UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 6, 1997

MEMORANDUM TO: John H. Austin, Chief
Performance Assessment and High-Level
Waste Integration Branch
Division of Waste Management/NMSS

THROUGH: Keith I. McConnell, Section Leader
Performance Assessment and Integration Section
Performance Assessment and High-Level
Waste Integration Branch
Division of Waste Management/NMSS

FROM: James R. Firth JRF
Performance Assessment and Integration Section
Performance Assessment and High-Level
Waste Integration Branch
Division of Waste Management/NMSS

SUBJECT: SEVENTH MEETING OF WORKING GROUP TO START AND OVERSEE DEVELOPMENT OF AN INTERNATIONAL DATABASE OF FEATURES, EVENTS, AND PROCESSES; PARIS, FRANCE, OCTOBER 15-16, 1996

An abstract and a detailed trip report are attached. These documents present the discussions and conclusions reached by the Working Group to Start and Oversee Development of an International Database of Features, Events, and Processes (FEPs). This was the final meeting of the working group. The working group made several recommendations to the Performance Assessment Advisory Group (PAAG) at the October PAAG meeting. These recommendations include: (1) the formation of a FEP Database "Core Group" to take care of the maintenance and development of the database and (2) the formation of a coordinating committee to organize a workshop to review recent developments in scenario methodology. The working group deliberations leading to its recommendations are summarized in the attached detailed trip report.

NRC has participated in the development of the International FEP Database. Its interest in the database has not been as great as that found in other organizations, however, and the future development of the database is likely to be driven by the needs of these other organizations. Although NRC can benefit from the use and availability of the database, the benefits it would realize through its participation in the "Core Group" are likely to be limited. Therefore, I would not recommend that NRC participate in the "Core Group" at this time.

I believe that NRC should consider participating in the planned workshop on scenario methodology. The potential benefits to NRC through its participation warrant this consideration. These benefits are not, however, contingent upon NRC participation in the coordinating committee.

Contact: J. Firth, DWM/PAHL
415-6628

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The International FEP Database will become more useful to NRC as more project-specific entries (e.g., Yucca Mountain) are contained within the database. NRC may wish to examine the costs and benefits of introducing information related to the NRC performance assessments for Yucca Mountain into the database. However, efforts to incorporate NRC information into the International FEP Database have to be weighed against other NRC priorities.

Attachments: As stated

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TRIP REPORT ABSTRACT

OFFICIAL TRAVELER: James R. Firth

TRAVEL TO: OECD/NEA Paris, France

BEGINNING ON: October 11, 1996

ENDING ON: October 18, 1996

OFFICE: Nuclear Material Safety and Safeguards
Division of Waste Management
Performance Assessment and High-Level
Waste Integration Branch

MEETING TITLE AND/OR AFFILIATION:

Working Group to Start and Oversee the Development of an International Database of Features, Events, and Processes (FEPs), Performance Assessment Advisory Group (PAAG), Nuclear Energy Agency (NEA)

ORGANIZED BY: NEA

James R. Firth, Systems Performance Analyst (Engineer), NMSS/DWM/PAHL, participated as a Working Group member from the U.S.A. at the seventh and final meeting of the working group to Start and Oversee the Development of an International Database of Features, Events, and Processes (FEPs). The working group meetings took place during the mornings and afternoons of October 15 and 16, 1996, at the NEA offices at Issy-les-Moulineaux. The meeting was initially scheduled to take place October 15-17, 1996. The working group completed its deliberations on October 16, 1996, in light of a scheduled strike by the French civil service and the associated uncertainty for international travel. Other members of the group included Timothy Hicks of Galson Sciences Ltd. (DOE WIPP), Pablo Thorner of France (ANDRA), Marie Wiborgh (KEMATKA) and Lena Morén (SKB) of Sweden, Celsa Ruiz Rivas of Spain (CIEMAT), Fritz van Dorp of Switzerland (NAGRA), and Bertrand Ruegger (NEA). Also in attendance was Trevor Sumerling (Safety Assessment Management), a consultant to the working group.

Major actions undertaken by the group included the development of working group recommendations to the PAAG, final decisions on the initial requirements of the database, and decisions on the content of the final report of the working group. Version 1.0 of the International FEP Database, a product of the working group, is scheduled for release in January 1997. Two major recommendations by the working group are: (1) the formation of a "Core Group" to continue the development and maintenance of the International FEP Database and (2) the arrangement of a workshop to review developments in scenario methodology and application to safety assessments since 1992 with the goal of establishing the current state-of-the-art.

Attachment 1

DETAILED TRIP REPORT

on

Working Group to Start and Oversee Development of
an International Database of Features, Events, and
Processes;
Paris, France, October 15-16, 1996.

James Firth participated as a member at the seventh and final meeting of the working group to start and oversee an international database of features, events, and processes (FEPs). The primary purpose of this meeting was to make decisions on the content of the final report of the working group, the working group recommendations to the Performance Assessment Advisory Group (PAAG), and the final form of the initial database.

The meetings were held at the NEA offices in the Seine-St. Germaine building in Paris, France, on October 15-16, 1996. Working group members in attendance included: Timothy Hicks (WIPP, USA), Pablo Thorner (ANDRA, France), Marie Wiborgh (KEMATKA, Sweden), Lena Morén (SKB, Sweden), Celsa Ruiz Rivas (CIEMAT, Spain), Fritz van Dorp (NAGRA, Switzerland), Bertrand Ruegger (NEA staff), and Trevor Sumerling (Safety Assessment Management, consultant to the working group).

Prior to the meeting an agenda was proposed as follows:

1. Discuss the International FEP Database
2. Discuss the Status of National Projects
3. Discuss and develop working group Recommendations to PAAG
4. Discuss the final report of the working group
5. Plan Future Actions

A copy of the agenda is attached. A strike by the French civil service was scheduled for October 17, 1996. The working group decided to complete, if possible, its deliberations in advance of the pending civil disturbance and modified the schedule to reflect this change.

The group discussed their experiences with Version 0.6 of the prototype database, which was circulated in June 1996. Version 0.6 was developed using Claris FileMaker Pro 2.1, a flat database. Working group members had differing levels of success with the database, ranging from an inability to get the database to run locally (i.e., problems with getting a version of FileMaker compatible with their currently available version of windows and locked files) through an inability to get the search routines to work to no difficulties in operation.

The group discussed the status of the International FEP Database, the options for the initial release of the database and recommendations on the future oversight and development of the software. The group determined that the working group would go forward with a FileMaker Pro 2.n or a FileMaker Pro 3.n version of the database. FileMaker Pro 3.n is a relational database (allowing direct links between the international FEPs and the project-specific FEP

Attachment 2

entries, which is not possible using FileMaker Pro 2.n) and could result in an improved product. Filemaker Pro 3.n is now available in a version that is compatible with Windows 3.1; the earlier version required Windows 95 to operate. The initial release of the database will be in FileMaker 3.n format, if possible -- given the remaining schedule. Also, Marie Wiborgh (KEMATKA) demonstrated a FileMaker Pro 3.n database that took advantage of menu screens and buttons. The use of these tools will be investigated for inclusion in the initial release of the software. The working group agreed that a "run-time" version of the database, created using a developer's version of the software would be the preferred option, if time and resources permitted. This "run-time" version would make the database easier to use, provide better protection of the database, and would remove the need for each user to purchase a copy of FileMaker Pro. Although this option was not practical with the remaining time and resources, the working group felt that efforts should be made to have a "run-time" version of the database developed to make the database more accessible. This development work was deferred to the envisioned "Core Group" (see below). The International FEP Database, Version 1.0, is to be made available upon request to the NEA Secretariat and will be available in formats compatible with IBM PC or Macintosh hardware platforms.

The working group endorsed the concept of establishing a "Core Group" of users that would take the responsibility for the oversight of: database development, addition of new project databases and a user's group. This "Core Group" could make enhancements to the database (e.g., development of a "run-time" version of the program) and would help to ensure the consistency of the project-specific entries into the database. The working group viewed this development of a "run-time" version of the software as an important step in the continued development of the database. Therefore, it was decided that the "Core Group" would need committed resources sufficient to operate for two years. Also, it was felt that the "Core Group" would need to be able to rely upon the services of a contractor to quickly enact the needed improvements to the database. The funding for the contractor would be recovered from the members of the "Core Group."

There was general agreement that there would be users that would not wish to make the commitment necessary to participate as a member of the "Core Group." The working group identified these users as being a "User Group." The working group was split on the form and function that the "User Group" should take. The "User Group" was viewed alternatively as being limited in size and scope -- the group would be structured to facilitate distribution of software upgrades and serve as a registry of users -- and being, potentially, a larger and more diverse collection of users -- the group would be structured to facilitate the sharing of comments and experiences. There were also differences in the desired threshold for participation in the "User Group," such as the entry requirements and fees. These divisions generally reflected the different perspectives of developers and regulators. The working group decided that the final form of the "User Group" should be deferred to the "Core Group."

Version 0.6 of the database includes the following project-specific databases: NEA92, AECL94, SKI/SKB89, and NAGRA94 (provisional). The working group identified two project-specific databases, SITE94 and WIPP96, that could be

incorporated into the international database within the current schedule. Future additions to the database could be made after the release of version 1.0 of the database. Version 1.0 of the database is scheduled for release by January 1997. NRC, as a participant in the working group, will receive a copy once the development work has been completed.

The status of various national programs were presented and discussed.

Switzerland: NAGRA is finalizing its report on the crystalline rock site and no further work on scenario development will be conducted at this time. Also, another vote is coming up that will define the future work of NAGRA.

United States (DOE WIPP): DOE's recent efforts have focussed on documenting compliance with the U.S. EPA disposal standards. The documentation will comprise the Compliance Certification Application (CCA). FEP lists, a discussion of the PA methodology, and the approach used in scenario screening can be found in the CCA. The final CCA (20 volumes) will be submitted by the end of October 1996.

United States (NRC): The current status of regulations for the potential repository at Yucca Mountain, Nevada, recent legislative activity, and recent and ongoing NRC activities were discussed. The release of recommendations by the National Academy of Sciences (NAS) on appropriate standards for Yucca Mountain in August 1995, the statutory requirements for U.S. EPA to promulgate environmental standards within one year of the NAS recommendations, and the absence of proposed environmental standards were also discussed. The recent legislative activity pertaining to interim storage and disposal of spent nuclear fuel and the changes in the NRC high-level waste program associated with the current budget constraints were highlighted. NRC activities such as: an examination of the NAS recommendations from the perspective of implementability; the development of a technical position on expert elicitation; and the NRC review of the DOE TSPA-95, were identified.

France: ANDRA has recently completed three reports that address its underground laboratories (one granite site and two clay sites). These reports will be considered in the decision on whether to proceed with laboratory studies at these sites. Disposal is not being discussed for these sites at this time. However, there will be a report that will examine and choose between a limited selection of technical techniques for disposal at each site. After this last report is completed, the study will progress from an examination of the technical solutions for the sites to a concept choice in the 1997-1998 time-frame. There will be at least two laboratories; if a site is determined to be satisfactory, then it may be used as a repository. A pending decision is whether the design attributes of the laboratories will include disposal considerations.

Spain: ENRESA is considering three disposal concepts (clay, salt, and crystalline rock). The performance assessment (PA) for crystalline rock is expected to be finished by the end of the year (1996). The final report, however, will have a restricted distribution, since it is considered by ENRESA to be limited in scope. A more complete PA will then be conducted,

incorporating a review of the initial PA and applying a scenario methodology. At the end of 1997, ENRESA expects to have its FEP list mapped to the international FEP list. In 1998, ENRESA expects to finish its more thorough PA for crystalline rock.

