**

Project Database: Main Screen

Project:
AECL Scenario Analysis for EIS of Canadian Disposal Concept | AECL94

FEP name: | | *Index no:*
Biological activity | **A** | **1.03**

FEP description:

Description

Biological activity (microorganisms, bacteria) could change the physical and chemical environment in the vault, affecting the corrosion of containers, mineralogy of the clay in the buffer and backfill, generation or stability of colloids, mobility of contaminants, selective release of specific contaminants, and the porosity and conductivity of the buffer, backfill, seals and rock. Bacteria and microbes may also chemically transform contaminants and thereby change their mobility in the environment (Loewen and Flett 1984).

Comments

Microbial activity is likely to be present, although it will be limited by the low nutrient supply, elevated temperatures and presence of radiation fields (Stroes-Gascoyne and West 1994). It is anticipated that the effects of such biological processes could be adequately addressed through the use of conservative assumptions used to define the various submodels and parameter distributions in the vault. This is the case, for example, in the calculations of solubility limits (Johnson et al. 1994a) and for the case of crevice corrosion of titanium, which is assumed to occur on all containers and may occur under a biofilm or any other crevice former. We have therefore assumed that no further evaluation is warranted for the postclosure assessment, although additional research effort may be indicated. See also Complexation by organics, Methylation and Mutation. Further discussion is provided under Complexation by organics, Methane and Microbes in the list of geosphere factors (Table B.2), and under Bacteria and microbes in soil, and Biological evolution in the list of biosphere factors (Table B.3).]

References:

Stroes-Gascoyne and West 1994
Loewen and Flett 1984
Johnson et al. 1994

Mapped to the following FEPs in International NEA database:

2.1.10	Biological/biochemical processes and conditions (in wastes and EBS)
3.2.06	Microbial/biological/plant-mediated processes, contaminant

Project codes P BCSW B CX V *Unique no.* A 1.03

Each project has been allocated a code letter, in this case "A", which is combined with a project index number to give a unique identifying code, e.g. "A 1.03". In the AECL database, the first number "1" indicates a FEP related to the vault. This particular FEP has been mapped to two FEPs from the International list 2.1.10 and 3.2.06, which cover biological processes and evolution within the engineered barriers, and biological-mediated contaminant transport processes, respectively.

The mapping process

Each project-specific FEP record has been examined and mapped to one or more FEP of the International List. In carrying out the mapping, the following guidelines have been observed, based on experience of trial mapping by the Working Group:

1. Each project-specific FEP (PFEP) must be mapped to at least one International FEP (IFEP). If necessary, a PFEP may be mapped to an IFEP category heading, although this is not ideal.

2. Map each PFEP to only one IFEP if reasonable and, in general, try to map to not more than two. The experience of the Working Group was that this was possible for the majority of PFEPs tested. For example, a process of a particular type acting on a particular repository element might be mapped both to the element and the process type.

3. Look at the FEP description, not just the title. PFEPs should be mapped to benefit the IFEP list, i.e. the PFEP description will provide a specific example of the IFEP.

4. Try to find the IFEP that is most appropriate to the PFEP and the aspect of the PFEP that is described in the PFEP description. It is very easy to find connections that could connect any PFEP to a large number of IFEPs, but this will tend make the International List less useful as a keyword guide to the PFEPs.

Aims and Expected Uses of the Database

The ways in which the International FEP Database may be used in future cannot be fully anticipated at present. The implementation on an easily modified database is intended to avoid constraining its future use. Possible uses that have been identified by the Working Group are as follows:

The International FEP List provides:

(a) a list of FEPs to be considered when deciding the scope of a new assessment;

(b) a list of FEPs against which completed assessments can be audited or reviewed.

(c) a common list that might be accepted as a starting point for discussion of assessment scope and completeness between a proponent and regulator;

(d) through connection to the various project-specific FEP entries, a convenient map to find out how given factors or processes have been dealt with in other projects and to find literature references.

The database should be used in an open way, as a prompt, not as a specification of what should be discussed or analysed in an assessment. That is, the List should be a starting point for discussion within a project, not a constraint on discussion.

The glossary entries provide:

(a) brief general descriptions of each International FEP that will help to define the intended meaning which might otherwise be ambiguous;

(b) some prompts on possible relevance to safety assessment and examples of specific FEPs encompassed by the broader terms of the International FEP.

In addition, the compilation and review of the glossary may help to identify differences in terminology between different countries or projects.

The associated project databases provide a means to:

(a) interrogate project-specific databases, e.g. which FEPs have been considered in a given project?

(b) compare projects, e.g. how have different projects treated the same FEP?

(c) identify references and data within each project database for a FEP of interest.

As the database develops, and more project databases are added, other uses may be found. For example, information on interactions between FEPs may be included in project databases, in this case, examining a project database may provide a convenient way to explore an assessment as an alternative to reading conventional documents.

The appearance of a FEP, or FEP category, on the International FEP List does not imply that these must be analysed or even considered in detail in a particular assessment. Rather, it is a check list against which, as the system comes into use, some statement might be expected in assessment documentation. In many cases, it may only be necessary to state the reason why detailed evaluation is not required, e.g.

> "FEPs x, y and z are not relevant in this assessment because . . ."

or

> "for FEPs p and q, it is assumed that . . . and therefore evaluation is not required".

Some FEPs may be discussed in detail in assessment documents but not included in quantitative analyses; others may be the subject of detailed modelling taking account of a large number of subsidiary FEPs specific to the disposal system under consideration.

In summary, the expected benefits and uses of the International FEP List and associated project databases will be:

(a) an aid to achieving and demonstrating comprehensiveness within an assessment;

(b) a tool to interrogate individual assessments as well as to assist in comparing assessments.

The database should prove useful both within well-developed and new performance assessment programmes, and will become more valuable as more project databases are added to it.

4. IMPLEMENTATION OF THE DATABASE

Current Implementation

Version 1.0 of the International FEP Database is implemented on Claris FileMaker Pro™, Version 3.0. This software was chosen because it is an easy package to use, and files created by IBM PC or Apple Macintosh versions of the software are directly interchangeable.

A suite of menus, supporting information and data display screens have been created to introduce the Database and to encourage the user to explore the International FEP List and project FEPs in a structured way. These are designed so that a user needs no prior knowledge of the database or the structure of the data files. Users are recommended to obtain a copy of the Claris FileMaker Pro software in order to take advantage of these facilities. The FEP data can, however, also be supplied as text files. In this case, the user will need to know the content and structure of the files, e.g. in order to import it into their own preferred software.

The following information and data are included in Version 1.0 of the Database

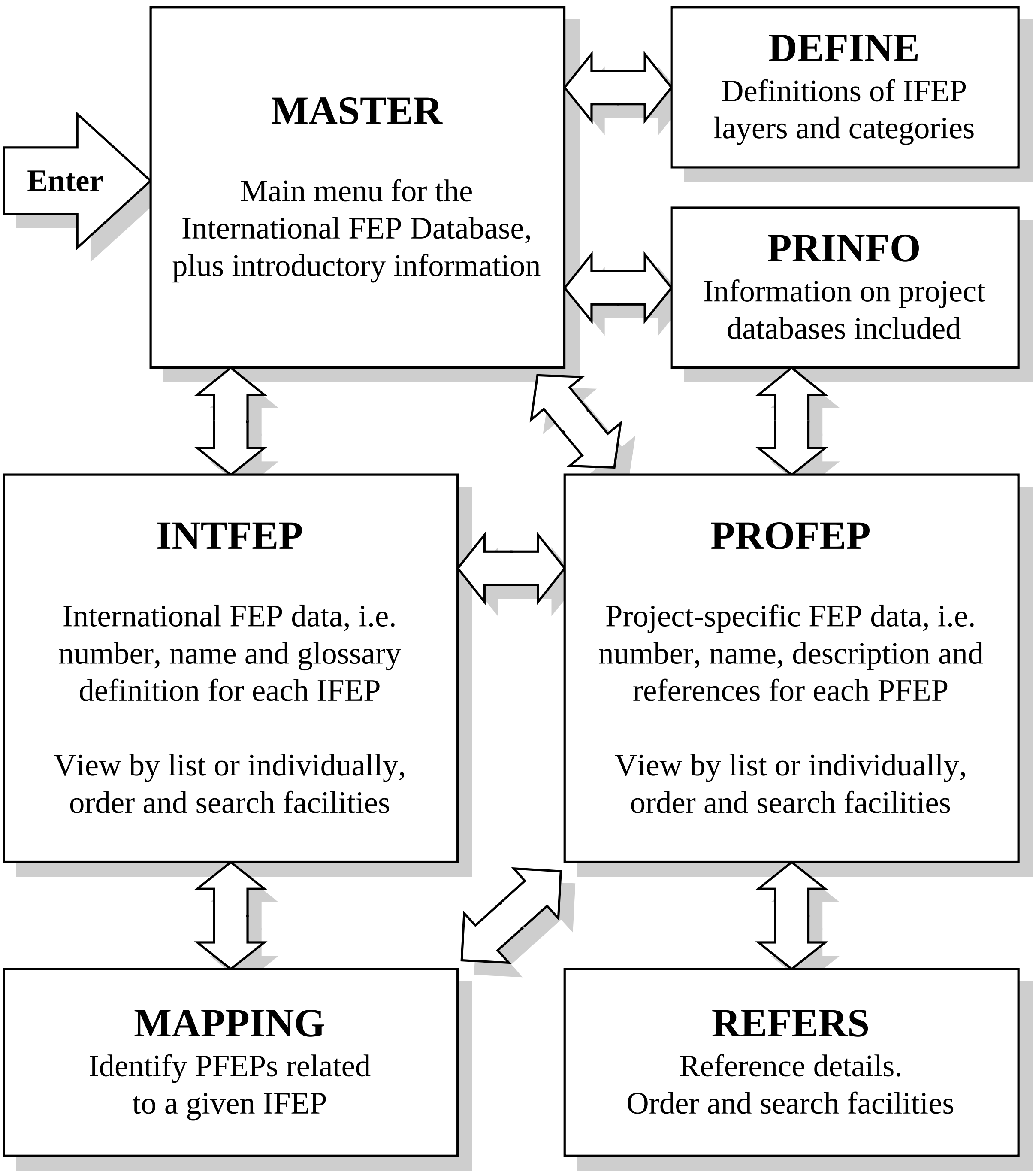
- explanatory information describing the International FEP Database concept and classification scheme;
- the International FEP List and associated glossary definitions and comments;
- information on project FEP databases included and their origins;
- project-specific FEP records from eight safety assessment or scenario development projects;
- references to individual project-specific FEPs.

The project-specific FEP information can be accessed directly or via the International FEP List. Figure 4 illustrates the modular file structure of the International FEP Database and transfer routes between files. The figure also indicates the content of each file and some of the functions that can be performed from each.

