Waste Isolation Pilot Plant

Compliance Certification Application

Reference 605


Scenario Development
FEP Audit List Preparation:
Methodology and Presentation

Michael Stenhouse
Neil Chapman
Trevor Sumerling

April 1993
This report concerns a study which has been conducted for the Swedish Nuclear Power Inspectorate (SKI). The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the SKI.
PREFACE

This report concerns a study which is part of the SKI performance assessment project SITE-94. SITE-94 is a performance assessment of a hypothetical repository at a real site. The main objective of the project is to determine how site specific data should be assimilated into the performance assessment process and to evaluate how uncertainties inherent in site characterization will influence performance assessment results. Other important elements of SITE-94 are the development of a practical and defensible methodology for defining, constructing and analyzing scenarios, the development of approaches for treatment of uncertainties, evaluation of canister integrity, and the development and application of an appropriate Quality Assurance plan for Performance Assessments.

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SCENARIO DEVELOPMENT
FEP Audit List Preparation:
Methodology and Presentation

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1 Introduction

A preliminary but essential stage of the SITE 94 scenario development process is the identification of all features, events, and processes (FEPs) which are considered important to the long-term isolation of radioactive waste. These FEPs may be of natural or of human origins, and should be relevant to both the disposal site under investigation, and the timescales under consideration. Before combining FEPs into scenarios, an audit of the FEP list is desirable. Thus, the objective of this summary report is to document the specifications and methodology by which an independent FEP list was generated for audit purposes. The intention of the audit is to ensure that all relevant natural and human-induced FEPs are identified at this early stage of scenario development.

The SITE 94 Project considers disposal of spent nuclear fuel according to the KBS3 concept, at a site with characteristics based on the Åspö Hard Rock Laboratory site.

2 Description of Methodology

The methodology adopted for producing such a FEP audit list involved the following tasks:

- Task 1: Compile raw FEP list
- Task 2: Categorise and add screening criteria
- Task 3: Consolidation coding of screened lists
- Task 4: Perform FEP audit

The overall process in developing the FEP audit list is shown schematically in Figure 1. Each of the above tasks is discussed in detail in the subsequent sections.
Figure 1. Schematic diagram of FEP audit list generation stages

- Compile
- Individual National FEP lists
  
  * Appendix 1
  Categorise and Add Screening Arguments

  8 FEP Lists by category
  
  * Appendix 3

  8 Lists of Screened FEPs
  
  * Appendix 5
  Add Consolidation code

  8 Lists of Screened FEPs, each with consolidation code and reduced list of new FEPs

  8 Lists of Screened-out FEPs sorted according to category and screening argument

  * Appendix 4

  CONSOLIDATE

  Final FEP Audit List
2.1 Task 1: Compile raw FEP list

Identification of FEPs has been performed previously for a variety of national radioactive waste management programmes, and resultant FEP lists apply to a number of disposal concepts and cover a range of disposal sites. As a starting point for the FEP audit list, therefore, the FEP lists from these national exercises were compiled as an electronic spreadsheet/database.

The database was compiled from the following published FEP lists:

- U.K. Department of Environment Dry Run 3; 305 entries: Thorne (1992)
- Nagra, Switzerland: Project Gewähr: high level waste (HLW); 44 entries; Project Gewähr (1985)
- Sandia National Laboratory, U.S.A.: HLW; 29 entries; Cranwell et al. (1982)
- U.K. Nirex: L/ILW; 131 entries; Hodgkinson and Sumerling (1989)
- Nuclear Energy Agency (NEA): Systematic Approaches to Scenario Development; 122 entries; NEA (1992)

Although Nagra is conducting a scenario development process for Kristallin-1, the FEP list was incomplete at the time of compilation. For this reason, this source of FEPs was not used. In addition, the Kemakta FEP list for the SFR assessment done for SKB was not included, as it was felt that Kemakta, who are responsible for developing the original FEP list, would be influenced by this work.

The final compilation comprises over 1200 entries and is listed in Appendix 1. The level of FEP detail for each national list is highly variable,
as indicated by the respective values for number of entries, and reflects differing degrees of generalisation. However, no screening or additional reductions were performed during this task. For some entries, text was added, but only to provide additional description to FEPs, the meaning of which would otherwise be too vague for subsequent screening.

2.2 Task 2: Categorise and add screening criteria

The list in Appendix 1 contains numerous entries which are neither relevant to the Swedish disposal concept nor to the disposal site. In addition, duplications abound in the raw list. Thus, to make the subsequent screening process easier, the first stage of this task was to separate entries into arbitrary categories. Eight categories were selected in total, viz.:

- Waste [W]
- Container [C]
- Buffer/Backfill [B]
- Repository [R]
- Far-field [F]
- Biosphere [L]
- Human actions [H]
- Geological/climatic evolution [G]

The letters in parentheses were used to code individual entries, and an attempt was made to classify FEPs according to where the FEP occurs (W; C; B; R; F; L) or which category is the responsible agent (G; H). Occasionally, it was difficult to categorise FEPs in this way, in which case the coding applies more to the category which is affected by the FEP. In addition, more than one code letter was applied to a FEP if it was considered to apply to one or more of the categories designated. It should be emphasised that assigning FEPs to the above categories was performed as a matter of convenience, and that this separation process is relatively arbitrary, given the different origins of the original FEP list (Appendix 1).

Screening criteria were then added to identify and to subsequently remove only those FEPs which are irrelevant to the Swedish disposal concept and disposal site. The criteria which were used are based on those applied by Nagra and presented in Sumerling et al. (1993). The preliminary “criteria” – referred to as screening arguments, are presented in Appendix 2. Included in Appendix 2 are NOTES: specific modifications to certain screening arguments, based on consultation with SKI (Johan Andersson, personal communication). An additional code was provided for those FEPs which were either too vague or all-encompassing to be useful. It should be stressed, however, that no FEP entries were destroyed as a result of the screening process – only removed to a separate appendix.
The modified screening arguments are summarised in Table 1, each argument having a corresponding code (for convenience, the subsection number of appropriate text in Appendix 2). The FEP lists, sorted by category, and with screening code added, are shown in Appendix 3. Finally, the screening process was performed on the eight category lists of FEPs to separate entries with screening codes from those without. As mentioned previously, no FEPs were removed permanently, screened-out FEPs being compiled in Appendix 4.

