Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

SCR Attachment 1

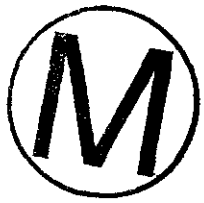
THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

FIGURES

TABLES

THIS PAGE INTENTIONALLY LEFT BLANK



Development of a WIPP-Specific List of Features, Events and Processes for the Compliance Certification Application

1 Introduction

The performance assessment (PA) process conducted for the Waste Isolation Pilot Plant (WIPP) uses scenario development as a tool for determining exactly what phenomena and components of the disposal system can and should be dealt with in PA calculations. The Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD/NEA) defined scenario development as the identification, broad description, and selection of alternative futures relevant to a reliable assessment of the safety of a disposal system, and set out four basic steps in the scenario development procedure (OECD/NEA, 1992):

(i) Identification and classification of all phenomena potentially relevant to the performance of the repository and site.

(ii) Elimination of phenomena according to well-defined screening criteria.

(iii) Identification or formation of scenarios relevant to the performance of the repository and site.

(iv) Specification of scenarios for consequence analysis.

The purpose of this report is to describe the development of a list of phenomena potentially relevant to the performance of the WIPP (stage (i) in this procedure). The resulting list of Features, Events and Processes (FEPs) is presented in the Compliance Certification Application (CCA). Screening of these FEPs (stage (ii) in the scenario development procedure) is presented in Appendix SCR of the CCA.

It is important to be as comprehensive and imaginative as possible during the initial stage of identifying FEPs, even if some of these FEPs may be eliminated in later stages of the process. This ensures that interactions between FEPs are not overlooked and that a well-documented response to possible "what-if" questions is available. It is also important that the classification and development of the FEP list is well documented to ensure that decisions can be traced and to build confidence that the scenarios used in PA are reasonable and sufficiently comprehensive.

In order to fulfill the requirements for comprehensiveness and traceability, an initial FEP list was assembled based on FEP lists in use for the WIPP and in other radioactive waste disposal programs. This initial FEP list was used in preparing Appendix SCR of the Draft Compliance Certification Application (DCCA) (U.S. DOE, 1995a, b). Appendix SCR for the final CCA is based in large part on the corresponding sections of the DCCA, with the addition of new screening arguments and revisions to clarify other screening discussions. As part of these revisions, consideration was given to the comments received on the DCCA text and, in

particular, the relationship of the text to the tables of FEPs. As a result, a new FEP list has been developed for the CCA that is closely linked to a generic list and at the same time includes issues specific to the WIPP site.

This document summarizes the development of the initial FEP list used in the DCCA (Section 2), and outlines the drawbacks of this list for use in the CCA (Section 2.3). The development of a WIPP-specific FEP list for the CCA is described in Section 3. A summary of the steps in this development that have built confidence in the comprehensiveness and appropriateness of the CCA FEP list is presented in Section 4. Appendices present the DCCA list and a mapping from this list to the CCA FEP list.

2 Development of an Initial FEP Database

The DCCA compiled by the Department of Energy in March 1995 (U.S. DOE, 1995a) included, in Appendix SCR, screening arguments for many FEPs. These FEPs were derived from a comprehensive list of FEPs established as a means of demonstrating that the WIPP PA had adequately documented the decisions leading to exclusion of FEPs from the PA calculations.

There have been several recent studies in which a variety of national FEP lists were compiled in order to help ensure comprehensiveness (e.g, in the Netherlands (Prij et al., 1993), Sweden (Stenhouse et al., 1993), and the United States (Guzowski and Newman, 1993)). In addition, work is underway at the OECD/NEA to develop a comprehensive FEP list that includes all national work; however, this list was not available at the time the WIPP FEP list was compiled in 1995.

The list established for the DCCA was based on a FEP compilation conducted by the Swedish Nuclear Power Inspectorate (SKI) (Stenhouse et al., 1993) because that compilation was the best documented and most comprehensive. During development of the initial FEP list for the WIPP, key project documents were reviewed, such as the 1991 and 1992 PAs (Sandia National Laboratories, 1991, 1992), and the March 1994 Compliance Status Report (U.S. DOE, 1994). Review of these documents illustrated the need to incorporate additional FEPs into the DCCA list.

2.1 The Swedish study

The Swedish Nuclear Power Inspectorate (SKI) study was conducted by Stenhouse et al. (1993) as part of the SITE-94 performance assessment exercise. This exercise considered the disposal of spent nuclear fuel in crystalline bedrock at a hypothetical site with characteristics based on the Äspö Hard Rock Laboratory site. The purpose of the FEP study was to ensure that all relevant FEPs were considered early in the SITE-94 assessment, and only limited screening of FEPs was done.

SKI compiled an initial raw FEP list based on the nine different FEP identification studies listed in Table 1.

Table 1. Studies used to derive the DCCA FEP list

Study	Country	Number of FEPs identified
Atomic Energy of Canada Limited (AECL) study of disposal of spent fuel in crystalline rock (Goodwin et al., 1994)	Canada	275
SKI & Swedish Nuclear Fuel and Waste Management Company (SKB) study of disposal of spent fuel in crystalline rock (Andersson, 1989)	Sweden	157
National Cooperative for the Storage of Radioactive Waste (NAGRA) Project Gewähr study (NAGRA, 1985)	Switzerland	44
UK Department of the Environment Dry Run 3 study of deep disposal of low- and intermediate-level waste (L/ILW) (Thorne, 1992)	United Kingdom	305
UK Department of the Environment assessment of L/ILW disposal in volcanic rock at Sellafield (Miller and Chapman, 1993)	United Kingdom	79
UK Nuclear Industry Radioactive Waste Executive (NIREX) study of the deep disposal of L/ILW (Hodgkinson and Sumerling, 1989)	United Kingdom	131
SNL study of disposal of spent fuel (Cranwell et al., 1990)[1]	United States	29
Nuclear Energy Agency (NEA) Working Group on Systematic Approaches to Scenario Development (NEA, 1992)	International	122
International Atomic Energy Agency (IAEA) Safety Series (IAEA, 1985)	International	56

SKI divided FEPs from these lists into eight primary categories ("Level 1") based on location of occurrence (six categories) and cause (two categories). The eight categories were waste, canister, buffer/backfill, repository/near-field, far-field, biosphere, geological/climatic evolution, and future human actions. SKI eliminated a number of FEPs from the component lists on the basis of irrelevancy to the SKI disposal concept and site, assessment scope, and incomprehensibility of the FEP.

Because of the way the disposal system was subdivided many FEPs appear more than once on the list. For example, a process such as sorption may occur in the backfill, in the near-field, in the far-field, and in the biosphere, and it would be included on the lists for all of these Level 1 categories. In addition, each Level 1 category was subdivided into between seven and twelve "Level 2" subcategories. Some FEPs occur several times within a single Level 1 category, where they are relevant to the consideration of more than one of the Level 2 subcategories.

[1] This list was in use previously by the WIPP project (Sandia National Laboratories, 1991, 1992).

2.2 *Development of the DCCA FEP list*

The DCCA FEP list was developed by taking the final SKI list, and re-inserting FEPs that had been screened out in the SKI study. Numerous additional FEPs of particular concern to the WIPP were added (see below), and several of the FEPs on the SKI list were subdivided in order to assist with screening them for the WIPP PA calculations. Finally, some duplicate FEPs were eliminated for clarity of presentation, although other duplicate FEPs were retained where a particular FEP could affect more than one part of the disposal system, or could interact with FEPs in more than one subcategory. No other changes were made. In particular, the titles of all FEPs on the SKI list were retained, even though some of them were vague or poorly stated for the situation at the WIPP.

The structure of the DCCA FEP list is provided in Table 2, and the full list is provided in Appendix A. This structure is similar to that in the SKI study. The most notable change to the SKI list was the creation of a new Level 1 category called "seal systems" for the DCCA to reflect the importance of the seal systems to the WIPP safety concept. The SKI list included consideration of seal degradation only under the Level 2 subcategory "repository degradation." The Level 2 subcategories and the FEPs in the DCCA FEP list for the seal systems category reflect those that are in the SKI Level 1 backfill category. A further change was to broaden consideration of radionuclide transport to consideration of all contaminants of concern (i.e., inclusion of volatile organic compounds (VOCs) and heavy metals), in order to improve the applicability of the list to performance assessments presented in the No Migration Variance Petition (NMVP) to satisfy the requirements of 40 CFR §268.6.

2.3 *Drawbacks of the DCCA FEP list*

Internal and external review of Chapter 6 and Appendix SCR of the DCCA highlighted a number of drawbacks in the use of the DCCA FEP list and the presentation of screening arguments. These drawbacks are outlined in the following sections.

2.3.1 Scope of a Generic List

The use of the SKI FEP list as a basis for the DCCA FEP list provided confidence that all FEPs of potential importance were considered. The wide range of disposal concepts that formed the basis of the list, however, led to a significant number of FEPs being classified as not relevant to WIPP. The component FEP lists considered, for example, a range of engineered barriers and were developed under different regulatory frameworks. Furthermore, FEPs relating to the marine environment that are relevant in programs considering coastal sites are not relevant to WIPP.

2.3.2 Use of Subsystems

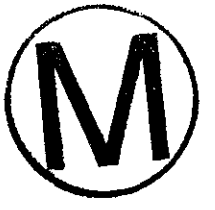
The SKI list was organized into a series of subsystems: waste, canister, backfill, near-field, far-field, biosphere, geology/climate, and human influences. An additional subsystem - seals - was added in the DCCA to make the list more applicable to the WIPP, but overall the SKI subsystem classification is not ideal for the WIPP disposal concept. For example, in contrast

to the Swedish disposal concept, canister integrity does not have a role in long-term performance of the WIPP. The terms near-field, far-field and biosphere are not unequivocally defined for the WIPP site, nor does the cumulative release criterion (40 CFR § 191.13) require consideration of radionuclide transport in the biosphere.

Table 2. Structure of the DCCA FEP Database - Levels 1 and 2.

1	**WASTE CATEGORY**
1.1	Initial waste characteristics
1.2	Radionuclide decay and growth
1.3	Radiological/radiation effects
1.4	Gas generation and effects
1.5	Heat generation
1.6	Thermo-mechanical effects
1.7	Thermo-chemical effects
1.8	Electro-chemical effects
1.9	Waste degradation/corrosion/ dissolution
1.10	Geochemical reactions/regime
1.11	Radionuclide and contaminant (e.g., heavy metal) chemistry
1.12	Others
2	**CANISTER CATEGORY**
2.1	Canister materials/construction
2.2	Corrosion/degradation processes
2.3	Gas production and effects
2.4	Microbiological effects/microbial activity
2.5	Thermo-mechanical effects
2.6	Electro-chemical effects
2.7	Stress/mechanical effects
2.8	Geochemical reactions/regime
2.9	Radionuclide and contaminant (e.g., heavy metal) transport through canisters
2.10	Others
3	**BACKFILL CATEGORY**
3.1	Buffer/backfill characteristics
3.2	Resaturation/desaturation
3.3	Mechanical effects
3.4	Thermal effects
3.5	Electro-chemical effects
3.6	Gas effects and transport
3.7	Microbiological effects/microbial activity
3.8	Backfill degradation
3.9	Geochemical regime
3.10	Radionuclide and contaminant (e.g., heavy metal) transport processes
3.11	Radionuclide and contaminant (e.g., heavy metal) chemistry
3.12	Others
4	**SEAL SYSTEMS CATEGORY**
4.1	Seal system characteristics
4.2	Resaturation/desaturation
4.3	Mechanical effects
4.4	Thermal effects
4.5	Electro-chemical effects
4.6	Gas effects and transport
4.7	Microbiological effects/microbial activity
4.8	Seal degradation
4.9	Geochemical regime
4.10	Radionuclide and contaminant (e.g., heavy metal) transport processes
4.11	Radionuclide and contaminant (e.g., heavy metal) chemistry
4.12	Others
5	**REPOSITORY/NEAR-FIELD CATEGORY**
5.1	Near-field; repository elements/materials
5.2	Repository degradation
5.3	Hydraulic effects/groundwater flow
5.4	Mechanical effects
5.5	Thermal effects

5.6	Gas effects and transport
5.7	Microbiological/biological activity
5.8	Geochemical regime
5.9	Radionuclide and contaminant (e.g., heavy metal) chemistry
5.10	Radionuclide and contaminant (e.g., heavy metal) transport processes
5.11	Others
6	**FAR-FIELD CATEGORY**
6.1	Rock properties
6.2	Hydrogeological effects
6.3	Physical/mechanical effects
6.4	Thermal effects
6.5	Gas effects and transport
6.6	Microbiological/biological activity
6.7	Geochemical regime
6.8	Radionuclide and contaminant (e.g., heavy metal) chemistry
6.9	Radionuclide and contaminant (e.g., heavy metal) transport processes
6.10	Others
7	**BIOSPHERE CATEGORY**
7.1	Human considerations
7.2	Ecological factors
7.3	Soil/sediment effects
7.4	Surface/near-surface water processes
7.5	Coastal water/ocean processes
7.6	Gas effects and transport
7.7	Microbiological/biological activity
7.8	Geochemical regime (general)
7.9	Radionuclide and contaminant (e.g., heavy metal) chemistry
7.10	Radionuclide and contaminant (e.g., heavy metal) transport processes
7.11	Radiological factors
7.12	Others
8	**GEOLOGY/CLIMATE CATEGORY**
8.1	Seismic events/major land movement
8.2	Rock deformation
8.3	Metamorphic processes
8.4	Erosion/weathering (surface)
8.5	Groundwater flow and effects
8.6	Surface water flow and effects
8.7	Sea-level effects
8.8	Magnetic effects
8.9	Glaciation /glacial effects
8.10	Climate effects (natural)
8.11	Others
9	**HUMAN INFLUENCES CATEGORY**
9.1	Inadvertent intrusion into repository
9.2	Surface activities
9.3	Subsurface activities
9.4	Water use
9.5	Agricultural and fisheries practices
9.6	Radiological factors
9.7	Others



2.3.3 Presentation of FEP Screening

The text of Appendix SCR in the DCCA did not discuss on an individual basis all FEPs from the comprehensive list of FEPs. Instead, the discussion was organized around a series of topics ranging from individual FEPs for which there was a semi-quantitative basis for screening (e.g. meteorite impact) to groups of FEPs that could be screened out collectively using a qualitative argument (e.g. all FEPs relating to the marine environment).

A series of check-lists was used to ensure that all the individual FEPs were included within the topics discussed in the DCCA. These check-lists were included as tables so that the reader could relate the topics discussed in the body of the report to the complete list of FEPs. Confusion has therefore arisen because individual FEPs in Tables SCR-1, 2 and 3 of the DCCA were not all explicitly discussed in the text of Appendix SCR.

2.3.4 FEP Classification

Appendix SCR of the DCCA (U.S. DOE, 1995b) lists and discusses FEPs included in PA calculations for undisturbed and disturbed performance (classifications UP and DP), FEPs screened out on regulatory, probability or consequence grounds (SO-R, SO-P and SO-C), FEPs not yet screened (RB), FEPs related to deviations from the design (RD), FEPs concerning potential design changes (RE), FEPs representing reserves of performance (RF), and FEPs considered not relevant to WIPP (NR). For the CCA, however, which presents PA calculations for a final design, the only classifications that are appropriate are inclusion in the calculations (UP, DP) or exclusion on well-defined criteria (SO-R, SO-C, SO-P). FEPs relating to the evaluation of different designs or disposal concepts (RD, RE and NR) have therefore been omitted from the CCA FEP list. Work undertaken since the DCCA has resulted in the screening of those FEPs previously categorized as RB, with the majority now screened as SO-C, and this category has become redundant with respect to the CCA. Finally, reviewers did not consider that a separate category for FEPs representing reserves of performance was appropriate, and that FEPs categorized as RF should be screened out on the basis of consequence to performance of the disposal system (SO-C). These relationships between the FEP classification scheme used in the DCCA and that adopted for the CCA are illustrated in Figure 1.

