A STRATEGY FOR CONDUCTING A REVIEW OF SCENARIO ANALYSIS

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ABSTRACT

This document describes a review approach, roles and responsibilities for different teams, and mechanisms to document the review of scenario analysis so that findings are transparent and traceable. This document is intended to support the development of model abstraction review plans to cover scenario analysis needs so that an appropriate level of integration can be ensured.

ACKNOWLEDGMENTS

This is an independent product of the CNWRA and does not necessarily reflect the views or regulatory positions of the U.S. Nuclear Regulatory Commission (NRC). The NRC staff views expressed here are preliminary and do not represent a final judgement or determination of the matters addressed or of the acceptability of a license application for a geologic repository at Yucca Mountain, Nevada.

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

No data, analyses, or codes are discussed in this document.

1 BACKGROUND

Performance assessment is a systematic analysis that (i) identifies features, events, and processes that might affect the performance of a geologic repository, (ii) examines the effects of these features, events, and processes on performance, and (iii) estimates the radiological exposures to the reasonably maximally exposed individual. It is an analysis that addresses the three questions of the risk triplet: what can happen?, how likely?, and what are the consequences? Scenario analysis is a component of performance assessment that evaluates the first two questions of the risk triplet. It includes a systematic enumeration of features, events, and processes that can reasonably occur in the repository system, supporting the identification of possible ways in which a geologic repository environment can evolve so a defensible representation of the system can be implemented in a total system performance assessment model. A scenario is defined as the plausible future conditions of the repository system during the period of regulatory concern. It includes a postulated sequence (or absence) of events and assumptions about initial repository characteristics and boundary conditions. The third question of the risk triplet (what are the consequences?) is evaluated under model abstraction, which will be a major endeavor of the license application review for postclosure safety requirements.

Scenario analysis is composed of four steps: (i) identification of features, events, and processes relevant to the potential high-level waste geologic repository; (ii) selection or screening of features, events, and processes important to estimating dose risk to a reasonably maximally exposed individual during the period of regulatory concern; (iii) formation of scenario classes from a screened or reduced collection of features, events, and processes; and (iv) selection or screening of the scenario classes for consideration in a total system performance assessment. Because consequences of potential radionuclide releases are weighted by event or scenario class probability, probability estimates and associated uncertainty are required to support total system performance assessments.

The Yucca Mountain Review Plan (NRC, 2003) provides generic guidance for a licensing review. The Risk Insight Baseline Report (NRC, 2004) is being used to provide risk information to support the licensing review. Evaluation of Multiple Barriers and Scenario Analysis must rely on feedback from the model abstraction or integrated subissues teams. Thus, model abstraction teams must incorporate support to multiple barriers and scenario analysis as part of their review activities.

The objective of this document is to develop a strategy to ensure a defensible, integrated, efficient, and risk-informed license application review of scenario analysis, consistent with the Yucca Mountain Review Plan and licensing schedule constraints. This document describes a review approach, roles and responsibilities for different teams, and mechanisms to document the review effort so that findings are transparent and traceable. This document is intended to support model abstraction review team activities to cover scenario analysis needs so that an appropriate level of integration can be ensured.

2 SCENARIO ANALYSIS

According to 10 CFR 63.114, a performance assessment used to demonstrate compliance must (i) consider only events that have at least 1 chance in 10,000 of occurring over 10,000 years; (ii) provide the technical basis for either inclusion or exclusion of specific features, events, and processes in the performance assessment; and (iii) provide the technical basis for either the inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Scenario analysis requirements for a safety analysis report supporting a license application are defined in 10 CFR 63.21(c)(1), and (9): a safety analysis report must include a description of the Yucca Mountain site, including those features, events, and processes that might affect the design of the geologic repository operations area and the performance of the geologic repository. The safety analysis report must include an assessment to the degree to which features, events, and processes are expected to materially affect repository compliance, in both beneficial or adverse terms.