Sweden (SKI): SKI is conducting the final editing for the SITE94 report. It is expected to be published by the end of the year. A follow-up activity planned for 1997 will be to respond to questions on the SITE94 report. SKI is developing a documentation system designed to show how FEPs have been treated within a safety assessment.

Sweden (SKB): SKB is working on a safety report that will include a safety assessment; a study of encapsulation; and a comparison of deep borehole disposal, transmutation, and interim storage. This report is expected to be completed by the end of 1997. There is currently an effort to identify a number of communities at which prestudies will be conducted. A total of five to ten communities is sought for the prestudies. There are currently three sites that have been identified and an agreement with a fourth site is close to completion. After these prestudies have been completed, two locations will be selected to conduct further tests. These tests will include the deposition of 10 percent of the spent fuel for a period of time. Also, there has been an evolution of the methodology used to create the Swedish FEP list.

England: A public inquiry on the Sellafield site is underway. This inquiry will determine whether NIREX will be able to proceed to build a laboratory for further studies. At the time of the meeting, NIREX was awaiting the inspectors' report, but was acting in a way that indicates that NIREX believes that they will be able to proceed. The inquiry focussed on the present and future conditions at the site. As a result of the inquiry there has been increased documentation of the NIREX safety assessment. NIREX is currently looking at selecting a set of scenarios from a FEP list. Also, there has been some reorganization of the English regulatory authority responsible for nuclear activities. As of April 1, 1996, Her Majesty's Inspectorate of Pollution (HMIP) has been incorporated into The National Rivers Authority.

The working group then discussed the recommendations that it would make to PAAG. A copy of these recommendations can be found in the attached document "The NEA FEP Database Working Group Summary Report and Recommendations to PAAG." The main recommendations of the working group were:

- The working group report should be published as an Organization for Economic Co-operation and Development (OECD) NEA document, with version 1.0 of the International FEP Database provided upon request to the NEA Secretariat.

- A "Core Group" to focus the future development and maintenance activities related to the International FEP Database should be established.

- A workshop to review developments in scenario methodology and application to safety assessments since 1992 (i.e., developments subsequent to the OECD

NEA report titled "Systematic Approaches to Scenario Development") should be arranged with the goal of establishing the current state-of-the art.

The working group reached a quick consensus on the recommendation concerning the working group report and initial release of the database. There was also a strong consensus that the value of the database will increase with the addition of new project-specific databases, so the working group is recommending that organizations continue to examine the database and submit information on their own projects for inclusion within the database. The working group concluded that continued activity of the working group would be unnecessary after the release of version 1.0 of the database. The working group decided that future oversight of the database should be handled by the "Core Group" and not this working group (see earlier discussion of the "Core Group"). The working group also reaffirmed its interest in the increased use and testing of the database and the expansion of the database to include more project-specific entries.

The working group discussed the breadth of changes in scenario methodology since the 1992 NEA report titled, "Systematic Approaches to Scenario Development." A quick consensus was reached that the changes since 1992 warranted another examination of scenario methodology. The 1992 report was the result of the work of an earlier NEA working group. The current working group discussed the lessons learned from the earlier work and reached consensus that a workshop would identify the current state-of-the-art in a more efficient and timely manner than through a working group.

The earlier discussions on the database and the working group recommendations also contributed to the discussions on the working group report. Written comments on the draft report were submitted by SKI and AECL prior to the meeting. The working group tried to limit the discussion to significant comments, with a mark-up sufficient for other comments. The working group discussed: issues related to the scope of the database (i.e., options other than disposal); the use of equivalent terms (e.g., container/canister and vault/area); the glossary accompanying the international FEP list; and whether the international FEP list is a list of FEPs or a categorization scheme for FEPs. These issues were discussed at earlier meetings and the most recent interpretations -- or decisions -- were reaffirmed as acceptable to the working group.

The working group adjourned the seventh meeting after the future actions were discussed on the afternoon of October 16, 1996. Trevor Sumerling, consultant to the working group, was assigned the task of reworking the recommendations in the working group's report to PAAG to reflect the discussions and decisions of the working group. In light of the altered schedule, these refined recommendations were sent to working group members for comment and a final round of revisions were made after the working group meeting.

The International FEP Database, Version 1.0, is scheduled to be completed and available for distribution by January 1997. The next draft of the working group report will be made available for comment in the near future. It is expected that the report will be ready for publication in February or March 1997. The first meeting of the "Core Group" and the first meeting of the

organizing committee for the scenario methodology workshop will be held in Spring 1997. (Note: PAAG agreed to the setting up of the "Core Group" and the co-ordinating committee for the scenario methodology workshop.)

Attached are copies of: agenda for the seventh NEA FEP Database Working Group Meeting, "Safety Assessment of Radioactive Waste Repositories: An International Database of Features, Events, and Processes" (9/8/96 draft), "The NEA FEP Database Working Group Summary Report and Recommendations to PAAG."

7th NEA FEP Database Working Group Meeting

NEA offices, Issy-les-Moulineaux, Paris
9h30, Tuesday, 15 October to
15h00 Thursday, 17 October, 1996

DRAFT AGENDA

- TUESDAY -

1. **INTRODUCTION**
   Agree agenda, any administrative matters

2. **THE INTERNATIONAL FEP DATABASE**
   Discuss experience with prototype database and agree
   - further work required on database format or presentation
   - project databases to be included in Version 1.0
   - schedule for completion
   - method of issue and control

   (Written comments have been received from SKI and AECL.)

3. **STATUS OF NATIONAL PROJECTS**
   Brief presentations from each organisation on work in national programmes.
   (Depending on progress in item 2. this item may be delayed until, or continued on, Thursday.)

- WEDNESDAY -

4. **RECOMMENDATIONS TO PAAG**
   Discuss and develop recommendations to PAAG in relation to
   - maintenance, use and development of the International FEP Database
   - review of developments in scenario methodology

   A draft paper to PAAG is being prepared which can be circulated on Tuesday for discussion on Wednesday. Hopefully, this can be updated so that a near final version can be re-circulated to the group on Thursday.

5. **FINAL REPORT**
   Discuss draft Working Group report and agree
   - any additional work and corrections required
   - schedule for completion and final review by WG members

   ("An International Database of Features, Events and Processes", draft 9/8/96, was circulated in August. So far comments have only been received from SKI.)

- THURSDAY -

5b. **STATUS OF NATIONAL PROJECTS** (continued)

6. **INPUTS TO CHAIRMAN'S REPORT TO PAAG**
   Review of 'Recommendations to PAAG' (see item 4). Any other inputs to reporting to PAAG ?

7. **PLAN OF FUTURE ACTIONS**
   Summary of group decisions and reminder of actions required.

- FINISH by 15h00 -

Attachment

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Attachment

1. OUTCOME OF THE PROJECT

1.1 Conduct of the Study

The FEP Database Working Group was set up by PAAG as a follow-up activity to the Working Group on the Identification and Selection of Scenarios which reported in 1992 [1]. 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. In addition, detailed technical work has been done by a sub-group and by a consultant.

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

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

Besides these general benefits, the following firm deliverables will come from the project:

- the NEA International FEP Database;
- the report of the Working Group.

A preliminary report of work by the Group has been given at the American Nuclear Society International High Level Radioactive Waste Management Conference, Las Vegas, 1996 [2].

1.2 The NEA International FEP Database

The NEA International FEP Database consists of two parts:

(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 FEP list and classification scheme by which to examine the project-specific database entries, see (2). A 'glossary' style definition is attached to each FEP.

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

Both parts are included as files in a computer database with simple screening and selection tools, and various screen display and print-out formats. Figure 1 illustrates how the International FEP List acts as a key to FEP descriptions and literature references held in project-specific databases. Alternative modes of use are facilitated by the simple database structure. In version 1.0 of the International FEP Database, seven project databases are included, see Table 1. The criteria for selecting these databases is that they are published lists or databases and, together, cover a range of solid waste disposal concepts.

The NEA FEP Database Working Group

Summary Report and Recommendations to PAAG

ABSTRACT

The FEP Database Working Group which was initiated in June 1993 will complete its work by the end of this year (1996). As well as the general benefits of information exchange, the following firm deliverables will come from the project:

- the NEA International FEP Database;
- the report of the Working Group.

The main recommendations of the Group are that:

1) the report of the Working Group should be published as an OECD NEA document, and version 1.0 the International FEP Database should be provided on request by the NEA Secretariat (R1-R2);

2) a Core Group should be set up to act as a focus for maintenance and development activities related to the International FEP Database, and to ensure the quality and consistency of additions to the Database (R3-R8); and

3) a Workshop should be arranged to review developments in scenario methodologies and application in safety assessments since 1992, and this should be the basis to prepare an overview of the state-of-the-art in this area (R9-R10).

More detailed recommendations and suggestions are given in Section 2 of this document.

CONTENTS

Attachment

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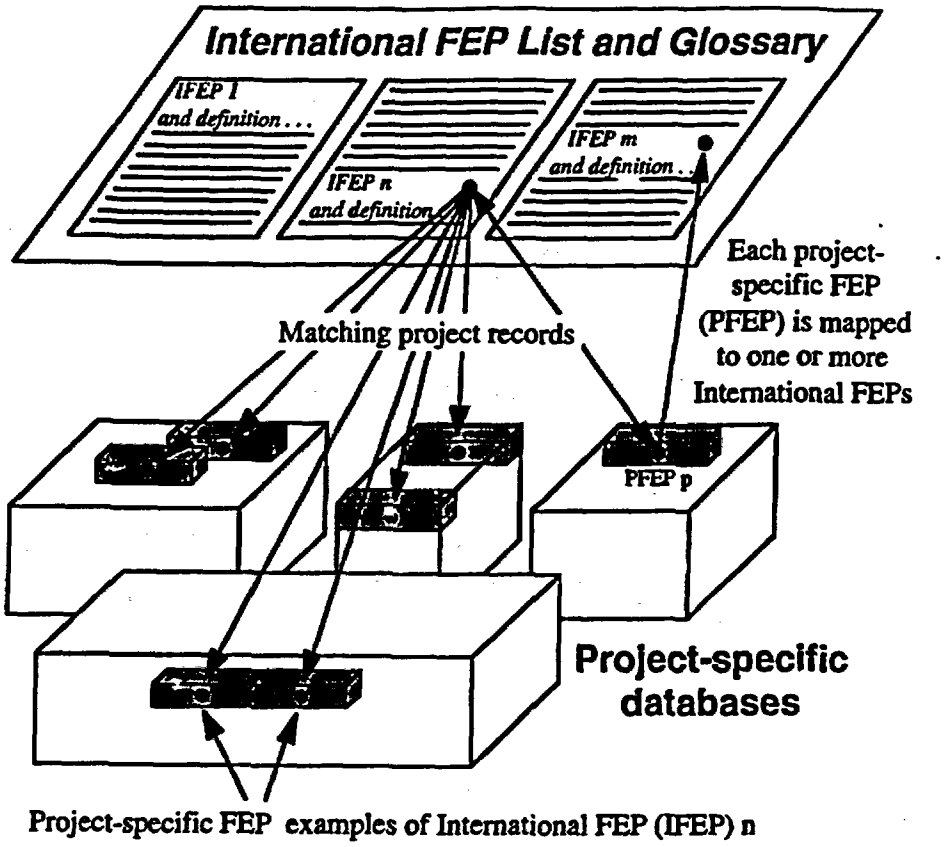

Figure 1 An overview of the International FEP Database, showing how the International FEP List acts as a key to FEP descriptions and literature references held in project-specific databases

Code	Comments	Ref.
SKIB89	the joint SKI/SKB database of 157 FEPs related to the Swedish KBS-3 spent fuel disposal concept	[3]
NEA92	example compilation of 150 FEPs (names only) relevant to deep geological repository that appears in the NEA Scenario Working Group report	[1]
HMIP92	the HMIP database of about 80 FEPs related to the assessment of disposal of low and intermediate-level waste in fractured hard rock	[4]
AECL94	the AECL database of about 250 FEPs (termed factors) related to the Canadian nuclear fuel waste disposal concept	[5]
NAG94	the Nagra database of about 240 FEPs related to the Kristallin-I assessment of disposal of vitrified high-level waste in the crystalline basement of Northern Switzerland	[6]
WIPP96	the USDOE database of about 240 FEPs related to the assessment of disposal of transuranic waste in bedded salt at the WIPP site	[7]
SITE94	the SKI database of about 165 FEPs related to the SITE-94 assessment of a hypothetical deep repository for spent fuel at the Äspö site	[8]

Table 1 Project databases included in the International FEP Database (version 1.0)

1.3 Report of the Working Group

A final report of the Working Group activities, focusing on the International FEP Database, its content, uses and development, will be produced. A draft of the report will be distributed at the PAAG meeting.