3 The CCA FEP List

For the reasons outlined in Section 2.3, a new, WIPP-specific list of FEPs has been developed for use in the Compliance Certification Application. This list has approximately 240 FEPs, in contrast to approximately 900 FEPs in the DCCA. The reduction in numbers removes the ambiguities caused by use of a generic list, without eliminating any issues from the discussion.

3.1 FEP Categorization

As a framework for the CCA FEP list, and as an aid to the presentation of screening arguments in Appendix SCR, a FEP categorization scheme has been developed for the CCA. FEPs have been categorized using the three major divisions of natural, waste- and repository-induced, and human actions. Each of these divisions is subdivided into categories corresponding to major subject areas such as geology, geochemical, and subsurface hydrology. Further subdivisions of these categories represent groups of related features or processes such as structural effects, gas generation, and repository-induced flow. The full categorization scheme is presented in Table 3.

FEP Classification in DCCA			FEP Classification in CCA
Accounted for in Performance Assessment Calculations	Containment Requirements 40 CFR §191.13	UP, DP	UP, DP
	Individual Dose 40 CFR §191.15 Groundwater Protection 40 CFR §191.24	UP	UP
Eliminated from Performance Assessment Calculations	Regulatory Guidance	SO-R	SO-R
	Consequence	SO-C	SO-C
	Probability	SO-P	SO-P
	Deviations from Design Specifications	RD	Not on CCA FEP list (Irrelevant to assessment of final design)
	Engineering Alternatives	RE	Not on CCA FEP list (Irrelevant to assessment of final design)
	Not Relevant	NR	SO-C (Natural FEPs)
			Not on CCA FEP list (Applicable to other disposal concepts)
Retained for Evaluation in Final CCA	Assumed Low Consequence	RB	Screened (Majority as SO-C)
	Reserve (Potentially Beneficial to Performance)	RF	SO-C

Figure 1. Relationships between the FEP classification scheme used in the DCCA and adopted for the CCA

3.2 Derivation of the CCA FEP list

The following steps have been used to derive the CCA FEP list from that compiled for the DCCA:

- References to subsystems have been eliminated from the CCA FEP list, because the SKI subsystem classification is not ideal for the WIPP disposal concept.

- Duplicate FEPs have been eliminated from the CCA FEP list. Duplicate FEPs arose in the DCCA list because individual FEPs could act in different subsystems. FEPs have a single entry in the CCA list whether they are applicable to several parts of the disposal system or to a single part only.

Table 3. Categorization scheme for the CCA FEP list

NATURAL	Geological	Stratigraphy	
		Tectonics	
		Structural effects	Deformation
			Fracture development
			Fault movement
			Seismic activity
		Crustal processes	Igneous activity
			Metamorphism
		Geochemical effects	Dissolution
			Mineralization
	Subsurface hydrological	Groundwater characteristics	
		Changes in groundwater flow	
	Subsurface geochemical	Groundwater geochemistry	
		Changes in groundwater chemistry	
	Geomorphological	Physiography	
		Meteorite impact	
		Denudation	Weathering
			Erosion
			Sedimentation
		Soil development	
	Surface hydrological	Fluvial	
		Lacustrine	
		Groundwater recharge and discharge	
		Changes in surface hydrology	
	Climatic	Climate	
		Climate change	Meteorological
			Glaciation
	Marine	Seas	
		Marine sedimentology	
		Sea level change	
	Ecological	Flora & fauna	
		Changes in flora & fauna	
WASTE AND REPOSITORY-INDUCED	Waste and repository characteristics	Repository characteristics	
		Waste characteristics	
		Container characteristics	
		Seal characteristics	
		Backfill characteristics	
		Postclosure monitoring	
	Radiological	Radioactive decay	

Table 3. Categorization scheme for the CCA FEP list (continued)

1			Heat from radioactive decay	
2			Nuclear criticality	
3			Radiological effects on material properties	
4		Geological / mechanical	Excavation-induced fracturing	
5			Rock creep	
6			Roof falls	
7			Subsidence	
8			Effects of fluid pressure changes	
9			Effects of explosions	
10			Thermal effects	
11			Mechanical effects on material properties	
12		Subsurface hydrological / fluid dynamical	Repository-induced flow	
13			Effects of gas generation	
14			Thermal effects	
15		Geochemical / chemical	Gas generation	Microbial gas generation
16				Corrosion
17				Radiolytic gas generation
18			Chemical speciation	
19			Precipitation / dissolution	
20			Sorption	
21			Redox chemistry	
22			Organic complexation	
23			Exothermic reactions	
24			Chemical effects on material properties	
25		Contaminant transport mode	Solute transport	
26			Colloid transport	
27			Particulate transport	
28			Microbial transport	
29			Gas transport	
30		Contaminant transport process	Advection	
31			Diffusion	
32			Thermochemical transport phenomena	
33			Electrochemical transport phenomena	

Table 3. Categorization scheme for the CCA FEP list (continued)

		Physicochemical transport phenomena	
	Ecological	Plant, animal and soil uptake	
		Human uptake	
HUMAN ACTIONS	Geological	Drilling	
		Excavation activities	
		Subsurface explosions	Resource recovery
			Underground nuclear device testing
	Subsurface hydrological and geochemical	Borehole fluid flow	Drilling-induced flow
			Fluid extraction
			Fluid injection
			Flow through abandoned boreholes
		Excavation-induced flow	
		Explosion-induced flow	
	Geomorphological	Land use and disturbances	
	Surface hydrological	Water control and use	
	Climatic	Anthropogenic climate change	
	Marine	Marine activities	
	Ecological	Agricultural activities	
		Social and technological developments	

- FEPs relating to high-level waste, long-term behavior of canisters, bentonite backfill, etc. (classified as NR in the DCCA) have been eliminated from the CCA FEP list. These FEPs are included on the generic list to ensure compatibility with a range of design concepts, but they are not relevant to the current WIPP design or inventory.

- FEPs relating to issues such as hazardous metal transport, VOCs, and chemical toxicity, that are not regulated by 40 CFR Part 191 (classified as NR in the DCCA), have been eliminated from the CCA FEP list.

- Natural FEPs classified as not relevant (NR in the DCCA) that will clearly not affect the WIPP (e.g. marine processes) have been composited into a few generalized FEPs on the CCA FEP list. These FEPs are discussed and screened out on the basis of low consequence in the CCA.

- FEPs relating to constructional, operational and decommissioning errors (classified as RD in the DCCA) have been eliminated from the CCA FEP list. The DOE has

administrative and quality control procedures to ensure that the facility will be constructed, operated and decommissioned as specified in the CCA.

- FEPs relating to engineering design changes (classified as RE in the DCCA) have been eliminated from the CCA FEP list. Such FEPs are not relevant to a compliance application based on the current design.

- Detailed FEPs relating to processes in the surface environment have been composited into a small number of generalized FEPs in the CCA FEP list. The surface environment is a significant part of the disposal system for programs required to calculate dose or risk, and hence detailed FEPs relating to this environment are included in generic FEP lists. The surface environment is of less significance for the WIPP PA calculations, and less detail is appropriate in this part of the WIPP-specific CCA FEP list.

- A few FEPs have been re-named to highlight their relationship to key WIPP issues (e.g. wicking, brine inflow).

In the DCCA, the classification SO-C was generally restricted to "low consequence," with the classifications NR and RF being used for "no consequence" and "positive consequence" respectively. In the CCA FEP list those FEPs classified as having a potentially beneficial effect on performance have been re-classified as SO-C. A number of FEPs previously classified as not relevant have also been re-classified as SO-C. These changes mean that the SO-C classification should be interpreted in the more general sense of "screened out on the basis of potential consequence."

A major change between the DCCA FEP list and the CCA FEP list is the elimination of subsystems, and the consequent removal of duplicate FEPs. For example, the DCCA FEP list had separate entries for sorption in canisters, backfill, seals, the near-field and the far-field. In contrast, the CCA FEP list has a single FEP for sorption. If a FEP is included in performance assessment calculations for only part of the disposal system, the UP or DP classification is used in the summary tables, along with a note to this effect, and the text of Appendix SCR is used to present screening arguments for other parts of the disposal system.

The CCA FEP list is presented in Table 4, together with the current screening classification of each FEP. Appendix B provides a mapping between the CCA FEP list and the DCCA FEP list. This mapping shows how duplicate FEPs from different subsystems have been consolidated into single FEPs, and how detailed FEPs relating to environments of little significance to the WIPP have been consolidated. The mapping also shows how some general FEPs on the DCCA list, and FEPs listing a number of more detailed processes, have been mapped to a category or subcategory rather than to individual FEPs on the CCA list.

A number of FEPs on the CCA list do not have corresponding FEPs on the DCCA list. This does not imply that the DCCA list was not comprehensive, but does indicate that a site-specific FEP list may include greater detail for particular parts of the disposal system than generic FEP lists. This detail corresponds to features or issues of concern at a particular site.

Dissolution is thus treated in detail at the WIPP site, with a number of specific FEPs, whereas the generic list includes only a few general FEPs on this topic.

Appendix C lists those FEPs in the DCCA FEP list that have been excluded because they relate to designs different to that forming the basis of the CCA, because they relate to issues such as chemical toxicity that are not regulated by 40 CFR Part 191, or because they are modeling issues rather than FEPs. Modeling issues are discussed elsewhere in the CCA (e.g. in Section 6.4 and Appendix MASS).

4 Comprehensiveness

Development of the CCA FEP list has taken place in parallel to the preparation of an international FEP list by an OECD/NEA Working Group[2]. The WIPP project is represented on the Working Group, and this has provided an assurance that the categorization scheme developed for the CCA is comparable with the international list. As noted above, the list of individual FEPs developed for a specific site is dependent to some degree on the particular features and issues of concern at that site. The OECD/NEA Working Group has not attempted, therefore, to define an international list of detailed FEPs.

- The stages in the development of the CCA FEP list that have built confidence in its comprehensiveness and appropriateness include:

- A compilation of 9 FEP lists developed in different countries and internationally was used as a starting point.

- An extension to WIPP through review of project literature.

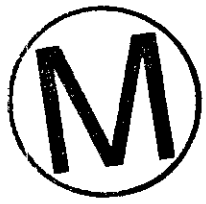
- Formal presentations to the EPA (22-23 September 1994) and stakeholders (28 September 1994) of the initial FEP list and screening arguments.

- Extensive, formal, documented review of the DCCA within the project, by stakeholders, and by the EPA.

- Reduction of the DCCA FEP list in a documented, logical manner.

- Formal documented review of the CCA FEP list within the project.

- Participation in the OECD/NEA Working Group to Develop an International Database of FEPs.



[2]The international list will not be available before late 1996.

Table 4. The CCA FEP List and Screening Classifications

FEPs			Screening Classification
NATURAL			
GEOLOGICAL			
	Stratigraphy		
		Stratigraphy	UP
		Brine reservoirs	DP
	Tectonics		
		Changes in regional stress	SO-C
		Regional tectonics	SO-C
		Regional uplift and subsidence	SO-C
	Structural FEPs		
	Deformation		
		Salt deformation	SO-P
		Diapirism	SO-P
	Fracture development		
		Formation of fractures	SO-P
		Changes in fracture properties	SO-C
	Fault movement		
		Formation of new faults	SO-P
		Fault movement	SO-P
	Seismic activity		
		Seismic activity	UP
	Crustal processes		
	Igneous activity		
		Volcanic activity	SO-P
		Magmatic activity	SO-C
	Metamorphism		
		Metamorphic activity	SO-P
	Geochemical FEPs		
	Dissolution		
		Shallow dissolution	UP
		Lateral dissolution	SO-C
		Deep dissolution	SO-P
		Solution chimneys	SO-P
		Breccia pipes	SO-P
		Collapse breccias	SO-P
	Mineralization		
		Fracture infills	SO-C
SUBSURFACE HYDROLOGICAL			
	Groundwater characteristics		
		Saturated groundwater flow	UP
		Unsaturated groundwater flow	UP
		Fracture flow	UP
		Density effects on groundwater flow	SO-C
		Effects of preferential pathways	UP
	Changes in groundwater flow		
		Thermal effects on groundwater flow	SO-C
		Saline intrusion	SO-P
		Freshwater intrusion	SO-P
		Hydrological response to earthquakes	SO-C
		Natural gas intrusion	SO-P

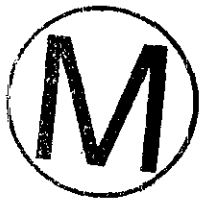


Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
SUBSURFACE GEOCHEMICAL			
	Groundwater geochemistry		
		Groundwater geochemistry	UP
	Changes in groundwater chemistry		
		Saline intrusion	SO-C
		Freshwater intrusion	SO-C
		Changes in groundwater Eh	SO-C
		Changes in groundwater pH	SO-C
		Effects of dissolution	SO-C
GEOMORPHOLOGICAL			
	Physiography		
		Physiography	UP
	Meteorite impact		
		Impact of a large meteorite	SO-P
	Denudation		
	Weathering		
		Mechanical weathering	SO-C
		Chemical weathering	SO-C
	Erosion		
		Aeolian erosion	SO-C
		Fluvial erosion	SO-C
		Mass wasting	SO-C
	Sedimentation		
		Aeolian deposition	SO-C
		Fluvial deposition	SO-C
		Lacustrine deposition	SO-C
		Mass wasting	SO-C
	Soil development		
		Soil development	SO-C
SURFACE HYDROLOGICAL			
	Fluvial		
		Stream and river flow	SO-C
	Lacustrine		
		Surface water bodies	SO-C
	Groundwater recharge and discharge		
		Groundwater discharge	UP
		Groundwater recharge	UP
		Infiltration	UP
	Changes in surface hydrology		
		Changes in groundwater recharge and discharge	UP
		Lake formation	SO-C
		River flooding	SO-C
CLIMATIC			
	Climate		
		Precipitation (e.g. rainfall)	UP
		Temperature	UP

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
	Climate change		
		Meteorological	
		Climate change	UP
		Glaciation	
		Glaciation	SO-P
		Permafrost	SO-P
MARINE			
	Seas		
		Seas and oceans	SO-C
		Estuaries	SO-C
	Marine sedimentology		
		Coastal erosion	SO-C
		Marine sediment transport and deposition	SO-C
	Sea level changes		
		Sea level changes	SO-C
ECOLOGICAL			
	Flora & fauna		
		Plants	SO-C
		Animals	SO-C
		Microbes	SO-C
	Changes in flora & fauna		
		Natural ecological development	SO-C
WASTE- AND REPOSITORY-INDUCED			
WASTE AND REPOSITORY CHARACTERISTICS			
	Repository characteristics		
		Disposal geometry	**UP**
	Waste characteristics		
		Waste inventory	**UP**
		Heterogeneity of waste forms	DP
	Container characteristics		
		Container form	SO-C
		Container material inventory	UP
	Seal characteristics		
		Seal geometry	UP
		Seal physical properties	UP
		Seal chemical composition	SO-C
	Backfill characteristics		
		Backfill physical properties	SO-C
		Backfill chemical composition	UP
	Postclosure monitoring		
		Postclosure monitoring	SO-C
RADIOLOGICAL			
	Radioactive decay		
		Radionuclide decay and ingrowth	UP
	Heat from radioactive decay		
		Heat from radioactive decay	SO-C
	Nuclear criticality		
		Nuclear Criticality: heat	SO-P