### 2.3 Task 3: Consolidation coding of screened lists

Eight lists of screened FEPs were produced from the screening process performed in Task 2 (in addition to the 8 lists of screened-out FEPs in Appendix 4). In order to consolidate these 8 lists of screened FEPs, an additional consolidation code was added, as shown in Appendix 5 (CON. CODE). The purpose of this consolidation code was to create a reduced set of ‘processes’ which included all screened FEPs, but which had a sufficiently small number to be manageable. Reduced sets in the range 10-15 ‘processes’ were considered an acceptable compromise – small enough to be manageable, but large enough to retain specific characteristics of the individual FEPs. i.e. not too general.

Accordingly, Appendix 5 contains the 8 lists of screened FEPs, each category list prefaced by the set of consolidated ‘processes’. For ease of review, individual, screened FEPs are grouped according to consolidation code.
Table 1: Summary of FEP Screening Arguments

<table>
<thead>
<tr>
<th>Code</th>
<th>Screening Argument</th>
<th>Specifically Excluded Phenomena relating to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Site and Disposal Concept</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Waste form and packaging</td>
<td>L/ILW, organic wastes; vitrified waste</td>
</tr>
<tr>
<td>2.2</td>
<td>Emplacement and repository</td>
<td>cementitious backfill;</td>
</tr>
<tr>
<td>2.3</td>
<td>Host geology</td>
<td>salt deposits: clays;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>near-surface disposal phenomena</td>
</tr>
<tr>
<td>2.4</td>
<td>Local and regional</td>
<td>thick soil/sediment sequences;</td>
</tr>
<tr>
<td></td>
<td>surface environment</td>
<td>large topographic influences;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>oceanic processes</td>
</tr>
<tr>
<td>2.5</td>
<td>Geo-climatic development</td>
<td>arid climate;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>coastal, fluvial erosion</td>
</tr>
<tr>
<td></td>
<td>Assessment Basis</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Repository design/closure</td>
<td>operational phase; retrievability;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>major design changes</td>
</tr>
<tr>
<td>3.2</td>
<td>Global/regional disasters</td>
<td>meteorites</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TREATED SEPARATELY*</td>
</tr>
<tr>
<td>3.3</td>
<td>Acts of war/sabotage</td>
<td>nuclear war; terrorism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TREATED SEPARATELY*</td>
</tr>
<tr>
<td>3.4</td>
<td>Deliberate intrusion</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Future human society and technology</td>
<td>futuristic assumptions about human behaviour and technology</td>
</tr>
<tr>
<td>3.6</td>
<td>Post-closure radiological assessment</td>
<td>chemical toxicity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>impacts to flora/fauna</td>
</tr>
<tr>
<td>3.7</td>
<td>Future life evolution</td>
<td>radiation sensitivity;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>metabolism changes</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>General issues</td>
<td>too vague, general; incomprehensible; philosophical</td>
</tr>
</tbody>
</table>

*: Arguments 3.2 and 3.3 were assigned screening code 'D'
2.4 Task 4: Perform FEP audit

The FEP lists contained in Appendix 5 were used to perform an audit of the Kemakta FEP list (in Stockholm, April 21st, 1993). Participants in the audit were Neil Chapman and Michael Stenhouse of Intera, and Kristina Skagius and Marie Wiborg of Kemakta (primarily responsible for developing the Kemakta system). The objective of this exercise was to ensure that all relevant features, events and processes had either been incorporated in the influence diagrams already generated by Kemakta (principally of the waste and the engineered systems), or were available for construction of influence diagrams of other parts of the Process System.

During the audit, each FEP in the Intera lists was examined within each category. A tick mark was added if it had been included in the Kemakta list, either as a FEP or as a 'LINK' between two FEPs. Duplicates in the Intera list were eliminated at this stage, and external FEPs were identified as 'EFEP'. For each FEP which was identified for inclusion in the Kemakta system, either as a new FEP or new LINK, a note was made of the addition, together with its cause and effect.

At the time of the audit, the near-field FEPs had been identified and fully documented, and the Intera categories which were used for comparison were WASTE, CANISTER, BUFFER/BACKFILL and REPOSITORY. Similar treatments for the far field and biosphere systems were incomplete, although the format of the influence diagram was expected to be similar to that of the near field. As a result, all Intera FEP categories except BIOSPHERE were examined in detail. For the biosphere, duplicates were identified and eliminated. Occasionally, where two slightly different FEPs overlapped in terms of description, they were combined, thereby reducing the overall number.

The end product of the audit was a final list of all FEPs, still retained under the 8 categories, which have to be considered in the scenario development for the Swedish waste disposal concept. This list is shown in Appendix 6, and the main headings for these FEPs are included in Table 2.
Table 2. Final FEP List Headings

<table>
<thead>
<tr>
<th>Category</th>
<th>Headings</th>
</tr>
</thead>
</table>
| 1. WASTE CATEGORY | Waste characteristics: initial (SYSTEM DESCRIPTION)  
Radionuclide decay and growth  
Radiological/radiation effects  
Gas generation and effects  
Heat generation  
Thermo-mechanical effects  
Thermo-chemical effects  
Electro-chemical effects  
Waste degradation/corrosion/dissolution  
Geochemical reactions/regime  
Radionuclide chemistry  
Specific factors |
| 2. CANISTER CATEGORY | Canister materials/construction (SYSTEM DESCRIPTION)  
Corrosion/degradation processes  
Gas production and effects  
Microbiological effects/microbial activity  
Thermo-mechanical effects  
Electro-chemical effects  
Stress/mechanical effects  
Geochemical reactions/regime  
Radionuclide transport through containers  
Specific factors |
| 3. BUFFER/BACKFILL CATEGORY | Buffer/backfill characteristics (SYSTEM DESCRIPTION)  
Resaturation/desaturation  
Mechanical effects  
Thermal effects  
Electro-chemical effects  
Gas effects  
Microbiological effects/microbial activity  
Backfill degradation  
Geochemical regime  
Radionuclide transport processes  
Radionuclide chemistry  
Specific factors |
| 4. REPOSITORY/NEAR-FIELD ROCK CATEGORY | Near-field rock; repository elements/materials (SYSTEM)  
Repository degradation  
Hydraulic effects/groundwater flow  
Mechanical effects  
Thermal effects  
Gas effects and transport  
Microbiological/biological activity  
Geochemical regime  
Radionuclide chemistry  
Radionuclide transport processes  
Specific factors |
<table>
<thead>
<tr>
<th>Table 2. Final FEP List Headings</th>
</tr>
</thead>
</table>