The Report and the International Database are currently under review by the Working Group. It is expected that final technical work will be complete by December 1996 and both deliverables will be ready for issue by February 1997.

2. RECOMMENDATIONS TO PAAG

Based on experience gained during the FEP Database Project, and related discussions, the Working Group makes recommendations to PAAG in three areas:

- dissemination of the deliverables from the Working Group;
- use, maintenance and development of the NEA International FEP Database;
- review of recent and ongoing developments in scenario methodologies.

In the following sections, **recommendations are given in bold type**; related comments and suggestions follow in normal type.

2.1 The Deliverables from the Working Group

R1 The Report of the Working Group should be issued as an OECD NEA document.

We believe the report is of sufficient interest in itself and will provide a useful reference to the work of the Group. In particular, it introduces the International FEP List which is a useful starting point for discussions on completeness of scope of assessments. The report also introduces the International FEP Database and should increase the interest in obtaining, using and adding to the Database. Moreover, both the report and Database are the result of consensus and work by an international group.

R2 The International FEP Database, Version 1.0, should be available on IBM PC (or Macintosh) diskettes from the NEA Secretariat on request, and a record should be kept of to whom copies of the Database have been sent.

Version 1.0 of the International FEP Database will be available as data files of a specific database software (Claris FileMaker Pro) and also as text files. Users must either have the specific software or must import the data into a database of their choice. We estimate that only a fraction of those who read the Working Group Report will wish to examine the database itself. In addition, it will be important to be able to stay in touch with users of the database, see R6. The diskettes should be accompanied by the basic information necessary to access the information plus a response form to encourage the submission of comments on Version 1.0 and possible improvements.

2.2 Use, Maintenance and Development of the International FEP Database

R3 We recommend to assessment groups that they examine the International FEP Database, Version 1.0, and, in due course (see below), submit FEP databases developed within their own projects for inclusion in the International FEP Database.

The International FEP Database is a product that should be of interest and use in repository safety assessment projects in many countries. The Database will become more useful as additional project databases are added to it. The aim is that each newly completed repository assessment or scenario development project in which a catalogue of FEP descriptions (and/or treatments) is developed should submit that database for inclusion in the International FEP Database.

R4 The International FEP Database should be both maintained and developed. In particular:
- **(a) a 'run-time' version of the Database should be produced;**
- **(b) procedures should be put in place to ensure the quality and consistency of additions to the Database.**

It would be advantageous to distribute future versions of the Database in the form of a 'run-time' code. Thus users would not need their own software to access the data, the interface could be better tailored to help users, e.g. with the use of menu screens and help facilities, and the data in the database could be better protected. Alternative 'run-time' versions might be developed, e.g. to allow search and examination only or to permit additional comments or project records to be added to a user's version.

It is important that a controlled version is maintained and that the quality and consistency of developments and additions to the Database are ensured. Some organisation and resources are necessary to achieve this.

R5 A 'Core Group' should be set up, under PAAG, whose members will specify and oversee developments of the Database and addition of new project databases. The Core Group will be responsible for overseeing a User Group plus paying and directing a technical contractor, see R6 and R7.

Many organisations with responsibilities for either waste management or regulation of waste management will find the International FEP Database useful and will benefit from its maintenance as an international resource. We believe that several organisations will be interested enough to participate in a Core Group which will specify and oversee developments and additions to the Database, and be willing to give financial support to pay for technical work to be carried out at the direction of the Core Group. The size of the Core Group is open, but we consider that a Group of between 4 and 8 organisations would be desirable.

The Core Group should meet to discuss the status of FEP database work internationally, possible uses, functions, control and dissemination of the International FEP Database, and the addition of project databases to the Database. Based on this discussion, the Core Group should outline a programme of technical work to progressively improve the function and utility of the International FEP Database. Thereafter, we expect that the Group would meet annually to oversee the programme.

R6 A register of users, or 'User Group', should be set up to encourage the use and dissemination of information related to the Database including updates and advice on capabilities and scope.

We believe that, in principle, the International FEP Database should be available to all organisations with an interest in repository safety assessment. It would be useful, however, to record to which organisations or persons the Database had been supplied and the use to which they were putting it; it would also be worthwhile to set up a mechanism by which users could return comments on their experiences and contact each other.

The form of a user group, and any entry requirement or fees, should be decided by the Core Group in agreement with NEA. A possible format would be a formal register of users maintained by the NEA Secretariat. Registered Users would receive updates of the International FEP Database as available, plus brief reports or newsletters describing developments or additions to the Database. A small fee might be necessary to cover administrative and material costs of supplying the Database if there is a practical way to collect this.

R7 We recommend that a technical contractor is retained through NEA to carry out maintenance and development tasks and prepare documents specified by the Core Group. The contractor costs should be recovered through payments from Core Group members to NEA, or directly to the contractor, through multi-party agreements.

Experience has shown that it is valuable to have a contractor to carry out specific technical tasks and to prepare documents required. This work may be appropriately assigned to a contractor because (1) the contractor has the responsibility and agreed resources to carry out the technical work in a timely fashion, and (2) the work is specified jointly by the Core Group and can rightly be claimed to be a product of an international consensus rather than of any one organisation. Thus, national organisations using the Database as a starting point or comparative tool in their studies can refer favourably to its international pedigree.

It is envisaged that the NEA Secretariat will be responsible for administrative support and distribution of working documents, reports and the Database copies, but the contractor will be responsible for providing the master materials.

R8 Initially, the Core Group members should commit resources sufficient to support the activities of the Group, including setting up of a User Group and technical work by a contractor, for a minimum period of two years.

A period of two years should be sufficient (1) to form a Core Group, (2) for the Core Group to specify a programme of work, select a contractor and agree to a budget, (3) for the contractor to produce a first 'run-time' version of the International FEP Database, (4) to decide the form of a User Group, and (5) to obtain and assess initial responses from users. The Core Group should meet initially, to agree a programme of work and estimate resources required, and thereafter as they see fit. The Chair of the Group should present the Group's recommendations for the continued maintenance, or otherwise, of the Database to PAAG in in October 1998.

The Working Group has discussed informally some options for the maintenance and development of the International FEP Database. We estimate that the *minimum* resource necessary to provide contractor support sufficient to act as a technical secretary to the Group over a two year period, carry out a basic level of development and make project record additions to the database is of the order of UK£ 30,000 (FFr 240,000). This indicates that a Core Group of about 6 member organisations, each prepared to commit participation of a member of staff plus contract funds of the order UK£ 5,000 (FFr 40,000) would be viable.

2.3 Review of Developments in Scenario Methodologies

During its discussions the Working Group has noted that, during the last few years, significant developments have taken place in the use of methodologies and tools to formalise and record the processes of scenario identification and selection. For example, the use of:

- the Rock Engineering System (RES) matrix method in Sweden, Finland, the U.K., and in the international BIOMOVS project;
- process influence diagrams (PID) in Sweden, and rather simpler influence diagrams in Switzerland;
- directed diagrams and the development of the FANFARE software system by AEA in U.K.;
- initiating event methodology for identifying and selecting scenarios within the CEC EVEREST project;
- event trees, scenario paths and illustrative graphics in the Yucca Mountain Project in the U.S.A.;
- formal elicitation, recording of conceptual model assumptions and tracking of model bias, e.g. in the U.K.;
- extensive FEP databases, e.g. in Switzerland, Sweden, the U.S.A (WIPP) and Canada.

The area of scenario identification is an area of fundamental importance to the comprehensive assessment of radioactive waste disposal and, in our opinion, continues to be an area in which international cooperation and exchange can be valuable. We stress that within the topic of scenario methodologies we include the methods for identification, selection and linking of FEPs within environmental simulation models that are used to generate alternative realisations of the future evolution of a disposal system, i.e. model-generated scenarios.

R9 **We recommend that a Workshop is arranged to review developments in scenario methodology and application in safety assessment. The Workshop should focus especially on developments since the publication of the NEA Scenario Working Group report of 1992 [1].**

Objectives for the Workshop would be:

- to review and discuss methods for scenario identification and their contribution to the overall formation of a comprehensive and justifiable safety assessment;
- to consider the available methods and compare their scope, consistency and function within the overall safety assessment process;
- to provide a basis from which to prepare a report summarising the current state-of-the-art in scenario methodologies, identifying where sufficient methods exist and any outstanding problem areas.

We believe that the Workshop should include:

- presentation of invited papers from organisations with recent experience of developing and/or applying scenario methodologies;
- discussion sessions on key common issues in scenario methodologies which would be seeded and guided by a questionnaire that should be circulated and completed before the workshop;
- parallel working sessions to draft position statements on key issues and define the state-of-the-art in these areas;
- plenary presentation and discussion of draft position statements.

Issues of common concern would be identified from analysis of the preliminary questionnaires, but might include topics such as:

- how to demonstrate 'completeness' or sufficiency of scope in an assessment;
- demonstration of traceability from data/information to assessment models and calculations in scenario identification and definition;
- use of expert judgement in scenario identification and definition;
- transparency of presentation of scenario identification and definition to different audiences, e.g. regulators, non-technical groups;
- the utility and (if useful) formulation of reference scenarios for repository assessment.

R10 We recommend that a Scenario Workshop Coordinating Committee should be formed under PAAG to take responsibility for organising the Workshop, including the preparation and analysis of preliminary questionnaires, plus preparation and editing of a Workshop Proceedings and Overview report.

We expect that the Coordinating Committee will discuss the organisation, attendance, timing and production of outputs from, and associated with, the Workshop. We suggest, however, that the following inputs and outputs may need to be managed:

- a questionnaire to identify issues of common concern and to explore views on issues identified initially by the Coordinating Committee;
- a compilation and/or preliminary analysis of the questionnaire answers;
- short written papers on scenario methodology and application in safety assessments prepared by the various national organisations;
- draft position papers on special issues prepared at the workshop;
- a short Overview Report on the state-of-the-art in scenario methodologies drawing together the position papers and results of plenary discussions;
- a Workshop Proceeding which might be prepared as a separate document or as an appendix to the Overview Report.