Possible Developments

The Working Group has discussed alternative database software packages and demonstrated the exchange of FEP data between many of the common packages. Members of the Group have also demonstrated project databases implemented on more sophisticated software packages, including graphical capabilities. In such project databases, the capabilities have been customised to suit the preferred project-specific procedures and methods used to manipulate the FEP information, e.g. in scenario and model development.

Figure 4. **The file structure of the International FEP Database (Version 1.0), transfer routes between files and an indication of the content and function of each file**



The view of the Working Group is that it is important to retain flexibility of use and to avoid implementing the International FEP Database in such a way that it would favour or appear to recommend particular methods of model or scenario development. Thus, there is an advantage in leaving the International FEP Database implemented on a simple database, as at present. The basic search, manipulation and print-out facilities allowed in FileMaker Pro will suffice for many users of the Database. Projects which use more sophisticated software packages for FEP documentation and manipulation can transfer the data from FileMaker Pro, or from text data files, to the software of their choice.

For this reason, no major functional developments of the International FEP Database are proposed at present. This decision could be reviewed by members of a future User Group, see next section. The Working Group does suggest, however, that in due course, the Database should be implemented as a "run-time" version. This would enable the Database to be used without the need to possess specific software and would also allow the data to be better protected. This development has cost and resource implications, however, and is beyond the remit of the current Working Group.

Use of the Database

The most important recommendation of the Working Group is that staff of repository safety assessment projects should obtain a copy of the International FEP Database, examine it, consider how this might be used within their own work and project, and report their experiences and views. The Database will also be of interest to regulatory bodies and those with more general interests in geological disposal projects.

The Working Group considers that a User Group should be established, with a Secretariat provided by NEA, to promote exchange of experiences, and to ensure proper maintenance and updating of the Database. An important function of a User Group should be to encourage organisations undertaking repository post-closure safety assessment in all OECD countries to send FEP information to the NEA for inclusion in the International FEP Database. The Database can be considered as a library for this information, and a source which those concerned with post-closure safety assessment can examine in order to determine what has been considered by others. The User Group, or a Core Group thereof, could also manage improvements to the database.

5. CONCLUSIONS AND RECOMMENDATIONS

Achievements of the Working Group

The FEP Database Working Group was set up by the PAAG as a follow-up activity to the Working Group on the Identification and Selection of Scenarios which reported in 1992 [NEA 1992]. The FEP Database Working Group met seven times in the period June 1993 to October 1996. The meetings were attended by representatives from fifteen organisations and seven countries. Detailed technical work has been carried out by a subgroup and by a consultant.

The primary achievement of the Working Group is the establishment of an "International FEP Database" consisting of:

- an international FEP classification scheme and glossary, and
- a compilation of project-specific FEP databases.

The classification scheme captures a range of waste disposal assessment projects within its scope. It is expected that this will be an aid to achieving comprehensiveness of assessments, and may be used as a starting point for the discussion of scope, e.g. in dialogue between implementers and regulators. The compilation of project databases is preliminary but more databases can be readily added. This is a useful source of information that can be searched and examined easily.

The Database system has been developed by consensus within an international group and is not biased towards any particular assessment approach. Therefore, it is hoped, the system will be of use within a broad range of assessment projects.

The discussions and interchange of information among the Working Group has allowed the participants to:

- learn of developments related to FEP identification and scenario development in other projects;
- obtain informal peer review of their own work;
- set their own work in an international perspective.

Lessons Learnt by the Group

Through the work on the International FEP Database, and more general discussions, lessons have been learnt related to FEP and scenario selection methods.

It has been shown that FEP databases, as commonly used in assessments, can be decoupled from methods of FEP manipulation and scenario identification. Moreover, the exchange of project databases, and review in other projects, can lead to a progressive improvement of FEP descriptions and related data. The International FEP Database should provide a mechanism to assist this exchange in future.

Methods for FEP manipulation and scenario identification are organisation-specific and may also be project or case-specific. The responsibility for defining methods appropriate to national regulations and project requirements should remain with individual organisations responsible for assessments. The International FEP Database does not offer guidance, and is designed not to bias the approach in these stages.

The Group observed that the aims and scope of assessments are important; they define the range of FEPs considered in an assessment and affect how FEPs are analysed. Thus, aims and scope need to be considered before compiling a case-specific FEP database; to reflect this, the "Assessment Basis" layer is added to the FEP classification scheme. It is hoped this will encourage fuller documentation of these aspects within project databases in future.

The International FEP classification scheme is not unique and is open to some degree of interpretation. The glossary definitions are important in drawing the boundaries between individual international FEPs and, thus, in mapping of project-specific FEPs to the most relevant international FEPs. Nevertheless, mapping of project-specific FEPs to the International FEP scheme requires care, and needs to be checked for consistency. Ensuring quality and consistency of mapping of new project databases should be one of the functions of a future User Group.

Although the Group discussed their own experiences related to scenario identification, and the use of databases to assist in this process, they did not undertake a review of work in this area. Significant developments have taken place in the last five years, since the publication of the NEA Scenario Working Group report [NEA 1992], e.g. see second section of Chapter 2. It would be valuable to review progress in this area, e.g. by means of a Workshop. This could involve participants from a wider range of organisations than involved in the present Group.

Recommendations

The main recommendations of the Working Group are as follows.

1. Performance assessment groups should obtain and examine the International FEP Database with a view to deciding how the Database might be used within their own work, and to improve harmonisation or communication between assessment groups.

2. A User Group should be set up (a) to encourage use of the Database and provide a forum for exchange of experiences, (b) to act as a focus for maintenance and development of the International FEP Database, and (c) to ensure the quality and consistency of additions to the Database.

3. A Workshop should be arranged to review developments in scenario methodologies and application in safety assessments since 1992; this should be the basis to prepare an overview of the current status of scenario and model formulation methods and their application.

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Appendix A
LIST OF PARTICIPANTS

The NEA International FEP Database Working Group met on seven occasions between June 1993 and October 1996. The following list includes all those who have attended at least one of the meetings.

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Appendix B

CLASSIFICATION SCHEME USED IN THE DERIVATION OF THE INTERNATIONAL FEP LIST

As described in Chapter 3, the International FEP List was derived with the assistance of a classification scheme illustrated in Figure 2.

Table B.1 gives the definition of layers and categories within the classification scheme. Table B.2 shows the International FEP List (Version 1.0) ordered according to the classification scheme under which it was derived. Each FEP has been assigned an identifying number:

Layer . category . number.

This information may be useful when examining the International FEP List arranged in alphabetical (or any other) order. For example:

Accidents and unplanned events 1.1.12

indicates that, in deriving the List, this FEP was considered as an "External Factor" and a "Repository Issue".

Table B.1. **Definition of layers and categories within the classification scheme used in the derivation of the International FEP List**

LAYERS AND CATEGORIES OF THE CLASSIFICATION SCHEME (p.1 of 2)

LAYER 0. ASSESSMENT BASIS

Assessment basis factors are factors that the analyst will consider in determining the scope of the analysis; these may include factors related to regulatory requirements, definition of desired calculation end-points and requirements in a particular phase of assessment. Decisions at this point will affect the phenomenological scope of a particular phase of assessment, i.e. what "physical FEPs" will be included. For example, some classes of future human actions or extreme future events unrelated to the repository may be excluded.

Layers 1, 2 and 3 are defined relative to a definition of the "Disposal System Domain".

The disposal system domain consists of the wastes, engineered and natural barriers which are expected to contain the wastes, together with the potentially contaminated geology and surface environment, plus the further geology, surface environment and human behaviour that are generally considered together in order to estimate the movement of radionuclides, and exposure to man, following repository closure. The domain thus has both spatial and temporal extent.

LAYER 1. EXTERNAL FACTORS

External Factors are FEPs with causes or origins outside the disposal system domain, i.e. natural or human factors of a more global nature and their immediate effects. Included in this layer are decisions related to repository design, operation and closure since these are outside the temporal bound of the disposal system domain.

In general, external factors are not influenced, or only weakly influenced, by processes within the disposal system domain. In developing models of the disposal system domain, external factors are often represented as boundary conditions or initiating events for processes within the disposal system domain.

The following categories are used:

1.1 Repository issues – decisions on design and waste allocation, and also events related to site investigation, operations and closure;
1.2 Geological processes and effects – processes arising from the wider geological setting and long-term processes;
1.3 Climatic processes and effects – processes related to global climate change and consequent regional effects;
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, see 2.4;
1.5 Other – a "catch-all" for anything not accommodated in 1.1 to 1.4, e.g. meteorite impact.

In general, there are few significant direct interactions between FEPs in the different categories of external factors.

Table B.1 (cont'd). **Definition of layers and categories within the classification scheme used in the derivation of the International FEP List**

LAYERS AND CATEGORIES OF THE CLASSIFICATION SCHEME (p.2 of 2)

Within the Disposal System Domain, Environmental and Radionuclide processes occur.

LAYER 2. DISPOSAL SYSTEM DOMAIN: ENVIRONMENTAL FACTORS

Disposal system domain environmental factors are features and processes occurring within that spatial and temporal domain whose principal effect is to determine the evolution of the physical, chemical, biological and human conditions of the domain that are relevant to estimating the release and migration of radionuclides and consequent exposure to man (see Layer 3).

The following categories are used:

2.1 Wastes & engineered features – features and processes within these components;

2.2 Geological environment – features and processes within this environment including, for example, the hydrogeological, geomechanical and geochemical features and processes, both in pre-emplacement state and as modified by the presence of the repository and other long-term changes;

2.2 Surface environment – features and processes within this environment, including near-surface aquifers and unconsolidated sediments but excluding human activities and behaviour, see 1.4 and 2.4;

2.4 Human behaviour – the habits and characteristics of the individual(s) or population(s), e.g. critical group, for which exposures are calculated, not including intrusive or other activities which will have an impact on the performance of the engineered or geological barriers, see 1.4.

Interactions between FEPs in the different categories of environmental factors may be very important.

LAYER 3. DISPOSAL SYSTEM DOMAIN: RADIONUCLIDE/CONTAMINANT FACTORS

Radionuclide factors are the processes that directly affect the release and migration of radionuclides in the disposal system environment, or directly affect the dose to members of a critical group from given concentrations of radionuclides in environmental media.

The following categories are used:

3.1 Contaminant characteristics – the characteristics of radio-toxic and chemo-toxic species that might be considered in a post-closure safety assessment;

3.2 Release/migration factors – the processes that directly affect the release and/or migration of radionuclides in the disposal system domain;

3.3 Exposure factors – processes and conditions that directly affect the dose to members of the critical group, from given concentrations of radionuclides in environmental media.