**FEP NAME: HEADER**

### 5. FAR FIELD CATEGORY
- Rock properties (SYSTEM DESCRIPTION)
- Hydrogeological effects
- Physical/mechanical effects
- Thermal effects
- Gas effects and transport
- Microbiological/biological activity
- Geochemical regime
- Radionuclide chemistry
- Radionuclide transport processes
- Specific factors

### 6. BIOSPHERE CATEGORY
- Human considerations
- Ecological factors
- Soil/sediment effects
- Surface/near-surface water processes
- Coastal water/ocean processes
- Gas effects
- Microbiological/biological activity
- Geochemical regime (general)
- Radionuclide chemistry
- Radionuclide transport processes
- Radiological factors
- Specific factors

### 7. GEOLOGY/CLIMATE CATEGORY
- Seismic events/major land movement
- Rock deformation
- Metamorphic processes
- Erosion/weathering (surface)
- Groundwater flow and effects
- Surface water flow and effects
- Sea-level effects
- Magnetic effects
- Glaciation/glacial effects
- Climate effects (natural)
- Specific factors

### 8. HUMAN INFLUENCES CATEGORY
- Inadvertent intrusion into repository
- Surface activities
- Subsurface activities
- Water use
- Agricultural and fisheries practices
- Specific factors
References


APPENDIX 1

Raw FEPs List
Appendix 1. Raw FEPs List

The composite list presented in the following pages (19) contains all FEPs from the following national exercises, listed in order of appearance (the initial letter coding, e.g. AECL, identifies the respective exercises):

- AECL: Canada
- DOE: Dry Run 3, U.K. Department of Environment
- IAEA: Safety Series
- PGA: Nagra, Switzerland
- SKI: SKI/SKB: Sweden
- SNL: Sandia, U.S.
- UKN: U.K. Nirex L/ILW
- HMIP: Sellafield Assessment, U.K. Department of Environment
- NEA: Safety Assessment

NOTE

References for the above lists are given in the main text (page 3). In the ‘DOE’ list, FEPs often exist at the quaternary level (W.X.Y.Z) and, in such cases, the corresponding tertiary heading (W.X.Y) has been incorporated in each FEP as additional description. As a result, these tertiary entries (shaded) become redundant and are excluded from subsequent edited lists. In the same way, AECL primary (X.), and HMIP primary (W.) and secondary (W.X), headers have been retained for clarity, but are excluded from the reduced lists.
<table>
<thead>
<tr>
<th>IDENTIFIER</th>
<th>FEP NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>AECL1, VAULT FACTORS</td>
<td></td>
</tr>
<tr>
<td>AECL1.1</td>
<td>Backfill characteristics</td>
</tr>
<tr>
<td>AECL1.2</td>
<td>Backfill evolution</td>
</tr>
<tr>
<td>AECL1.3</td>
<td>Biological activity</td>
</tr>
<tr>
<td>AECL1.4</td>
<td>Boundary conditions</td>
</tr>
<tr>
<td>AECL1.5</td>
<td>Buffer additives</td>
</tr>
<tr>
<td>AECL1.6</td>
<td>Buffer characteristics</td>
</tr>
<tr>
<td>AECL1.7</td>
<td>Buffer evolution</td>
</tr>
<tr>
<td>AECL1.8</td>
<td>Core loss</td>
</tr>
<tr>
<td>AECL1.9</td>
<td>Chemical gradients</td>
</tr>
<tr>
<td>AECL1.10</td>
<td>Chemical interactions (expected)</td>
</tr>
<tr>
<td>AECL1.11</td>
<td>Chemical interactions (long-term)</td>
</tr>
<tr>
<td>AECL1.12</td>
<td>Chemical interactions (other)</td>
</tr>
<tr>
<td>AECL1.13</td>
<td>Chemical kinetics</td>
</tr>
<tr>
<td>AECL1.14</td>
<td>Climate change</td>
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<td>AECL1.15</td>
<td>Colloids</td>
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<tr>
<td>AECL1.16</td>
<td>Complexation by organics</td>
</tr>
<tr>
<td>AECL1.17</td>
<td>Concrete</td>
</tr>
<tr>
<td>AECL1.18</td>
<td>Container corrosion products</td>
</tr>
<tr>
<td>AECL1.19</td>
<td>Container failure (early)</td>
</tr>
<tr>
<td>AECL1.20</td>
<td>Container failure (long-term)</td>
</tr>
<tr>
<td>AECL1.21</td>
<td>Container failure (other long-term processes)</td>
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<td>AECL1.22</td>
<td>Container heating</td>
</tr>
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<td>AECL1.23</td>
<td>Containers - partial corrosion</td>
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<td>AECL1.24</td>
<td>Convective</td>
</tr>
<tr>
<td>AECL1.25</td>
<td>Correlation</td>
</tr>
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<td>AECL1.26</td>
<td>Corrosion</td>
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<td>Coupled processes</td>
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<td>Criticality</td>
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<td>Diffusion</td>
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<td>Dispersion</td>
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<td>Earthquakes</td>
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<td>Electrochemical gradients</td>
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<td>Evolution of buffer</td>
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<td>Excessive hydrostatic pressures</td>
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<td>AECL1.35</td>
<td>Explosions</td>
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<td>AECL1.36</td>
<td>Faulty buffer emplacement</td>
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<td>AECL1.37</td>
<td>Formation of cracks</td>
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<td>AECL1.38</td>
<td>Formation of gases</td>
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<td>AECL1.39</td>
<td>Galvanic coupling</td>
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<td>Geochronal pump</td>
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<td>Glaciation</td>
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<td>AECL1.42</td>
<td>Global effects</td>
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<td>Hydraulic conductivity</td>
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<td>Hydraulic head</td>
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<td>AECL1.45</td>
<td>Hydrolytic cracking</td>
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<td>AECL1.46</td>
<td>Hydrothermally altered rock</td>
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<td>AECL1.47</td>
<td>Improper operation</td>
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<td>AECL1.48</td>
<td>Incomplete closure</td>
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<td>AECL1.49</td>
<td>Incomplete filling of containers</td>
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<td>AECL1.50</td>
<td>Interfaces (boundary conditions)</td>
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<td>AECL1.51</td>
<td>Intrusion (animal)</td>
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<td>Intrusion (human)</td>
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<td>Inventory</td>
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<td>Other wastes (other than vitrified HLW)</td>
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<td>Long-term physical stability</td>
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<td>Long-term transients</td>
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<td>Microorganisms</td>
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<tr>
<td>AECL1.60</td>
<td>Monitoring and remedial activities</td>
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<tr>
<td>AECL1.61</td>
<td>Mutation</td>
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<td>AECL1.62</td>
<td>Percolation in shafts</td>
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<td>Pitting</td>
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<td>AECL1.64</td>
<td>Preclosure events</td>
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<td>AECL1.65</td>
<td>Precipitation and dissolution</td>
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<td>AECL1.66</td>
<td>Pseudo-colloids</td>
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<td>Radiation damage</td>
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<td>AECL1.68</td>
<td>Radioactive decay</td>
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<td>Radiolysis</td>
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<td>AECL1.70</td>
<td>Recharge groundwater</td>
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<td>AECL1.71</td>
<td>Reflooding</td>
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<td>AECL1.72</td>
<td>Retrievalability</td>
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<td>AECL1.73</td>
<td>Sabotage and improper operation</td>
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<td>Seal evolution</td>
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<td>AECL1.75</td>
<td>Seal failure</td>
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<td>AECL1.76</td>
<td>Sorption</td>
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<td>AECL1.77</td>
<td>Sorption: non-linear</td>
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<td>AECL1.78</td>
<td>Source terms (expected)</td>
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<td>AECL1.79</td>
<td>Source terms (other)</td>
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<td>AECL1.80</td>
<td>Speciation</td>
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<td>AECL1.81</td>
<td>Stability</td>
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<td>AECL1.82</td>
<td>Stability of glass</td>
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<td>AECL1.83</td>
<td>Swelling pressure</td>
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<td>AECL1.84</td>
<td>Temperature rises (unexpected effects)</td>
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<td>AECL1.85</td>
<td>Time dependence</td>
</tr>
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<td>AECL1.86</td>
<td>Transport in gases or of gases</td>
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APPENDIX 2