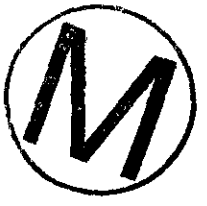


Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
	Radiological effects on material properties		
		Radiological effects on waste	SO-C
		Radiological effects on containers	SO-C
		Radiological effects on seals	SO-C
GEOLOGICAL / MECHANICAL			
	Excavation-induced fracturing		
		Disturbed rock zone	UP
		Excavation-induced changes in stress	UP
	Rock creep		
		Salt creep	UP
		Changes in the stress field	UP
	Roof falls		
		Roof falls	UP
	Subsidence		
		Subsidence	SO-C
		Large scale rock fracturing	SO-P
	Effects of fluid pressure change		
		Disruption due to gas effects	UP
		Pressurization	UP
	Effects of explosions		
		Gas explosions	UP
		Nuclear explosions	SO-P
	Thermal effects		
		Thermal effects on material properties	SO-C
		Thermally-induced stress changes	SO-C
		Differing thermal expansion of repository components	SO-C
	Mechanical effects on material properties		
		Consolidation of waste	UP
		Movement of containers	SO-C
		Container integrity	SO-C
		Mechanical effects of backfill	SO-C
		Consolidation of seals	UP
		Mechanical degradation of seals	UP
		Investigation boreholes	SO-C
		Underground boreholes	UP
SUBSURFACE HYDROLOGICAL / FLUID DYNAMICAL			
	Repository-induced flow		
		Brine inflow	UP
		Wicking	UP
	Effects of gas generation		
		Fluid flow due to gas production	UP
	Thermal effects		
		Convection	SO-C
GEOCHEMICAL / CHEMICAL			
	Gas generation		
	Microbial gas generation		
		Degradation of organic material	UP
		Effects of temperature on microbial gas generation	UP
		Effects of pressure on microbial gas generation	SO-C
		Effects of radiation on microbial gas generation	SO-C

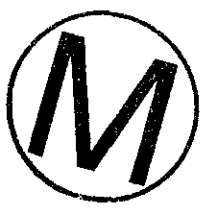


Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
		Effects of biofilms on microbial gas generation	UP
	Corrosion		
		Gases from metal corrosion	UP
		Galvanic coupling	SO-P
		Chemical effects of corrosion	UP
	Radiolytic gas generation		
		Radiolysis of brine	SO-C
		Radiolysis of cellulose	SO-C
		Helium gas production	SO-C
		Radioactive gas	SO-C
	Chemical speciation		
		Speciation	UP
		Kinetics of speciation	SO-C
	Precipitation / dissolution		
		Dissolution of waste	UP
		Precipitation	SO-C
		Kinetics of precipitation / dissolution	SO-C
	Sorption reactions		
		Actinide sorption	UP
		Kinetics of sorption	UP
		Changes in sorptive surfaces	UP
	Redox chemistry		
		Effect of metal corrosion	UP
		Redox fronts	SO-P
		Redox kinetics	UP
		Localized reducing zones	SO-C
	Organic complexation		
		Organic complexation	SO-C
		Organic ligands	SO-C
		Humic and fulvic acids	UP
		Kinetics of organic complexation	SO-C
	Exothermic reactions		
		Exothermic reactions	SO-C
		Concrete hydration	SO-C
	Chemical effects on material properties		
		Chemical degradation of seals	UP
		Chemical degradation of backfill	SO-C
		Microbial growth on concrete	UP
CONTAMINANT TRANSPORT MODE			
	Solute transport		
		Solute transport	UP

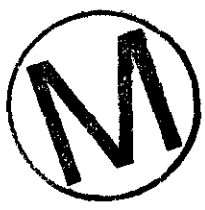


Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
	Colloid transport		
		Colloid transport	UP
		Colloid formation and stability	UP
		Colloid filtration	UP
		Colloid sorption	UP
	Particulate transport		
		Suspensions of particles	DP
		Rinse	SO-C
		Cuttings	DP
		Cavings	DP
		Spallings	DP
	Microbial transport		
		Microbial transport	UP
		Biofilms	SO-C
	Gas transport		
		Transport of radioactive gases	SO-C
CONTAMINANT TRANSPORT PROCESS			
	Advection		
		Advection	UP
	Diffusion		
		Diffusion	UP
		Matrix diffusion	UP
	Thermochemical transport phenomena		
		Soret effect	SO-C
	Electrochemical transport phenomena		
		Electrochemical effects	SO-C
		Galvanic coupling	SO-P
		Electrophoresis	SO-C
	Physicochemical transport phenomena		
		Chemical gradients	SO-C
		Osmosis	SO-C
		Alpha recoil	SO-C
		Enhanced diffusion	SO-C
ECOLOGICAL			
	Plant, animal and soil uptake		
		Plant uptake	SO-R
		Animal uptake	SO-R
		Accumulation in soils	SO-C
	Human uptake		
		Ingestion	SO-R
		Inhalation	SO-R
		Irradiation	SO-R
		Dermal sorption	SO-R
		Injection	SO-R

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification: Historical, ongoing, and near future	Screening Classification: Future
HUMAN ACTIONS				
GEOLOGICAL				
Drilling				
		Oil and gas exploration	SO-C	DP
		Potash exploration	SO-C	DP
		Water resources exploration	SO-C	SO-C
		Oil and gas exploitation	SO-C	DP
		Groundwater exploitation	SO-C	SO-C
		Archeological investigations	SO-R	SO-R
		Geothermal	SO-R	SO-R
		Other resources	SO-C	DP
		Enhanced oil and gas recovery	SO-C	DP
		Liquid waste disposal	SO-R	SO-R
		Hydrocarbon storage	SO-R	SO-R
		Deliberate drilling intrusion	SO-R	SO-R
Excavation activities				
		Potash mining	UP	DP
		Other resources	SO-C	SO-R
		Tunneling	SO-R	SO-R
		Construction of underground facilities	SO-R	SO-R
		Archeological excavations	SO-C	SO-R
		Deliberate mining intrusion	SO-R	SO-R
Subsurface explosions				
	Resource recovery			
		Explosions for resource recovery	SO-C	SO-R
	Underground nuclear device testing			
		Underground nuclear device testing	SO-C	SO-R
SUBSURFACE HYDROLOGICAL AND GEOCHEMICAL				
Borehole fluid flow				
	Drilling-induced flow			
		Drilling fluid flow	SO-C	DP
		Drilling fluid loss	SO-C	DP
		Blowouts	SO-C	DP
		Drilling-induced geochemical changes	UP	DP
	Fluid extraction			
		Oil and gas extraction	SO-C	SO-R
		Groundwater extraction	SO-C	SO-R
	Fluid injection			
		Liquid waste disposal	SO-C	SO-R
		Enhanced oil and gas production	SO-C	SO-R
		Hydrocarbon storage	SO-C	SO-R
		Fluid injection-induced geochemical changes	UP	SO-R
	Flow through abandoned boreholes			
		Natural borehole fluid flow	SO-C	DP
		Waste-induced borehole flow	SO-R	DP
		Flow through undetected boreholes	SO-P	NA
		Borehole-induced solution and subsidence	SO-C	SO-C
		Borehole-induced mineralization	SO-C	SO-C
		Borehole-induced geochemical changes	UP	DP

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification: Historical, ongoing, and near future	Screening Classification: Future
	Excavation-induced flow			
		Changes in groundwater flow due to mining	UP	DP
		Changes in geochemistry due to mining	SO-C	SO-R
	Explosion-induced flow			
		Changes in groundwater flow due to explosions	SO-C	SO-R
GEOMORPHOLOGICAL				
	Land use and disturbances			
		Land use changes	SO-R	SO-R
		Surface disruptions	SO-C	SO-R
SURFACE HYDROLOGICAL				
	Water control and use			
		Damming of streams or rivers	SO-C	**SO-R**
		Reservoirs	SO-C	**SO-R**
		Irrigation	SO-C	**SO-R**
		Lake usage	SO-R	**SO-R**
		Altered soil or surface water chemistry by human activities	SO-C	**SO-R**
CLIMATIC				
	Anthropogenic climate change			
		Greenhouse gas effects	SO-R	**SO-R**
		Acid rain	SO-R	**SO-R**
		Damage to the ozone layer	SO-R	**SO-R**
MARINE				
	Marine activities			
		Coastal water use	SO-R	**SO-R**
		Sea water use	SO-R	**SO-R**
		Estuarine water use	SO-R	**SO-R**
ECOLOGICAL				
	Agricultural activities			
		Ranching	SO-C	**SO-R**
		Arable farming	SO-C	**SO-R**
		Fish farming	SO-R	**SO-R**
	Social and technological developments			
		Demographic change and urban development	SO-R	**SO-R**
		Loss of records	NA	**DP**

Legend:

UP	FEPs accounted for in the assessment calculations for undisturbed performance for 40 CFR § 191.13 (as well as 40 CFR § 191.15 and Subpart C of 40 CFR Part 191).
DP	FEPs accounted for (in addition to all UP FEPs) in the assessment calculations for disturbed performance for 40 CFR § 191.13.
SO-R	FEPs eliminated from performance assessment calculations on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.
SO-C	FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of consequence.
SO-P	FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of low probability of occurrence.

5 References

Andersson, J. (Editor) 1989 *The Joint SKI/SKB Scenario Development Project.* SKB Technical Report 89:35, Stockholm.

Cranwell, R.M., R.V. Guzowski, J.E. Campbell, and N.R. Ortiz. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste: Scenario Selection Procedure.* SAND80-1429, NUREG/CR-1667. Albuquerque, NM: Sandia National Laboratories.

Goodwin, B.W., Stephens, M.E., Davison, C.C., Johnson, L.H. and Zach, R. 1994. *Scenario Analysis for the Postclosure Assessment of the Canadian concept for Nuclear Fuel Waste Disposal.* Atomic Energy of Canada Limited Report, AECL-10969, COG-94-247.

Guzowski, R.V. and Newman, G. 1993. *Preliminary Identification of Potentially Disruptive Scenarios at the Greater Confinement Disposal Facility, Area 5 of the Nevada Test Site.* SAND93-7100. Albuquerque, NM: Sandia National Laboratories.

Hodgkinson, D and Sumerling, T. 1989. A review of approaches to scenario analysis for repository safety assessment. In: *Proceedings of NEA/IAEA/CEC Symposium on "Safety Assessment of Radioactive Waste Repositories,"* Nuclear Energy Agency, Paris.

IAEA, 1985. *Performance Assessment for Underground Radioactive Waste Disposal Systems.* International Atomic Energy Authority Safety Series, No. 68.

Miller, W.M. and Chapman, N.A. 1993. *Identification of Relevant Processes (System Concept Group Report).* HMIP Assessment of Nirex Proposals, Technical Report IZ3185-TR1.

NAGRA, 1985. *Project Gewahr 1985 - Nuclear Waste Management in Switzerland - Feasibility studies and safety analyses.* Nagra Project Gewähr Report Series, NGB 85-09, Nagra, Baden.

Nuclear Energy Agency. 1992. *Systematic Approaches to Scenario Development.* Paris: OECD/NEA.

Prij, J. 1993. *PROSA. PRObabilistic Safety Assessment - Final Report.* OPLA-1A. Petten, The Netherlands: ECN, Netherlands Energy Research Foundation.

Sandia National Laboratories. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991.* SAND91-0893, Vols 1-4. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

Sandia National Laboratories. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992.* SAND92-0700, Vols 1-5. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

Stenhouse, M.J., Chapman, N.A., and Sumerling, T.J. 1993. *SITE-94 Scenario Development FEP Audit List Preparation: Methodology and Presentation.* SKI Technical Report 93:27. SKI Nuclear Power Inspectorate, Stockholm.

Thorne, M.C. 1992. *Dry Run 3 - A Trial Assessment of Underground Disposal of Radioactive Wastes Based on Probabilistic Risk Analysis - Volume 8: Uncertainty and Bias Audit.* DoE/HMIP/RR/92.040, London: UKDoE/HMIP.

U.S. DOE (Department of Energy). 1994. *Compliance Status Report for the Waste Isolation Pilot Plant.* DOE/WIPP 94-019, Revision 0, Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office.

U.S. DOE (Department of Energy). 1995a. *Draft Title 40 CFR Part 191 Compliance Certification Application for WIPP.* DOE/CAO-Predecisional Draft-2056, Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office.

U.S. DOE (Department of Energy). 1995b. *Draft Title 40 CFR Part 191 Compliance Certification Application for WIPP.* DOE/CAO-Predecisional Draft-2056, July Update, Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office.

APPENDIX A: DCCA FEP LIST BY CATEGORY

This Appendix presents the complete list of FEPs developed as part of the Draft Compliance Certification Application (DCCA). They are categorized according to the following sub-systems:

(1) Waste

(2) Canister

(3) Backfill

(4) Seal systems

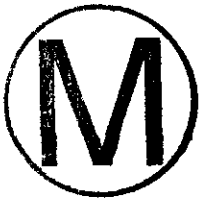
(5) Near-field

(6) Far-field

(7) Biosphere

(8) Geology/climate changes

(9) Human influences



WASTE

1.1 Waste: characteristics (initial)

- Inventory: radionuclides
- Inventory: hazardous constituents (e.g. VOCs, heavy metals)
- Long-term physical stability
- Heterogeneity of waste forms (chemical, physical)
- Stability of glass
- Teratogenic contaminants

1.2 Waste: radionuclide decay and ingrowth

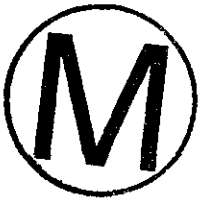
- Waste: radionuclide decay and ingrowth

1.3 Waste: radiological/radiation effects

- Radiolysis
- Recoil of alpha-decay
- Release of stored energy
- Nuclear criticality (preclosure)
- Nuclear criticality (postclosure)
- Radiation damage of the matrix including embrittlement

1.4 Waste: gas generation and effects

- Gas generation: He production
- Methane and carbon dioxide by microbial degradation of cellulose and other organic wastes
- Active methane, carbon dioxide, radon, tritiated hydrogen and other active gases
- Hydrogen by metal corrosion
- Gas effects: pressurization
- Gas effects: disruption
- Gas effects: explosions
- Gas effects: fire
- Chemical changes due to gas production
- Hydrogen: effects of microbial growth on concrete
- Methane/CO_2 production: aerobic degradation
- Methane/CO_2 production: effects of temperature
- Methane/CO_2 production: effects of lithostatic pressure
- Methane/CO_2 production: energy and nutrient control of metabolism
- Methane/CO_2 production: effects of radiation on microbial populations
- Microbiological effects due to cellulose degradation
- Gas generation from concrete
- Methane/CO_2 production: anaerobic production
- Methane/CO_2 production: Inhibition due to the pressure of toxic materials
- Methane/CO_2 production: Effects of biofilms
- Methane/CO_2 production: Carbonate/bicarbonate exchange with concrete



WASTE (Continued)

1.5 Waste: heat generation
- Radioactive decay: heat
- Nuclear criticality: heat
- Material property changes: heat

1.6 Waste: thermomechanical effects
- Thermal cracking
- Material property changes
- Differing thermal expansion of glass matrix and canister

1.7 Waste: thermochemical effects
- Thermally induced chemical changes (water chemistry)

1.8 Waste: electrochemical effects
- Electrochemical gradients
- Electrical effects of metal corrosion
- Galvanic coupling

1.9 Waste: degradation/corrosion/dissolution
- Dissolution
- Precipitation
- Source terms
- Source terms (hazardous constituents)
- Degradation of plastics and cellulosics
- Release of sorbed VOCs
- Metal corrosion: wastes
- Leaching: wastes
- Rinse
- Internal corrosion due to waste
- Fracturing
- External stress