The Yucca Mountain Review Plan (NRC, 2003) describes four review methods for scenario analysis namely: (i) identification of an initial list of features, events, and processes; (ii) screening of the initial list of features, events, and processes; (iii) formation of scenario classes using the reduced set of events, and (iv) screening of scenario classes. The Integrated Issue Resolution Status Report (NRC, 2005a) provides a summary of the scenario analysis status as of 2004. Additional information to respond to key technical issue agreements was reviewed (NRC, 2005b) after completion of the Integrated Issue Resolution Status Report. Scenario analysis agreements were considered completed, with the exception of agreements TSPAI.2.02 and 2.07. Agreement TSPAI.2.07 requests implementing the Enhanced Plan for Features, Events, and Processes (Bechtel SAIC Company, LLC, 2002). Information addressing TSPAI.2.07, a database of features, events, and processes, still has not been made publicly available. Nevertheless, the analysis and model reports that present the U.S. Department of Energy (DOE) treatment of features, events, and processes are publically available and review can be conducted. Screening arguments for a number of features, events, and processes under agreement TSPAI.2.02 were identified as requiring additional technical bases. For the third and fourth scenario analysis review methods in the Yucca Mountain Review Plan, staff identified that enough information will be available at the time of the license application to initiate a review (NRC, 2005a).

The following section delineates a strategy to accomplish an effective and efficient license application review process that should result in a defensible, integrated, risk-informed, and performance-based safety evaluation report.

2.1 Review Approach

Successful evaluation of scenario analysis requires integration among all model abstraction teams. A schematic of the flow of information, as well as the chronology on the review, is presented in Figure 2-1.

Proposed tasks to accomplish an integrated review, as well as a delineation of responsibilities, are discussed in the following sections.

2.1.1 Identification of an Initial List of Features, Events, and Processes

Scenario analysis identifies the features, events, and processes that could influence, directly or indirectly, dose risk from the potential high-level waste repository to a reasonably maximally exposed individual. It is thereby an integral part of the performance assessment. Staff will evaluate whether the initial list includes all features, events, and processes having a potential to influence repository performance.