The boundaries between the different layers and categories are subjective and will depend on individual analysts' concepts and extent of models. This should not prevent a self-consistent assignment of FEPs within the International List itself or when mapping project FEPs to the International List.

Table B.2. **The International FEP List (Version 1.0) in classification scheme order**

0	**ASSESSMENT BASIS**
0.01	Impacts of concern
0.02	Timescales of concern
0.03	Spatial domain of concern
0.04	Repository assumptions
0.05	Future human action assumptions
0.06	Future human behaviour (target group) assumptions
0.07	Dose response assumptions
0.08	Aims of the assessment
0.09	Regulatory requirements and exclusions
0.10	Model and data issues
1	**EXTERNAL FACTORS**
1.1	REPOSITORY ISSUES
1.1.01	Site investigation
1.1.02	Excavation/construction
1.1.03	Emplacement of wastes and backfilling
1.1.04	Closure and repository sealing
1.1.05	Records and markers, repository
1.1.06	Waste allocation
1.1.07	Repository design
1.1.08	Quality control
1.1.09	Schedule and planning
1.1.10	Administrative control, repository site
1.1.11	Monitoring of repository
1.1.12	Accidents and unplanned events
1.1.13	Retrievability
1.2	GEOLOGICAL PROCESSES AND EFFECTS
1.2.01	Tectonic movements and orogeny
1.2.02	Deformation, elastic, plastic or brittle
1.2.03	Seismicity
1.2.04	Volcanic and magmatic activity
1.2.05	Metamorphism
1.2.06	Hydrothermal activity
1.2.07	Erosion and sedimentation
1.2.08	Diagenesis
1.2.09	Salt diapirism and dissolution
1.2.10	Hydrological/hydrogeological response to geological changes
1.3	CLIMATIC PROCESSES AND EFFECTS
1.3.01	Climate change, global

Table B.2 (cont'd) **The International FEP List (Version 1.0) in classification scheme order**

1.3.02	Climate change, regional and local
1.3.03	Sea level change
1.3.04	Periglacial effects
1.3.05	Glacial and ice sheet effects, local
1.3.06	Warm climate effects (tropical and desert)
1.3.07	Hydrological/hydrogeological response to climate changes
1.3.08	Ecological response to climate changes
1.3.09	Human response to climate changes
1.4	FUTURE HUMAN ACTIONS
1.4.01	Human influences on climate
1.4.02	Motivation and knowledge issues (inadvertent/deliberate human actions)
1.4.03	Un-intrusive site investigation
1.4.04	Drilling activities (human intrusion)
1.4.05	Mining and other underground activities (human intrusion)
1.4.06	Surface environment, human activities
1.4.07	Water management (wells, reservoirs, dams)
1.4.08	Social and institutional developments
1.4.09	Technological developments
1.4.10	Remedial actions
1.4.11	Explosions and crashes
1.5	OTHER
1.5.01	Meteorite impact
1.5.02	Species evolution
1.5.03	Miscellaneous and FEPs of uncertain relevance
2	**DISPOSAL SYSTEM DOMAIN: ENVIRONMENTAL FACTORS**
2.1	WASTES AND ENGINEERED FEATURES
2.1.01	Inventory, radionuclide and other material
2.1.02	Waste form materials and characteristics
2.1.03	Container materials and characteristics
2.1.04	Buffer/backfill materials and characteristics
2.1.05	Seals, cavern/tunnel/shaft
2.1.06	Other engineered features materials and characteristics
2.1.07	Mechanical processes and conditions (in wastes and EBS)
2.1.08	Hydraulic/hydrogeological processes and conditions (in wastes and EBS)
2.1.09	Chemical/geochemical processes and conditions (in wastes and EBS)
2.1.10	Biological/biochemical processes and conditions (in wastes and EBS)
2.1.11	Thermal processes and conditions (in wastes and EBS)
2.1.12	Gas sources and effects (in wastes and EBS)
2.1.13	Radiation effects (in wastes and EBS)

Table B.2 (cont'd). **The International FEP List (Version 1.0) in classification scheme order**

2.1.14	Nuclear criticality
2.2	GEOLOGICAL ENVIRONMENT
2.2.01	Excavation disturbed zone, host rock
2.2.02	Host rock
2.2.03	Geological units, other
2.2.04	Discontinuities, large scale (in geosphere)
2.2.05	Contaminant transport path characteristics (in geosphere)
2.2.06	Mechanical processes and conditions (in geosphere)
2.2.07	Hydraulic/hydrogeological processes and conditions (in geosphere)
2.2.08	Chemical/geochemical processes and conditions (in geosphere)
2.2.09	Biological/biochemical processes and conditions (in geosphere)
2.2.10	Thermal processes and conditions (in geosphere)
2.2.11	Gas sources and effects (in geosphere)
2.2.12	Undetected features (in geosphere)
2.2.13	Geological resources
2.3	SURFACE ENVIRONMENT
2.3.01	Topography and morphology
2.3.02	Soil and sediment
2.3.03	Aquifers and water-bearing features, near surface
2.3.04	Lakes, rivers, streams and springs
2.3.05	Coastal features
2.3.06	Marine features
2.3.07	Atmosphere
2.3.08	Vegetation
2.3.09	Animal populations
2.3.10	Meteorology
2.3.11	Hydrological regime and water balance (near-surface)
2.3.12	Erosion and deposition
2.3.13	Ecological/biological/microbial systems
2.4	HUMAN BEHAVIOUR
2.4.01	Human characteristics (physiology, metabolism)
2.4.02	Adults, children, infants and other variations
2.4.03	Diet and fluid intake
2.4.04	Habits (non-diet-related behaviour)
2.4.05	Community characteristics
2.4.06	Food and water processing and preparation
2.4.07	Dwellings
2.4.08	Wild and natural land and water use
2.4.09	Rural and agricultural land and water use (incl. fisheries)

Table B.2 (cont'd). **The International FEP List (Version 1.0) in classification scheme order**

2.4.10	Urban and industrial land and water use
2.4.11	Leisure and other uses of environment
3	**RADIONUCLIDE/CONTAMINANT FACTORS**
3.1	CONTAMINANT CHARACTERISTICS
3.1.01	Radioactive decay and in-growth
3.1.02	Chemical/organic toxin stability
3.1.03	Inorganic solids/solutes
3.1.04	Volatiles and potential for volatility
3.1.05	Organics and potential for organic forms
3.1.06	Noble gases
3.2	CONTAMINANT RELEASE/MIGRATION FACTORS
3.2.01	Dissolution, precipitation and crystallisation, contaminant
3.2.02	Speciation and solubility, contaminant
3.2.03	Sorption/desorption processes, contaminant
3.2.04	Colloids, contaminant interactions and transport with
3.2.05	Chemical/complexing agents, effects on contaminant speciation/transport
3.2.06	Microbial/biological/plant-mediated processes, contaminant
3.2.07	Water-mediated transport of contaminants
3.2.08	Solid-mediated transport of contaminants
3.2.09	Gas-mediated transport of contaminants
3.2.10	Atmospheric transport of contaminants
3.2.11	Animal, plant and microbe mediated transport of contaminants
3.2.12	Human-action-mediated transport of contaminants
3.2.13	Foodchains, uptake of contaminants in
3.3	EXPOSURE FACTORS
3.3.01	Drinking water, foodstuffs and drugs, contaminant concentrations in
3.3.02	Environmental media, contaminant concentrations in
3.3.03	Non-food products, contaminant concentrations in
3.3.04	Exposure modes
3.3.05	Dosimetry
3.3.06	Radiological toxicity/effects
3.3.07	Non-radiological toxicity/effects
3.3.08	Radon and radon daughter exposure

Appendix C
GLOSSARY DEFINITIONS AND COMMENTS ATTACHED TO THE INTERNATIONAL FEP LIST

The following pages are extracted from Version 1.0 of the International FEP Database.

The FEP records are printed in classification scheme order, see Table B.2 in Appendix B. International FEP names and scheme numbers are in bold, definitions are in normal type, and comments in italics.

ASSESSMENT BASIS **0**

Factors that the analyst will consider in determining the scope of the analysis. These may include factors related to regulatory requirements, definition of desired calculation end-points and requirements in a particular phase of assessment. Decisions at this point will affect the phenomenological scope of a particular phase of assessment, i.e. what "physical FEPs" will be included.

"Assessment Basis" is a category in the International FEP List and is subdivided into individual FEPs.

Impacts of concern **0.01**

The long-term human health and environmental effects or risks that may arise from the disposed wastes and repository. These FEPs include health or environmental effects of concern in an assessment (what effect and to whom/what), and health or environmental effects ruled to be of no concern.

The impact most frequently considered is the radiation dose or risk to man, often represented by the annual dose rate or risk to a member of a "critical group" of potentially most exposed individuals (see FEP 0.06). Examples of other impacts that have been considered in safety assessments are increases in radiation levels in the environment, and release or concentrations of non-radiological toxic contaminants.

Timescales of concern **0.02**

The time periods over which the disposed wastes and repository may present some significant human health or environmental hazard.

These may correspond to the timescale over which the safety of the disposed wastes and repository is estimated or discussed. In some countries national regulations set a limit up to which quantitative assessment is required, with more qualitative arguments to demonstrate safety being sufficient at later times.

Spatial domain of concern **0.03**

The domain over which the disposed wastes and repository may present some significant human health or environmental hazard.

This may correspond to the spatial domain over which the safety of the disposed wastes and repository is estimated, or the domain which it is necessary to model in order to develop an understanding of the movement of contaminants and exposures.

Repository assumptions **0.04**

The assumptions that are made in the assessment about the construction, operation, closure and administration of the repository.

For example, most post-closure assessments make the assumption that a repository has been successfully closed, although, in practice such decisions may be delayed or the subject of uncertainty.

Future human action assumptions **0.05**

The assumptions made in the assessment concerning general boundary conditions for assessing future human action.

For example, it can be expected that human technology and society will develop over the timescales of relevance for repository safety assessment, however, this development is unpredictable. Therefore, it is usual to make some assumptions in order to constrain the range of future human activities that are considered. A common assumption is that only present-day technologies, or technologies practised in the past will be considered.

Future human behaviour (target group) assumptions **0.06**

The assumptions made concerning potentially exposed individuals or population groups that are considered in the assessment.

Doses or risks are usually estimated for individuals or groups (critical groups) thought to be representative of the individuals or population groups that may be at highest risk or receive the highest doses as a result of the disposed wastes and repository. This is the accepted approach for assessing radiological risk or dose to members of the public resulting from a source of radioactive release to the environment. To assess the doses or risks at times in the far future, when the characteristics of potentially exposed populations are unknown a hypothetical critical group, or groups, is/are usually defined.