Screening Arguments Applied to FEPs
Screening Arguments for SITE 94 Scenario Development

1. INTRODUCTION

This Letter Report presents proposed screening arguments for use in the SKI SITE 94 scenario development project. These will be used to screen cut features, events and processes (FEPs) from a comprehensive catalogue compiled from a number of published and available lists and catalogues.

Screening arguments developed for Nagra for use in safety assessments for the Kristallin-1 project (Sumerling et al. 1993) have been taken as a starting point. This project considers disposal of vitrified high-level waste from nuclear fuel reprocessing in crystalline basement rock in northern Switzerland. The arguments have been adapted to be appropriate to the SITE 94 project, which considers disposal of spent nuclear fuel according to the KBS3 concept at a site with characteristics based on the Åspö Hard Rock Laboratory site, and also to take account of the assessment scope for SITE 94 which differs from the Kristallin-1 project.

Two groups of screening arguments are defined.

1. Site and Disposal Concept – These allow phenomena that are physically impossible or irrelevant for the given site and disposal concept to be screened out.

2. Assessment Basis – These define the scope of the safety assessment and allow phenomena outside that scope to be screened out.

Note that the term argument is preferred to criterion because the conditions for screening are arguments taking account of knowledge of the site and disposal concept, and the desired scope of the assessment. They are not strict ‘yes/no’ or quantitative criteria that can be rigidly applied rather they are guidance for the scenario development and screening of FEPs. The screening arguments are presented in the following sections.
2. SITE AND DISPOSAL CONCEPT

2.1 Waste Form and Packaging

The waste is spent nuclear fuel rods from BWR and PWR reactors. The fuel rods consist of cylindrical pellets of uranium dioxide in zirconium alloy (zircaloy) cladding tubes. These are bound together in fuel assemblies designed to be handled as a unit from supply to the reactor to final disposal. For disposal 6 to 9 fuel assemblies (depending on fuel type and respecting thermal loading limits) are contained in a steel canister with copper overpack of external dimensions 4.5m x 0.8m diameter. Voids within the canister are filled with copper powder or lead. The wastes will be heat generating.

Phenomena related specifically to other wastes types, eg. L/ILW, organic wastes and vitrified wastes, can be screened out or modified (if possible) to apply to the above concept.

[NOTE ADDED:
Consideration should be given to the possibility of voids within the canister.]

2.2 Emplacement and Repository

The copper-steel canisters (containing the wastes) are emplaced individually in vertical deposition holes (7.5m depth x 1.5m diameter) drilled in the floor of self-supporting horizontal tunnels (3.3m width x 4.5m height). The space between waste canister and deposition hole walls (~0.5m) and the upper part of the deposition hole is filled with blocks of highly-compacted sodium bentonite. The horizontal tunnels are backfilled with a sand-bentonite mix. There will be an axial decompressed/damaged zone around the horizontal tunnels which may be excavated by blasting. The disposal tunnels will be arranged in several panels each consisting of tunnels on a more or less parallel grid but avoiding significant water bearing features. Tunnels and shafts will be sealed with highly compacted bentonite and/or concrete and concrete shotcrete and steel rockbolts may be used to improve stability of the tunnels during the operational period.