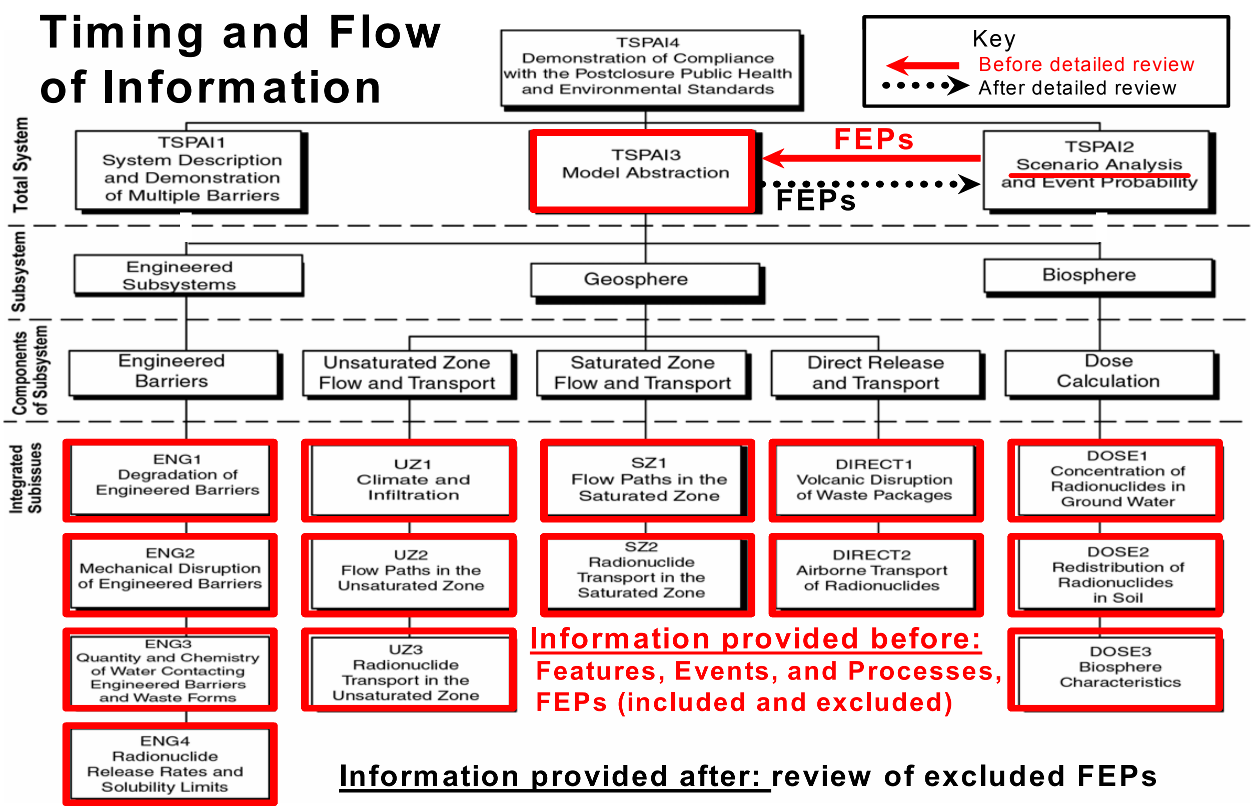

Figure 2-1. Flow of Information Among Teams for the Evaluation of Scenario Analysis

The scenario analysis team will be responsible for reviewing the response to agreement TSPAI.2.07. Several features, events, and processes analyses and model reports are publicly available that allow evaluation of the implementation of the Enhanced Plan for Features, Events, and Processes (Bechtel SAIC Company, LLC, 2002). Staff will summarize the results of the evaluation in a brief memorandum.

The scenario analysis team will be responsible for implementing this review method, with conclusions to be summarized in the safety evaluation report.

Tasks (Scenario Analysis Team)

The scenario analysis team will evaluate information to address agreement TSPAI.2.07. The team will then develop a section in the safety evaluation report addressing this review method and, if necessary, a Request for Additional Information.

2.1.2 Screening of the Initial List of Features, Events, and Processes

After identifying features, events, and processes, the second step in the scenario analysis is the evaluation for further consideration in the total system performance assessment model. Those features, events, and processes with a chance of occurring greater than 1 in 10,000 over 10,000 years that pose a risk because of dose consequences (i.e., have the potential to affect compliance as defined in 10 CFR 63.113) must be included in further scenario analyses. Therefore, staff will evaluate whether screening rationales are robust enough that no feature, event, or process influential to repository performance is excluded from consideration in the performance assessment model.

For this review method, the main scope of the scenario analysis team is assessing the technical basis of exclusion arguments. Model abstraction teams will assess the adequacy of the total system performance assessment model to account for included features, events, and processes. Exclusion arguments can be based on low consequence or low probability. Exclusion can also be based on regulatory constraints. For example, the human intrusion scenario is restricted to a stylized system defined in 10 CFR 63; and features, events, and processes related to a human intrusion scenario outside the stylized description can be excluded from further consideration in a total system performance assessment. Previous editions of screening arguments have also relied on design criteria or quality control procedures to disregard the occurrence or consequence of certain processes. The technical bases of screening arguments appealing to design criteria or quality control procedures should be complete enough, commensurate with the risk significance of the feature, event, and process under consideration, to support a screening decision.

Screening arguments for a number of features, events, and processes under agreement TSPAI.2.02 were identified as requiring additional technical bases (NRC, 2005b).

The following specific items still require additional technical bases:

- 2.1.08.04.0B Condensation Forms at Repository Edges (Repository-Scale Cold Traps)
- 2.1.06.05.0B Mechanical Degradation of Invert; 2.1.06.05.0C Chemical Degradation of Emplacement Pallet; 2.1.06.05.0D Chemical Degradation of Invert
- 2.2.08.03.0B Geochemical Interactions and Evolution in the Unsaturated Zone
- 2.2.10.07.0A Thermo-Chemical Alteration of the Calico Hills Unit
- 2.2.10.09.0A Thermo-Chemical Alteration of the Topopah Spring Basal Vitrophyre
- 2.2.07.05.0A Flow and Transport in the Unsaturated Zone From Episodic Infiltration
- 2.2.11.02.0A Gas Effects in the Unsaturated Zone

The scenario analysis team, supported by model abstraction teams, will evaluate screening rationale from all relevant integrated subissue perspectives for all of the excluded features, events, and processes, including those identified as requiring additional technical bases (NRC, 2005b). The integrated subissues teams will document relevant findings, such as the identification of screening arguments necessitating additional technical bases and justification of why those technical bases are relevant, based on the Risk Insight Baseline Report or some other analyses. Integrated subissue teams are referred to Appendix B of the Integrated Issue Resolution Report (NRC, 2005a) for examples of questions on the technical bases of previous (now outdated) screening arguments. Additional examples are available in the evaluation letter for agreement TSPAI.2.02 (NRC, 2005b). A minimal record will be generated for screening arguments of features, events, and processes deemed to have sufficient technical bases. The record may focus on stating that the screening argument provides sufficient technical bases to exclude the feature, event, and process under a particular integrated subissue perspective. Based on risk significance, particular features, events, and processes, such as criticality, may be identified independently from the adequacy of the technical bases for exclusion, for detailed discussion in the safety evaluation report.