Dose response assumptions **0.07**

Those assumptions made in an assessment in order to convert received dose to a measure of risk to an individual or population.

Usually this will refer to individual human dose response, e.g. by a dose-risk conversion factor where the factor is the probability of a specified health effect per unit of radiation exposure. If other organisms are considered then a risk to individual organisms or a species might be considered.

The variation of a given response or human health effect (e.g. cancer incidence, cancer mortality) with the amount of radiation dose an individual or a group of individuals received is referred to as the dose-response relation. It is not possible to determine the shape of the dose response curve at low doses with any precision, because the incidence of health effects is very low. A linear dose-response relation with no dose threshold is generally assumed to be cautious.

Aims of the assessment **0.08**

The purpose for which the assessment is being undertaken.

For example, it may be to demonstrate the feasibility of a disposal concept (concept assessment), or for the purposes of site selection, or for the demonstration of regulatory compliance. The aim of the assessment is likely to depend on the stage in the repository development project at which the assessment is carried out and may also affect the scope of assessment.

Regulatory requirements and exclusions **0.09**

The specific terms or conditions in the national regulations or guidance relating to repository post closure safety assessment.

Regulatory requirements and exclusions may be expressed in terms of release, dose or risk limits or targets to individuals or populations effective over a specified timescale; they may also make demands about procedures following closure of the repository. In some regulations, the long-term scenarios to be assessed are specified, or some scenarios or events are specifically ruled out of consideration.

Model and data issues **0.10**

General (i.e. methodological) issues affecting the assessment modelling process and use of data.

Examples of general model and data issues are:

- *treatment of uncertainty (see below);*
- *method of handling site data;*
- *model and data reduction/simplification.*

EXTERNAL FACTORS **1**

FEPs with causes or origin outside the disposal system domain, i.e. natural or human factors of a more global nature and their immediate effects. Included in this category are decisions related to repository design, operation and closure since these are outside the temporal boundary of the disposal system domain for post-closure assessment.

“External Factors” is a category in the International FEP List and is divided into sub-categories.

REPOSITORY ISSUES **1.1**

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.

Site investigation **1.1.01**

FEPs 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.

Site investigation activities provide detailed site-specific data that characterise the site, provide performance assessment data and establish baseline conditions.

Excavation/construction **1.1.02**

FEPs related to the excavation of shafts, tunnels, disposal galleries, silos etc. of a repository, the stabilisation of these openings and installation/assembly of structural elements.

This includes rock bolting, shotcrete, grouting construction of tunnel/shaft linings, drain layers and installation of services and waste handling components.

Emplacement of wastes and backfilling **1.1.03**

FEPs related to the placing of wastes (usually in containers) at their final position within the repository and placing of buffer and/of backfill materials.

This includes methods and schedule of emplacement.

Closure and repository sealing **1.1.04**

FEPs related to the cessation of waste disposal operations at a site and the backfilling and sealing of access tunnels and shafts.

The intention of repository sealing is to prevent human access to the wastes. Sealing should also promote a return to pre-excavation hydrogeological conditions. Individual sections of a repository may be closed in sequence, but closure usually refers to final closure of the whole repository, and will probably include removal of surface installations. The schedule and procedure for sealing and closure may need to be considered in the assessment.

Records and markers, repository **1.1.05**

FEPs related to the retention of records of the content and nature of a repository after closure and also the placing of permanent markers at or near the site.

It is expected that records will be kept to allow future generations to recall the existence and nature of the repository following closure. In some countries, the use of site markers has been proposed where the intention is that the location and nature of the repository might be recalled even in the event of a lapse of present-day administrative controls.

Waste allocation **1.1.06**

FEPs related to the choices on allocation of wastes to the repository, including waste type(s) and amount(s).

The waste type and waste allocation is established in a general way in the repository disposal concept. There may, however, be a number of options concerning these factors. Final decisions may not be made until the repository is operating and will be subject to regulation. In safety assessments, assumptions may need to be made about future waste arisings and future waste allocation strategies.

Repository design **1.1.07**

FEPs related to the design of the repository including both the safety concept, i.e. the general features of design and how they are expected to lead to a satisfactory performance, and the more detailed engineering specification for excavation, construction and operation.

The repository design and construction is established in a general way in the disposal concept for the repository which is based on expected host rock characteristics, waste and backfill characteristics, construction technology, and economics. There may, nevertheless, be a range of engineering design and construction options still open. As the repository project proceeds, and more detailed site-specific information becomes available, the range of options may be constrained and decisions will be made. At any stage, repository safety assessments may only analyse a subset of the total range of options.

Quality control **1.1.08**

FEPs related to quality assurance and control procedures and tests during the design, construction and operation of the repository, as well as the manufacture of the waste forms, containers and engineered features.

It can be expected that a range of quality control measures will be applied during construction and operation of the repository, as well as to the manufacture of the waste forms, containers etc. In an assessment these may be invoked to avoid analysis of situations which, it is expected, can be prevented by quality control. There may be specific regulations governing quality control procedures, objectives and criteria.

Schedule and planning **1.1.09**

FEPs related to the sequence of events and activities occurring during repository excavation, construction, waste emplacement and sealing.

Relevant events may include phased excavation of caverns and emplacement of wastes, backfilling, sealing and closure of sections of the repository after wastes are emplaced, and monitoring activities to provide data on the transient behaviour of the system or to provide input to the final assessment. The sequence of events and time between events may have implications for long term performance, e.g. decline of activity and heat production from the wastes, material degradation, chemical and hydraulic changes during a prolonged "open" phase.

Administrative control, repository site **1.1.10**

FEPs related to measures to control events at or around the repository site both during the operational period and after closure.

The responsibility for administrative control of the site before closure of the repository during the construction and operational phases, and subsequently following closure of the repository may not be the same. Furthermore, the type of administrative control may vary depending on the stage in the repository lifetime.

Monitoring of repository **1.1.11**

FEPs related to any monitoring that is carried out during operations or following closure of sections of, or the total, repository. This includes monitoring for operational safety and also monitoring of parameters related to the long-term safety and performance.

The extent and requirement for such monitoring activities may be determined by repository design and geological setting, regulations and public pressure.

Accidents and unplanned events **1.1.12**

FEPs related to accidents and unplanned events during excavation, construction, waste emplacement and closure which might have an impact on long-term performance or safety.

Accidents are events that are outside the range of normal operations although the possibility that certain types of accident may occur should be anticipated in repository operational planning. Unplanned events include accidents but could also include deliberate deviations from operational plans, e.g. in response to an accident, unexpected geological event or unexpected waste arising during operations.

Retrievability **1.1.13**

FEPs related to any special design, emplacement, operational or administrative measures that might be applied or considered in order to enable or ease retrieval of wastes.

Designs may specifically allow for retrieval or rule it out. In some cases, an interim period might be planned, between waste emplacement and final repository sealing, during which time retrieval is possible.

GEOLOGICAL PROCESSES AND EFFECTS **1.2**

Processes arising from the wider geological setting and long-term processes.

"Geological Processes and Effects" is a sub-category in the International FEP List and is divided into individual FEPs.

Tectonic movements and orogeny **1.2.01**

Tectonic movements are movements of rock masses as a result of movements of the Earth's crustal plates; regionally the surface rocks respond to the underlying movements of plates. Orogeny is the process or period of mountain-building, often occurring over periods of hundreds of millions of years.

Orogenies may be associated with metamorphism, plutonism, and plastic deformation in deeper layers as well as thrusting, faulting and folding in the lithosphere which is the name given to the rigid, outermost layer of the earth, made up predominantly of solid rocks.

Deformation, elastic, plastic or brittle **1.2.02**

FEPs related to the physical deformation of geological structures in response to geological forces. This includes faulting, fracturing, extrusion and compression of rocks.

A fault is a fracture in the Earth's crust accompanied by displacement of one side of the fracture relative to the other. Fractures may be caused by compressional or tensional forces in the Earth's crust. Such forces may result in the activation of existing faults and, less likely, the generation of new faults.

Seismicity **1.2.03**

FEPs related to seismic events and also the potential for seismic events. A seismic event is caused by rapid relative movements within the Earth's crust usually along existing faults or geological interfaces. The accompanying release of energy may result in ground movement and/or rupture, e.g. earthquakes.

Seismic events may result in changes in the physical properties of rocks due to stress changes and induced hydrological changes. Seismic events are most common in tectonically active or volcanically active regions at crustal plate margins. The seismic waves that are generated by a tectonic or volcanic disturbance of the ocean floor may result in a giant sea wave, known as a tsunami.

Volcanic and magmatic activity **1.2.04**

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.

The high temperatures and pressures associated with volcanic and magmatic activity may result in permanent changes in the surrounding rocks; this process is referred to as metamorphism but is not confined to volcanic and magmatic activity (see FEP 1.2.05).

Metamorphism **1.2.05**

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.

Metamorphic processes are unlikely to be important at typical mined repository depths, but past metamorphic history of a host rock may be very important to understanding its present-day characteristics.

Hydrothermal activity **1.2.06**

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.

Groundwater temperature is determined by the large-scale geological and petrophysical properties of the rock formations (e.g. radiogenic heat formation, thermal conductivity), as well as the hydrogeological characteristics (e.g. hydraulic conductivity) of the rock.

Erosion and sedimentation **1.2.07**

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.

Compare FEP 2.3.12 which is concerned with more local processes over shorter periods of time.

Diagenesis **1.2.08**

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.

Salt diapirism and dissolution **1.2.09**

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.

Diapirism is most commonly associated with salt formations where a salt diapir comprises a mass of salt that has flowed in a ductile manner from a source layer and pierces or intrudes into the over-lying rocks. The term can also be applied to magmatic or migmatic intrusion.

Hydrological/hydrogeological response to geological changes **1.2.10**

FEPs arising from large-scale geological changes. These could include changes of hydrological boundary conditions due to effects of erosion on topography, and changes of hydraulic properties of geological units due to changes in rock stress or fault movements.

In and below low-permeability geological formations, hydrogeological conditions may evolve very slowly and often reflect past geological conditions, i.e. be in a state of disequilibrium.

CLIMATIC PROCESSES AND EFFECTS **1.3**

Processes related to global climate change and consequent regional effects.

"Climatic Processes and Effects" is a sub-category in the International FEP List and is divided into individual FEPs.

Climate change, global **1.3.01**

FEPs related to the possible future, and evidence for past, long term change of global climate. This is distinct from resulting changes that may occur at specific locations according to their regional setting and also climate fluctuations, c.f. FEP 1.3.02.

The last two million years of the Quaternary have been characterised by glacial/interglacial cycling. According to the Milankovitch Theory, the Quaternary glacial/interglacial cycles are caused by long term changes in seasonal and latitudinal distribution of incoming solar radiation which are due to the periodic variations of the Earth's orbit about the Sun (Milankovitch cycles). The direct effects are magnified by factors such as changes in ice, vegetation and cloud cover, and atmospheric composition.