Phenomena related specifically to cementitious backfill can be screened out (or modified) but cement-bentonite reactions may be relevant. Phenomena related to interaction between canisters/waste packages can be screened out.

[NOTE ADDED:
Although phenomena related specifically to cementitious backfill should be screened out, interactions between structural concrete in the repository and bentonite should be considered.]
2.3 Host Geology

The repository will be sited in crystalline (granitic) basement rock at a depth of about 500 metres below ground. The basement rock includes regional fracture zones with a spacing of one to a few kilometres, ranging from metres to tens of metres in width, plus connected 2nd order fracture zones at spacings of typically 500m. A 'respect zone' of 100 m is assumed between disposal tunnels and any such feature. Groundwater at depth includes both saline and freshwater zones.

Phenomena related specifically to other host rocks, eg. salt deposits, clays etc., can be screened out. Phenomena related to near-surface disposal, eg. hurricanes, burrowing animals etc., can be screened out.

2.4 Local and Regional Surface Environment

The Åspö site is located below a small island within a sea area enclosed by other small islands on the Baltic coast of Sweden. The region is low topography glaciated basement rock with thin discontinuous soil cover supporting mainly coniferous woodland. Under present-day conditions, possible leakage from the repository is most likely to occur to the marine environments with associated dose pathways. Doses through other pathways are also possible, eg. via a local well.

Phenomena related to large topographic influences, thick soil/sediment sequences, perched water tables, [high yield wells] and oceanic processes can be screened out.

[NOTE ADDED: Remove high-yield wells from the previous paragraph.]

2.5 Geo-climatic Development

The Scandinavian shield is rising at the present time due to isostatic rebound following the last glaciation. This will result in a relative sea-level fall so that the region will become terrestrial with numerous shallow freshwater lakes in the order of one to a few thousand years in the future. Assuming a continuation of the glacial-interglacial climate cycling observed in the last 0.8 My, the site is expected to be periodically covered by ice in the future, up to a depth of a few kilometres. The basement rock will resist significant erosion and soil/sediment covers (where present) will be thin and transient.

Phenomena related to warm climates can be screened out. Phenomena related to coastal and fluvial erosion can be screened out.

[NOTE ADDED: Although arid climates can be excluded, the possibility of a greenhouse-induced warmer, wetter climate should be considered.]
3. Assessment Basis or “Ground-rules”

3.1 Repository Design and Closure

It is assumed that the repository is constructed and operated, as planned, as a final disposal facility for spent nuclear fuel. No other wastes will be disposed in the facility. Some local variation in quality and minor deviations are expected. No repository monitoring or remedial activities are expected.

Phenomena related to operational accidents (which should be dealt with in an assessment of the operational phase), major design changes and disposal of other wastes in the repository can be screened out. However, long-term effects due to the expected operation of the repository should be considered. Retrievability of the wastes is not a consideration. The consequences of possible non-closure or improper closure of the repository should be considered.

[NOTE ADDED:
Failure of repository due to poor quality assurance should be considered.]

3.2 Global and Regional Disasters

It is not reasonable to make assessments of the radiological impacts from a repository for conditions which are associated with some global or regional catastrophe or serious accident that has immediate impacts that are orders of magnitude more serious, eg. in terms of loss of human life. All human endeavours are at risk from extreme natural and human induced events that are not usually accounted for in safety assessments of industrial developments.

Phenomena such as nuclear war, massive sea level rise due to global ice-cap melting and large meteorite strike on the site can be screened out.

[NOTE ADDED:
FEPs in this category will not be coupled to the Process System, and can be separated out for direct treatment. This applies also to 3.3]

3.3 Acts of War and Sabotage

Acts of war, should be excluded from the assessment. Malicious human acts, eg. terrorist acts, aimed at damaging the repository should be considered. However, in the pre-closure period, security measures will be in force to minimise the risk of successful attack; risks in this period might be considered in the assessment of operational plans and impacts; in the post-closure period, a closed repository will be an extraordinarily hard target to damage and a considerably less attractive target than surface industrial installations or civilian targets.
3.3 Acts of War and Sabotage (continued)

Phenomena related to acts of war should be screened out.

[NOTE ADDED: See previous note (3.3).]

3.4 Deliberate Intrusion

Future deliberate intrusive actions, taken with full knowledge of the nature and content of the repository, eg. to retrieve valuable materials, are excluded from the assessment. It is assumed that any such action would be undertaken after due consideration of safety aspects and with regard to the economic and environmental values of the time.

Phenomena related specifically to deliberate intrusion can be screened out, phenomena related to inadvertent intrusion are retained.

3.5 Future Human Society and Technology

Over the timescales considered in post-closure radiological assessment it is recognised that human civilisation and technology is likely to change considerably, but it is not possible to estimate other than in very general terms what changes may occur. Considering that a general tenet of post-closure radiological assessment is to afford future generations and individuals the same level of protection as that specified for current generations and individuals, it is appropriate to assume future human behaviours similar to that observed in the World today. Impacts to hypothetical critical groups dwelling in the future and with habits and technologies broadly similar to some group at some location in the World today can then be regarded as indicators of safety.

The possibility of cure for cancer is not relevant since the aim is to ensure environmental and human protection (good public health management should be based on prevention not cure).

Phenomena related to extreme futuristic assumptions about human behaviour and technology can be screened out.
3.6 Post-Closure Radiological Assessment

The scenario analysis is aimed at providing a framework for calculations of radiological impact (only) to human individuals and populations represented by a critical group. It is assumed that protection of human individuals ensures protection of the environment, see IAEA 1992.

Consideration of radiological impacts to flora and fauna should be screened out. Chemical toxicity effects of the disposed wastes may be addressed as a separate issue and can be screened out of the radiological assessment.

[NOTE ADDED:
FEPs in this category will not be considered in the SITE 94 scenario development process, and can be screened out as a separate item.]