1.10 Waste: geochemical reactions/regime
- Chemical gradients, osmosis
- Chemical kinetics
- Complex formation: wastes
- Chemical changes due to metal corrosion
- Chemical changes due to gas production
- Chemical effects: geochemical change
- Recrystallization
- Redox potential
- Dissolution chemistry
- Interactions with corrosion products and waste
- Solubility with fuel matrix

1.11 Waste: radionuclide and contaminant chemistry
- Speciation
- Complex formation: wastes
- Solubility within fuel matrix
- Recrystallization
- Solubility
- Precipitation
- Solubility, speciation, precipitation: hazardous constituents

WASTE (Continued)

1.12 Waste: Others

Colloid formation: wastes
Damaged or deviating waste contents
Role of eventual channelling within the canister
I, Cs-migration to fuel surface
Boundary conditions
Correlation
Sudden energy release
Waste incompatibility
Design modifications: waste (e.g. buffer additives)
Nuclear criticality: explosions
Capillary action

CANISTER

2.1 Canister: materials/construction

Inventory

2.2 Canister: corrosion/degradation processes

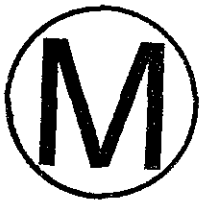
Container failure (early)
Container failure (long term)
Container healing
Corrosion (including partial corrosion)
Pitting
Radiation damage to container (embrittlement)
Uniform corrosion
Structural container metal corrosion: localized
Structural container metal corrosion: bulk
Structural container metal corrosion: crevice
Structural container metal corrosion: stress corrosion cracking
Chemical changes due to metal corrosion
Chemical reactions (copper corrosion)
Role of chlorides in copper corrosion
Corrosive agents, sulphides, oxygen, etc.
Backfill effects on container corrosion
Swelling of corrosion products

2.3 Canister: gas generation and effects

Hydrogen: corrosion of container steel
Gas transport in the waste container
Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire

2.4 Canister: microbiological effects/microbial activity

Canister: microbiological effects/microbial activity



CANISTER (Continued)

2.5 Canister: thermomechanical effects

- Differing thermal expansion of canister and backfill
- Thermal cracking
- Differing thermal expansion of materials (glass, canister)

2.6 Canister: electrochemical effects

- Electrochemical gradients
- Coupled effects (electrophoresis)
- Natural telluric electrochemical reactions
- Electrochemical cracking
- Galvanic coupling

2.7 Canister: stress/mechanical effects

- Canister movement
- Mechanical canister damage (failure)
- Creeping of copper
- Stress corrosion cracking
- Loss of ductility
- Cracking along welds
- External stress
- Hydrostatic pressure on canister
- Internal pressure
- Swelling of corrosion products
- Hydride cracking

2.8 Canister: geochemical reactions/regime

- Chemical kinetics
- Container corrosion products
- Precipitation
- Dissolution
- Speciation of corrosion products (include in water chemistry)
- Chemical effects: Interactions of waste canister and rock
- Chemical gradients (electrochemical effects and osmosis)

2.9 Canister: Radionuclide and contaminant transport through containers

- Release of radionuclides from the failed canister
- Release of hazardous constituents from the failed canister

2.10 Canister: others

- Channelling within the canister (preferential pathways)
- Radiation effects on canister
- Random canister defects - quality control
- Common cause canister defects - quality control
- Material defects, e.g. early canister failure
- Incomplete filling of canisters
- Boundary conditions
- Correlation
- Time dependence
- Design modifications: canister
- Nuclear criticality: explosions

BACKFILL

3.1 Backfill: characteristics

Backfill characteristics (e.g. hydraulic conductivity)
Long-term physical stability
Buffer additives

3.2 Backfill: resaturation/desaturation

Backfill: resaturation/desaturation

3.3 Backfill: mechanical effects

Preferential pathways in the backfill
Mechanical effects: local fractures/cracks (preferential pathways)
Mechanical failure of backfill (preferential pathways)
Swelling pressure
Movement of canister in backfill
Uneven swelling of bentonite
Swelling of corrosion products
Cracking: concrete
Sealing of cracks: concrete
External stress

3.4 Backfill: thermal effects

Convection (contaminant transport)
Hydrothermal alteration
Variations in groundwater temperature
Differing thermal expansion (canister-backfill, buffer-host rock)
Thermal effects on the backfill material
Soret effect
Natural thermal effects
Thermal effects (e.g. concrete hydration)
Thermochemical effects

3.5 Backfill: electrochemical effects

Natural telluric electrochemical reactions

3.6 Backfill: gas effects and transport

Groundwater flow due to gas production
Gas transport in the near field as gas phase and in solution
Chemical effects: gas generation
Transport of active gases
Methane/CO_2 production
Effects of hydrogen from metal corrosion
Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire
Methane/CO_2 production: effects of hydrogen from metal corrosion
Gas generation from concrete

BACKFILL (Continued)

3.7 Backfill: microbiological effects/microbial activity

Backfill: microbiological effects/microbial activity
Hydrogen: effects of microbial growth on concrete

3.8 Backfill: degradation

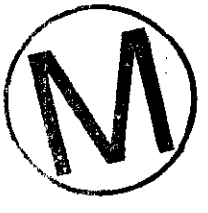
Degradation of the bentonite by chemical reactions
Coagulation of bentonite
Radiation effects on bentonite
Erosion of backfill
Alkali-aggregate reaction

3.9 Backfill: geochemical regime

Chemical gradients
Chemical kinetics
Precipitation
Dissolution
Chemical changes due to waste degradation
Chemical changes due to gas production
Chemical changes due to complex formation
Chemical changes due to colloid production
Chemical changes due to sorption
Chemical changes due to speciation
Isotopic dilution
Chemical changes due to corrosion
Saturation of sorption sites
Effects of bentonite on groundwater chemistry
Reactions with cement pore water (include in chemical degradation)
Redox front
Thermochemical changes
Saline groundwater intrusion
Effects at saline-freshwater interface
Natural changes in groundwater flow direction
Biogeochemical changes
Exchange capacity exceeded
Cement sulphate reaction

3.10 Backfill: Radionuclide and contaminant transport processes

Groundwater and gas flow
Advection/dispersion: radionuclides
Advection/dispersion: hazardous constituents
Diffusion: radionuclides
Diffusion: hazardous constituents
Unsaturated transport
Transport of chemically active substances into the near-field
Transport of radionuclides bound to microbes



BACKFILL (Continued)

3.11 Backfill: radionuclide and contaminant chemistry

Precipitation, reconcentration
Recrystallization
Dissolution
Sorption (linear, nonlinear, irreversible)
Speciation
Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)
Dissolution, speciation, sorption, precipitation; hazardous constituents
Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)
Changes in sorptive surfaces
Radiolysis

3.12 Backfill: others

Faulty backfill emplacement
Colloid transport (inorganic and organic)
Extreme channel flow of oxidants and nuclides (preferential pathways)
Inadequate backfill or compaction, voidage
Anion exchange
Groundwater flow: initial conditions
Backfill material deficiencies
Boundary conditions
Correlation
Time dependence
Nuclear criticality: explosions
Nuclear criticality: heat
Design modifications: backfill
Capillary action

SEALS

4.1 Seals: characteristics

Seal characteristics (e.g. hydraulic conductivity)
Long-term physical stability
Concrete
Buffer additives

4.2 Seals: resaturation/desaturation

Seals: resaturation/desaturation

4.3 Seals: mechanical effects

Preferential pathways in the seals
Mechanical effects: local fractures/cracks (preferential pathways)
Mechanical failure of seals (preferential pathways)
Swelling pressure

SEALS (Continued)

External stress
Movement of canister
Uneven swelling of bentonite
Swelling of corrosion products
Cracking: concrete
Sealing of cracks: concrete

4.4 Seals: thermal effects

Convection (contaminant transport)
Hydrothermal alteration
Variations in groundwater temperature
Differing thermal expansion (canister-seal, buffer-host rock)
Thermal effects on the seal material
Soret effect
Natural thermal effects
Thermal effects (e.g. concrete hydration)
Thermochemical effects

4.5 Seals: electrochemical effects

Natural telluric electrochemical reactions

4.6 Seals: gas effects and transport

Groundwater flow due to gas production
Gas transport in the near field as gas phase and in solution
Chemical effects: gas generation
Transport of active gases
Methane/CO_2 production
Effects of hydrogen from metal corrosion
Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire
Methane/CO_2 production: effects of hydrogen from metal corrosion
Gas generation from concrete

4.7 Seals: microbiological effects/microbial activity

Seal: microbiological effects/microbial activity
Hydrogen: effects of microbial growth on concrete

4.8 Seals: degradation

Degradation of the bentonite by chemical reactions
Coagulation of bentonite
Radiation effects on bentonite
Erosion of seals
Alkali-aggregate reaction

4.9 Seals: geochemical regime

Chemical gradients
Chemical kinetics
Precipitation

SEALS (Continued)

Dissolution
Chemical changes due to waste degradation
Chemical changes due to gas production
Chemical changes due to complex formation
Chemical changes due to colloid production
Chemical changes due to sorption
Chemical changes due to speciation
Isotopic dilution
Chemical changes due to corrosion
Saturation of sorption sites
Effects of bentonite on groundwater chemistry
Reactions with cement pore water (include in chemical degradation)
Redox front
Thermochemical changes
Saline groundwater intrusion
Effects at saline-freshwater interface
Natural changes in groundwater flow direction
Biogeochemical changes
Exchange capacity exceeded
Cement sulphate reaction

4.10 Seals: Radionuclide and contaminant transport processes

Groundwater and gas flow
Advection/dispersion: radionuclides
Advection/dispersion: hazardous constituents
Diffusion: radionuclides
Diffusion: hazardous constituents
Unsaturated transport
Transport of chemically active substances into the near-field
Transport of radionuclides bound to microbes

4.11 Seals: radionuclide and contaminant chemistry

Precipitation, reconcentration
Sorption (linear, nonlinear, irreversible)
Speciation
Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)
Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)
Changes in sorptive surfaces
Radiolysis
Dissolution
Recrystallization
Dissolution, speciation, sorption, precipitation; hazardous constituents

SEALS (Continued)

4.12 Seals: others

- Faulty seal emplacement
- Colloid transport (inorganic and organic)
- Extreme channel flow of oxidants and nuclides (preferential pathways)
- Inadequate seal or compaction, voidage
- Anion exchange
- Groundwater flow: initial conditions
- Seal material deficiencies
- Boundary conditions
- Investigation borehole seal failure/degradation
- Shaft seal failure/degradation
- Design modifications: seals
- Correlation
- Time dependence
- Nuclear criticality: explosions
- Nuclear criticality: heat

NEAR-FIELD

5.1 Near-field rock: elements/materials

- Disposal geometry
- Rock properties (porosity, permeability, hydraulic head, conductivity)
- Colloids

5.2 Near-field rock: degradation

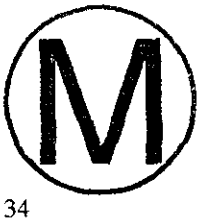
- Rock property changes (hydraulic conductivity, fractures, pore blocking, channel formation/closure)
- Creeping of rock mass
- Caving/roof collapse
- Physico-chemical degradation of concrete

5.3 Near-field rock: hydraulic effects/groundwater flow

- Unsaturated transport
- Groundwater flow due to gas production
- Groundwater flow (saturated conditions, including fracture flow)
- Groundwater flow, effects of solution channels (preferential pathways)
- Repository thermally-induced groundwater transport
- Naturally thermally-induced groundwater transport

Thermo-hydro-mechanical effects

- Resaturation
- Disturbed zone (hydromechanical) effects
- Natural changes in groundwater chemistry and flow direction



NEAR-FIELD (Continued)

Repository-induced changes in groundwater flow direction

5.4 Near-field rock: mechanical effects

Formation of cracks
Changes in in-situ stress field
Changes in moisture content due to stress relief
Differential elastic response
Non-elastic response
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

5.5 Near-field rock: thermal effects

Convection
Hydrothermal alteration
Variations in groundwater temperature
Thermal effects (e.g. concrete hydration)
Thermal effects and transport (diffusion) properties
Thermal effects on hydrochemistry
Thermal differential elastic response
Thermal non-elastic response

5.6 Near-field rock: gas effects and transport

Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire
Gas transport in the near field as gas phase and in solution
Methane/CO_2 production: effects of microbial growth on properties of concrete
Accumulation of gases under permafrost
Methane intrusion
Transport of active gases
Methane CO_2 production: effects of lithostatic pressure
Methane CO_2 production: effects of hydrogen from metal corrosion
Methane CO_2 production: effects of radiation on microbial populations
Methane and CO_2 production: energy and nutrient control of metabolism

5.7 Near-field rock: microbiological/biological activity

Natural microbial activity
Transport of microbes into the near-field
Rock property changes: microbial pore blocking
Biogeochemical changes

NEAR-FIELD (Continued)

5.8 Near-field rock: geochemical regime

- Chemical gradients
- Chemical kinetics
- Pore blockage: concrete
- Cement-sulphate reaction: concrete
- Changes in pore water composition, pH, Eh: concrete
- Chemical changes due to colloid production (chemical changes)
- Chemical changes due to sorption (chemical changes)
- Chemical changes due to speciation (chemical changes)
- Fracture mineralization
- Fluid interactions: dissolution
- Chemical effects: interactions of waste canister and rock
- Physico-chemical phenomena/effects (e.g. colloid formation)
- Reconcentration
- Thermochemical changes
- Chemical effects of rock reinforcement
- Saline (or fresh) groundwater intrusion
- Effects at saline-freshwater interface
- Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)
- Physico-chemical degradation of concrete
- Changes in groundwater flow direction

5.9 Near-field rock: radionuclide and contaminant chemistry

- Precipitation, reconcentration
- Dissolution
- Recrystallization
- Sorption (linear, nonlinear, irreversible)
- Speciation
- Dissolution, speciation, sorption, precipitation; hazardous constituents
- Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)
- Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)
- Changes in sorptive surfaces
- Dilution (mass, isotopic, species)

5.10 Near-field rock: Radionuclide and contaminant transport processes

- Groundwater and gas flow
- Advection/dispersion: radionuclides
- Advection/dispersion: hazardous constituents
- Diffusion: radionuclides
- Diffusion: hazardous constituents
- Soret effect
- Transport of radionuclides bound to microbes
- Colloid transport

NEAR-FIELD (Continued)

5.11 Near-field rock: others

Incomplete repository or borehole closure
Unmodeled design features
Inadequate design: shaft seal and exploration borehole seal failure
Open boreholes
Extreme channel flow of oxidants and nuclides (preferential pathways)
Poor quality construction
Abandonment of unsealed repository
Effects of phased operations
Repository flooding during operations
Dehydration of salt minerals
Release of stored energy
Nuclear criticality: heat
Methylation
Cavitation
Improper operation
Monitoring and remedial activities
Preclosure events
Retrievability
Blasting and vibration
Design modification: geometry
Design modification: DRZ (e.g. grouting)
Accidents during operation
Mutation
Boundary conditions
Correlation
Time-dependence
Sabotage
Nuclear criticality: explosions

FAR-FIELD

6.1 Rock properties

Rock properties (porosity, permeability, discharge zones, fractures)

6.2 Hydrogeological effects

Natural rock property changes (porosity, permeability, fractures, pore blocking)
Dewatering
Geothermal gradient effects
Salinity effects on flow
Saturated groundwater flow
Variations in groundwater temperature
Gas-induced groundwater transport

FAR-FIELD (Continued)

Groundwater recharge
Thermal effects: fluid pressure, density, viscosity changes
Thermal effects: fluid migration
Saline groundwater intrusion
Fresh groundwater intrusion
Groundwater conditions (saturated/unsaturated)
Changes in geometry of the flow system
Changes in driving forces of the flow system
Changes in groundwater flow direction
Borehole - well