We suggest that the Coordinating Committee should consider retaining a contractor to assist in document drafting and editing, as this will assist in managing the timely production of inputs and outputs.

3. REFERENCES

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Safety Assessment of Radioactive Waste Repositories

An International Database of Features, Events and Processes

Draft 9/8/96

A report of the NEA Working Group on development of a database of features, events and processes relevant to the assessment of post-closure safety of radioactive waste repositories.

This draft document has been produced for circulation to the NEA FEP Database Working Group and will be discussed at the 7th Working Group meeting, 15-17 October 1996.

Written comments are invited and should be submitted by 30th September 1996.

The document has been produced by Safety Assessment Management Limited under joint funding from AECL, ANDRA, ENRESA, HMIP, NAGRA, PSI and SKB. However, these organisations do not necessarily endorse any of the views expressed.

Attachment

SAM-J012-R1, Version 2

Invitation to Comment

This document has been produced for circulation to the NEA FEP Database Working Group and will be discussed at the 7th Working Group meeting to be held on 15-17th October 1996.

Written comments are invited and should be sent to:

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and copied to:

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France

to be received by 30th September 1996 in order to be collated prior to the Working Group meeting.

Temporary comments, which will be replaced in a final draft, are indicated by *italic script*.

FOREWORD

The management of radioactive wastes 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. Although a general consensus has been reached in OECD Member countries on the use of geological repositories for radioactive waste disposal, analysis of the long-term safety of these repositories, using quantitative performance assessment, is required prior to implementation. Such assessments involve detailed analysis of the potential for release of radionuclides from the disposed wastes and subsequent transport to the human environment. An important stage of safety assessment is the identification and documentation of all the features, events and processes that could either initiate release of radionuclides, or promote or suppress the migration of radionuclides in the engineered barriers geology or surface environment, and promote or suppress the consequent radiation exposures to humans. This activity provides a basis for the broader activity of identifying and selecting scenarios that should be considered in quantitative performance assessment.

The NEA Performance Assessment Advisory Group (PAAG) was established in 1986 with the mandate to advise the Radioactive Waste Management Committee (RWMC) on technical aspects of the performance assessment of radioactive waste disposal systems and to help coordinate NEA activities in this area. PAAG provides an international forum for discussion and information exchange between OECD Member countries on performance assessment matters. The overall aims of PAAG are to assist in the development of methods and tools of high quality for the assessment of the safety of radioactive waste disposal systems, and to promote a balanced and coherent use of these methodologies within national radioactive waste disposal programmes.

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 then state-of-the art in this area including experiences of scenario studies in several member countries. Further discussions at PAAG and RWMC confirmed that scenario development continued to be an area of high priority and particularly suitable for international cooperation. It was suggested that the development of an international database of features, events and processes (FEPs) that are the bases for scenario construction 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 report documents the outcome of efforts by the Working Group to develop a database containing a generic list of factors, or FEPs, relevant to the post-closure safety of repositories for solid radioactive waste. The report also describes how this FEP list is linked to project databases which document information concerning the understanding of FEPs relevant to specific disposal systems and safety assessment studies.

This report is published under the responsibility of the Secretary-General of the OECD and it does not in any way commit the Member countries of the OECD.

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SUMMARY

INTRODUCTION

Key activities in development of a repository safety analysis are the comprehensive identification of the relevant factors, often termed "features, events and processes" - or FEPs, and the selection of factors that should be included in performance assessment. The processes of identifying, classifying and screening the factors form the first stages of the broader activity of identification and selection of alternative futures relevant to assessment of repository safety, 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[1] provided a summary of the then state-of-the art in this area. Further discussions confirmed that scenario development continued to be an area of high priority and particularly suitable for international cooperation. It was suggested that the development of an international database of FEPs would be a valuable follow up activity and, in 1993, PAAG set a Working Group to oversee the development of such a database. This report documents the outcome of efforts by the NEA Working Group.

OBJECTIVES AND CONDUCT OF THE PROJECT

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

- determine what FEP information is currently held by member countries;
- formulate 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.

The Working Group met seven times in the period June 1993 to October 1996. All of the countries represented at the Working Group have been engaged in, or are preparing for, performance assessment studies in which the identification of potentially relevant FEPs has 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 individual experiences and results.

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1 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.

Some of the detailed work of developing the International FEP List and design of a 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 documentation of the Working Group progress and development of a prototype database.

THE INTERNATIONAL FEP DATABASE

The NEA International FEP Database consists of two parts:

(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 at a given level of detail and within defined bounds. The forms a master keyword list by which to examine the various project-specific database entries, see (2). A 'glossary' style definition is attached to each FEP.

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

Both parts are included as files in a computer database with simple screening and selection tools, and various screen display and print-out formats.

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

(a) Select an International FEP (or FEPs) that most closely matches an enquirer's interest; the FEP list may be sorted or ordered on alternative criteria or categories to facilitate this;

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

Alternative modes of use are possible and are facilitated by the simple database structure. In version 1.0 of the International FEP Database, six project databases are included. The criteria for selecting these databases is that they are published lists or databases and, together, cover a range of solid waste disposal concepts. Procedures for including further project databases are defined.

Possible uses of the International FEP Database are as follows. The International FEP List provides:

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

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

(c) an indication of completeness of an assessment, if it can be demonstrated that all FEPs listed have either been considered or shown not to be relevant or significant for the particular disposal system or regulatory requirement;

The associated project databases provide a means to:

(a) interrogate project-specific databases to discover which FEPs have been considered in a given project and how they are treated;

(b) compare projects and to examine how different projects have treated the same FEP;

(c) trace to underlying references within each project database for a FEP of interest.

CONCLUDING REMARKS

The expected benefits and uses of the International FEP Database 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.

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Atomic Energy Canada Limited (AECL),
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1. INTRODUCTION

1.1 Background

The Radioactive Waste Management Committee (RWMC) of the OECD Nuclear Energy Agency (OECD/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, which 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." (p. 7, NEA 1991)

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 . . ." (p. 11, NEA 1991)

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" - or FEPs, and the logical screening and selection of factors that should be included in performance assessment. The processes of identifying, classifying and screening the factors or FEPs is sometimes called FEP analysis. This activity comprises the first stages of the broader activity of identification and selection of alternative futures relevant to assessment of radioactive waste repository safety, which is termed scenario development

A Working Group on the identification and selection of scenarios for performance assessment of radioactive waste repositories was set up by NEA Performance Assessment Advisory Group (PAAG) in 1987. The final report of that Group, "Systematic Approaches to Scenario Development" [NEA 1992], provided a summary of the then state-of-the art in this area including experiences of scenario studies in several member countries. Further discussions at PAAG and RWMC confirmed that scenario development continued to be an area of high priority and particularly suitable for international cooperation. It was suggested that the development of an international database of features, events and processes (FEPs) that are the bases for scenario construction would be a valuable follow up activity and, in 1993, PAAG decided to set up a new Working Group to start and oversee the development of such a database

This report documents the outcome of efforts by the Working Group, formed under the direction of the PAAG, to develop a database containing a generic list of factors, or FEPs, relevant to the post-closure safety of repositories for solid radioactive waste. The report also describes how this FEP list is linked to project databases which document information concerning the understanding of FEPs relevant to specific disposal systems and safety assessment studies.

1.2 Terms of Reference for the Working Group

Following discussions at PAAG and RWMC during 1993, the terms of reference for the Working Group were stated 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;
> - formulate 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 analyze the information available in the database and identify, for example, differences resulting from national regulations, traditions, cultures, etc..

1.3 Objectives for 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 overall scope and treatment of individual 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 QA 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 Working Group experiences. These are consistent with the guidance given by PAAG, see Section 1.2, and were accepted as objectives for completion of the project.

(1) To provide a computerised database of FEP names, descriptions and other information being the sum of information provided from individual assessment or scenario/model development projects.

(2) To provide a list of FEPs – "the International FEP List" – that is comprehensive, at some level of detail and within defined bounds, and will be a master keyword list by which to examine the various project-specific database entries.

(3) To provide a brief general scientific description of each master keyword FEP at the level of detail of a glossary.

(4) To enact the above 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.

Table 1 - Objectives for the NEA International FEP Database Project

1.4 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, United Kingdom and United States) have been engaged in, or are preparing for, performance assessment studies in which the identification and description of potentially relevant FEPs forms 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 design of a database was carried out by subgroups which met on three occasions in the period January 1995 to June 1996. In addition, a consultant carried out work on behalf of the Working Group, including preparation of documents related to the work of the Working Group and subgroups, and development of a prototype database.

1.5 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 construction. Scenario construction has been the subject of a previous NEA Working Group report [NEA 1992], and PAAG have indicated that this topic may be the subject of a further Working Group study.

Chapter 2 of this notes some of the benefits of using formal FEP lists or databases within assessment projects, which have, in part, provided the motivation for this Working Group study. 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 two parts:

(1) *The International FEP List* – a list of factors relevant to the assessment of long-term safety of solid radioactive waste repositories. This forms a master keyword list by which to examine the various project-specific database entries. A 'glossary' style definition of scope is attached to each of the FEPs.

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

Both parts are included as files in a computer database with simple screening and selection tools, and various screen display and print-out formats.

The chapter sets out principles of design and operation of the Database, discusses the claim to comprehensiveness of the International FEP List, and presents the List and examples of glossary entries. The derivation of the List is described and

classification schemes are discussed. 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 complemented by Appendix B, which defines the classification scheme that was used in the derivation of the International List, and Appendix C, which gives information on the scope and content of project FEP databases that have been included in the International FEP Database.

Chapter 4 sets out recommendations from the Working Group for the consolidation and maintenance of the International FEP Database. The chapter is complemented by Appendix D, which provides a User's Guide to the Database, Appendix E, which gives instructions for submitting project databases for inclusion in the Database, and Appendix F which gives information on joining a User Group.

Chapter 6 sets down conclusions and final remarks from the Working Group.

In this draft, Chapters 5 and 6, and Appendices D, E and F are incomplete. They will completed after further discussion by the Working Group and to agree with decisions made by PAAG and NEA.

2 FEP LISTS AND DATABASES IN NATIONAL PROJECTS

2.1 Benefits of FEP Lists and Databases

An activity that is common to all assessments of long-term safety of radioactive wastes is the identification of the factors, or FEPs, that will be considered, although the formality with which this is done and documented may vary considerably between projects. In recent years, 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 about what the relevant processes may be;

- descriptive information and references added against each FEP provides a repository for ideas and data that can be used during scenario or model development activities;

- a FEP list and database provides a framework to record information about a FEP, even if the FEP is not included in assessment models or its importance is uncertain;

- the models and data 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 model developments or data gathering that may be necessary.

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

- the extent of the project list gives a clear indication of the range of FEPs that have been given at least qualitative consideration, and

- if, for each FEP, a clear description is given of its relevance and importance, and whether or how it is treated in quantitative analysis, then confidence is generated in the scope and comprehensiveness 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 firm basis for subsequent phases. In some countries, the use of such databases has been extended so that they are linked to scenario or conceptual model development systems, or to provide a tool to assist in project management.

2.2 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 referenced subsequently 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 *(in the context of the Basalt Waste Isolation Project?)*.

Also during the 1980s in the USA, Sandia National Laboratories (SNL) were developing the well-known scenario development methodology on behalf of the USNRC [Cranwell et al. 1982]. Within Cranwell et al. [1982] and related reports a list of 30 "potentially disruptive events and processes" is reproduced that have been the basis for scenario development studies, for example for the assessment of safety of disposal of transuranic wastes in bedded salt at the WIPP site [Guzowski 1990]. In Europe, a list of 25 "primary events" was used as a starting 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 included what can be mainly thought of as scenario initiating (e.g. potentially disruptive) phenomena or phenomena that would lead to changes in the state of 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 Inpectorate (SKI) carried out a Joint Scenario Development Exercise in which was different in several respects [Andersson (ed.) 1989].