3.7 Future Life Evolution

Humans and plant and animal species may evolve. Especially evolution of food plant and domesticated animals is to be expected. Hence metabolism, radionuclide uptake and radiation sensitivity may change. These changes cannot be anticipated and should not be accounted for in quantitative assessments (see also 2.5).

Assessments should be carried out assuming metabolic and physiological characteristics and radiosensitivity of humans, animals and plants similar to that observed today.

4. REFERENCES


APPENDIX 3

FEP Lists by Category

including screening arguments
Appendix 3. FEP Lists by Category

The 8 FEP lists in the following pages have been sorted according to the categories identified in section 2.2. The additional coding “XXXX” which occasionally appears under the “ARGUMENT” column is used to screen out those FEPs which, after additional examination, do not belong to the assigned category, or which are obvious duplicates within the same national FEP list. In such cases, the duplicate is identified under the “COMMENTS” column.
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| UKN1.6.23 | BF | Significant interactions of waste and repository materials with host materials (e.g., electrochemical, corrosion)
| UKN1.6.24 | BF | Non-radioactive solute volume in geosphere (effect on redox, effect on pH, sorption) |
| UKN1.6.25 | BF | Changes in in-situ stress field                  |

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ARGUMENT: UNDERGROUND CONSTRUCTION

COMMENT: FEPs LIST: HUMAN FACTORS CATEGORY

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APPENDIX 5

Screened FEP Lists

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### BUFFERBACKFILL CATEGORY

#### SCREENED FEPs

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### REPOSITORY CATEGORY:
**SCREENED FEPs**
(sorted)

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#### 4.1 Repository elements/materials

| AEC1L.8    | R        | 4.2       | Core ins |
| AEC1L.74   | R        | 4.2       | Seal evolution |
| AEC1L.75   | R        | 4.2       | Seal failure |
| DOE2.3.3.1 | FF       | 4.2       | Rock property changes: Porosity |
| DOE2.3.3.2 | FF       | 4.2,4.3   | Rock property changes: Permeability |
| DOE2.3.3.3 | FF       | 4.2,4,3.4.7 | Rock property changes: Microbial pore plugging |
| DOE2.3.3.4 | FF       | 4.2,4.4   | Rock property changes: Channel termocrystallisation |
| DOE4.1.1.1 | RRL      | 4.2       | Borehole seal failure |
| DOE4.1.1.2 | RRL      | 4.2       | Borehole seal degradation |
| DOE4.1.2.1 | R        | 4.2       | Shaft/tunnel seal failure |
| DOE4.1.2.2 | R        | 4.2       | Shaft/tunnel seal degradation |
| PGA3.16    | R        | 4.2,4.11  | Failure of shaft seating |
| SKK4.2.9   | R        | 4.2       | Creeping of rock mass |
| SKK5.11    | FF       | 4.2       | Degradation of hole- and shaft seals |
| SNS.1      | BR       | 4.2       | Subsidence and Caving |
| SNL.2      | RRL      | 4.2       | Shaft and Borehole Seal Degradation |
| UKN2.1.2   | RH       | 4.2       | Investigation borehole seal failure and degradation |
| UKN2.1.3   | RH       | 4.2       | Shaft or access tunnel seal failure and degradation |
| UKN2.1.4   | R        | 4.2,4.4.4.8 | Stress field changes, settling, subsidence or caving |
| HMIP.1.1   | R        | 4.2       | Seismic-chemical degradation of concrete |
| HMIP.1.2   | R        | 4.2       | Vault collapse |
| HMIP.1.11  | RRL      | 4.2       | Loss of integrity of borehole seals |
| HMIP.1.12  | R        | 4.2       | Loss of integrity of shaft or access tunnel seals |
| NEA2.1.1   | HR       | 4.2       | Investigation borehole seal failure and degradation |
| NEA2.1.3   | HR       | 4.2       | Shaft or access tunnel seal failure and degradation |
| NEA2.1.4   | HR       | 4.2,4.4.4.8 | Stress field changes, settling, subsidence or caving |
| NEA2.1.7   | HR       | 4.2       | Common cause failures |

#### 4.2 Repository degradation

<p>| AEC1L.34   | R        | 4.3       | Excessive hydrostatic pressures |
| AEC1L.40   | R        | 4.3       | Hydraulic conductivity |
| AEC1L.44   | R        | 4.3       | Hydraulic head |
| AEC1L.70   | R        | 4.3,4.10  | Recharge groundwater |
| AEC1L.71   | R        | 4.3       | Reflooding |
| AEC1L.90   | BR       | 4.3,4.10  | Unsaturated transport |
| DOE1.5.1.1 | FF       | 4.3       | Changes in moisture content due to dewatering |
| DOE1.5.1.2 | FF       | 4.3,4.4.4 | Changes in moisture content due to stress level |
| DOE1.5.2.2 | BR       | 4.3       | Groundwater flow due to gas production |
| DOE1.5.3.3 | BR       | 4.3       | Groundwater flow (saturated conditions) |
| DOE1.6.3.1 | FF       | 4.3       | Fracture changes: aperture |
| DOE1.6.3.2 | FF       | 4.3       | Fracture changes: length |
| DOE3.3.3   | FF       | 4.2,4.2.3 | Rock property changes: Permeability |
| DOE3.3.33  | FF       | 4.2,4.2.3.4.7 | Rock property changes: Microbial pore plugging |
| DOE3.3.4.1 | FF       | 4.3       | Groundwater flow: Darcy |
| DOE3.3.4.2 | FF       | 4.3       | Groundwater flow: Non-Darcy |
| DOE3.3.4.3 | FF       | 4.3       | Groundwater flow: Intergranular (matrix) |
| DOE3.3.4.4 | EFF      | 4.3       | Groundwater flow: Fracture |
| DOE3.3.4.5 | EFF      | 4.3       | Groundwater flow: Effects of solution channels |
| DOE3.4.1.7 | EFF      | 4.5,4.3   | Gas-induced groundwater transport |
| DOE3.4.13.3 | BR      | 4.5,4.4.13.2 | Repository thermally-induced groundwater transport |
| DOE3.4.13.2 | EFF      | 4.5,4.4.13.2 | Naturally thermally-induced groundwater transport |
| IAEA1.13.4 | EFF      | 4.3       | Fluid interactions: Groundwater flow |
| IAEA1.14   | EFF      | 4.5       | Thermal effects: Fluid migration |
| PGA4.1     | FF       | 4.3       | Direct alterations in hydrogeology |
| SKK4.2.5   | FF       | 4.3       | Changes of groundwater flow |
| SKK4.2.7   | R        | 4.3,4.4.4.4 | Thermodynamic-mechanical effects |
| SKK4.3.1   | BR       | 4.3       | Redistribution |
| SKK4.3.4   | FF       | 4.3,4.4.5 | Geothermally induced flow |
| UKN2.1.5   | R        | 4.3       | Dewatering of host rock |
| UKN3.1.4   | R        | 4.3       | Induced hydrological changes (fluid pressure, density convection, viscosity) |
| HMIP.1.1   | R        | 4.3       | Degradation (sapping) effects |
| HMIP.1.5   | R        | 4.3       | Disturbed zone (hydromechanical) effects |
| HMIP.1.6   | EFF      | 4.3       | Saturated groundwater flow |
| HMIP.1.7   | R        | 4.5,4.3   | Thermal effects and Hydrogeological changes |
| HMIP.1.3.7 | EFF      | 4.8,4.3   | Changes in groundwater chemistry and flow direction |
| NEA1.1.5   | HR       | 4.3       | Dewatering of host rock |
| NEA1.2.4   | R        | 4.3       | Induced hydrological changes (fluid pressure, density convection, viscosity) |</p>
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**4.4 Thermal effects**