Due to the more than 300 features, events, and processes requiring evaluation from 14 integrated subissue perspectives, a tool will be required to manage the screening argument review effort. This tool will be a simple Microsoft® Excel file classifying features, events, and processes by (i) Integrated Subissue, (ii) inclusion or exclusion into the DOE performance assessment model, (iii) dependence of screening arguments on the scenario class (seismic, igneous, nominal), (iv) risk significance, (v) dependence of screening arguments on the length of the performance period, and (vi) status of the review of excluding screening arguments.

The Excel file will be flexible enough to introduce new categories, if needed. This file will allow model abstraction teams to identify (i) assigned features, events, and processes; (ii) which integrated subissues must communicate to develop an integrated assessment; (iii) progress of the review effort or additional issues of consideration (e.g., whether disruptive scenarios or long performance periods must be accounted for in the evaluation of the screening argument); and (iv) communicate updates to the database of features, events, and processes by DOE.

The division of responsibilities is as follows. The scenario analysis team is in charge of developing the Excel file with an initial categorization of features, events, and processes. An initial version of the classification of features, events, and processes is tabulated in the Appendix. The initial classification and the format of the Excel file are open for refinement. The scenario analysis team comprises at least one representative of all of the integrated subissues. The integrated subissue representatives will ensure that all of the associated features, events, and processes are reviewed by the integrated subissue teams. In the interim, review results will be documented in scientific notebooks or another staff preferred method. Relevant result findings (e.g., screening arguments necessitating additional technical bases) will be brought to the attention of the scenario analysis team so that adequate integration and risk insight perspectives are accounted for. The scenario analysis team will decide the appropriate level of documentation to include in the safety evaluation report. The integrated subissues representative will monitor review of the included features, events, and processes as part of the model abstraction review. Model integration is the responsibility of each model abstraction team.

Tasks (Scenario Analysis Team)

- Classify features, events, and processes in an Excel file to assign review tasks

- Track review progress

- Track updates to the database of features, events, and processes, and adjust the review effort accordingly

- Support discussions regarding integrated subissues of screening arguments identified as requiring additional technical bases

- Compile a list of included features, events, and processes to support model abstraction review activities

- Summarize integrated subissues feedback, develop a section in the safety evaluation report to address this review method, and if necessary, develop a request for additional information.

Integrated Subissue Teams

- Provide feedback on the adequacy of the classification of features, events, and processes in the Excel file.

- Review screening arguments and document review results of excluded features, events, and processes. For examples on the appropriate level of detail for documentation, consult Appendix B of the Integrated Issue Resolution Status Report (NRC, 2005a) and the evaluation letter for agreement TSPAI.2.02 (NRC, 2005b).

- Assess whether updated screening arguments address outstanding comments of agreement TSPAI.2.02.

- Communicate promptly to the scenario analysis team those screening arguments identified as needing additional technical bases.

- Participate in discussions of review findings with the scenario analysis team.

- Provide written input for the safety evaluation report and, if necessary, requests for additional information.

- Verify, as part of integration activities, that included features, events, and processes are evaluated in the model abstraction review activities.

2.1.3 Formation of Scenario Classes Using the Reduced Set of Events

Those features, events, and processes or sequences of events or processes screened for inclusion into the total system performance assessment model are further grouped into scenario or event classes. The staff will evaluate whether all relevant scenario classes have been identified. The scenario analysis team will be responsible for evaluating this review method and summarizing conclusions in the safety evaluation report.

Tasks (Scenario Analysis Team)

Develop a section in the safety evaluation report addressing this review method, and if necessary, develop requests for additional Information.

2.1.4 Screening of Scenario Classes

After identifying scenario classes, probability or consequence arguments are developed to support inclusion or exclusion of the scenario classes from the total system performance assessment model. Therefore, staff will evaluate whether all relevant scenario classes have been incorporated into the total system performance assessment model or properly excluded based on a sufficient analysis of potential consequences or probability of occurrence. The scenario analysis team will be responsible for evaluating this review method and summarizing conclusions in the safety evaluation report.