(1) A list of features, events and processes (the term "FEP" was used) were derived by four groups of experts working semi-independently and including experts both from the national waste management programme and from other countries and broader scientific disciplines; previous studies seem to have derived such lists through in-house expertise.

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

(3) For each FEP a "memo comment" was written which recorded information on the process itself, its effects, references to the process and whether the FEP could be screened from the safety analysis. This information was said to be included in a computer database.

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

During a similar period, Atomic Energy of Canada Limited (AECL) were preparing a catalogue of factors for use in scenario development for post-closure assessment of the Canadian 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 features, events and processes that appears in the NEA Scenario Working Group report [NEA 1992, pp. 24-25].

More recently, developments have been made in more formal methods of FEP manipulation and analysis, compilations of more extensive FEP catalogues and 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], Finland [Vieno et al. 1994], the United Kingdom [Hudson 1995] and in international BIOMOVS study [BIOMOVS II 1994]. The method appears to assist in identifying FEPs and checking for comprehensiveness of a FEP list.

- The SKI, in Sweden, have developed a method based on "process influence diagrams" that illustrates graphically the potential 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 on database software, for example for the assessment of high-level waste in crystalline basement rock [Nagra 1994a; Sumerling et al. 1996]. A feature of this work is that the FEP database and analysis is seen as a method of active management of development of a safety case [Sumerling et al. 1993], e.g. through identification of so-called "reserve FEPs" and "open questions".

- *More short paragraphs, could be added, e.g. the FANFARE work from AEA (is there a reference yet?) or from WIPP - any other suggestions. Please feel free to draft something.*

2.3 Survey of Project FEP Databases

A large number of FEP lists, catalogues and databases have been developed in OECD countries. These consider a range of radioactive waste types, repository designs and geological environments. The size of the lists etc. vary, as does the content and level of detail of entries. Table 2 gives summary information on published FEP lists, catalogues and databases from OECD countries and international organisations or projects. Where several are known from a single country, preference is given to more recently published lists or databases containing detailed FEP descriptions.

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], see below. 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 reference disposal system consisting of spent CANDU fuel in durable containers in bentonite backfilled 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 judged importance of the factor for the specific assessment study.	Goodwin et al. 1994
CEC ANDRA/IPSN/ CEN-SCK/GRS /ECN	Scenario selection in the framework of the CEC EVEREST Project	Identification of scenarios for repositories in alternative geological environments: 7 in clay, 5 in granite, 7 in salt.	Raimbault et al. 1992
France			
Germany			
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
Japan			
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

Table 2 - Published FEP lists, catalogues and databases from OECD countries (page 1 of 3)

Country /organisation	Project /disposal concept	Contents and format of FEP list/database	Reference
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 are given, 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 et al. 1993
Spain			
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 mainly 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 et al. 1989
Sweden SKB	Scenario identification for assessment of disposal of intermediate and low level wastes in the SFR facility.	~150 FEPs classified according to elements of the disposal system. FEP names only.	Skagius and Högland 1991
Sweden SKI	'SITE-94' assessment of spent fuel in copper canisters in Swedish bedrock.	~165 FEPs in the "reference case of the Central Scenario" (names only) plus note of very much larger number of influences between FEPs with short descriptions.	Chapman et al. 1995

Table 2 - Published FEP lists, catalogues and databases from OECD countries (page 2 of 3)

Country /organisation	Project /disposal concept	Contents and format of FEP list/database	Reference
Switzerland Nagra	'Kristallin-I' assessment of 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. 1996
Switzerland Nagra	Assessment of disposal intermediate and low level wastes disposal in concrete lined tunnels in marl at Wellenberg.	~50 FEPs classified according to model domain or external influences. No FEP descriptions.	Nagra 1994b
United Kingdom DoE/HMIP	'Dry Run 3' assessment 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. 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 relevance of each process.	Miller and Chapman 1994
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 and - waste and repository-induced events and processes. Phenomenon names only.	Cranwell et al. 1982
United States USDOE	WIPP Project - assessment of disposal of transuranic waste in bedded salt in southeastern New Mexico	~240 FEPs classified as - natural, - waste- and repository-induced - human-initiated.	USDOE 1996

Table 2 - Published FEP lists, catalogues and databases from OECD countries (page 3 of 3)

3. THE INTERNATIONAL FEP DATABASE

3.1 Design and Principles of Operation

The NEA International FEP Database consists of two parts:

(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 keyword list by which to examine the various project-specific database entries, see (2). A 'glossary' style definition is attached to each FEP; this defines the scope and indicates the range of project FEPs that might be mapped to the International FEP.

(2) **Project Databases** – a collection of FEP lists, FEP descriptions and references, compiled during repository safety assessment and scenario development projects. Every FEP of each project database is mapped to one or more of the international FEPs. The information given within each project is quite variable but, generally, may include 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 are included as files in a computer 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 (p. 9).

The basic mode in which the database has been designed to operate, illustrated in Figure 3.1, is as follows:

(a) Select an international FEP (or FEPs) that most closely match an enquirer's interest; the International FEP List may be sorted or ordered on alternative criteria or categories to facilitate this.

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

Alternative modes of use are possible, however, and are facilitated by the simple database structure.

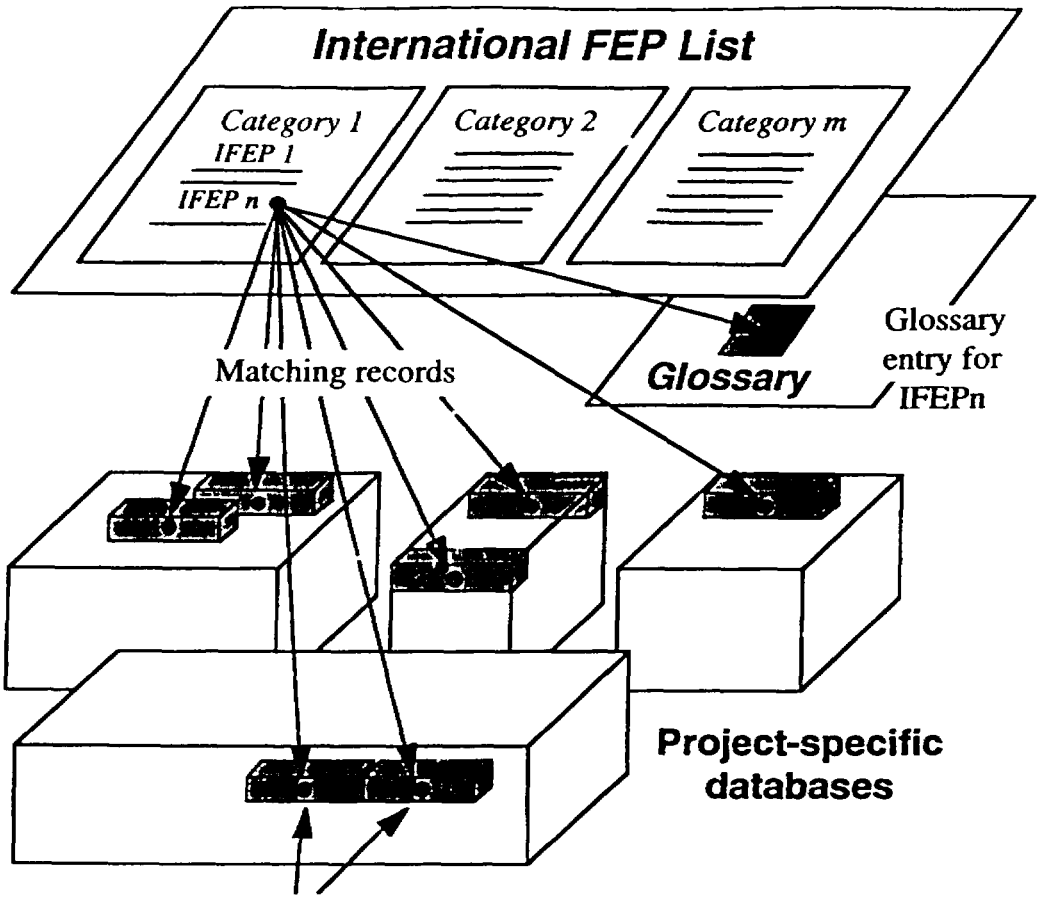


Figure 3.1 The International FEP List as a key to FEP descriptions and literature reference held in project-specific databases

3.2 Comprehensiveness of the International FEP List

It is unrealistic to believe that a safety assessment of any facility can include consideration of all features, events and processes (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 "life time" over which consideration might be required may extend to tens or hundreds of thousand of years in the future. What can be expected is that reasonable efforts have been made to identify those FEPs that might be significant to long-term safety, and logical procedures have been used to evaluate these FEPs and decide which should be included in quantitative safety or performance analyses.

The claim to "comprehensiveness" of the International FEP List is essential to its usefulness, see Section 3.6, yet 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 determine a broad range of FEPs that it might be relevant to consider in a safety assessment;
- to relate the information in the different project databases in a consistent way.

The following paragraphs discuss the scope over which the list is expected to be comprehensive and the level of detail expected.

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

- the definition of appropriate limits for discussion and analysis within post-closure safety assessment, e.g. operational and worker safety are not included;
- the practical limits of what has been considered in previous post-closure safety assessments, e.g. disposal concepts that have not been considered before are necessarily not included.

Table 3.1 provides an indication of the intended scope and applicability of the International FEP List at present. However, it is not the intention to "turn away" project databases that may be submitted in future because they do not meet the current definition of scope. If for, example, a project database is submitted that contains information that is potentially useful to other safety assessment projects but falls outside the scope of the list then it will be necessary to extend the list to include the additional general factors or FEPs identified.

The level of detail that should to be included in the International FEP List depends on the intended uses and value that is attached to competing requirements of comprehensiveness and use of the list as a prompt. A list that is too general will not be useful. On the other hand, if the list descends to a too detailed level this risks leading the analyst; in addition, the list will tend to become incomplete as some FEPs at an equivalent level of detail to those included may be omitted.

Included	Excluded
Assessment applicability	
• post-closure safety assessment	• operational safety assessment • environmental impact assessment • economic assessment • technical design assessment
Physical applicability	
• solid radioactive wastes (spent fuel, high-level, transuranic, intermediate- and low-level wastes) • deep geological disposal* facilities - deep mine and cavern disposal - deep boreholes • near-surface disposal facilities - engineered facilities - shallow-land burial	• non-radioactive wastes, including very low-level (exempted) wastes • 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 • demographic/sociological processes • radiation health effects • release, migration and exposure processes specific to other toxins

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

Table 3.1 - The scope and applicability of the NEA International FEP List

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 material or container types would not be appropriate. These FEPs may be found in the project-specific entries which are mapped to the International FEP. However, 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 specified that, as a guide, the International List should not exceed about 100 FEPs. This is so that a user can become generally familiar with the list and not miss finding a FEP that is present.

3.3 The International FEP List and Glossary

Table 3.2 shows version 1.0 of the International FEP List that has been developed by the Working Group. This consists of 150 FEPs presented here in alphabetical order[2].

Alphabetical order is chosen so that the list is as neutral as possible. To make the list more accessible in this order, FEPs 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 is attached to each FEP which relates to the classification scheme that has been used in deriving the List, see Section 3.4.