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### Specific factors

<p>| AECL1.29   | R         | 4.11      | Colloids |
| AECL1.46   | R         | 4.11      | Incomplete closure |
| AECL1.62   | R         | 4.11      | Percolation in shafts |
| AECL1.66   | R         | 4.11      | Pseudo-colloids |
| AECL1.89   | R         | 4.11      | Unmodelled design features |
| AECL2.4    | BF        | 4.11      | Borehole seal failures/open boreholes |
| AECL2.6    | BF        | 4.11      | Boreholes - unsualsed |
| DOE1.5.4.5 | R         | 4.11      | Transport of colloids into the near-field |
| DOE2.3.4.6 | BF        | 4.11      | Inorganic colloid transport: Porous media |
| DOE2.3.5.1 | BF        | 4.11      | Inorganic colloid transport: Effects of pH and Eh |
| DOE2.3.6.2 | BF        | 4.11      | Inorganic colloid transport: Effects of ionic strength |
| DOE2.3.7   | BF        | 4.11      | Inorganic colloid transport: Porous media |
| DOE2.4.8.2 | BF        | 4.11      | Inorganic colloid transport: Fractured media |
| DOE2.4.8.3 | BF        | 4.11      | Inorganic colloid transport: Effects of pH and Eh |
| DOE2.4.8.4 | BF        | 4.11      | Inorganic colloid transport: Effects of ionic strength |
| IAE2.2.1   | RF        | 4.11      | Inadequate design: Shaft seal failure |
| IAE2.2.2   | RF        | 4.11      | Inadequate design: Exploration borehole seal failure |
| PGA3.16    | R         | 4.2,4.11  | Failure of shaft sealing |
| SKK4.23    | BF        | 4.11      | Extreme channel flow of oxidants and nuclides |
| SKK5.45    | BF        | 4.11      | Colloid generation and transport |
| UKN1.6.9   | BF        | 4.11      | Colloid formation, dissolution and transport |
| UKN2.2.10  | RF        | 4.11      | Poor closure |
| HMIP2.3.8  | BF        | 4.11      | Colloid transport |
| HMIP2.1.3  | R         | 4.11      | Incomplete near-field chemical conditioning |
| NEA1.6.9   | BF        | 4.11      | Colloid formation, dissolution, and transport |
| NEA2.1.6   | R         | 4.11      | Material defects (e.g. early canister failure) |
| NEA2.1.8   | R         | 4.11      | Poor quality construction |
| NEA2.2.1   | R         | 4.11      | Radioactive waste disposal error |
| NEA2.2.2   | R         | 4.11      | Inadequate backfill or compaction voidage |
| NEA2.2.4   | WR        | 4.11      | Inadequate inclusion of undesirable materials |
| NEA2.2.10  | R         | 4.11      | Abandonment of unsialsed repository |
| NEA2.2.12  | R         | 4.11      | Effects of phased operation |
| PGA4.2     | R         | 4.11      | Injection of liquid waste |</p>
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5.2 Hydrogeological effects

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### 5.3 Physical/mechanical effects

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### 5.4 Thermal effects

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### 5.5 Gas effects and transport

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### 5.6 Microbiological/biological activity

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5.9 Radionuclide transport processes

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6.4 Surface/near-surface water processes:

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**BIOSPHERE CATEGORY:**

**SCENED FEPs LIST**

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6.11 Radiological factors

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7.2 Rock deformation

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7.3 Metamorphic processes

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### GEOLOGY/CLIMATE CATEGORY:
**SCREENED FEPs LIST**

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### 7.5 Groundwater flow and effects

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### 7.7 Sea-level effects

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### 7.9 Oscillation/glacial effects

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### 7.10 Climate effects (natural)

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**Footnotes:**

- Additional details and notes are provided in the table entries where applicable.

**Abbreviations:**
- **G**: General
- **LG**: Local Geology
- **GR**: Geophysical Risk
- **KS**: Karst Setting
- **HG**: Hydrogeological Setting
- **HMIP**: Human-Made Interventions
- **NEA**: Natural Environmental Anomalies

**Notes:**
- The table includes specific categories and their corresponding codes related to geological and environmental factors.
- Each entry provides a detailed description of the impact or effect associated with the given category or factor.
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<td>land/earth moving, land use practices (non-agricultural)</td>
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<td>tunneling, underground construction, injection of liquid wastes</td>
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**8.2 Surface activities**

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**8.3 Subsurface activities**

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### 8.5 Agricultural and Fisheries Practices

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### 8.6 Radiological Factors

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APPENDIX 6

Final List of FEPs
Appendix 6. Final List of FEPs

The following pages (13) contain the final list of FEPs generated as a result of the audit held at Kemakta on April 21st, 1993. Additions to FEP descriptions, based on discussions during the audit, have been added in parentheses, mainly in UPPER CASE.