Tasks (Scenario Analysis Team)

Develop a section in the Safety Evaluation Report addressing this review method, and Request for Additional Information, if necessary.

2.2 Proposed Schedule

The scenario analysis review and completion of the corresponding safety evaluation report draft chapter could occur within 155 days after the acceptance review. Most of the time (140 days) is devoted to completion of the draft safety evaluation report chapter and requests for additional information. The following schedule is recommended.

Prelicense Application Activities

- Completion of the Excel file classification: 30 days
- Review of screening arguments in analysis and model reports, and documenting the review effort: 60 days

License Application Activities

- Review License Application updates: 30 days
- Discussion of review results: 30 days
- Write section of safety evaluation report and requests for additional information: 80 days
- Documenting a list of included features, events, and processes: 10 days

3 References

Bechtel SAIC Company, LLC. "The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain." TDR–WIS–PA–000005. Rev. 00. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2002.

NRC. NUREG–1762, "Integrated Issue Resolution Status Report. Rev. 1. Washington, DC: NRC. 2005a.

———. "The U.S. NRC NMSS Review of the U.S. DOE KTI Agreement Responses to the Potential Geologic Repository at YM, NV: TSPAI.2.01, 2.02, 2.03, 2.04, and 2.07." Washington, DC: NRC. 2005b.

———. "Risk Insights Baseline Report." Washington, DC: NRC. 2004.

———. NUREG–1804, "Yucca Mountain Review Plan, Rev. 2." Washington, DC: NRC. 2003.

APPENDIX

This appendix associates features, events, and processes with integrated subissues. The table is intended to facilitate integrated subissues identifying the collection of features, events, and processes to be reviewed. Acronyms used in the table are spelled at the end. The features, events, and processes screened as included are indicated in shadowed rows in Table A.1. The X symbol is used to indicate which features, events, and processes are associated to the 14 integrated subissues.

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
0.1.02.00.0A	Timescales of concern															X
0.1.03.00.0A	Spatial domain of concern															X
0.1.09.00.0A	Regulatory requirements and exclusions	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
0.1.10.00.0A	Model and data issues															X
1.1.01.01.0A	Open-site investigation boreholes					X	X									
1.1.01.01.0B	Influx through holes drilled in drift wall or crown			X			X									
1.1.02.00.0A	Chemical effects of excavation and construction in the engineered barrier system			X	X		X	X								
1.1.02.00.0B	Mechanical effects of excavation and construction in the engineered barrier system		X													
1.1.02.01.0A	Site flooding (during construction and operation)					X										
1.1.02.02.0A	Preclosure ventilation		X				X									
1.1.02.03.0A	Undesirable materials left	X		X	X		X	X								
1.1.03.01.0A	Error in waste emplacement	X	X		X											X
1.1.03.01.0B	Error in backfill emplacement		X													
1.1.04.01.0A	Incomplete closure						X				X					
1.1.05.00.0A	Records and markers for the repository														X	
1.1.07.00.0A	Repository design	X	X	X	X		X				X					
1.1.08.00.0A	Inadequate quality control and deviations from design	X	X	X	X											
1.1.09.00.0A	Schedule and planning															X
1.1.10.00.0A	Administrative control of the repository site															X
1.1.11.00.0A	Monitoring of the repository															X
1.1.12.01.0A	Accidents and unplanned events during construction and operation	X	X		X											
1.1.13.00.0A	Retrievability	X	X													
1.2.01.01.0A	Tectonic activity - large scale															X
1.2.02.01.0A	Fractures		X			X	X		X							
1.2.02.02.0A	Faults						X	X	X	X						
1.2.02.03.0A	Fault displacement damages engineered barrier system components		X													X
1.2.03.02.0A	Seismic ground motion damages engineered barrier system components		X		X											X
1.2.03.02.0B	Seismic-induced rockfall damages engineered barrier system components		X													X
1.2.03.02.0C	Seismic-induced drift collapse damages engineered barrier system components		X		X											X
1.2.03.02.0D	Seismic-induced drift collapse alters in-drift thermohydrology		X	X	X		X									X
1.2.03.02.0E	Seismic-induced drift collapse alters in-drift chemistry		X	X	X		X									X
1.2.03.03.0A	Seismicity associated with igneous activity															X