6.3 Physical/mechanical effects

Repository-induced seismicity
Externally-induced seismicity
Fault activation
Differential elastic response
Subsidence
Non-elastic response

6.4 Thermal effects

Geothermal gradient effects
Thermal differential elastic response
Thermal non-elastic response

6.5 Gas effects and transport

Gas transport into and through the far-field (gas phase and in solution)
Multiphase flow and gas-driven flow
Effects of natural gases
Transport of active gases

6.6 Microbiological/biological activity

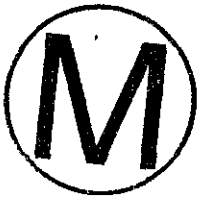
Microbial activity
Transport of radionuclides bound to microbes
Biogeochemical changes

6.7 Geochemical regime

Groundwater composition changes (pH, Eh, chemical composition)
Fracture mineralization
Weathering, mineralization
Dissolution of fracture fillings, precipitation
Far field hydrochemistry - acids, oxidants, nitrates
Effects at saline-freshwater interface
Chemical gradients (electrochemical effects and osmosis)
Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)
Salinity: implications of evaporite deposits/minerals

6.8 Radionuclide and contaminant chemistry

Complexation by organics (including humic and fulvic acids)



FAR-FIELD (Continued)

Precipitation, dissolution, recrystallization, reconcentration
Sorption (linear, nonlinear, irreversible)
Speciation
Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)
Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)
Changes in sorptive surfaces
Dilution (mass, isotopic, species)

6.9 Radionuclide and contaminant transport processes

Groundwater flow, advection/dispersion (saturated conditions)
Diffusion (bulk, matrix, surface)
Unsaturated transport
Groundwater flow: fracture
Groundwater flow: effects of solution channels (preferential pathways)
Soret effect
Transport of radionuclides bound to microbes
Gas mediated transport
Colloids: formation & effects (including inorganic and organic colloid transport)

6.10 Others

Boreholes unsealed
Incomplete vault closure
Inadequate design: exploration borehole seal failure
Undetected features (e.g. faults, fracture networks, shear zones, discontinuities, gas)
Radiolysis, radiation damage
Cavitation
Correlation
Nuclear criticality
Explosion

BIOSPHERE

7.1 Human considerations

Space heating
Charcoal production
Land use changes
Demographic change, urban development
Crop fertilization
Crop storage
Peat and leaf litter harvesting
Hydroponics

BIOSPHERE (Continued)

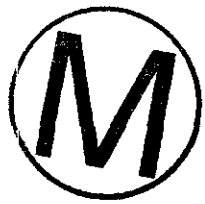
Water leak into underground living space

7.2 Ecological factors

Animal habits (grooming and fishing, soil ingestion, diets, scavengers/predators)
Houseplants
Tree sap
Terrestrial ecological development: natural and agricultural systems
Terrestrial ecological development: Effects of succession
Terrestrial ecological development: Estuarine
Plants: Root uptake, including deep rooting species
Plants: Deposition on surfaces
Plants: Vapor uptake
Plants: Internal translocation and retention
Plants: Washoff and leaching by rainfall
Plants: Leaf-fall and senescence
Plants: Cycling processes
Animals: Uptake by ingestion
Animals: Uptake by inhalation
Animals: Internal translocation and retention
Animals: Cycling processes
Animals: Effects of relocation and migration
Precipitation, temperature and soil water balance
Ecological change (e.g. forest fire cycles)
Ecological response to climate, including glacial/interglacial cycling, (e.g. desert formation)
Biological evolution
Intrusion (animal)

7.3 Soil/sediment effects

Lake infilling
Erosion - wind
Alkali flats
Capillary rise in soil
Soil properties (type, depth, porewater pH, moisture, sorption)
Soil leaching
Ionic 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
Solid discharge via erosional processes
Saltation



BIOSPHERE (Continued)

7.4 Surface/near-surface water processes

Groundwater discharge (to surface water)
Groundwater discharge (springs)
Groundwater discharge (wells)
Flushing of water bodies
Surface water bodies: properties (e.g., pH)
Near-surface runoff processes: overland flow, interflow, return flow, macropore flow
Near-surface runoff processes: variable source area response
Surface flow characteristics: stream/river flow
Surface flow characteristics: sediment transport
Surface flow characteristics: meander migration or other fluvial response
Surface flow characteristics: lake formation/sedimentation
Surface flow characteristics: effects of sea level change
Estuarine surface flow characteristics: tidal cycling, sediment transport, successional development, effects of sea level change
Surface water bodies: water flow
Surface water bodies: suspended sediments
Surface water bodies: bottom sediments
Surface water bodies: effects on vegetation
Surface water bodies: effects of fluvial system development
Surface water mixing
Sediment/water/gas interaction with the atmosphere
Terrestrial water use (including wells and dams)
River flow and lake level changes
Dams
Rivercourse meander
Wetlands
Flood (short-term)
Acid rain
Artificial lake mixing
Drought

7.5 Coastal water/ocean processes

Coastal waters: tidal mixing, residual current mixing, effects of sea level change
Ocean waters: water exchange, effects of sea level change
Groundwater discharge to marine waters including coastal
Estuaries: water flow, suspended sediments, bottom sediments, effects of salinity variation, effects on vegetation, estuarine development and sea level change

BIOSPHERE (Continued)

Coastal waters: water transport, bottom and suspended sediment transport, effects of sea level change, estuarine development and coastal erosion
Estuarine water use
Coastal water use
Sea water use

7.6 Gas effects and transport

Gas leakage into underground living space
Radon emission
Gas transport: gas phase and in solution
Gas discharge

7.7 Microbiological/biological activity

Microbial activity
Bioaccumulation and translocation
Biotoxicity
Soil and sediment transport including bioturbation
Burrowing animals
Transport of radionuclides bound to microbes
Biogeochemical changes

7.8 Geochemical regime (general)

Soil and surface water chemistry (pH, Eh)
Fluid interactions: dissolution, precipitation
Weathering, mineralization
Physico-chemical phenomena/effects (e.g. colloid formation)
Altered soil or surface water chemistry (pH, Eh)
Thermal effects on hydrochemistry
Chemical gradients (electrochemical effects and osmosis)
Colloids, complexing agents

7.9 Radionuclide and contaminant chemistry

Complexation by organics (including humic and fulvic acids)
Precipitation, dissolution, recrystallization, reconcentration
Sorption (linear, nonlinear, irreversible)
Speciation
Chemical changes due to sorption, complex formation, speciation, gas, solubility
Solubility effects (pH and Eh)
Sorption effects (pH and Eh)
Changes in sorptive surfaces
Dilution (mass, isotopic, species)

7.10 Radionuclide and contaminant transport processes

Water flow: advection and dispersion
Diffusion (bulk, matrix, surface)
Gas-mediated transport
Transport of active gases: gas phase and in solution

BIOSPHERE (Continued)

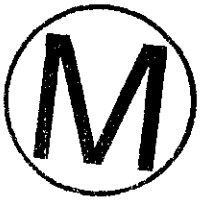
Transport of radionuclides bound to microbes

7.11 Radiological factors

Building materials
Carcasses
Carcinogenic contaminants
Convection, turbulence and diffusion (atmospheric)
Critical group - agricultural labor,
clothing and home furnishings
evolution
house location
individuality
leisure pursuits
pets
Dermal sorption - nuclides other than tritium
Household dust and fumes
Human diet
Food preparation
Human soil ingestion
Precipitation (meteoric)
Deposition (wet and dry)
Radiotoxic contaminants
Showers and humidifiers
Suspension in air
Wind
External exposure: land, sediments, water bodies
Ingestion and drinking water
Ingestion and agricultural crops
Ingestion and domestic animal products
Ingestion and wild plants
Ingestion and wild animals
Ingestion and soils and sediments
Inhalation and soils and sediments
Inhalation and gases and vapors (indoor/outdoor)
Inhalation and biotic material
Inhalation and salt particles
Sediment/water/gas interaction with the atmosphere
Mutagenic contaminants
Dermal sorption - tritium
Sensitization to radiation
Radioactive decay

7.12 Others

Colloids: formation and effects (including inorganic and organic colloid transport)
Greenhouse-induced ecological effects (including food production)
Smoking
Boreholes - unsealed



BIOSPHERE (Continued)

Loss of integrity of borehole seals: seal failure or degradation
Inadequate design: exploration borehole seal failure
Intrusion in accumulation zone in the biosphere (animals)
Chemical toxicity
Correlation
Seasons
Terrestrial surface
Uncertainties
Toxicity of mined rock
Ozone layer failure
Herbicides, pesticides, fungicides

GEOLOGY / CLIMATE CHANGES

8.1 Seismic Events/major land movement

Earthquakes
Regional uplift and subsidence (e.g. orogenic, isostatic)
Externally-induced seismicity
Natural seismicity

8.2 Rock deformation

Salt deformation/diapirism
Faulting/fracturing: change of properties - natural
Faulting/fracturing: change of properties - human-induced
Major incision
Movements at faults
Formation of new faults
Formation of interconnected fracture systems

8.3 Metamorphic and igneous processes

Metamorphic activity
Magmatic activity
Volcanism

8.4 Erosion/weathering (surface)

Aeolian and fluvial denudation
Mass wasting
Changes in topography
Weathering
Extreme erosion and denudation: glacial-induced (e.g. coastal/stream erosion)
Coastal erosion due to sea level change
Erosion: glacial
Stream erosion
Sedimentation
Land slide
Freshwater sediment transport and deposition

GEOLOGY / CLIMATE CHANGES (Continued)

Marine sediment transport and deposition
Solifluction

8.5 Groundwater flow and effects
Variation in groundwater recharge

8.6 Surface water flow and effects
Hydrological change
Flooding
Precipitation, temperature and soil water balance
Snow melt
River flow and lake level changes
Alkali flats
Rivercourse meander

8.7 Sea level effects
Sea level change
River incision/sedimentation due to sea level change

8.8 Magnetic effects
Changes in the Earth's magnetic field

8.9 Glaciation/glacial effects
Glaciation
Glacial/interglacial cycling effects (including sea level changes)
Permafrost
Accumulation of gases under permafrost
No ice age

8.10 Climate effects (natural)
Drought
Dust storms and desertification (massive)
Climate change
Insolation
Ozone layer (failure)
Acid rain

8.11 Others
Anthropogenic climate change drought (greenhouse effect)
Greenhouse-induced effects (e.g. sea level change, precipitation, temp.)
Hurricanes
Tsunamis
Seiches
Meteorite impact
Diagenesis
Greenhouse-induced storm surges
Global effects
Terrestrial surface
Formation of dissolution cavities

HUMAN INFLUENCES

9.1 Inadvertent intrusion into repository

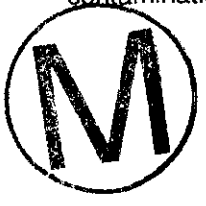
Archeological investigations
Exploratory boreholes (oil, gas)
Resource exploitation (e.g. hydrocarbon, geothermal)
Reuse of boreholes
Intrusion in accumulation zone in the biosphere
Injection wells
Intrusion (deliberate)
- recovery of wastes or associated materials (mining)
- malicious (sabotage, act of war (nuclear))
- recovery of repository materials

9.2 Surface activities

Earthmoving
Altered soil or surface water chemistry by human activities
Human-induced changes in surface hydrology
Heat storage in lakes
Hydrologic stresses: damming of streams or rivers
Quarrying, peat extraction
Quarrying, near surface extraction
Artificial lake mixing
Ashes and sewage sludge
Crop fertilization
Crop storage
Herbicides, pesticides, fungicides
Inject/ingest/inhaling locally produced drugs
Peat and leaf litter harvesting
Biogas production
Earth moving projects
Lake infilling
Blasting and vibration
Hydroponics
Technological advances in food production
Other future uses of crystalline rock
Near storage of other waste

9.3 Subsurface activities

Exploratory boreholes (oil, gas): nonintrusive
Drilling: enhanced oil/gas production: nonintrusive
Drilling: liquid waste disposal: nonintrusive
Drilling: hydrocarbon storage: nonintrusive
Drilling: archeology: nonintrusive
Exploratory boreholes (water, potash)
Dewatering
Wells
Wells (high demand)
Resource exploitation (intersection of zone of contamination)



HUMAN INFLUENCES (Continued)

Heat storage underground
Geothermal energy production
Tunnelling
Construction of underground storage/disposal facilities (e.g. gas storage)
Construction of underground dwellings/shelters
Injection of liquid wastes: nonintrusive
Potash mining
Solution mining
Underground weapons testing (nuclear device)
Mining other than potash
Geothermal energy exploration (and other unidentified resources)
Resource exploitation following intrusion
Injection wells: enhanced oil/gas production, hydrocarbon storage: nonintrusive

9.4 Water use

Industrial use of water
Outdoor spraying of water
Groundwater extraction
Irrigation
Reservoirs
Intentional artificial groundwater recharge or withdrawal

9.5 Agricultural and fisheries practices

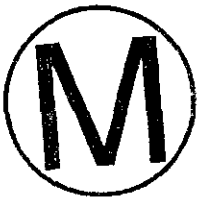
Fish farming
Ranching
Agricultural and fisheries practice changes

9.6 Radiological factors (smoking, transport agents)

Radiological factors (smoking, transport agents)

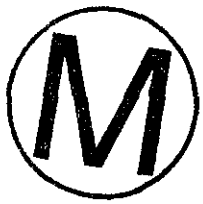
9.7 Others

Demographic change, urban development
Undetected repository intrusions (boreholes, mining)
Undetected boreholes (existing): nonintrusive
Stray materials left
Decontamination materials left
Loss of records
Radioactive waste disposal error
Inadvertent inclusion of undesirable materials
Poor quality construction
Design modifications
Accidents during operation
Backfill/seal material deficiencies
Postclosure monitoring
Unsuccessful attempt of site improvement
Poorly designed repository
Cure for cancer
Sabotage



HUMAN INFLUENCES (Continued)

Acid rain
Sudden energy release
Chemical sabotage
Explosions (resource recovery)
Borehole-induced solution and subsidence
Explosions (act of war)



APPENDIX B: MAPPING OF THE DCCA AND CCA FEP LISTS

This Appendix presents a mapping of the FEPs included in the Draft Compliance Certification Application (DCCA) FEP list to the FEPs on the WIPP-specific FEP list developed for the Compliance Certification Application (CCA).

The DCCA list is presented in Appendix A of this report, ordered by sub-system and by second-level category. For the purposes of this mapping, a number of FEPs have been excluded because they relate to designs different to that forming the basis of the CCA, because they relate to issues such as chemical toxicity that are not regulated by 40 CFR Part 191, or because they are modeling issues rather than FEPs. A list of these FEPs is presented in Appendix C of this report.

In general, the mapping shown in this Appendix links one or more FEPs from the DCCA with a FEP from the CCA list. Exceptions to this occur for two reasons:

- When there are no FEPs on the DCCA list corresponding to WIPP-specific issues. Examples include breccia pipes, cuttings, and blowouts. These are of potential concern to WIPP but are too detailed to have been included on the generic list from which the DCCA FEP list was drawn.

- When the FEP on the DCCA is of a general nature or includes a number of component FEPs. These general FEPs are mapped to a category or sub-category on the CCA list. Examples include:
  - Groundwater conditions (saturated/unsaturated);
  - Chemical changes due to sorption, complex formation, speciation, gas, solubility;
  - Human-induced changes in surface hydrology.