Climate change, regional and local **1.3.02**

FEPs related to the possible future changes, and evidence for past changes, of climate at a repository site. This is likely to occur in response to global climate change, but the changes will be specific to situation, and may include shorter term fluctuations, c.f. FEP 1.3.01.

Climate is characterised by a range of factors including temperature, precipitation and pressure as well as other components of the climate system such as oceans, ice and snow, biota and the land surface. The Earth's climate varies by location and for convenience broad climate types have been distinguished in assessments, e.g. tropical, savannah, mediterranean, temperate, boreal and tundra. Climatic changes lasting only a few decades are referred to as climatic fluctuations. These are unpredictable at the current state of knowledge although historical evidence indicates the degree of past fluctuations.

Sea level change **1.3.03**

FEPs related to changes in sea level which may occur as a result of global (eustatic) change and regional geological change, e.g. isostatic movements.

The component of sea-level change involving the interchange of water between land ice and the sea is referred to as eustatic change. As ice sheets melt so the ocean volume increases and sea levels rise. Sea level at a given location will also be affected by vertical movement of the land mass, e.g. depression and rebound due to glacial loading and unloading, referred to as isostatic change.

Periglacial effects **1.3.04**

FEPs related to the physical processes and associated landforms in cold but ice-sheet-free environments.

An important characteristic of periglacial environments is the seasonal change from winter freezing to summer thaw with large water movements and potential for erosion. The frozen subsoils are referred to as permafrost. Meltwater of the seasonal thaw is unable to percolate downwards due to permafrost and saturates the surface materials, this can result in a mass movement called solifluction (literally soil-flow). Permafrost layers may isolate the deep hydrological regime from surface hydrology, or flow may be focused at "taliks" (localised unfrozen zones, e.g. under lakes, large rivers or at regions of groundwater discharge).

Glacial and ice sheet effects, local **1.3.05**

FEPs related to the effects of glaciers and ice sheets within the region of a repository, e.g. changes in the geomorphology, erosion, meltwater and hydraulic effects. This is distinct from the effect of large ice masses on global and regional climate, c.f. FEPs 1.3.01, 1.3.02.

Erosional processes (abrasion, overdeepening) associated with glacial action, especially advancing glaciers and ice sheets, and with glacial meltwaters beneath the ice mass and at the margins, can lead to morphological changes in the environment e.g. U-shaped valleys, hanging valleys, fjords and drumlins. Depositional features associated with glaciers and ice sheets include moraines and eskers. The pressure of the ice mass on the landscape may result in significant hydrogeological effects and even depression of the regional crustal plate.

Warm climate effects (tropical and desert) **1.3.06**

FEPs related to warm tropical and desert climates, including seasonal effects, and meteorological and geomorphological effects special to these climates.

Regions with a tropical climate may experience extreme weather patterns (monsoons, hurricanes), that could result in flooding, storm surges, high winds etc. with implications for erosion and hydrology. The high temperatures and humidity associated with tropical climates result in rapid biological degradation and soils are generally thin. In arid climates, total rainfall, erosion and recharge may be dominated by infrequent storm events.

Hydrological/hydrogeological response to climate changes **1.3.07**

FEPs related to changes in hydrology and hydrogeology, e.g. recharge, sediment load and seasonality, in response to climate change in a region.

The hydrology and hydrogeology of a region is closely coupled to climate. Climate controls the amount of precipitation and evaporation, seasonal ice cover, and thus the soil water balance, extent of soil saturation, surface runoff and groundwater recharge. Vegetation and human actions may modify these responses.

Ecological response to climate changes **1.3.08**

FEPs related to changes in ecology, e.g. vegetation, plant and animal populations, in response to climate change in a region.

The ecology of an environment is linked to climate. Ecological adaptation has allowed flora and fauna to survive and exploit even the most hostile of environments. For example, cacti have evolved to survive extreme heat and desiccation of the desert environment, and certain plant species complete their entire lifecycle over very short time periods following rare rain events in the desert. Some tree and plant species have evolved to survive natural events such as forest fires, and may require them to complete their lifecycle.

Human response to climate changes **1.3.09**

FEPs related to changes in human behaviour, e.g. habits, diet, size of communities, in response to climate change in a region.

Human response is closely linked to climate. Climate affects the abundance and availability of natural resources such as water, as well as the types of crops that can be grown. The more extreme a climate, the greater the extent of human control over these resources is necessary to maintain agricultural productivity, e.g. through the use of dams, irrigation systems, controlled agricultural environments (greenhouses).

FUTURE HUMAN ACTIONS (ACTIVE) **1.4**

Human actions and regional practices, in the post-closure period, that can potentially affect the performance of the engineered and/or geological barriers, e.g. intrusive actions, but not the passive behaviour and habits of the local population, c.f. 2.4.

“Human Actions (Active)” is a sub-category in the International FEP List and is divided into individual FEPs.

Human influences on climate **1.4.01**

FEPs related to human activities that could affect the change of climate either globally or in a region.

For example, man-made emissions of "greenhouse" gases such as CO_2 *and* CH_4 *have been implicated as a factors in global warming. Regionally, climate can be modified by de-forestation.*

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

FEPs related to the degree of knowledge of the existence, location and/or nature of the repository. Also, reasons for deliberate interference with, or intrusion into, a repository after closure with complete or incomplete knowledge.

Some future human actions, e.g. see FEPs 1.4.04, 1.4.05, could directly impact upon the repository performance. Many assessments distinguish between:

- *inadvertent actions, which are actions taken without knowledge or awareness of the repository, and*
- *deliberate actions, which are actions that are taken with knowledge of the repository's existence and location, e.g. deliberate attempts to retrieve the waste, malicious intrusion and sabotage.*

Intermediate cases, of intrusion with incomplete knowledge, could also occur.

Un-intrusive site investigation **1.4.03**

FEPs related to airborne, geophysical or other surface-based investigation of a repository site after repository closure.

Such investigation, e.g. prospecting for geological resources, might occur after information of the location of a repository had been lost. The evidence of the repository itself, e.g. discovery of an old shaft, might itself prompt investigation, including research of historical archives.

Drilling activities (human intrusion) **1.4.04**

FEPs related to any type of drilling activity in the vicinity of the repository. These may be taken with or without knowledge of the repository (see FEP 1.4.02).

Drilling activities include:

- *exploratory and/or exploitation drilling for natural resources;*
- *water well drilling;*
- *drilling for research or site characterisation studies;*
- *drilling for waste injection;*
- *drilling for hydrothermal resources.*

Mining and other underground activities (human intrusion) **1.4.05**

FEPs related to 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 1.4.02).

Mining and other excavation activities include:

- *resource mining;*
- *excavation for industry;*
- *excavation for storage or disposal;*
- *excavation for military purposes;*
- *geothermal energy production;*
- *injection of liquid wastes and other fluids;*
- *scientific or archaeological investigation;*
- *shaft construction, underground construction and tunnelling;*
- *underground nuclear testing;*
- *malicious intrusion, sabotage or war;*
- *recovery of repository materials.*

Surface environment, human activities **1.4.06**

FEPs related to any type of 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 1.4.07.

Examples include:
- *quarrying, trenching;*
- *excavation for construction;*
- *residential, industrial, transport and road construction;*
- *pollution of surface environment and groundwater.*

Quarrying, excavation and shallow site investigation may lead to direct human intrusion in the case of a near-surface repository.

Water management (wells, reservoirs, dams) **1.4.07**

FEPs related to groundwater and surface water management including water extraction, reservoirs, dams, and river management.

Water is a valuable resource and water extraction and management schemes provide increased control over its distribution and availability through construction of dams, barrages, canals, pumping stations and pipelines. Groundwater and surface water may be extracted for human domestic use (e.g. drinking water, washing), agricultural uses (e.g. irrigation, animal consumption) and industrial uses. Extraction and management of water may affect the movement of radionuclides to and in the surface environment.

Social and institutional developments **1.4.08**

FEPs related to changes in social patterns and degree of local government, planning and regulation.

Potentially significant social and institutional developments include:
- *changes in planning controls and environmental legislation;*
- *demographic change and urban development;*
- *changes in land use;*
- *loss of archives/records, loss/degradation of societal memory.*

Technological developments **1.4.09**

FEPs related to future developments in human technology and changes in the capacity and motivation to implement technologies. This may include retrograde developments, e.g. loss of capacity to implement a technology.

Of interest are those technologies that might change the capacity of man to intrude deliberately or otherwise into a repository, to cause changes that would affect the movement of contaminants, to affect the exposure or its health implications. Technological developments are likely but may not be predictable especially at longer times into the future. In most assessments assumptions are made to limit the scope of consideration.

Remedial actions **1.4.10**

FEPs related to actions that might be taken following repository closure to remedy problems with a waste repository that, either, was not performing to the standards required, had been disrupted by some natural event or process, or had been inadvertantly or deliberately damaged by human actions.

Explosions and crashes **1.4.11**

FEPs related to deliberate or accidental explosions and crashes such as might have some impact on a closed repository, e.g. underground nuclear testing, aircraft crash on the site, acts of war.

OTHER **1.5**

A “catch-all” for any external factor not accommodated in 1.1 to 1.4, e.g. meteorite impact.

“Other” is a sub-category in the International FEP List and is divided into individual FEPs.

Meteorite impact **1.5.01**

The possibility of a large meteorite impact occurring at or close to the repository site and related consequences.

The probability of impact of a meteorite sufficiently large and close to a repository to cause damage to the repository can be estimated based on the estimated frequency of large meteorite impacts in the past, and taking account of the repository depth.

Species evolution **1.5.02**

FEPs related to the biological evolution of humans, other animal or plant species, by both natural selection and selective breeding/culturing.

Animal (including man) and plant species have evolved with time. Over the timescales considered in some repository safety assessments natural evolution of plants and animal species is possible. Forced evolution of plant and animal species by selective breeding, especially species used for human foods, has occurred over very recent timescales and presumably will continue. In safety assessments, assumptions are usually made to avoid consideration of new species whose characteristics would be speculative.

Miscellaneous and FEPs of uncertain relevance **1.5.03**

FEPs that cannot be mapped anywhere else on the International FEP List also FEPs which have been identified, but no connection made to possible effects on repository performance.

There are a number of phenomena that have been suggested (i.e. added to FEP lists) during project scenario and FEP identification studies, for which no mechanism leading to any significant effect has been identified, e.g. changes in the Earth’s magnetic field. For completeness, such phenomena of uncertain relevance or effect are retained by mapping to this FEP in the International List.