The requirement to make the list applicable to a wide range of waste disposal concepts results in many of the FEPs having very general names. Additional words are sometimes given in parenthesis which may give more specific clues to the scope of the FEP. The scope of each FEP is defined by the 'glossary' entries which consist of two parts:

- a FEP definition, which defines the scope of the FEP 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 FEP name.

Table 3.3 gives a few examples of FEP glossary entries which illustrate the style of information included. The glossary entries have been developed with reference to the IAEA Radioactive Waste Management Glossary [IAEA 1993] where appropriate.

2 The 150 FEPs in Table 3.2 include 16 higher-order FEPs that define the classification scheme used to derive the International List (see Appendix B). These higher-order FEPs are indicated by capital script.

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
ASSESSMENT BASIS	0
Atmosphere	2.3.07
Atmospheric transport of contaminants	3.2.10
Biological/biochemical processes and evolution of conditions	2.1.10
Biological/biochemical processes and evolution of conditions	2.2.09
Buffer/backfill materials and characteristics	2.1.04
Chemical/complexing agents, effects on contaminant speciation/transport	3.2.05
Chemical/geochemical processes and evolution of conditions	2.1.09
Chemical/geochemical processes and evolution of conditions (mineralogy and hydrochemistry)	2.2.08
Chemical/organic toxin stability	3.1.02
Climate change, global	1.3.01
Climate change, regional and local	1.3.02
CLIMATIC PROCESSES AND EFFECTS	1.3
Closure and repository sealing	1.1.04
Coastal features	2.3.05
Colloids, contaminant interactions and transport with	3.2.04
Community characteristics (e.g. size, sufficiency)	2.4.05
Container materials and characteristics (incl. container degradation/failure)	2.1.03
CONTAMINANT CHARACTERISTICS	3.1
CONTAMINANT RELEASE/MIGRATION FACTORS	3.2
Contaminant transport path characteristics (spatial distribution of porosity, fractures)	2.2.05
Deformation, elastic, plastic or brittle	1.2.02
Diagenesis	1.2.08
Diet (incl. water intake)	2.4.03
Discontinuities, large scale	2.2.04
DISPOSAL SYSTEM DOMAIN: ENVIRONMENTAL FACTORS	2
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 (e.g. air, soil, water, vegetation)	3.3.02
Erosion and deposition	2.3.12
Erosion and sedimentation	1.2.07
Excavation disturbed zone, host rock	2.2.01
Excavation/construction	1.1.02
Explosions and crashes	1.4.11
EXPOSURE FACTORS	3.3
Exposure modes (e.g. inhalation, ingestion, injection, external exposure)	3.3.04

Table 3.2 - The International FEP List (version 1.0) in alphabetical order (p. 1 of 3)

EXTERNAL FACTORS	1
Food and water processing and preparation	2.4.06
Foodchains, uptake of contaminants in	3.2.14
Future human action assumptions	0.05
FUTURE HUMAN ACTIONS (ACTIVE)	1.4
Future human behaviour (target group) assumptions	0.06
Gas sources and effects	2.1.12
Gas sources and effects	2.2.11
Gas-mediated transport of contaminants	3.2.09
GEOLOGICAL ENVIRONMENT	2.2
GEOLOGICAL PROCESSES AND EFFECTS	1.2
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 (undisturbed by excavation)	2.2.02
HUMAN BEHAVIOUR	2.4
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	3.2.11
Hydraulic/hydrogeological processes and evolution of conditions	2.1.08
Hydraulic/hydrogeological processes and evolution of conditions	2.2.07
Hydrological regime and water balance	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, mainly (e.g. Cs, Sr, La, Ac)	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 evolution of conditions	2.1.07
Mechanical processes and evolution of conditions (rock stress)	2.2.06
Metamorphism	1.2.05
Meteorite impact	1.5.01
Meteorology	2.3.10
Microbial/biological/plant mediated processes, contaminant (incl. species/phase change)	3.2.06
Mining and other underground activities (human intrusion)	1.4.05
Miscellaneous and of uncertain relevance or effect	1.5.03
Model and data issues	0.10
Monitoring (long term safety) 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 (e.g. C, H)	3.1.05
OTHER	1.5

Table 3.2 - The International FEP List (version 1.0) in alphabetical order (p. 2 of 3)

Other engineered features materials [illegible]	2.1.06
Periglacial effects	1.3.04
Quality control	1.1.08
Radiation effects	2.1.13
Radioactive decay and in-growth	3.1.01
Radiological toxicity/effects	3.3.06
RADIONUCLIDE/CONTAMINANT FACTORS	3
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
REPOSITORY ISSUES	1.1
Retrievabili	1.1.13
Rural and agricultural land and water use (inc. agricultural practices/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 (incl. degradation/failure)	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	2.3
Surface environment, human activities	1.4.06
Technological developments	1.4.09
Tectonic movements and orogeny	1.2.01
Thermal processes and evolution of conditions	2.1.11
Thermal processes and evolution of conditions (geothermal regime)	2.2.10
Timescales of concern	0.02
Topography morphology	2.3.0[illegible]
Un-intrusive site investigation	1.4.03
Undetected features	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
WASTES AND ENGINEERED FEATURES	2.1
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

Table 3.2 - The International FEP List (version 1.0) in alphabetical order (p. 3 of 3)

NEA International FEP Database: Glossary Entries

Int FEP name	*Int FEP number*
Accidents and unplanned events	1.1.12

FEP definition

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

Comments

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.

Int FEP name	*Int FEP number*
Administrative control, repository site	1.1.10

FEP definition

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

Comments

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.

Int FEP name	*Int FEP number*
Adults, children, infants and other variations	2.4.02

FEP definition

Adults, children, infants and other variations refers to FEPs related to considerations of variability in individual humans of physiology, metabolism and habits.

Comments

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

Int FEP name	*Int FEP number*
Aims of the assessment	0.08

FEP definition

The aims of the assessment relate to the purpose for which the assessment is being undertaken.

Comments

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.

Table 3.3 - Selected examples of FEP glossary entries from the International FEP List (version 1.0)

The International FEP List is a result of iterative development working from pre-existing lists and classification schemes, and taking account of experiences in mapping of project databases to the List, see Section 3.4. It is intended that the list can remain relatively stable since any changes imply re-examination of the mapping of project FEPs to the list, see Section 3.6. However, minor changes are to be expected, for example, if a new project database is attached that includes FEPs of a type not previously considered. It is expected that the glossary entries may also be developed.

3.4 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 considerations, for example starting from comprehensive classification schemes;

(c) brainstorming, i.e. unstructured identification of FEPs.

An example of approach (a) is provided in Stenhouse et al [1993]. This describes the integration of over 1000 FEPs from 9 different lists, although, the integrated list was intended for audit of an assessment of a specific site and disposal concept, and 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 would be very 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 would also be necessary to supplement the list with FEPs that were 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, the subgroup employed a hybrid procedure where the work was carried out over several meetings. In summary, the procedure consisted of:

- reclassification of an existing FEP list, according to an alternative classification scheme in order to generalize 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. The list appearing in the NEA Scenario Working Group report [NEA 1992] was chosen as the starting point as this list has been used as the starting point for scenario development in several countries.

- 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 Section 3.5.

- 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 attachment and mapping of project databases is discussed in Section 3.6.

- the name of each FEP was checked for consistency of style within the overall list and to assist in alphabetical ordering, see Section 3.3.

This procedure led to the International FEP List presented in Table 3.2. The list is presented according to the classification scheme used to develop the list in Appendix B.

3.5 Classification Schemes

The advantage of a computer-based database is that FEPs can be readily re-organised according to different given keywords or other criteria. However, in forming the list 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, i.e. similar numbers of FEPs might be found in each category.

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 FEP classification schemes used in various post-closure assessment projects indicates that most classifications that have been used in practice are based on either cause, field of effect, or 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; Goodwin et al. 1994], (Thorne [1992] also includes "short-circuit pathway" as a class);

- 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].

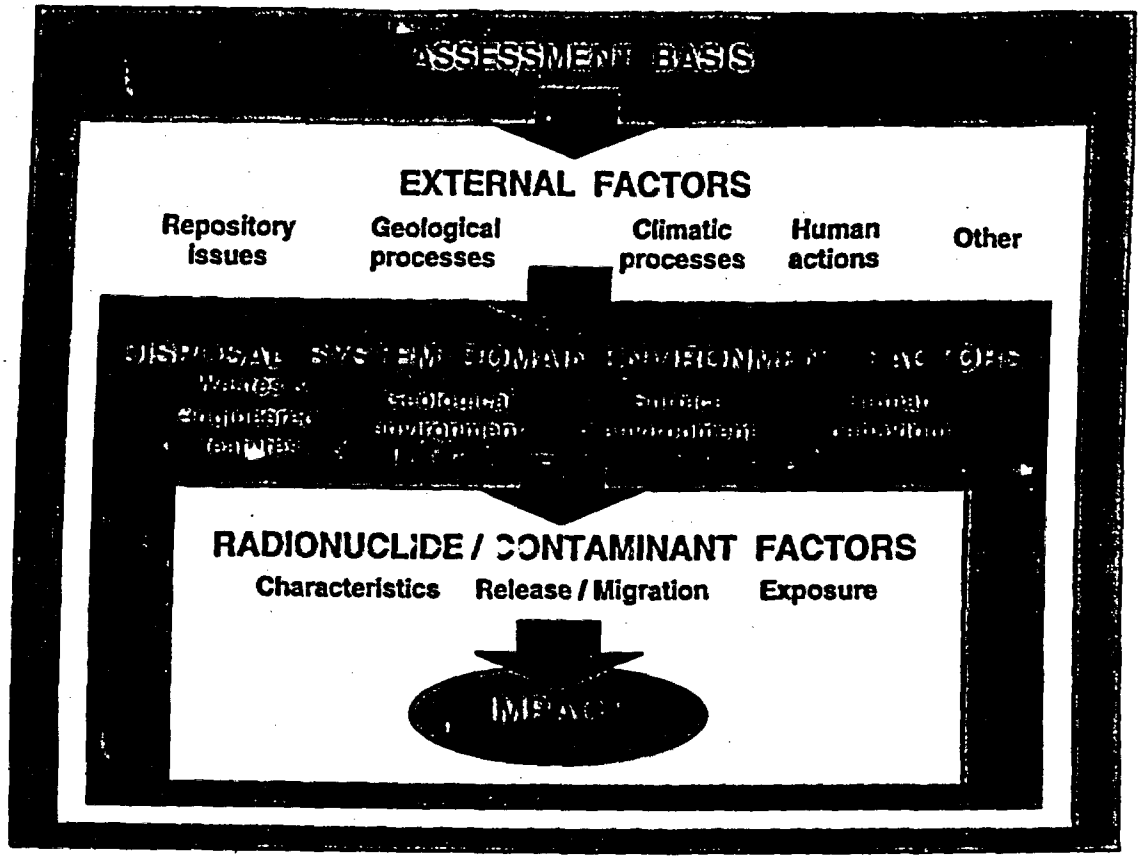
There is a danger of leading future analyses by classification. Schemes based too closely on features that are important in particular disposal systems should be avoided and schemes based on model domains may be criticised, since they presuppose an approach to modelling. However, the history of the subject will (unavoidably) 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 recorded in underlying project databases.

The Working Group agreed that a final presentation of the International FEP List should be made in alphabetical order, see Table 3.2, but that a classification scheme was necessary to assist in devising the list and could provide some evidence for comprehensiveness of the list. Users should be free to devise alternative classification schemes, and to re-classify and re-order the list if desired.