Natural FEPs

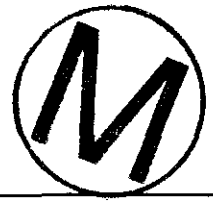
WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Geological	Stratigraphy		Stratigraphy	Rock properties (porosity, permeability, hydraulic head, conductivity)	Near-field
				Undetected features (e.g. faults, fracture networks, shear zones, discontinuities, gas)	Far-field
				Rock properties (porosity, permeability, discharge zones, fractures)	Far-field
			Brine reservoirs		
	Tectonics		Changes in regional stress		
			Regional tectonics	Changes in the Earth's magnetic field	Geology/climate changes
			Regional uplift and subsidence	Regional uplift and subsidence (e.g. orogenic, isostatic)	Geology/climate changes
	Structural FEPs	Deformation	Salt deformation	Salt deformation/diapirism	Geology/climate changes
			Diapirism		
		Fracture development	Formation of fractures	Formation of interconnected fracture systems	Geology/climate changes
			Changes in fracture properties	Faulting/fracturing: change of properties - natural	Geology/climate changes
		Fault movement	Formation of new faults	Formation of new faults	Geology/climate changes
			Fault movement	Fault activation	Far-field
				Movements at faults	Geology/climate changes
		Seismic activity	Seismic activity	Earthquakes	Geology/climate changes
				Externally-induced seismicity	Near-field
				Natural seismicity	Geology/climate changes
				Externally-induced seismicity	Far-field
				Externally-induced seismicity	Geology/climate changes
				Differential elastic response	Far-field
	Crustal processes	Igneous activity	Volcanic activity	Volcanism	Geology/climate changes
			Magmatic activity	Magmatic activity	Geology/climate changes

Natural FEPs

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
		Metamorphism	Metamorphic activity	Metamorphic activity	Geology/climate changes
	Geochemical FEPs	Dissolution		Diagenesis	Geology/climate changes
			Shallow dissolution	Dissolution of fracture fillings, precipitation	Far-field
			Lateral dissolution	Fluid interactions: dissolution	Near-field
				Dissolution	Near-field
			Deep dissolution		
			Solution chimneys	Formation of dissolution cavities	Geology/climate changes
			Breccia pipes		
			Collapse breccias		
		Mineralization	Fracture infills	Fracture mineralization	Far-field
				Weathering, mineralization	Far-field
Subsurface hydrological	Groundwater characteristics			Groundwater conditions (saturated/unsaturated)	Far-field
			Saturated groundwater flow	Saturated groundwater flow	Far-field
			Unsaturated groundwater flow	Dewatering	Far-field
				Sediment/water/gas interaction with the atmosphere	Biosphere
			Fracture flow	Groundwater flow: fracture	Far-field
			Density effects on groundwater flow	Salinity effects on flow	Far-field
			Effects of preferential pathways	Groundwater flow: effects of solution channels (preferential pathways)	Far-field
	Changes in groundwater flow			Natural changes in groundwater flow direction	Seals
				Natural changes in groundwater flow direction	Backfill
				Changes in groundwater flow direction	Near-field
				Changes in the geometry of the flow system	Far-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Changes in the driving forces of the flow system	Far-field
				Natural rock property changes (porosity, permeability, fractures, pore blocking)	Far-field
				Changes in groundwater flow direction	Far-field
			Thermal effects on groundwater flow	Naturally thermally-induced groundwater transport	Near-field
				Thermal effects: fluid migration	Far-field
				Geothermal gradient effects	Far-field
				Variations in groundwater temperature	Far-field
				Thermal effects: fluid pressure, density, viscosity changes	Far-field
			Saline intrusion	Saline groundwater intrusion	Far-field
			Freshwater intrusion	Fresh groundwater intrusion	Far-field
			Natural gas intrusion	Methane intrusion	Near-field
				Effects of natural gases	Far-field
			Hydrological response to earthquakes		
Subsurface geochemical	Groundwater geochemistry		Groundwater geochemistry	Salinity: implications of evaporite deposits/minerals	Far-field
	Changes in groundwater chemistry			Natural changes in groundwater chemistry and flow direction	Near-field
				Groundwater composition changes (pH, Eh, chemical composition)	Far-field
			Saline intrusion		
			Freshwater intrusion		
			Changes in groundwater Eh		
			Changes in groundwater pH		

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Effects of dissolution	Fluid interactions: dissolution, precipitation	Biosphere
Geomorphological	Physiography		Physiography	Terrestrial surface	Geology/climate changes
				Terrestrial surface	Biosphere
	Meteorite impact		Impact of a large meteorite	Meteorite impact	Geology/climate changes
	Denudation			Changes in topography	Geology/climate changes
		Weathering		Weathering	Geology/climate changes
			Mechanical weathering		
			Chemical weathering	Weathering, mineralization	Biosphere
		Erosion		Major incision	Geology/climate changes
			Aeolian erosion	Erosion - wind	Biosphere
				Aeolian and fluvial denudation	Geology/climate changes
			Fluvial erosion	Rivercourse meander	Biosphere
				Sediment resuspension in water bodies	Biosphere
				Stream erosion	Geology/climate changes
				Rivercourse meander	Geology/climate changes
			Mass wasting	Mass wasting	Geology/climate changes
		Sedimentation		Sedimentation	Geology/climate changes
			Aeolian deposition	Saltation	Biosphere
			Fluvial deposition	Freshwater sediment transport and deposition	Geology/climate changes
				Surface flow characteristics: sediment transport	Biosphere
				Sedimentation in water bodies	Biosphere
			Lacustrine deposition	Surface water bodies: bottom sediments	Biosphere
				Surface water bodies: suspended sediments	Biosphere
			Mass wasting	Land slide	Geology/climate changes
				Solifluction	Geology/climate changes



WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
	Soil development		Soil development	Soil properties (type, depth, porewater pH, moisture, sorption)	Biosphere
				Soil and surface water chemistry (pH, Eh)	Biosphere
				Pedogenesis	Biosphere
				Soil and sediment transport including bioturbation	Biosphere
				Altered soil or surface water chemistry (pH, Eh)	Biosphere
				Soil leaching	Biosphere
Surface hydrological	Fluvial		Stream and river flow	River flow and lake level changes	Geology/climate changes
				River flow and lake level changes	Biosphere
				Surface flow characteristics: meander migration or other fluvial response	Biosphere
				Surface flow characteristics: stream/river flow	Biosphere
	Lacustrine		Surface water bodies	Wetlands	Biosphere
				Surface water bodies: water flow	Biosphere
				Surface water bodies: effects on vegetation	Biosphere
				Surface water bodies: properties (e.g., pH)	Biosphere
				Flushing of water bodies	Biosphere
				Surface water mixing	Biosphere
				Surface flow characteristics: lake formation/sedimentation	Biosphere
				Surface water bodies: effects of fluvial system development	Biosphere
				Alkali flats	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Alkali flats	Geology/climate changes
	Groundwater recharge and discharge		Groundwater discharge	Groundwater discharge to soils: advective, diffusive, biotic, volatilization	Biosphere
				Groundwater discharge to marine waters including coastal	Biosphere
				Groundwater discharge (springs)	Biosphere
				Groundwater discharge (to surface water)	Biosphere
			Groundwater recharge	Groundwater recharge	Far-field
				Near-surface runoff processes: variable source area response	Biosphere
				Near-surface runoff processes: overland flow, interflow, return flow, macropore flow	Biosphere
				Capillary rise in soil	Biosphere
			Infiltration	Evaporation of soil moisture	Biosphere
	Changes in surface hydrology		Changes in groundwater recharge and discharge	Hydrological change	Geology/climate changes
				Variation in groundwater recharge	Geology/climate changes
			Lake formation	Lake infilling	Biosphere
			River flooding	Flooding	Geology/climate changes
				Flood (short-term)	Biosphere
Climatic				Insolation	Geology/climate changes
	Climate			Precipitation, temperature and soil water balance	Biosphere
				Precipitation, temperature and soil water balance	Geology/climate changes
				Convection, turbulence and diffusion (atmospheric)	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Wind	Biosphere
				Hurricanes	Geology/climate changes
				Seasons	Biosphere
			Precipitation	Precipitation (meteoric)	Biosphere
			Temperature		
	Climate change	Meteorological	Climate change	Global effects	Geology/climate changes
				Climate change	Geology/climate changes
				Drought	Geology/climate changes
				Drought	Biosphere
				Dust storms and desertification (massive)	Geology/climate changes
		Glaciation	Glaciation	No ice age	Geology/climate changes
				Erosion: glacial	Geology/climate changes
				Glaciation	Geology/climate changes
				Snow melt	Geology/climate changes
				Extreme erosion and denudation: glacial-induced (e.g. coastal/stream erosion)	Geology/climate changes
				Glacial/interglacial cycling effects (including sea level changes)	Geology/climate changes
			Permafrost	Accumulation of gases under permafrost	Geology/climate changes
				Permafrost	Geology/climate changes
				Accumulation of gases under permafrost	Near-field
Marine	Seas		Seas and oceans	Coastal waters: water transport, bottom and suspended sediment transport, effects of sea level change, estuarine development and coastal erosion	Biosphere
				Tsunamis	Geology/climate changes
				Seiches	Geology/climate changes

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Coastal waters: tidal mixing, residual current mixing, effects of sea level change	Biosphere
				Ocean waters: water exchange, effects of sea level change	Biosphere
			Estuaries	Estuaries: water flow, suspended sediments, bottom sediments, effects of salinity variation, effects on vegetation, estuarine development and sea level change	Biosphere
				Estuarine surface flow characteristics: tidal cycling, sediment transport, successional development, effects of sea level change	Biosphere
	Marine sedimentology		Coastal erosion	Coastal erosion due to sea level change	Geology/climate changes
			Marine sediment transport and deposition	Marine sediment transport and deposition	Geology/climate changes
	Sea level changes		Sea level changes	Sea level change	Geology/climate changes
				River incision/sedimentation due to sea level change	Geology/climate changes
				Surface flow characteristics: effects of sea level change	Biosphere
Ecological	Flora & fauna		Plants		
			Animals	Burrowing animals	Biosphere
			Microbes	Microbial activity	Biosphere
				Natural microbial activity	Near-field
	Changes in flora & fauna		Natural ecological development	Animals: Effects of relocation and migration	Biosphere

Natural FEPs

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Ecological change (e.g. forest fire cycles)	Biosphere
				Terrestrial ecological development: Estuarine	Biosphere
				Biogeochemical changes	Biosphere
				Terrestrial ecological development: natural and agricultural systems	Biosphere
				Biological evolution	Biosphere
				Terrestrial ecological development: Effects of succession	Biosphere
				Critical group - evolution	Biosphere
				Ecological response to climate, including glacial/interglacial cycling, (e.g. desert formation)	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Waste and repository characteristics	Repository characteristics		Disposal geometry	Disposal geometry	Near-field
				Retrievability	Near-field
	Waste characteristics		Waste inventory	Inventory: radionuclides	Waste
				Source terms	Waste
			Heterogeneity of waste forms	Channelling within the canister (preferential pathways)	Canister
				Role of eventual channelling within the canister	Waste
				Heterogeneity of waste forms (chemical, physical)	Waste
	Container characteristics		Container form		
			Container material inventory	Inventory	Canister
	Seal characteristics		Seal geometry		
			Seal physical properties	Seal characteristics (e.g. hydraulic conductivity)	Seals
				Swelling pressure	Seals
			Seal chemical composition	Concrete	Seals
	Backfill characteristics		Backfill physical properties	Backfill characteristics (e.g. hydraulic conductivity)	Backfill
				Swelling pressure	Backfill
			Backfill chemical composition	Buffer additives	Backfill
	Postclosure monitoring		Postclosure monitoring	Postclosure monitoring	Human influences
				Monitoring and remedial activities	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Radiological	Radioactive decay		Radionuclide decay and ingrowth	Waste: radionuclide decay and ingrowth	Waste
				Radioactive decay	Biosphere
			Heat from radioactive decay	Radioactive decay: heat	Waste
	Nuclear criticality		Nuclear criticality: heat	Nuclear criticality (preclosure)	Waste
				Nuclear criticality	Far-field
				Nuclear criticality: heat	Near-field
				Nuclear criticality: heat	Waste
				Nuclear criticality (postclosure)	Waste
				Nuclear criticality: heat	Backfill
				Nuclear criticality: heat	Seals
	Radiological effects on material properties		Radiological effects on waste		
			Radiological effects on containers	Radiation effects on canister	Canister
			Radiological effects on seals	Radiation effects on bentonite	Seals
Geological / mechanical	Excavation-induced fracturing		Disturbed rock zone	Rock property changes (hydraulic conductivity, fractures, pore blocking, channel formation/closure)	Near-field
				Disturbed zone (hydromechanical) effects	Near-field
				Formation of cracks	Near-field
				Differential elastic response	Near-field
				Blasting and vibration	Near-field
			Excavation-induced changes in stress	Excavation-induced stress/fracturing in host rock	Near-field
				Repository-induced seismicity	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Repository-induced seismicity	Far-field
	Rock creep		Salt creep	Non-elastic response	Near-field
				Non-elastic response	Far-field
				External stress	Canister
				External stress	Backfill
				Creeping of rock mass	Near-field
			Changes in the stress field	Changes in in-situ stress field	Near-field
	Roof falls		Roof falls	Caving/roof collapse	Near-field
	Subsidence		Subsidence	Subsidence	Far-field
			Large-scale rock fracturing		
	Effects of fluid pressure changes		Disruption due to gas effects	Gas effects: disruption	Seals
				Gas effects: disruption	Backfill
				Gas effects: disruption	Waste
				Gas effects: disruption	Canister
				Gas effects: disruption	Near-field
			Pressurization	Gas effects: pressurization	Seals
				Gas effects: pressurization	Backfill
				Gas effects: pressurization	Waste
				Gas effects: pressurization	Canister
				Gas effects: pressurization	Near-field
	Effects of explosions		Gas explosions	Gas effects: fire	Canister
				Gas effects: fire	Seals
				Gas effects: fire	Near-field
				Gas effects: fire	Backfill
				Gas effects: explosions	Backfill
				Explosion	Far-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Gas effects: explosions	Seals
				Gas effects: explosions	Waste
				Gas effects: explosions	Near-field
				Gas effects: fire	Waste
				Gas effects: explosions	Canister
			Nuclear explosions	Nuclear criticality: explosions	Seals
				Nuclear criticality: explosions	Backfill
				Nuclear criticality: explosions	Near-field
				Nuclear criticality: explosions	Waste
				Nuclear criticality: explosions	Canister
	Thermal effects		Thermal effects on material properties	Material property changes: heat	Waste
				Material property changes	Waste
				Hydrothermal alteration	Near-field
				Thermal effects on the seal material	Seals
				Hydrothermal alteration	Seals
				Hydrothermal alteration	Backfill
				Dehydration of salt minerals	Near-field
				Natural thermal effects	Backfill
				Natural thermal effects	Seals
				Thermal non-elastic response	Near-field
				Thermal non-elastic response	Far-field
			Thermally-induced stress changes	Thermal cracking	Waste
				Thermally-induced stress/fracturing in host rock	Near-field
				Thermal cracking	Canister
			Differing thermal expansion of repository components	Differing thermal expansion (canister-seal, buffer-host rock)	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Differing thermal expansion of host rock zones	Near-field
				Differing thermal expansion (canister-backfill, buffer-host rock)	Backfill
				Differing thermal expansion of canister and backfill	Canister
				Thermal effects on the backfill material	Backfill
				Thermal differential elastic response	Near-field
				Thermal differential elastic response	Far-field
	Mechanical effects on material properties		Consolidation of waste	External stress	Waste
			Movement of containers	Canister movement	Canister
				Movement of canister in backfill	Backfill
				Movement of canister	Seals
			Container integrity	Release of radionuclides from the failed canister	Canister
				Structural container metal corrosion: stress corrosion cracking	Canister
				Hydrostatic pressure on canister	Canister
				Uniform corrosion	Canister
				Structural container metal corrosion: localized	Canister
				Structural container metal corrosion: crevice	Canister