DISPOSAL SYSTEM DOMAIN: ENVIRONMENTAL FACTORS **2**

Features and processes occurring within that spatial and temporal (postclosure) domain whose principal effect is to determine the evolution of the physical, chemical, biological and human conditions of the domain that are relevant to estimating the release and migration of radionuclides and consequent exposure to man.

“Disposal System Domain: Environmental Factors” is a category in the International FEP List and is divided into sub-categories.

WASTES AND ENGINEERED FEATURES **2.1**

Features and processes within the waste and engineered components of the disposal system.

“Wastes and Engineered Features” is a sub-category in the International FEP List and is divided into individual FEPs.

Inventory, radionuclide and other material **2.1.01**

FEPs related to the total content of the repository of a given type of material, substance, element, individual radionuclides, total radioactivity or inventory of toxic substances.

The FEP often refers to content of radionuclides but the content of other materials, e.g. steels, other metals, concrete or organic materials, could be of interest.

Waste form materials and characteristics **2.1.02**

FEPs related to the physical, chemical, biological characteristics of the waste form at the time of disposal and also as they may evolve in the repository, including FEPs which are relevant specifically as waste degradation processes.

The waste form will usually be conditioned prior to disposal, e.g. by solidification and inclusion of grout materials. The waste characteristics will evolve due to various processes that will be affected by the physical and chemical conditions of the repository environment. Processes that are relevant specifically as waste degradation processes, as compared to general evolution of the near field, are included in this FEP.

Container materials and characteristics **2.1.03**

FEPs related to the physical, chemical, biological characteristics of the container at the time of disposal and also as they may evolve in the repository, including FEPs which are relevant specifically as container degradation/failure processes.

The container characteristics will evolve due to various processes that will be affected by the physical and chemical conditions of the repository environment. Processes which are relevant specifically as container degradation/failure processes, as compared to general evolution of the near field, are included in this FEP.

Buffer/backfill materials and characteristics **2.1.04**

FEPs related to the physical, chemical, biological characteristics of the buffer and/or backfill at the time of disposal and also as they may evolve in the repository, including FEPs which are relevant specifically as buffer/backfill degradation processes.

Buffer and backfill are sometimes used synonymously. In some HLW/spent fuel concepts, the term buffer is used to mean material immediately surrounding a waste container and having some chemical and/or mechanical buffering role whereas backfill is used to mean material used to fill other underground openings. However, in ILW/LLW concepts the term backfill is used to describe the material placed between waste containers which may have a chemical role. Buffer/backfill materials may include clays, cement and mixtures of cement with aggregates, e.g. of crushed rock.

The buffer/backfill characteristics will evolve due to various processes that will be affected by the physical and chemical conditions of the repository environment. Processes which are relevant specifically as buffer/backfill degradation processes, as compared to general evolution of the near field, are included in this FEP.

Seals, cavern/tunnel/shaft **2.1.05**

FEPs related to the design, physical, chemical, hydraulic etc. characteristics of the cavern/tunnel/shaft seals at the time of sealing and also as they may evolve in the repository, including FEPs which are relevant specifically as cavern/tunnel/shaft seal degradation processes.

Cavern/tunnel/shaft seal failure may result from gradual degradation processes, or may be the result of a sudden event. The importance is that alternative routes for groundwater flow and radionuclide transport may be created along the tunnels and/or shafts and associated EDZ (see FEP 2.2.01).

Other engineered features materials and characteristics **2.1.06**

FEPs related to the physical, chemical, biological characteristics of the engineered features (other than containers, buffer/backfill, and seals) at the time of disposal and also as they may evolve in the repository, including FEPs which are relevant specifically as degradation processes acting on the engineered features.

Examples of other engineered features are rock bolts, shotcrete, tunnel liners, silo walls, any services and equipment not removed before closure. The engineered features, materials and characteristics will evolve due to various processes that will be affected by the physical and chemical conditions of the repository environment. Processes which are relevant specifically as degradation processes acting on the features, as compared to general evolution of the near field, are be included in this FEP.

Mechanical processes and conditions (in wastes and EBS) **2.1.07**

FEPs related to the mechanical processes that affect the wastes, containers, seals and other engineered features, and the overall mechanical evolution of near field with time. This includes the effects of hydraulic and mechanical loads imposed on wastes, containers and repository components by the surrounding geology.

Examples of relevant processes are:
- *container collapse,*
- *buffer swelling pressure,*
- *material volume changes,*
- *tunnel roof or lining collapse.*

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

FEPs related to the hydraulic/hydrogeological processes that affect the wastes, containers, seals and other engineered features, and the overall hydraulic/hydrogeological evolution of near field with time. This includes the effects of hydraulic/hydrogeological influences on wastes, containers and repository components by the surrounding geology.

Examples of relevant processes are:
- *infiltration and movement of fluids in the repository environment;*
- *resaturation/desaturation of the repository or its components;*
- *water flow and contaminant transport paths within the repository.*

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

FEPs related to the chemical/geochemical processes that affect the wastes, containers, seals and other engineered features, and the overall chemical/geochemical evolution of near field with time. This includes the effects of chemical/geochemical influences on wastes, containers and repository components by the surrounding geology.

Examples of relevant processes are:
- *general corrosion processes;*
- *chemical conditioning and buffering processes;*
- *electrochemical processes;*
- *precipitation/dissolution reactions;*
- *evolution of redox (Eh) and acidity/alkalinity (pH) etc.*

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

FEPs related to the biological/biochemical processes that affect the wastes, containers, seals and other engineered features, and the overall biological/biochemical evolution of near field with time. This includes the effects of biological/biochemical influences on wastes, containers and repository components by the surrounding geology.

Examples of relevant processes are:
- *microbial growth and poisoning;*
- *microbially/biologically mediated processes;*
- *microbial/biological effects of evolution of redox (Eh) and acidity/alkalinity (pH), etc.*

Thermal processes and conditions (in wastes and EBS) **2.1.11**

FEPs related to the thermal processes that affect the wastes, containers, seals and other engineered features, and the overall thermal evolution of the near field with time. This includes the effects of heat on wastes, containers and repository components from the surrounding geology.

Examples of relevant processes are:
- *radiogenic, chemical and biological heat production from the wastes;*
- *chemical heat production from engineered features, e.g. concrete hydration;*
- *temperature evolution;*
- *temperature dependence of physical/chemical/biological/hydraulic processes, e.g. corrosion and resaturation.*

Gas sources and effects (in wastes and EBS) **2.1.12**

FEPs within and around the wastes, containers and engineered features resulting in the generation of gases and their subsequent effects on the repository system.

Gas production may result from degradation and corrosion of various waste, container and engineered feature materials, as well as radiation effects. The effects of gas production may change local chemical and hydraulic conditions, and the mechanisms for radionuclide transport, i.e. gas-induced and gas-mediated transport.

Radiation effects (in wastes and EBS) **2.1.13**

FEPs related to the effects that result from the radiation emitted from the wastes that affect the wastes, containers, seals and other engineered features, and the overall radiogenic evolution of the near field with time.

Examples of relevant effects are ionisation, radiolytic decomposition of water (radiolysis), radiation damage to waste matrix or container materials, helium gas production due to alpha decay.

Nuclear criticality **2.1.14**

FEPs related to the possibility and effects of spontaneous nuclear fission chain reactions within the repository.

A chain reaction is the self-sustaining process of nuclear fission in which each neutron released from a fission triggers, on average, at least one other nuclear fission. Nuclear criticality requires a sufficient concentration and localised mass (critical mass) of fissile isotopes (e.g. U-235, Pu-239) and 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).

GEOLOGICAL ENVIRONMENT **2.2**

The features and processes within this environment including, for example, the hydrogeological, geomechanical and geochemical features and processes, both in pre-emplacement state and as modified by the presence of the repository and other long-term changes.

"Geological Environment" is a sub-category in the International FEP List and is divided into individual FEPs.

Excavation disturbed zone, host rock **2.2.01**

FEPs related to the zone of rock around caverns, tunnels, shafts or other underground openings that may be mechanically disturbed during excavation, and the properties and characteristics as they may evolve both before and after repository closure.

The excavation damaged zone may have different properties to the undisturbed host rock, e.g. opening of fractures or change of hydraulic properties due to stress relief. This zone may become desaturated to some degree during the period in which the tunnels are open and also subject to chemical changes both in the "open" period and after closure.

Host rock **2.2.02**

FEPs related to the properties and characteristics of the rock in which the repository is sited (excluding the rock that may be mechanically disturbed by the excavation) as they may evolve both before and after repository closure.

Relevant properties include thermal and hydraulic conductivity, compressive and shear strength, porosity etc.

Geological units, other **2.2.03**

FEPs related to the properties and characteristics of rocks other than the host rock as they may evolve both before and after repository closure.

Geological units are the separate rock structures and types that make up the region in which the repository is located. These units are identified in the geological investigations of the region. Each geological unit is characterised according to its geometry and its general physical properties and characteristics. A unit may be comprised of more than one rock formation, e.g. Quaternary sediments. Details concerning inhomogeneity and uncertainty associated with each unit are included in the characterisation.

Discontinuities, large scale (in geosphere) **2.2.04**

FEPs related to the properties and characteristics of discontinuities in and between the host rock and geological units, including faults, shear zones, intrusive dykes and interfaces between different rock types.

Contaminant transport path characteristics (in geosphere) **2.2.05**

FEPs related to the properties and characteristics of smaller discontinuities and features within the host rock and other geological units that are expected to be the main paths for contaminant transport through the geosphere, as they may evolve both before and after repository closure.

Groundwater flow and contaminant transport through rocks may occur in a variety of systems depending on the rock characteristics. Porous flow is predominantly through pores in the medium or through the interstitial spaces between small grains of materials. Fracture flow is predominantly along fractures in the rock which represent the only connected open spaces. Changes in the contaminant transport path characteristics due to the repository construction or its chemical influence etc. are included.

Mechanical processes and conditions (in geosphere) **2.2.06**

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.

Hydraulic/hydrogeological processes and conditions (in geosphere) **2.2.07**

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.

The hydrogeological regime is the characterisation of the composition and movement of water through the relevant geological formations in the repository region and the factors that control this. This requires knowledge of the recharge and discharge zones, the groundwater flow systems, saturation, and other factors that may drive the hydrogeology, such as density effects due to salinity gradients or temperature gradients. Changes of the hydrogeological regime due to the construction and/or presence of the repository are included.

Chemical/geochemical processes and conditions (in geosphere) **2.2.08**

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.

The hydrochemical regime refers to the groundwater chemistry in the geological formations in the repository region, and the factors that control this. This requires knowledge of the groundwater chemistry including speciation, solubility, complexants, redox (reduction/oxidation) conditions, rock mineral composition and weathering processes, salinity and chemical gradients. Changes of the hydrochemical regime due to the construction and/or presence of the repository are included.