Various classification schemes were discussed by the Working Group and trial exercises using different classification schemes were carried out by a subgroup. Figure 3.2 illustrates the scheme that was eventually selected 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]. An important element in the scheme is the separation of processes that affect the repository and natural environments, and the processes of radionuclide (and other contaminant) release, transport and exposure that occur in those environments.

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 core, therefore, the scheme must include processes related to contaminant release, migration and exposures. It is also necessary to consider the properties of the disposal system (wastes, engineered and natural barriers and human behaviour) which define the state of the system or may cause the system to evolve. Beyond this there are processes and events originating outside the disposal system but which act upon it. This leads to a three-layer categorisation based on:

- Radionuclide/Contaminant Factors,
- Disposal System Domain Factors, and
- External Factors.



The rationale for choice of the scheme layers is presented in Section 3.6. A feature of the scheme is that, 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 is given in Appendix B.

Figure 3.2 - Illustration of the classification scheme used in the derivation of the International FEP List

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 or 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. the use of conservatively defined critical groups as representative of future human populations at risk. Therefore, a fourth layer is added termed:

- Assessment Basis.

This leads to a general structure illustrated in Figure 3.2 above.

3.6 Inclusion of Project Databases

The prime function of the International FEP Database is to provide a collation of FEP information from various safety assessment studies. The International FEP List, discussed in the preceding sections, provides the framework and master keyword list by which to relate and access the information contained in project databases. Table 2 indicates that there are already a large number of such databases with varying levels of information included.

In version 1.0 of the International FEP Database, six project databases are included[3]. The criteria for selecting these has been that they are published lists or databases and together cover a range of solid waste disposal concepts. Three project databases were mapped (see below) to International FEP List during the iterative process of developing the list:

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

For these databases, the mapping was carried out by subgroups of the FEP Database Working Group. Since that time a further three databases have been included:

- the HMIP database of FEPs related to the assessment of disposal of low and intermediate-level waste in fractured hard rock [Chapman and Miller 1994];
- the Nagra database of FEPs related to the Kristallin-I assessment of disposal of high-level waste in crystalline basement rock of Northern Switzerland [Nagra 1994a];
- the USDOE database of FEPs related to the assessment of disposal of transuranic waste in bedded salt at the WIPP site [USDOE 1996];

3 Version 1.0 should include at least the databases listed here. Hopefully, a few other might also be included.

Further information on the scope, derivation and contents of each of these databases is given in Appendix C. In general, however, each database entry consists of

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

Table 3.4 illustrates a typical FEP entry, in this case from the AECL project database.

Each project FEP entry has been examined and mapped to one or more FEP of the International List, see Table 3.4. In carrying out the mapping, the following guidelines, based on experience of trial mapping by the Working Group, have been observed:

1. Each project 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 great majority of PFEPs tested, for example a process of a particular type acting on a specific 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. information in the PFEP description will provide a specific example of the IFEP.

4. Try to find the IFEP that is most specific to the PFEP and 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.

Project Database: Main Screen

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

FEP name: | Project letter: A | Reference no: 1.03

Biological activity

FEP 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).

References:

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

Mapped to the following FEPs in International NEA database (INT95):

2.1.10	Biological/biochemical processes and evolution of conditions
3.2.06	Microbial/biological/plant mediated processes, contaminant (incl. species/phase change)

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).

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

Table 3.4 - Example of a project FEP entry from the AECL database

Each project included 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.

3.7 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 structure 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 determining the scope of a new assessment;

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

(c) an indication of completeness of an assessment, if it can be demonstrated that all FEPs listed have either been considered or shown not to be relevant or significant for the particular disposal system or regulatory requirement;

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

(e) and, by connection to the various national/project FEP entries, a convenient map to find out how given factors or processes have been dealt with in other projects and trace to relevant literature references.

It is important to warn that the International FEP List should be used in open way, that is, it should be a starting point for discussion within a project, not a constraint.

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, i.e. what FEPs have been considered and how in a given project ?

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

(c) trace to underlying 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 will not imply that these must be analysed or even considered in any detail in a given 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

"in the case of 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 be used in an open way and as a prompt, not as a specification of what should be discussed or analysed in an assessment. 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. RECOMMENDATIONS FOR CONSOLIDATION AND MAINTENANCE

This chapter contains, in part, recommendations that might be made to PAAG and depending on decisions by PAAG and NEA, e.g. whether to support a User Group, would change the way in which this chapter is written.

4.1 Database Development

Version 1.0 of the International FEP Database is implemented on Claris FileMaker Pro™, version 2.1. This software is chosen because it is an easy package to use, requiring no programming skills, and files created by IBM PC or Apple Macintosh versions of the software are directly interchangeable. The FEP data in version 1.0 of the Database is also supplied as a text (ASCII) file, so that it may be accessed by any other database software (see Appendix D).

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

The view of the Working Group is that it is important to retain flexibility of use and 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. The Group concludes there is 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 easily transfer the data from FileMaker Pro, or from the text data file, to the software of their choice.

For this reason, no database development associated with the International FEP Database is proposed at present. However, this decision could be reviewed by members of a future User Group, see Section 4.2.

4.2 Use of the International FEP 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. A User Group could be established, with Secretariat provided by NEA, in order to promote exchange of experiences. This Group might be related to establishment of a Working Group to review recent experiences in model and scenario development methods, i.e to update the NEA Scenario Working Group report [NEA 1992].

4.3 Addition of Project Databases

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 NEA for inclusion in the International FEP Database. The Database can be considered as a repository 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.

Appendices E and F will give information on submitting new project databases and on joining a User Group.

5. CONCLUSIONS AND FINAL REMARKS

To be discussed at the Working Group Meeting, 15-17 October 1996.

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APPENDIX A

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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 Sections 3.4 and 3.5, the International FEP List was derived with the assistance of a classification scheme illustrated in Figure 3.2 (p. 30).

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 when arranged in alphabetical (or any other) order, e.g.

Accidents and unplanned events 1.1.12

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

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 "disaster" scenarios 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 origin 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 (active) - 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 influences between FEPs in the different categories of external factors.

Table B.1 - Definition of layers and categories within the classification scheme used in the derivation of the International FEP List (p. 1 of 2)

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.

Influences 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.1 - Definition of layers and categories within the classification scheme used in the derivation of the International FEP List (p. 2 of 2)

NEA International FEP Database: FEP Number and Name

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 (long term safety) of repository
1.1.12	Accidents and unplanned events
1.1.13	Retrievability
1.2	GEOLOGICAL PROCESSES AND EFFECTS
1.2.01	Tectonic movements and orogeny
1.2.02	Deformation, elastic, plastic or brittle
1.2.03	Seismicity
1.2.04	Volcanic and magmatic activity
1.2.05	Metamorphism
1.2.06	Hydrothermal activity
1.2.07	Erosion and sedimentation
1.2.08	Diagenesis
1.2.09	Salt diapirism and dissolution
1.2.10	Hydrological/hydrogeological response to geological changes
1.3	CLIMATIC PROCESSES AND EFFECTS
1.3.01	Climate change, global
1.3.02	Climate change, regional and local
1.3.03	Sea level change
1.3.04	Periglacial effects
1.3.05	Glacial and ice sheet effects, local
1.3.06	Warm climate effects (tropical and desert)
1.3.07	Hydrological/hydrogeological response to climate changes
1.3.08	Ecological response to climate changes
1.3.09	Human response to climate changes
1.4	FUTURE HUMAN ACTIONS (ACTIVE)
1.4.01	Human influences on climate
1.4.02	Motivation and knowledge issues (inadvertent/deliberate human actions)

Table B.2 - The International FEP List (version 1.0) in scheme order (p. 1 of 3)

NEA International FEP Database: FEP Number and Name

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 of uncertain relevance or effect
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 (incl. container degradation/failure)
2.1.04	Buffer/backfill materials and characteristics
2.1.05	Seals, cavern/tunnel/shaft (incl. degradation/failure)
2.1.06	Other engineered features materials and characteristics
2.1.07	Mechanical processes and evolution of conditions
2.1.08	Hydraulic/hydrogeological processes and evolution of conditions
2.1.09	Chemical/geochemical processes and evolution of conditions
2.1.10	Biological/biochemical processes and evolution of conditions
2.1.11	Thermal processes and evolution of conditions
2.1.12	Gas sources and effects
2.1.13	Radiation effects
2.1.14	Nuclear criticality
2.2	GEOLOGICAL ENVIRONMENT
2.2.01	Excavation disturbed zone, host rock
2.2.02	Host rock (undisturbed by excavation)
2.2.03	Geological units, other
2.2.04	Discontinuities, large scale
2.2.05	Contaminant transport path characteristics (spatial distribution of porosity, fractures)
2.2.06	Mechanical processes and evolution of conditions (rock stress)
2.2.07	Hydraulic/hydrogeological processes and evolution of conditions
2.2.08	Ch. ical/geochemical proce ses and evc tion of conditions (mineralo y and hydrochem y)
2.2.09	Biological/biochemical processes and evolution of conditions
2.2.10	Thermal processes and evolution of conditions (geothermal regime)
2.2.11	Gas sources and effects
2.2.12	Undetected features
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

Table B.2 - The International FEP List (version 1.0) in scheme order (p. 2 of 3)

NEA International FEP Database: FEP Number and Name

2.3.07	Atmosphere
2.3.08	Vegetation
2.3.09	Animal populations
2.3.10	Meteorology
2.3.11	Hydrological regime and water balance
2.3.12	Erosion and deposition
2.3.13	Ecological/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 (incl. water intake)
2.4.04	Habits (non-diet-related behaviour)
2.4.05	Community characteristics (e.g. size, sufficiency)
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 (inc. agricultural practices/fisheries)
2.4.10	Urban and industrial land and water use
2.4.11	Leisure and other uses of environment
3	RADIONUCLIDE/CONTAMINANT FACTORS
3.1	CONTAMINANT CHARACTERISTICS
3 1.01	Radioactive decay and in-growth
3.1.02	Chemical/organic toxin stability
3.1.03	Inorganic solids/solutes, mainly (e.g. Cs, Sr, La, Ac)
3.1.04	Volatiles and potential for volatility
3.1.05	Organics and potential for organic forms (e.g. C, H)
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 (incl. species/phase change)
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	Human-action-mediated transport of contaminants
3.2.11	Animal, plant and microbe mediated transport of contaminants
3.2.14	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 (e.g. air, soil, water, vegetation)
3.3.03	Non-food products, contaminant concentrations in
3.3.04	Exposure modes (e.g. inhalation, ingestion, injection, external exposure)
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

Table B.2 - The International FEP List (version 1.0) in scheme order (p. 3 of 3)

APPENDIX C

PROJECT FEP DATABASES INCLUDED IN THE INTERNATIONAL FEP DATABASE

C.1 Introduction

The following project FEP databases are included in the International FEP Database (version 1.0), where each is identified by an alphanumeric code:

SKIB89 the joint SKI/SKB database of FEPs related to the Swedish KBS-3 spent fuel disposal concept [Andersson (ed.) 1989];

NEA92 the example compilation of FEPs (names only) relevant to deep geological repository that appears in the NEA Scenario Working Group report [NEA 1992];

AECL94 the AECL database of FEPs (termed factors) related to the Canadian nuclear fuel waste disposal concept [Goodwin et al. 1994];

HMIP94 the HMIP database of FEPs related to the assessment of disposal of low and intermediate-level waste in fractured hard rock [Chapman and Miller 1994];

NAG94 the Nagra database of FEPs related to the Kristallin-I assessment of disposal of high-level waste in crystalline basement rock of Northern Switzerland [Nagra 1994a];

WIPP96 the USDOE database of FEPs related to the assessment of disposal of transuranic waste in bedded salt at the WIPP site [USDOE 1996];

In the following sections, each of these databases is described in terms of:

- the context in which it was developed and the method of elicitation;
- the number of phenomena included and classification scheme adopted;
- subsequent use of the list or database.