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Structural container metal corrosion: bulk	Canister
				Corrosion (including partial corrosion)	Canister
				Container failure (long term)	Canister
				Container failure (early)	Canister
				Mechanical canister damage (failure)	Canister
				Pitting	Canister
				Swelling of corrosion products	Canister
				Container corrosion products	Canister
			Mechanical effects of backfill	Erosion of backfill	Backfill
				Extreme channel flow of oxidants and nuclides (preferential pathways)	Backfill
				Long-term physical stability	Backfill
				Mechanical failure of backfill (preferential pathways)	Backfill
				Preferential pathways in the backfill	Backfill
				Swelling of corrosion products	Backfill
				Mechanical effects: local fractures/cracks (preferential pathways)	Backfill
			Consolidation of seals	Long-term physical stability	Seals
				External stress	Seals
			Mechanical degradation of seals	Mechanical effects: local fractures/cracks (preferential pathways)	Seals
				Mechanical failure of seals (preferential pathways)	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Erosion of seals	Seals
				Shaft seal failure/degradation	Seals
				Preferential pathways in the seals	Seals
				Swelling of corrosion products	Seals
				Sealing of cracks: concrete	Seals
				Cracking: concrete	Seals
				Physico-chemical degradation of concrete	Near-field
				Uneven swelling of bentonite	Near-field
				Uneven swelling of bentonite	Seals
				Coagulation of bentonite	Seals
			Investigation boreholes	Loss of integrity of borehole seals: seal failure or degradation	Biosphere
				Investigation borehole seal failure/degradation	Seals
			Underground boreholes		
Subsurface hydrological / fluid dynamical	Repository-induced flow		Brine inflow	Repository-induced changes in groundwater flow direction	Near-field
				Groundwater flow (saturated conditions, including fracture flow)	Near-field
				Cavitation	Near-field
				Saline (or fresh) groundwater intrusion	Near-field
				Backfill:resaturation/desaturation	Backfill
				Seals: resaturation/desaturation	Seals
				Cavitation	Far-field
				Resaturation	Near-field
				Saline groundwater intrusion	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Saline groundwater intrusion	Backfill
				Groundwater flow, effects of solution channels (preferential pathways)	Near-field
				Changes in moisture content due to stress relief	Near-field
			Wicking	Capillary action	Waste
				Capillary action	Backfill
				Unsaturated transport	Near-field
	Effects of gas generation		Fluid flow due to gas production	Groundwater flow due to gas production	Seals
				Gas transport into and through the far-field (gas phase and in solution)	Far-field
				Gas transport in the near field as gas phase and in solution	Backfill
				Groundwater flow due to gas production	Backfill
				Groundwater and gas flow	Backfill
				Gas transport in the near field as gas phase and in solution	Seals
				Gas transport in the waste container	Canister
				Gas-induced groundwater transport	Far-field
				Multiphase flow and gas-driven flow	Far-field
				Groundwater flow due to gas production	Near-field
				Groundwater and gas flow	Seals
				Groundwater and gas flow	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
M				Gas transport in the near field as gas phase and in solution	Near-field
				Gas transport: gas phase and in solution	Biosphere
				Gas mediated transport	Far-field
				Gas-mediated transport	Biosphere
	Thermal effects			Thermo-hydro-mechanical effects	Near-field
			Convection	Repository thermally-induced groundwater transport	Near-field
				Variations in groundwater temperature	Backfill
				Variations in groundwater temperature	Seals
				Variations in groundwater temperature	Near-field
				Convection	Near-field
				Convection (contaminant transport)	Backfill
				Convection (contaminant transport)	Seals
Geochemical / chemical				Chemical changes due to sorption, complex formation, speciation, gas, solubility	Biosphere
	Gas generation			Gas generation from concrete	Waste
				Gas generation from concrete	Seals
		Microbial gas generation		Methane/CO2 production: Carbonate/bicarbonate exchange with concrete	Waste
				Canister: microbiological effects/microbial activity	Canister
			Degradation of organic material	Methane/CO2 production	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Methane/CO2 production: Inhibition due to the pressure of toxic materials	Waste
				Methane/CO2 production: anaerobic production	Waste
				Degradation of plastics and cellulosics	Waste
				Methane/CO2 production: aerobic degradation	Waste
				Methane and carbon dioxide by microbial degradation of cellulose and other organic wastes	Waste
				Backfill: microbiological effects/microbial activity	Backfill
				Microbiological effects due to cellulose degradation	Waste
			Effects of biofilms on microbial gas generation	Methane/CO2 production: energy and nutrient control of metabolism	Waste
				Methane and CO2 production: energy and nutrient control of metabolism	Near-field
				Methane/CO2 production: Effects of biofilms	Waste
			Effects of temperature on microbial gas generation	Methane/CO2 production: effects of temperature	Waste
			Effects of pressure on microbial gas generation	Methane/CO2 production: effects of lithostatic pressure	Waste
				Methane CO2 production: effects of lithostatic pressure	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Effects of radiation on microbial gas generation	Methane CO2 production: effects of radiation on microbial populations	Near-field
				Mutation	Near-field
				Methane/CO2 production: effects of radiation on microbial populations	Waste
		Corrosion	Gases from metal corrosion	Effects of hydrogen from metal corrosion	Seals
				Effects of hydrogen from metal corrosion	Backfill
				Hydrogen by metal corrosion	Waste
				Internal corrosion due to waste	Waste
				Hydrogen: corrosion of container steel	Canister
				Methane CO2 production: effects of hydrogen from metal corrosion	Near-field
				Metal corrosion: wastes	Waste
				Methane/CO2 production: effects of hydrogen from metal corrosion	Backfill
				Methane/CO2 production: effects of hydrogen from metal corrosion	Seals
				Dissolution	Canister
			Galvanic coupling	Galvanic coupling	Canister
			Chemical effects of corrosion		
		Radiolytic gas generation		Radiolysis	Seals
				Radiolysis	Backfill
			Radiolysis of brine		
			Radiolysis of cellulose	Radiolysis	Waste

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Helium gas production	Gas generation: He production	Waste
			Radioactive gas	Methane/CO2 production	Backfill
	Chemical speciation		Speciation	Speciation	Far-field
				Chemical effects: Interactions of waste canister and rock	Canister
				Speciation	Biosphere
				Thermochemical changes	Backfill
				Thermochemical changes	Seals
				Thermochemical changes	Near-field
				Chemical changes due to complex formation	Backfill
				Chemical changes due to complex formation	Seals
				Chemical changes due to waste degradation	Backfill
M				Chemical changes due to waste degradation	Seals
				Thermal effects on hydrochemistry	Biosphere
				Speciation	Near-field
				Chemical changes due to speciation (chemical changes)	Near-field
				Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)	Near-field
				Chemical effects: interactions of waste canister and rock	Near-field
				Thermally induced chemical changes (water chemistry)	Waste
				Chemical effects: geochemical change	Waste

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Chemical changes due to speciation	Backfill
				Chemical changes due to speciation	Seals
				Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)	Far-field
				Speciation	Backfill
				Speciation	Seals
				Changes in pore water composition, pH, Eh: concrete	Near-field
				Chemical changes due to gas production	Waste
				Chemical changes due to gas production	Backfill
				Chemical changes due to gas production	Seals
				Speciation	Waste
				Biogeochemical changes	Backfill
				Biogeochemical changes	Near-field
				Effects of bentonite on groundwater chemistry	Seals
				Speciation of corrosion products (include in water chemistry)	Canister
				Interactions with corrosion products and waste	Waste
			Kinetics of speciation	Chemical kinetics	Seals
				Chemical kinetics	Backfill
				Chemical kinetics	Waste
				Chemical kinetics	Canister
				Chemical kinetics	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
	Precipitation / dissolution			Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	Near-field
				Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	Backfill
				Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	Seals
				Solubility	Waste
				Solubility effects (pH and Eh)	Biosphere
				Precipitation, dissolution, recrystallization, reconcentration	Far-field
				Precipitation, dissolution, recrystallization, reconcentration	Biosphere
				Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	Far-field
				Reconcentration	Near-field
			Dissolution of waste	Dissolution chemistry	Waste
				Dissolution	Waste
			Precipitation	Precipitation	Waste
				Precipitation	Canister
				Precipitation	Backfill
				Precipitation	Seals
				Recrystallization	Near-field
				Recrystallization	Backfill
				Recrystallization	Waste
				Recrystallization	Seals
				Precipitation, reconcentration	Seals
				Precipitation, reconcentration	Backfill

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Precipitation, reconcentration	Near-field
				Fracture mineralization	Near-field
			Kinetics of precipitation / dissolution	Leaching: wastes	Waste
	Sorption reactions		Actinide sorption	Chemical changes due to sorption	Seals
				Ionic exchange in soil	Biosphere
				Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)	Near-field
				Sorption (linear, nonlinear, irreversible)	Near-field
				Anion exchange	Backfill
				Anion exchange	Seals
				Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)	Far-field
				Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)	Backfill
				Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)	Seals
				Sorption (linear, nonlinear, irreversible)	Backfill
				Sorption (linear, nonlinear, irreversible)	Seals
				Sorption (linear, nonlinear, irreversible)	Far-field
				Sorption (linear, nonlinear, irreversible)	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Chemical changes due to sorption	Backfill
				Chemical changes due to sorption (chemical changes)	Near-field
				Sorption effects (pH and Eh)	Biosphere
			Kinetics of sorption		
			Changes in sorptive surfaces	Changes in sorptive surfaces	Biosphere
				Changes in sorptive surfaces	Backfill
				Changes in sorptive surfaces	Near-field
				Changes in sorptive surfaces	Seals
				Saturation of sorption sites	Seals
				Saturation of sorption sites	Backfill
				Exchange capacity exceeded	Backfill
				Exchange capacity exceeded	Seals
				Changes in sorptive surfaces	Far-field
	Redox chemistry		Effect of metal corrosion	Redox potential	Waste
				Chemical changes due to metal corrosion	Waste
				Chemical changes due to metal corrosion	Canister
				Electrical effects of metal corrosion	Waste
				Chemical effects of rock reinforcement	Near-field
				Chemical changes due to corrosion	Backfill
				Chemical changes due to corrosion	Seals
			Redox fronts	Redox front	Backfill
				Redox front	Seals
			Redox kinetics		

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Localized reducing zones		
	Organic complexation		Organic complexation	Complex formation: wastes	Waste
				Complex formation: wastes	Waste
			Organic ligands	Methylation	Near-field
			Humic and fulvic acids	Complexation by organics (including humic and fulvic acids)	Biosphere
				Complexation by organics (including humic and fulvic acids)	Far-field
			Kinetics of organic complexation		
	Exothermic reactions			Thermal effects on hydrochemistry	Near-field
			Exothermic reactions	Thermochemical effects	Backfill
			Concrete hydration	Thermal effects (e.g. concrete hydration)	Near-field
				Thermal effects (e.g. concrete hydration)	Seals
				Thermochemical effects	Seals
	Chemical effects on material properties		Chemical degradation of seals	Chemical effects: gas generation	Seals
				Cement sulphate reaction	Seals
				Alkali-aggregate reaction	Seals
				Reactions with cement pore water (include in chemical degradation)	Seals
				Cement-sulphate reaction: concrete	Near-field
				Dissolution	Seals
				Degradation of the bentonite by chemical reactions	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Chemical degradation of backfill	Chemical effects: gas generation	Backfill
				Dissolution	Backfill
				Reactions with cement pore water (include in chemical degradation	Backfill
			Microbial effects on concrete	Hydrogen: effects of microbial growth on concrete	Waste
				Biogeochemical changes	Seals
				Hydrogen: effects of microbial growth on concrete	Seals
				Seal: microbiological effects/microbial activity	Seals
				Methane/CO2 production: effects of microbial growth on properties of concrete	Near-field
Contaminant transport mode	Solute transport		Solute transport	Isotopic dilution	Seals
				Isotopic dilution	Backfill
				Transport of chemically active substances into the near-field	Seals
				Transport of chemically active substances into the near-field	Backfill
				Dilution (mass, isotopic, species)	Near-field
				Dilution (mass, isotopic, species)	Far-field
				Dilution (mass, isotopic, species)	Biosphere
	Colloid transport		Colloid transport	Colloid transport (inorganic and organic)	Seals
				Colloid transport (inorganic and organic)	Backfill
				Colloid transport	Near-field
			Colloid formation and stability	Colloid formation: wastes	Waste

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Colloids	Near-field
				Colloids, complexing agents	Biosphere
				Colloids: formation & effects (including inorganic and organic colloid transport)	Far-field
				Chemical changes due to colloid production (chemical changes)	Near-field
				Colloids: formation and effects (including inorganic and organic colloid transport)	Biosphere
				Physico-chemical phenomena/effects (e.g. colloid formation)	Biosphere
				Chemical changes due to colloid production	Backfill
				Chemical changes due to colloid production	Seals
				Physico-chemical phenomena/effects (e.g. colloid formation)	Near-field
			Colloid filtration	Pore blockage: concrete	Near-field
			Colloid sorption		
	Particulate transport		Suspensions of particles		
			Rinse	Rinse	Waste
			Cuttings		
			Cavings		
			Spallings		
	Microbial transport		Microbial transport	Biogeochemical changes	Far-field
				Transport of radionuclides bound to microbes	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Transport of radionuclides bound to microbes	Backfill
				Transport of radionuclides bound to microbes	Seals
				Transport of radionuclides bound to microbes	Far-field
				Transport of radionuclides bound to microbes	Biosphere
				Microbial activity	Far-field
				Transport of microbes into the near-field	Near-field
			Biofilms	Rock property changes: microbial pore blocking	Near-field
	Gas transport		Transport of radioactive gases	Transport of active gases: gas phase and in solution	Biosphere
				Active methane, carbon dioxide, radon, tritiated hydrogen and other active gases	Waste
				Transport of active gases	Near-field
				Transport of active gases	Far-field
				Radon emission	Biosphere
				Gas discharge	Biosphere
				Transport of active gases	Backfill
				Transport of active gases	Seals
Contaminant transport process	Advection		Advection	Advection/dispersion: radionuclides	Near-field
				Advection/dispersion: radionuclides	Backfill
				Groundwater flow, advection/dispersion (saturated conditions)	Far-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Extreme channel flow of oxidants and nuclides (preferential pathways)	Seals
				Extreme channel flow of oxidants and nuclides (preferential pathways)	Near-field
				Advection/dispersion: radionuclides	Seals
				Water flow: advection and dispersion	Biosphere
				Unsaturated transport	Backfill
				Unsaturated transport	Seals
				Unsaturated transport	Far-field
	Diffusion		Diffusion	Diffusion: radionuclides	Near-field
				Diffusion: radionuclides	Backfill
				Diffusion: radionuclides	Seals
				Diffusion (bulk, matrix, surface)	Biosphere
				Diffusion (bulk, matrix, surface)	Far-field
			Matrix diffusion		
	Thermochemical transport phenomena		Soret effect	Soret effect	Seals
				Soret effect	Backfill
				Soret effect	Far-field
				Soret effect	Near-field
				Thermal effects and transport (diffusion) properties	Near-field
	Electrochemical transport phenomena		Electrochemical effects	Electrochemical gradients	Waste
				Electrochemical cracking	Canister