Biological/biochemical processes and conditions (in geosphere) **2.2.09**

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.

Thermal processes and conditions (in geosphere) **2.2.10**

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.

Geothermal regime refers to sources of geological heat, the distribution of heat by conduction and transport (convection) in fluids, and the resulting thermal field or gradient. Changes of the geothermal regime due to the construction and/or presence of the repository are included.

Gas sources and effects (in geosphere) **2.2.11**

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.

Gas movement in the geosphere will be determined by many factors including the rate of production, gas permeability and solubility, and the hydrostatic pressure regime.

Undetected features (in geosphere) **2.2.12**

FEPs related to natural or man-made features within the geology that may not be detected during the site investigation.

Examples of possible undetected features are fracture zones, brine pockets or old mine workings. Some physical features of the repository environment may remain undetected during site surveys and even during pilot tunnel excavations. The nature of the geological environment will indicate the likelihood that certain types of undetected features may be present and the site investigation may be able to place bounds on the maximum size or minimum proximity to such features.

Geological resources **2.2.13**

FEPs related to natural resources within the geosphere, particularly those that might encourage investigation or excavation at or near the repository site.

Geological resources could include oil and gas, solid minerals, water, and geothermal resources. For a near-surface repository, quarrying of near-surface deposits, e.g. sand, gravel or clay, may be of interest.

SURFACE ENVIRONMENT **2.3**

The features and processes within the surface environment, including near-surface aquifers and unconsolidated sediments but excluding human activities and behaviour, see 1.4 and 2.4.

“Surface Environment” is a sub-category in the International FEP List and is divided into individual FEPs.

Topography and morphology **2.3.01**

FEPs related to the relief and shape of the surface environment and its evolution.

This FEP refers to local land form and land form changes with implications for the surface environment, e.g. plains, hills, valleys, and effects of river and glacial erosion thereon. In the long term, such changes may occur as a response to geological changes, see 1.3.

Soil and sediment **2.3.02**

FEPs related to the characteristics of the soils and sediments and their evolution.

Different soil and sediment types, e.g. characterised by particle-size distribution and organic content, will have different properties with respect erosion/deposition and contaminant sorption etc.

Aquifers and water-bearing features, near surface **2.3.03**

FEPs related to the characteristics of aquifers and water-bearing features within a few metres of the land surface and their evolution.

Aquifers are water-bearing features geological units or near-surface deposits that yield significant amounts of water to wells or springs. The presence of aquifers and other water-bearing features will be determined by the geological, hydrological and climatic factors.

Lakes, rivers, streams and springs **2.3.04**

FEPs related to the characteristics of terrestrial surface water bodies and their evolution.

Streams, rivers and lakes often act as boundaries on the hydrogeological system. They usually represent a significant source of dilution for materials (including) radionuclides entering these systems, but in hot dry environments, where evaporation dominates, concentration is possible.

Coastal features **2.3.05**

FEPs related to the characteristics of coasts and the near shore, and their evolution. 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 system and may represent a significant mechanism for dilution or accumulation of materials (including radionuclides) entering the system.

Marine features **2.3.06**

FEPs related to the characteristics of seas and oceans, including the sea bed, and their evolution. 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 system and may represent a significant mechanism for dilution or accumulation of materials (including radionuclides) entering the system.

Atmosphere **2.3.07**

FEPs related to the characteristics of the atmosphere, including capacity for transport, and their evolution.

Relevant processes include physical transport of gases, aerosols and dust in the atmosphere and chemical and photochemical reactions.

Vegetation **2.3.08**

FEPs related to the characteristics of terrestrial and aquatic vegetation both as individual plants and in mass, and their evolution.

Animal populations **2.3.09**

FEPs related to the characteristics of the terrestrial and aquatic animals both as individual animals and as populations, and their evolution.

Meteorology **2.3.10**

FEPs related to the characteristics of weather and climate, and their evolution.

Meteorology is characterised by precipitation, temperature, pressure and wind speed and direction. The variability in meteorology should be included so that extremes such as drought, flooding, storms and snow melt are identified.

Hydrological regime and water balance (near-surface) **2.3.11**

FEPs related to near-surface hydrology at a catchment scale and also soil water balance, and their evolution.

The hydrological regime is a description of the movement of water through the surface and near-surface environment. It includes the movement of materials associated with the water such as sediments and particulates. Extremes such as drought, flooding, storms and snow melt may be relevant.

Erosion and deposition **2.3.12**

FEPs related to all the erosional and depositional processes that operate in the surface environment, and their evolution.

Relevant processes may include, fluvial and glacial erosion and deposition, denudation, eolian erosion and deposition. These processes will be controlled by factors such as the climate, vegetation, topography and geomorphology.

Ecological/biological/microbial systems **2.3.13**

FEPs related to living organisms and relations between populations of animals, plants and their evolution.

Characteristics of the ecological system include the vegetation regime, and natural cycles such as forest fires or flash floods that influence the development of the ecology. The plant and animal populations occupying the surface environment are an intrinsic component of its ecology. Their behaviour and population dynamics are regulated by the wide range of processes that define the ecological system. Human activities have significantly altered the natural ecology of most environments.

HUMAN BEHAVIOUR **2.4**

The habits and characteristics of the individuals or populations, e.g. critical groups, to whom exposures are calculated, not including intrusive or other activities which will have an impact on the performance of the engineered or geological barriers, see 1.4.

"Human Behaviour (passive)" is a sub-category in the International FEP List and is divided into individual FEPs.

Human characteristics (physiology, metabolism) **2.4.01**

FEPs related to characteristics, e.g. physiology, metabolism, of individual humans.

Physiology refers to body and organ form and function. Metabolism refers to the chemical and biochemical reactions which occur within an organism, or part of an organism, in connection with the production and use of energy.

Adults, children, infants and other variations **2.4.02**

FEPs related to considerations of variability, in individual humans, of physiology, metabolism and habits.

Children and infants, although similar to adults, often have characteristic differences, e.g. metabolism, respiratory rates, habits (e.g. pica, ingestion of soil) which may lead to different exposure characteristics.

Diet and fluid intake **2.4.03**

FEPs related to intake of food and water by individual humans and the compositions and origin of intake.

The human diet refers to the range of food products consumed by humans.

Habits (non-diet-related behaviour) **2.4.04**

FEPs related to non-diet related behaviour of individual humans, including time spent in various environments, pursuit of activities and uses of materials.

The human habits refers to the time spent in different environments in pursuit of different activities and other uses of materials. The diet and 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.

Community characteristics **2.4.05**

FEPs related to characteristics, behaviour and lifestyle of groups of humans that might be considered as target groups in an assessment.

Relevant characteristics might be the size of a group and degree of self-sufficiency in food stuffs/diet. For example, hunter/gathering describes a subsistence lifestyle employed by nomadic or semi-nomadic groups who roam relatively large areas of land hunting wild game and/or fish, and gathering native fruits, berries, roots and nuts, to obtain their dietary requirements.

Food and water processing and preparation **2.4.06**

FEPs related to 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 preparational activities prior to human or livestock consumption. These may change the radionuclide distribution and/or content of the product. For example, radioactive decay during storage, chemical processing, washing losses and cooking losses during food preparation. Water sources may be treated prior to human or livestock consumption, e.g. chemical treatment and/or filtration.

Dwellings **2.4.07**

FEPs related to houses or other structures or shelter in which humans spend time.

Dwellings are the structures which humans live in. The materials used in their construction and their location may be significant factors for determining potential radionuclide exposure pathways.

Wild and natural land and water use **2.4.08**

FEPs related to 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 which may lead to significant modes of exposure.

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

FEPs related to 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.

Urban and industrial land and water use **2.4.10**

FEPs related to urban and industrial developments, including transport, and their effects on hydrology and potential contaminant pathways.

Human populations are concentrated in urban areas in modern societies. Significant areas of land may be devoted to industrial activities. Water resources may be diverted over considerable distances to serve urban and/or industrial requirements.

Leisure and other uses of environment **2.4.11**

FEPs related to 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.

RADIONUCLIDE/CONTAMINANT FACTORS **3**

FEPs that take place in the disposal system domain that directly affect the release and migration of radionuclides and other contaminants, or directly affect the dose to members of a critical group from given concentrations of radiotoxic and chemotoxic species in environmental media.

"Disposal System Domain: Radionuclide Factors" is a category in the International FEP List and is divided into sub-categories.

CONTAMINANT CHARACTERISTICS **3.1**

The characteristics of the radiotoxic and chemotoxic species that might be considered in a postclosure safety assessment.

"Contaminant Characteristics" is a sub-category in the International FEP List and is divided into individual FEPs.

Radioactive decay and in-growth **3.1.01**

Radioactivity is the spontaneous disintegration of an unstable atomic nucleus resulting in the emission of sub-atomic particles. Radioactive isotopes are known as radionuclides. Where a parent radionuclide decays to a daughter nuclide so that the population of the daughter nuclide increases this is known as in-growth.

In post-closure assessment models, radioactive decay chains are often simplified, e.g. by neglecting the shorter-lived nuclides in transport calculations, or adding dose contributions from shorter-lived nuclides to dose factors for the longer-lived parent in dose calculations.

Chemical/organic toxin stability **3.1.02**

FEPs related to chemical stability of chemotoxic species.

Inorganic solids/solutes **3.1.03**

FEPs related to the characteristics of inorganic solids/solutes that may be considered.

Volatiles and potential for volatility **3.1.04**

FEPs related to the characteristics of radiotoxic and chemotoxic species that are volatile or have the potential for volatility in repository or environmental conditions.

Some radionuclides may be isotopes of gaseous elements (e.g. Kr isotopes) or may form volatile compounds. Gaseous radionuclides or species may arise from chemical or biochemical reactions, e.g. metal corrosion to yield hydrogen gas and microbial degradation of organic material to yield methane and carbon dioxide.

Organics and potential for organic forms **3.1.05**

FEPs related to the characteristics of radiotoxic and chemotoxic species that are organic or have the potential to form organics in repository or environmental conditions.

Noble gases **3.1.06**

FEPs related to the characteristics of noble gases.

Radon and thoron are special cases, see FEP 3.3.08.

CONTAMINANT RELEASE/MIGRATION FACTORS **3.2**

The processes that directly affect the release and/or migration of radionuclides in the disposal system domain.

"Release/Migration Factors" is a sub-category in the International FEP List and is divided into individual FEPs.

Dissolution, precipitation and crystallisation, contaminant **3.2.01**

FEPs related to the dissolution, precipitation and crystallisation of radiotoxic and chemotoxic species under repository or environmental conditions.