C.2 The Joint SKI/SKB Scenario Development Project - SKIB89

The Swedish Nuclear Power Inspectorate (SKI) and Nuclear Fuel and Waste Management Company (SKB) carried out a scenario development exercise [Andersson (ed.) 1989] for a hypothetical repository for spent fuel and HLW based on the KBS-3 concept (spent fuel in copper canister in bentonite back-filled bore holes from tunnels in crystalline basement rock in Sweden). Four groups of named experts worked independently to identify relevant features, events and processes (FEPs) under different systems of classification based on probability, field of importance, timescale of impact and cause; the lists were then merged. The elicitation focused on the near-field and geosphere, i.e. the biosphere was not considered explicitly since this was to be treated in another project.

The merged list, which includes 157 FEPs, is classified roughly according to field of effect although the report warns that this classification is "not to be taken too seriously'. Although the FEP classes are not named, examination of the FEPs show the classes are as follows:

1. FEPs affecting the waste
2. FEPs affecting the canister
3. FEPs affecting the backfill
4. FEPs affecting the near-field rock
5. Repository problems and natural phenomena affecting the far-field
6. Far-field geosphere
7. Near-surface and human actions

Memo-comments are given for each FEP of between one sentence and about one page. These describe the process, causes and effects; references are given in some cases. Project-specific codes are also included which indicate whether the FEP is to be "lumped" with another FEP, screened out, included in the "process system", "kept" but not included in the process system, or to be treated as an "isolated scenario".

The joint SKI/SKB database has been referred to as the starting point for scenario development activities in assessment studies by both SKI and SKB [SKI 1991; SKB 1992].

C.3 NEA Scenario Working Group Example List - NEA92

The list presented in the Scenario Working Group report [NEA 1992] appeared previously in Hodgkinson and Sumerling [1989]. This list was developed for UK Nirex Ltd. in the context of a hypothetical repository for L/ILW in caverns in hard rock. The list was based on the IAEA list and experience in the SKI/SKB study but included a wider range of phenomena. The list includes about 150 phenomena classified according to cause, see below.

1. **Natural Phenomena**
1.1 Extraterrestrial
1.2 Geological
1.3 Climatological
1.4 Geomorphological
1.5 Hydrological
1.6 Transport and geochemical
1.7 Ecological

2. **Human Activities**
2.1 Design and construction
2.2 Operation and closure
2.3 Post-closure sub-surface activities
2.4 Post-closure surface activities

3. **Waste and Repository Effects**
3.1 Thermal
3.2 Chemical
3.3 Mechanical
3.4 Radiological

No FEP descriptions are included. The list has been referred to as the starting point for scenario development activities in several countries including Belgium [Broeders et al. 1994], the Netherlands [Prij et al. 1994] and Japan [PNC 1992].

C.4 The Canadian Scenario Analysis Project - AECL94

Atomic Energy of Canada Ltd (AECL) have carried out a scenario analysis for the postclosure assessment of the Canadian concept of spent fuel disposal in plutonic rock of the Canadian Shield [Goodwin et al. 1994a]. The list of relevant factors was developed by "brainstorming" meetings amongst the waste disposal assessment staff which considered three draft lists based on previous studies including the IAEA list [IAEA 1981]. Initially, over 1000 factors were identified which were reduced by combining closely related factors to a list of about 250. The factors are compiled in alphabetical order in three lists headed:

- vault factors,
- geosphere factors and
- biosphere factors.

A description of a few sentences is given for each factor plus, for most factors, a longer discussion of the importance of the factor in respect of the reference repository design which considers a hypothetical repository at the site of the AECL Underground Research Laboratory at the Whiteshell site in Manitoba. Project-specific codes are included which indicate, for each factor, whether it is a feature, event or process, the component affected, and the mechanism. The classification system that could be inferred from this is shown below.

Vault Factors	Geosphere Factors	Biosphere Factors
Component affected		
Backfill and buffer Container Seals and grouts Waste form	Flow Rock properties Transport Wastes	Route to man: (contact, ingestion, respiration) Cause: (anthropogenic, facility, natural)
Mechanism		
Biological Chemical Physical	Anthropogenic Expected (natural) Unexpected (natural) Vault-induced	Biological Physical Chemical

The AECL database is the starting point for scenario development for the postclosure assessment of a reference system for disposal of Canada's nuclear fuel waste [Goodwin et al. 1994b].

C.5 The HMIP System Elicitation Exercise - HMIP94

HMIP carried out an exercise to identify and document processes most important to the assessment of a low- and intermediate-level waste repository at the Sellafield site [Chapman and Miller (ed.) 1994]. This was in the context of preparation for regulatory review of safety documentation related to the Sellafield site expected from U.K. Nirex Ltd..

A meeting was convened of a group of 8 experts in various topics important to the assessment of deep disposal of radioactive waste; these experts were independent of Nirex and had not had previous involvement in HMIP assessment modelling studies. The group, named the "System Concept Group" was charged with making a preliminary but comprehensive overview of processes and factors relevant to the assessment of Nirex's potential repository at Sellafield. The starting point was the list of processes elicited in the earlier Dry Run 3 exercise [Thorne 1992], plus preliminary information on the geology of Sellafield and the Nirex repository concept.

The group identified and documented about 80 processes which, in their view, would be most important and also indicated a minimum set which should be included in assessment modelling in order to produce a model of performance of the Sellafield site that would have an acceptable level of bias. The FEPs were classified according to the conventional model fields for groundwater modelling - near field, far-field and biosphere - with the addition of "short-circuit pathway" and "climatology" classes. Classes were further subdivided as shown below:

1. **NEAR-FIELD**
1.1 Chemical/physical degradation
1.2 Gas production, transport and flammability
1.3 Radiation phenomenon
1.4 Structural integrity
1.5 Hydrogeological effects
1.6 Thermal effects

2. **FAR-FIELD**
2.1 Geological
2.2 Hydrogeological
2.3 Transport and geochemical
2.4 Geomorphology

3. **CLIMATOLOGY**
3.1 Climate change

4. **BIOSPHERE**
4.1 Radionuclide entry points into the biosphere
4.2 Transfer (concentration/dilution) mechanisms
4.3 Land and surface water use
4.4 Human exposure

5. **SHORT-CIRCUIT PATHWAYS**
5.1 Related to repository construction
5.2 Unrelated to repository construction

Each process was briefly described, then discussed in the context of assessment of the Sellafield site and Nirex repository concept. These descriptions and discussions range between one half page and two pages long.

C.6 The Nagra Scenario Development for Kristallin-I

Nagra carried out a scenario development for the Kristallin-I Safety Assessment [Nagra 1994a]. This considers the disposal of vitrified high-level waste in steel canisters surrounded by pre-compacted bentonite blocks emplaced in tunnels at about 1000 m depth in the crystalline basement of Northern Switzerland.

Relevant FEPs were elicited from Kristallin-I project staff through a combination of discussion and the use of structured tables. Attention was first focused on the basic characteristics of the system that are expected to provide for its long-term safety; influence diagrams were used to understand the interaction between FEPs within each of the main safety-relevant features (see below). The processes and events that might compromise safety were considered against this background. Screening arguments were used to rule out FEPs not relevant to the specific disposal concept or scope of the safety assessment.

This led to a list of about 240 FEPs which were classified under headings of the main-safety relevant features of the Kristallin-I disposal concept plus the main external influences, i.e.

Main safety-relevant features:

1. Vitrified waste form
2. Canister
3. Bentonite
4. Bentonite-host rock interface
5. Low-permeability domain of the crystalline basement (LPD)
6. Major water-conducting faults (MWCF)
7. Higher-permeability domain of the crystalline basement (HPD)
8. Biosphere

Main external influences:

9. Geological processes and events
10. Climate processes and events
11. Human activities

For each FEP, a description of between a few sentences and a page is given plus discussion of the treatment of each FEP within the Kristallin-I safety assessment and references. These are reproduced in a supporting report [Sumerling et el. 1996] to the main safety assessment report (Nagra 1994a).

C.7 The DOE/WIPP Compliance Certification Application - WIPP96

In October 1996, the U.S. Department of Energy (DOE) will request the U.S. Environmental Protection Agency (EPA) to certify compliance with the radioactive waste disposal standards found in 40 CFR Part 191 for the Waste Isolation Pilot Plant (WIPP). The WIPP repository is located in a bedded salt formation in southeastern New Mexico, and is intended for the disposal of transuranic wastes generated by DOE defense programs. Demonstrating compliance with EPA regulations requires an assessment of the long-term performance of the disposal system. Scenario development has formed a part of this assessment, consisting of three main tasks: (i) identifying and classifying features, events and processes (FEPs), (ii) screening FEPs according to well-defined criteria, and (iii) forming scenarios (combinations of FEPs) in the context of the regulatory performance criteria.

A compilation prepared by Stenhouse et al. (1993) for the Swedish Nuclear Power Inspectorate (SKI) was used as a starting point for construction of a comprehensive list of FEPs for the WIPP. This SKI list was based on a series of nine FEP lists developed for other disposal programmes, and was considered to be the best documented and most comprehensive starting point for the WIPP. Many other FEPs specific to the WIPP were added based on review of key project documents, resulting in a list of about 900 FEPs. Broad examination of the resulting WIPP-specific PEP list, both within the project and by project stakeholders, built confidence in its comprehensiveness. Finally, the list was

substantially restructured and the number of FEPs reduced to 237. This reduction removed the ambiguities caused by the use of a generic list, without removing any substantive issues from the discussion. At the uppermost level, FEPs are classified as 'natural', 'waste and repository-induced' or 'human-initiated'.

The purpose of FEP screening was to identify those FEPs that should be accounted for in PA calculations, and those FEPs that could justifiably be eliminated. Screening-out criteria included regulation, probability, and/or consequence. Scenarios were formed from combinations of FEPs that survived the screening process.

In addition to the WIPP FEP list itself, a detailed screening argument has been provided for inclusion in the International FEP Database for each FEP that bas been eliminated from WIPP PA calculations. Only a brief discussion is included for the set of 90 "screened-in" FEPs that are accounted for in PA calculations. However, a table is included that provides a cross reference to where in the CCA further information can be found on the modelling treatment of these "screened-in" FEPs.

Completion of these Appendices await

- *completion of the database,*
- *agreement on how a User Group might operate, and*
- *whether NEA would maintain the database*

APPENDIX D

USER GUIDE TO THE INTERNATIONAL FEP DATABASE

TO BE ADDED

- a CD ROM could be included with report with FileMaker Pro files and ASCII format files, or should this only be available on application to NEA ?

APPENDIX E

INSTRUCTIONS FOR SUBMITTING PROJECT DATABASES FOR INCLUSION

TO BE ADDED

- updating of database is required, will this be done by NEA or contractor ?

APPENDIX F

APPLYING TO JOIN THE INTERNATIONAL FEP DATABASE USER GROUP

TO BE ADDED

- i.e. to receive database and document updates; a small payment might be involved to cover the cost of database maintenance, updating etc.