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Natural telluric electrochemical reactions	Canister
				Electrochemical gradients	Canister
				Natural telluric electrochemical reactions	Backfill
				Natural telluric electrochemical reactions	Seals
			Galvanic coupling	Galvanic coupling	Waste
			Electrophoresis	Coupled effects (electrophoresis)	Canister
	Physicochemical transport phenomena		Chemical gradients	Chemical gradients	Near-field
				Chemical gradients (electrochemical effects and osmosis)	Biosphere
				Chemical gradients (electrochemical effects and osmosis)	Far-field
				Chemical gradients	Backfill
				Chemical gradients	Seals
				Chemical gradients (electrochemical effects and osmosis)	Canister
			Osmosis	Chemical gradients, osmosis	Waste
			Alpha recoil	Recoil of alpha-decay	Waste
				Radiolysis, radiation damage	Far-field
				Release of stored energy	Waste
				Sudden energy release	Waste
				Release of stored energy	Near-field
			Enhanced diffusion	Effects at saline-freshwater interface	Far-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Effects at saline-freshwater interface	Near-field
				Effects at saline-freshwater interface	Backfill
				Effects at saline-freshwater interface	Seals
	Plant, animal and soil uptake			Bioaccumulation and translocation	Biosphere
			Plant uptake	Plants: Cycling processes	Biosphere
				Plants: Internal translocation and retention	Biosphere
				Tree sap	Biosphere
				Houseplants	Biosphere
				Plants: Vapor uptake	Biosphere
				Plants: Leaf-fall and senescence	Biosphere
				Plants: Root uptake, including deep rooting species	Biosphere
				Plants: Washoff and leaching by rainfall	Biosphere
				Plants: Deposition on surfaces	Biosphere
			Animal uptake	Animal habits (grooming and fishing, soil ingestion, diets, scavengers/predators)	Biosphere
				Animals: Cycling processes	Biosphere
				Animals: Uptake by inhalation	Biosphere
				Critical group - pets	Biosphere
				Animals: Internal translocation and retention	Biosphere
				Intrusion (animal)	Biosphere
				Animals: Uptake by ingestion	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Intrusion in accumulation zone in the biosphere (animals)	Biosphere
			Accumulation in soils	Accumulation in soils and organic debris, including peat	Biosphere
				Accumulation in sediments	Biosphere
				Solid discharge via erosional processes	Biosphere
	Human uptake			Radiotoxic contaminants	Biosphere
				Cure for cancer	Human influences
				Critical group - agricultural labor,	Biosphere
				Critical group - individuality	Biosphere
				Sensitization to radiation	Biosphere
			Ingestion	Carcasses	Biosphere
				Ingestion and wild plants	Biosphere
				Human diet	Biosphere
				Ingestion and domestic animal products	Biosphere
				Ingestion and agricultural crops	Biosphere
				Ingestion and wild animals	Biosphere
				Human soil ingestion	Biosphere
				Ingestion and drinking water	Biosphere
				Ingestion and soils and sediments	Biosphere
			Inhalation	Outdoor spraying of water	Human influences
				Inhalation and salt particles	Biosphere
				Smoking	Biosphere
				Showers and humidifiers	Biosphere
				Radiological factors (smoking, transport agents)	Human influences
				Inhalation and biotic material	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Household dust and fumes	Biosphere
				Deposition (wet and dry)	Biosphere
				Inhalation and soils and sediments	Biosphere
				Inhalation and gases and vapors (indoor/outdoor)	Biosphere
				Suspension in air	Biosphere
			Irradiation	Building materials	Biosphere
				Critical group - clothing and home furnishings	Biosphere
				External exposure: land, sediments, water bodies	Biosphere
			Dermal sorption	Dermal sorption - nuclides other than tritium	Biosphere
				Food preparation	Biosphere
				Dermal sorption - tritium	Biosphere
			Injection	Inject/ingest/inhaling locally produced drugs	Human influences

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Geological	Drilling		Oil and gas exploration	Exploratory boreholes (oil, gas)	Human influences
				Undetected repository intrusions (boreholes, mining)	Human influences
				Exploratory boreholes (oil, gas): nonintrusive	Human influences
			Potash exploration	Exploratory boreholes (water, potash)	Human influences
			Water resources exploration		
			Oil and gas exploitation	Resource exploitation (e.g. hydrocarbon, geothermal)	Human influences
			Groundwater exploitation		
			Archeological investigations	Drilling: archeology: nonintrusive	Human influences
			Geothermal	Geothermal energy production	Human influences
				Geothermal energy exploration (and other unidentified resources)	Human influences
			Other resources		
			Enhanced oil and gas recovery	Drilling: enhanced oil/gas production: nonintrusive	Human influences
			Liquid waste disposal	Drilling: liquid waste disposal: nonintrusive	Human influences
			Hydrocarbon storage	Drilling: hydrocarbon storage: nonintrusive	Human influences
			Deliberate drilling intrusion	Intrusion (deliberate)	Human influences
				Sabotage	Human influences
				Sabotage	Near-field
				Intrusion (deliberate) - malicious (sabotage, act of war (nuclear))	Human influences
				Chemical sabotage	Human influences
	Excavation activities			Intrusion in accumulation zone in the biosphere	Human influences

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Resource exploitation (intersection of zone of contamination)	Human influences
			Potash mining	Potash mining	Human influences
			Other resources	Mining other than potash	Human influences
			Tunneling	Tunnelling	Human influences
			Construction of underground facilities	Gas leakage into underground living space	Biosphere
				Construction of underground storage/disposal facilities (e.g. gas storage)	Human influences
				Heat storage underground	Human influences
				Space heating	Biosphere
				Water leak into underground living space	Biosphere
				Near storage of other waste	Human influences
				Construction of underground dwellings/shelters	Human influences
			Archeological excavations	Archeological investigations	Human influences
			Deliberate mining intrusion	Unsuccessful attempt of site improvement	Human influences
				Intrusion (deliberate) - recovery of repository materials	Human influences
				Intrusion (deliberate) - recovery of wastes or associated materials (mining)	Human influences
	Subsurface explosions			Sudden energy release	Human influences
		Resource recovery	Resource recovery	Explosions (resource recovery)	Human influences
		Underground nuclear device testing	Underground nuclear device testing	Underground weapons testing (nuclear device)	Human influences

Human-initiated EPs

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Subsurface hydrological and geochemical	Borehole fluid flow	Drilling-induced flow	Drilling fluid flow		
			Drilling fluid loss		
			Blowouts		
			Drilling-induced geochemical changes		
		Fluid extraction	Oil and gas extraction	Resource exploitation following intrusion	Human influences
			Groundwater extraction	Industrial use of water	Human influences
				Intentional artificial groundwater recharge or withdrawal	Human influences
				Groundwater discharge (wells)	Biosphere
				Wells (high demand)	Human influences
				Groundwater extraction	Human influences
				Dewatering	Human influences
				Borehole - well	Far-field
				Wells	Human influences
		Fluid injection		Reuse of boreholes	Human influences
				Injection wells	Human influences
			Liquid waste disposal	Injection of liquid wastes: nonintrusive	Human influences
			Enhanced oil/gas production	Injection wells: enhanced oil/gas production, hydrocarbon storage: nonintrusive	Human influences
				Faulting/fracturing: change of properties - human-induced	Geology/climate changes
			Hydrocarbon storage		
			Fluid injection-induced geochemical changes		

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
		Flow through abandoned boreholes		Boreholes - unsealed	Biosphere
			Natural borehole fluid flow		
			Waste-induced borehole flow		
			Flow through undetected boreholes	Undetected boreholes (existing): nonintrusive	Human influences
			Borehole-induced solution and subsidence	Borehole-induced solution and subsidence	Human influences
			Borehole-induced mineralization		
			Borehole-induced geochemical changes		
	Excavation-induced flow		Changes in groundwater flow due to mining		
			Changes in geochemistry due to mining	Solution mining	Human influences
	Explosion-induced flow		Changes in groundwater flow due to explosions		
Geomorphological	Land use and disturbances		Land use changes	Charcoal production	Biosphere
				Peat and leaf litter harvesting	Human influences
				Land use changes	Biosphere
				Ashes and sewage sludge	Human influences
				Peat and leaf litter harvesting	Biosphere
			Surface disruptions	Explosions (act of war)	Human influences
				Quarrying, peat extraction	Human influences
				Quarrying, near surface extraction	Human influences
				Earth moving projects	Human influences
				Earthmoving	Human influences
				Blasting and vibration	Human influences

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Surface hydrological	Water control and use			Human-induced changes in surface hydrology	Human influences
			Damming of streams or rivers	Hydrologic stresses: damming of streams or rivers	Human influences
				Dams	Biosphere
				Terrestrial water use (including wells and dams)	Biosphere
			Reservoirs	Reservoirs	Human influences
			Irrigation	Irrigation	Human influences
			Lake usage	Artificial lake mixing	Human influences
				Artificial lake mixing	Biosphere
				Heat storage in lakes	Human influences
				Lake infilling	Human influences
			Altered soil or surface water chemistry by human activities	Herbicides, pesticides, fungicides	Human influences
				Altered soil or surface water chemistry by human activities	Human influences
				Herbicides, pesticides, fungicides	Biosphere
				Crop fertilization	Biosphere
				Hydroponics	Biosphere
				Hydroponics	Human influences
				Far field hydrochemistry - acids, oxidants, nitrates	Far-field
				Crop fertilization	Human influences
Climatic	Anthropogenic climate change		Greenhouse gas effects	Anthropogenic climate change drought (greenhouse effect)	Geology/climate changes
				Greenhouse-induced effects (e.g. sea level change, precipitation, temp.)	Geology/climate changes

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Greenhouse-induced ecological effects (including food production)	Biosphere
				Greenhouse-induced storm surges	Geology/climate changes
			Acid rain	Acid rain	Biosphere
				Acid rain	Human influences
				Acid rain	Geology/climate changes
			Damage to ozone layer	Ozone layer (failure)	Geology/climate changes
				Ozone layer failure	Biosphere
Marine	Marine activities		Coastal water use	Coastal water use	Biosphere
			Sea water use	Sea water use	Biosphere
			Estuarine water use	Estuarine water use	Biosphere
Ecological	Agricultural activities		Ranching	Ranching	Human influences
			Arable farming	Biogas production	Human influences
				Crop storage	Biosphere
				Crop storage	Human influences
			Fish farming	Fish farming	Human influences
	Social and technological developments		Demographic change and urban development	Demographic change, urban development	Human influences
				Agricultural and fisheries practice changes	Human influences
				Critical group - leisure pursuits	Biosphere
				Demographic change, urban development	Biosphere
				Critical group - house location	Biosphere
				Technological advances in food production	Human influences
			Loss of records	Loss of records	Human influences

Appendix C: FEPs Excluded from the DCCA FEP List in the Development of the CCA FEP List

Table C-1. FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as modeling issues

DCCA FEP name	Sub-system
Boundary conditions	Backfill
Boundary conditions	Canister
Boundary conditions	Near-field
Boundary conditions	Seals
Boundary conditions	Waste
Correlation	Backfill
Correlation	Biosphere
Correlation	Canister
Correlation	Far-field
Correlation	Near-field
Correlation	Seals
Correlation	Waste
Groundwater flow: initial conditions	Backfill
Groundwater flow: initial conditions	Seals
Time dependence	Backfill
Time dependence	Canister
Time dependence	Seals
Time-dependence	Near-field
Uncertainties	Biosphere

Table C-2. FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as issues not regulated by 40 CFR Part 191

DCCA FEP name	Sub-system
Advection/dispersion: hazardous constituents	Backfill
Advection/dispersion: hazardous constituents	Near-field
Advection/dispersion: hazardous constituents	Seals
Biotoxicity	Biosphere
Carcinogenic contaminants	Biosphere
Chemical toxicity	Biosphere
Diffusion: hazardous constituents	Backfill
Diffusion: hazardous constituents	Near-field
Diffusion: hazardous constituents	Seals
Dissolution, speciation, sorption, precipitation; hazardous constituents	Backfill
Dissolution, speciation, sorption, precipitation; hazardous constituents	Near-field
Dissolution, speciation, sorption, precipitation; hazardous constituents	Seals
Inventory: hazardous constituents (e.g. VOCs, heavy metals)	Waste
Mutagenic contaminants	Biosphere
Release of hazardous constituents from the failed canister	Canister
Release of sorbed VOCs	Waste
Solubility, speciation, precipitation: hazardous constituents	Waste
Source terms (hazardous constituents)	Waste
Teratogenic contaminants	Waste
Toxicity of mined rock	Biosphere

Table C-3 FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as issues relating to designs different to that forming the basis of the CCA

DCCA FEP name	Sub-system
Alkali-aggregate reaction	Backfill
Backfill material deficiencies	Backfill
Cement sulphate reaction	Backfill
Coagulation of bentonite	Backfill
Cracking: concrete	Backfill
Degradation of the bentonite by chemical reactions	Backfill
Design modifications: backfill	Backfill
Effects of bentonite on groundwater chemistry	Backfill
Faulty backfill emplacement	Backfill
Gas generation from concrete	Backfill
Hydrogen: effects of microbial growth on concrete degradation	Backfill
Inadequate backfill or compaction, voidage	Backfill
Radiation effects on bentonite	Backfill
Sealing of cracks: concrete	Backfill
Thermal effects (e.g. concrete hydration)	Backfill
Uneven swelling of bentonite	Backfill
Inadequate design: exploration borehole seal failure	Biosphere
Backfill effects on container corrosion	Canister
Chemical reactions (copper corrosion)	Canister
Common cause canister defects - quality control	Canister
Container healing	Canister
Corrosive agents, sulphides, oxygen, etc.	Canister
Cracking along welds	Canister
Creeping of copper	Canister
Design modifications: canister	Canister
Differing thermal expansion of materials (glass, canister)	Canister
Hydride cracking	Canister
Incomplete filling of canisters	Canister
Internal pressure	Canister
Loss of ductility	Canister
Material defects, e.g. early canister failure	Canister
Radiation damage to container (embrittlement)	Canister
Random canister defects - quality control	Canister
Role of chlorides in copper corrosion	Canister
Stress corrosion cracking	Canister
Boreholes unsealed	Far-field
Inadequate design: exploration borehole seal failure	Far-field
Incomplete vault closure	Far-field
Accidents during operation	Human influences

Table C-3 FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as issues relating to designs different to that forming the basis of the CCA (Continued)

DCCA FEP name	Sub-system
Backfill/seal material deficiencies	Human influences
Decontamination materials left	Human influences
Design modifications	Human influences
Inadvertent inclusion of undesirable materials	Human influences
Other future uses of crystalline rock	Human influences
Poor quality construction	Human influences
Poorly designed repository	Human influences
Radioactive waste disposal error	Human influences
Stray materials left	Human influences
Abandonment of unsealed repository	Near-field
Accidents during operation	Near-field
Design modification: DRZ (e.g. grouting)	Near-field
Design modification: geometry	Near-field
Effects of phased operations	Near-field
Improper operation	Near-field
Inadequate design: shaft seal and exploration borehole seal failure	Near-field
Incomplete repository or borehole closure	Near-field
Open boreholes	Near-field
Poor quality construction	Near-field
Preclosure events	Near-field
Repository flooding during operations	Near-field
Unmodeled design features	Near-field
Buffer additives	Seals
Design modifications: seals	Seals
Faulty seal emplacement	Seals
Inadequate seal or compaction, voidage	Seals
Seal material deficiencies	Seals
Damaged or deviating waste contents	Waste
Design modifications: waste (e.g. buffer additives)	Waste
Differing thermal expansion of glass matrix and canister	Waste
Fracturing	Waste
I, Cs-migration to fuel surface	Waste
Long-term physical stability	Waste
Radiation damage of the matrix including embrittlement	Waste
Solubility within fuel matrix	Waste
Solubility with fuel matrix	Waste
Stability of glass	Waste
Waste incompatibility	Waste

THIS PAGE INTENTIONALLY LEFT BLANK