Dissolution is the process by which constituents of a solid dissolve into solution. Precipitation and crystallisation are processes by which solids are formed out of liquids. Precipitation occurs when chemical species in solution react to produce a solid that does not remain in solution. Crystallisation is the process of producing pure crystals of an element, molecule or mineral from a fluid or solution undergoing a cooling process.

Speciation and solubility, contaminant **3.2.02**

FEPs related to the chemical speciation and solubility of radiotoxic and chemotoxic species in repository or environmental conditions.

The solubility of a substance in aqueous solution is an expression of the degree to which it dissolves. Factors such as temperature and pressure affect solubility, as do the pH and redox conditions. These factors affect the chemical form and speciation of the substance. Thus different species of the same element may have different solubilities in a particular solution. Porewater and groundwater speciation and solubility are very important factors affecting the behaviour and transport of radionuclides.

Sorption/desorption processes, contaminant **3.2.03**

FEPs related to sorption/desorption of radiotoxic and chemotoxic species in repository or environmental conditions.

Sorption describes the physico-chemical interaction of dissolved species with a solid phase. Desorption is the opposite effect. Sorption processes are very important for determining the transport of radionuclides in groundwater. Sorption is often described by a simple partition constant (K_d) which is the ratio of solid phase radionuclide concentration to that in solution. This assumes that sorption is reversible, reaches equilibrium rapidly, is independent of variations in water chemistry or mineralogy along the flow path, the solid-water ratio, or concentrations of other species. More sophisticated approaches involve the use of sorption isotherms.

Colloids, contaminant interactions and transport with **3.2.04**

FEPs related to the transport of colloids and interaction of radiotoxic and chemotoxic species with colloids in repository or environmental conditions.

Colloids are particles in the nanometre to micrometre size range which can form stable suspensions in a liquid phase. Metastable solid phases are unstable thermodynamically but exist due to the very slow kinetics of their alteration into more stable products. Colloids are present in groundwaters and may also be produced during degradation of the wastes or engineered barrier materials. Colloids may influence radionuclide 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.

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

FEPs related to the modification of speciation or transport of radiotoxic and chemotoxic species in repository or environmental conditions due to association with chemical and complexing agents.

This FEP refers to any chemical agents that are present in the repository system and the effects that they may have on the release and migration of radionuclides from the repository environment. Chemical agents may be present in the wastes or in repository materials or introduced, e.g. from spillage during repository construction and operation, e.g. oil, hydraulic fluids, organic solvents. Chemical agents may be used during construction and operation, e.g. in drilling fluids, as additives to cements and grouts etc.

Microbial/biological/plant-mediated processes, contaminant **3.2.06**

FEPs related to the modification of speciation or phase change due to microbial/biological/plant activity.

Microbial activity may facilitate chemical transformations of various kinds.

Water-mediated transport of contaminants **3.2.07**

FEPs related to transport of radiotoxic and chemotoxic species in groundwater and surface water in aqueous phase and as sediments in surface water bodies.

Water-mediated transport of radionuclides includes all processes leading to transport of radionuclides in water. Radionuclides may travel in water as aqueous solutes (including dissolved gases), associated with colloids (see FEP 3.2.04) or, if flow conditions permit, with larger particulates/sediments. Relevant processes include:

- *advection, i.e. movement with the bulk movement of the fluid;*
- *molecular diffusion, i.e. random movement of individual atoms or molecules within the fluid;*
- *dispersion, i.e. the spread of spatial distribution with time due to differential advection;*
- *matrix diffusion, i.e. the diffusion or micro-advection of solute/colloids etc. into non-flowing pores;*
- *percolation, i.e. movement of the fluid under gravity;*
- *multiphase transport processes.*

Solid-mediated transport of contaminants **3.2.08**

FEPs related to transport of radiotoxic and chemotoxic species in solid phase, for example large-scale movements of sediments, landslide, solifluction and volcanic activity.

Relevant processes include transport by suspended sediments and erosion.

Gas-mediated transport of contaminants **3.2.09**

FEPs related to transport of radiotoxic and chemotoxic species in gas or vapour phase or as fine particulate or aerosol in gas or vapour.

Radioactive gases may be generated from the wastes, e.g. C-14-labelled carbon dioxide or methane. Radioactive aerosols or particulates may be transported along with non-radioactive gases, or gases may expel contaminated groundwater ahead of them.

Atmospheric transport of contaminants **3.2.10**

FEPs related to 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. The atmospheric system may represent a significant source of dilution for these radionuclides. It may also provide exposure pathways e.g. inhalation, immersion.

Animal, plant and microbe mediated transport of contaminants **3.2.11**

FEPs related to transport of radiotoxic and chemotoxic species as a result of animal, plant and microbial activity.

Burrowing animals, deep rooting species and movement of contaminated microbes are included.

Human-action-mediated transport of contaminants **3.2.12**

FEPs related to transport of radiotoxic and chemotoxic species as a direct result of human actions.

Human-action-mediated transport of contaminants includes processes such as drilling into or excavation of the repository, the dredging of contaminated sediments from lakes, rivers and estuaries and placing them on land. Earthworks and dam construction may result in the significant movement of solid material from one part of the biosphere to another. Ploughing results in the mixing of the top layer of agricultural soil, usually on an annual basis.

Foodchains, uptake of contaminants in **3.2.13**

FEPs related to incorporation of radiotoxic and chemotoxic species into plant or animal species that are part of the possible eventual food chain to humans.

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.

EXPOSURE FACTORS **3.3**

Processes and conditions that directly affect the dose to members of the critical group, from given concentrations of radionuclides in environmental media.

“Exposure Factors” is a sub-category in the International FEP List and is divided into individual FEPs.

Drinking water, foodstuffs and drugs, contaminant concentrations in **3.3.01**

FEPs related to the presence of radiotoxic and chemotoxic species in drinking water, foodstuffs or drugs that may be consumed by human.

Environmental media, contaminant concentrations in **3.3.02**

FEPs related to the presence of radiotoxic and chemotoxic species in environmental media other than drinking water, foodstuffs or drugs.

The comparison of calculated contaminant concentrations in environmental media with naturally-occurring concentrations of similar species or species of similar toxic potential, may provide alternative or additional criteria for assessment less dependent on assumptions of human behaviour.

Non-food products, contaminant concentrations in **3.3.03**

FEPs related to the presence of radiotoxic and chemotoxic species in human manufactured materials or environmental materials that have special uses, e.g. clothing, building materials, peat.

Contaminants may be concentrated in non-food products to which humans are exposed. For example, building materials, natural fibres or animal skins used in clothing, and the use of peat for fuel.

Exposure modes **3.3.04**

FEPs related to the exposure of man (or other organisms) to radiotoxic and chemotoxic species.

The most important modes of exposure to radionuclides are generally:
- *ingestion (internal exposure) from drinking or eating contaminated water or foodstuffs;*
- *inhalation (internal exposure) from inhaling gaseous or particulate radioactive materials;*
- *external exposure as a result of direct irradiation from radionuclides deposited on, or present on, the ground, buildings or other objects.*

Exposure can also come from immersion in contaminated water bodies, direct radiation from airborne plumes of radioactive materials, injection through wounds, and cutaneous absorption of some species.

Dosimetry **3.3.05**

FEPs related to the dependence between radiation or chemotoxic effect and amount and distribution of radiation or chemical agent in organs of the body.

Dosimetry involves the estimation of radiation dose to individual organs, tissues, or the whole body, as a result of exposure to radionuclides. The radiation dose will depend on: the form of exposure, e.g. ingestion or inhalation of radionuclides leading to internal exposure or proximity to concentrations of radionuclides leading to external exposure; the metabolism of the radioelement and physico-chemical form if inhaled or ingested, which will determine the extent to which the radionuclide may be taken up and retained in body tissues; and the energy and type of radioactive emissions of the radionuclide which will affect the distribution of energy within tissues of the body.

Radiological toxicity/effects **3.3.06**

FEPs related to the effect of radiation on man or other organisms.

Radiation effects are classified as somatic (occurring in the exposed individual), genetic (occurring in the offspring of the exposed individual), stochastic (the probability of the effect is a function of dose received), non-stochastic (the severity of the effect is a function of dose received and no effect may be observed below some threshold).

Non-radiological toxicity/effects **3.3.07**

FEPs related to the effects of chemotoxic species on man or other organisms.

Radon and radon daughter exposure **3.3.08**

FEPs related to exposure to radon and radon daughters.

Radon and radon daughter exposure is considered separately to exposure to other radionuclides because the behaviour of radon and its daughter, and the modes of exposure, are different to other radionuclides. Radon (Rn 222) is the immediate daughter of radium (Ra-226). It is a noble gas with a half-life of about 4 days and decays through a series of very short-lived radionuclides (radon daughters), with half-lives of 27 minutes or less, to a lead isotope (Pb-210) with a half-life of 21 years. The principal mode of exposure is through the inhalation of radon daughters attached to dust particles which may deposit in the respiratory system.

Appendix D
OBTAINING THE INTERNATIONAL FEP DATABASE

The International Database is currently available as an unprotected version for professional use or as a stand-alone version for consultation only.

Database for professional use

Versions of the International FEP Database with full capabilities, e.g. print and mapping information, and also unprotected versions of the data files are available through a User Group organised by the NEA. The objectives of the group are:

- to promote the use of the Database including the controlled addition of new project-specific data;
- to ensure proper maintenance and development of the Database;
- to provide technical support to users, including advice on the use, contents and interfacing of the Database;
- thus, to ensure that the Database is available as a growing resource and record of the understanding and treatment of relevant features, events and processes in repository safety assessments.

A fee is charged to members of the User Group to cover the costs of distribution of the Database and contractor support, e.g. for maintenance and updating tasks.

The present version of the International FEP Database for professional use (Version 1.2) consists of data files produced in FileMaker Pro. These data files are only available to members of the NEA FEP Database User Group. Used with a licensed copy of FileMaker Pro (Version 3 or 4) the user has complete flexibility to manipulate, add or amend data, layouts and database functions at will.

Please send enquiries concerning the User Group and obtaining the Database to:

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Stand-Alone Version of the Database for Consultation

A CD-ROM with a limited capability, protected, electronic version of the International FEP Database (Version 1.1) can be bought from the OECD Bookshop.

Version 1.1 was prepared to accompany the NEA FEP Working Group Report. It is intended as a demonstration of the concept of the International FEP Database for wide circulation and uncontrolled use. This version may be quite adequate for many casual users, e.g. those that only use the database as an occasional source of reference.

The data contained in Version 1.1 and in the professional Version 1.2 (see above) are identical and there are minor cosmetic differences in the display screens. The main difference is that access privileges are more restricted in Version 1.1, disabling the “Print” capability and access to mapping information. The user cannot modify the database. Version 1.1 is a “run-time” solution produced under license from FileMaker Pro Inc. The FileMaker Pro software is **not** needed to run Version 1.1.

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