The key to the coding (letters) added to the left-hand column of the tables (AUDIT CODE) is given below.

<table>
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<th>EFEP</th>
<th>A feature, event or process (FEP) which is external to the Process System.</th>
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<td>new FEP</td>
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<tr>
<td>L</td>
<td>new link in the influence diagram</td>
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<tr>
<td>L*</td>
<td>new link to other parts of the Process System (e.g. far-field, biosphere)</td>
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The eight categories have been retained for FEP descriptions. For the biosphere, several FEP descriptions may be combined. Rather than reduce these FEPs to one entry, however, the original descriptions have been retained and 'group' has been added to one of the first two columns. Shading has also been added, where appropriate, to help identify individual groups.
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## Near-field rock: elements/materials

**SYSTEM DESCRIPTION**

- **Inventorystock geometry**
- **Rock properties (porosity, permeability, hydraulic head, conductivity)**

### Near-field rock: degradation
- Rock property changes (fractures, pore blocking, channel formation/closure)
- Borehole seal failure (including investigation boreholes and shaft/tunnel)
- Borehole seal degradation (including investigation boreholes and shaft/tunnel)
- Creeping of rock mass
- Subsidence and caving
- Physico-chemical degradation of concrete

### Near-field rock: hydraulic effects/groundwater flow

**F, L, L**
- Unsaturated transport
  - Groundwater flow due to gas production
  - Groundwater flow (saturated conditions; including fracture flow)
- L
  - Groundwater flow: effects of solution channels (PREFERENTIAL PATHWAYS)
- L
  - Repository thermally-induced groundwater transport
- L
  - Naturally thermally-induced groundwater transport
- Thermo-hydro-mechanical effects
- Resaturation
- Disturbed zone (hydromechanical) effects
- Saturated groundwater flow
- Changes in groundwater chemistry and flow direction

### Near-field rock: mechanical effects

- Formation of cracks
- Changes in in-situ stress field
- Changes in moisture content due to stress relief

**F**
- Differential elastic response

**L**
- Non-elastic response

**BEP**
- Repository-induced seismicity
- Externally-induced seismicity
- Differing thermal expansion of host rock zones
- *Uneven swelling of bentonite*
- Thermally-induced stress/fracturing in host rock
- Excavation-induced stress/fracturing in host rock

### Near-field rock: thermal effects

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<td>Variations in groundwater temperature</td>
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<td>Thermal effects on hydrochemistry</td>
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**L**
- Thermal differential elastic response

**L**
- Thermal non-elastic response

### Near-field rock: gas effects and transport

- Transport in gases or of gases
- Hydrogen: corrosion of structural steel
- Methane/CO2 production: effects of microbial growth on properties of concrete
- Gas transport in the near field, as gas phase and in solution
- Accumulation of gases under permafrost

**BEP**
- Methane intrusion
- Transport of active gases
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<td>Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)</td>
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### Geochemical regime
- Groundwater composition changes (pH, Eh, chemical composition)
- Fracture mineralisation
- Weathering, mineralisation
- Dissolution of fracture fillings/precipitations

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<td>5.9</td>
<td>Radiounclide chemistry</td>
<td>Dilution (mass, isotopic, species)</td>
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</tbody>
</table>

#### Radionuclide chemistry
- Complexation by organics (including humic and fulvic acids)
- Precipitation, dissolution, recrystallisation, reorganisation
- Sorption (linear, non-linear, irreversible)
- Speciation
- Chemical changes due to sorption, complex formation, speciation, gas, solubility
- Solubility effects (pH and Eh; ionic strength, complexing agents, colloids)
- Sorption effects (pH and Eh; ionic strength, complexing agents, colloids)
- Changes in sorbent surfaces
- Transport of radionuclides bound to colloids

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<td>Groundwater flow: effects of solution channels (PREFERENTIAL PATHWAYS)</td>
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<td>Gas-mediated transport</td>
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#### Specific factors
- Boreholes - unsealed
- Colloids: formation & effects (including inorganic and organic colloid transport)
- Incomplete vault closure
- Rock properties - undetected features
- Inadequate design: shaft seal or exploration borehole seal failure
- Extreme channel flow of oxidants and nuclides
- Undetected features (e.g., faults, fracture networks, shear zones, discontinuities, gas
- Shaft and borehole seal degradation
FINAL FEPs: BIOSPHERE

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<td>Terrestrial ecological development: natural and agricultural systems</td>
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<td>Terrestrial ecological development: Effects of succession</td>
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Soil/sediment effects
- Capillary rise in soil
- Soil properties (type, depth, porewater pH, moisture, sorption)
- Soil leaching
- Toxic exchange in soil
- Sediment resuspension in water bodies
- Sedimentation in water bodies
- Groundwater discharge to soils; advective, diffusive, biotic, volatilization
- Accumulation in sediments
- Accumulation in soils and organic debris, including peat
- Pedogenesis
- Evaporation of soil moisture
- Sediment/water/gas interaction with the atmosphere
- Terrestrial water use (including wild)
- River flow and lake level changes

Near-surface runoff processes: Variable source area response
- Group: Surface flow characteristics (freshwater): Sediment transport
- Group: Surface flow characteristics (freshwater): Lake formation/sedimentation
- Group: Near-surface runoff processes; Variable source area response

Near-surface runoff processes: Water flow
- Group: Surface water bodies: Water flow
- Group: Surface water bodies: Suspended sediments
- Group: Surface water bodies: Bottom sediments
- Group: Surface water bodies: Effects of fluvial system development
- Group: Surface water mixing
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**Surface activities**

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**Subsurface activities**

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**Water use**

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**Agricultural and fisheries practices**

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**Specific factors**

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