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
1.2.04.02.0A	Igneous activity changes rock properties		X				X	X	X	X	X					
1.2.04.03.0A	Igneous intrusion into repository		X								X					X
1.2.04.04.0A	Igneous intrusion interacts with engineered barrier system components	X	X	X	X						X					
1.2.04.04.0B	Chemical effects of magma and magmatic volatiles	X	X		X						X					
1.2.04.05.0A	Magma or pyroclastic base surge transports waste										X	X				X
1.2.04.06.0A	Eruptive conduit to surface intersects repository		X								X	X				
1.2.04.07.0A	Ashfall												X	X	X	X
1.2.04.07.0B	Ash redistribution in groundwater													X	X	X
1.2.04.07.0C	Ash redistribution via soil and sediment transport											X		X	X	
1.2.05.00.0A	Metamorphism															X
1.2.06.00.0A	Hydrothermal activity			X			X		X	X						
1.2.07.01.0A	Erosion/denudation					X								X	X	
1.2.07.02.0A	Deposition					X								X		
1.2.08.00.0A	Diagenesis					X										
1.2.09.00.0A	Salt diapirism and dissolution															X
1.2.09.01.0A	Diapirism															X
1.2.09.02.0A	Large-scale dissolution						X	X	X	X						
1.2.10.01.0A	Hydrological response to seismic activity					X	X		X							X
1.2.10.02.0A	Hydrologic response to igneous activity					X	X		X							X
1.3.01.00.0A	Climate change					X	X	X	X	X			X	X	X	
1.3.04.00.0A	Periglacial effects					X								X	X	
1.3.05.00.00A	Glacial and ice sheet effects					X							X	X	X	
1.3.07.01.0A	Water table decline								X	X			X		X	
1.3.07.02.0A	Water table rise affects saturated zone								X	X			X		X	
1.3.07.02.0B	Water table rise affects unsaturated zone						X	X								
1.4.01.00.0A	Human influences on climate					X							X		X	
1.4.01.01.0A	Climate modification increases recharge					X	X						X		X	
1.4.01.02.0A	Greenhouse gas effects					X									X	
1.4.01.03.0A	Acid rain					X									X	
1.4.01.04.0A	Ozone layer failure					X									X	
1.4.02.01.0A	Deliberate human intrusion															X
1.4.02.02.0A	Inadvertent human intrusion															X
1.4.02.03.0A	Igneous event precedes human intrusion															X
1.4.02.04.0A	Seismic event precedes human intrusion															X
1.4.03.00.0A	Unintrusive site investigation															X
1.4.04.00.0A	Drilling activities (human intrusion)															X
1.4.04.01.0A	Effects of drilling intrusion															X
1.4.05.00.0A	Mining and other underground activities (human intrusion)															X

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
1.4.06.01.0A	Altered soil or surface water chemistry			X						X					X	
1.4.07.01.0A	Water management activities								X	X			X	X	X	
1.4.07.02.0A	Wells								X				X		X	
1.4.07.03.0A	Recycling of accumulated radionuclides from soil to groundwater														X	
1.4.08.00.0A	Social and institutional developments												X	X	X	
1.4.09.00.0A	Technological developments												X	X	X	
1.4.11.00.0A	Explosions and crashes (human activities)													X		X
1.5.01.01.0A	Meteorite impact													X	X	X
1.5.01.02.0A	Extraterrestrial events														X	X
1.5.02.00.0A	Species evolution														X	
1.5.03.01.0A	Changes in the Earth's magnetic field															X
1.5.03.02.0A	Earth tides								X							
2.1.01.01.0A	Waste inventory				X						X		X	X		
2.1.01.02.0A	Interactions between co-located waste	X		X	X											
2.1.01.02.0B	Interactions between co-disposed waste	X		X	X											
2.1.01.03.0A	Heterogeneity of waste inventory				X											
2.1.01.04.0A	Repository-scale spatial heterogeneity of emplaced waste	X			X											
2.1.02.01.0A	Defense spent nuclear fuel degradation (alteration, dissolution, and radionuclide release)			X	X											
2.1.02.02.0A	Commercial spent nuclear fuel degradation (alteration, dissolution, and radionuclide release)			X	X											
2.1.02.03.0A	High-level waste glass degradation (alteration, dissolution, and radionuclide release)			X	X											
2.1.02.04.0A	Alpha recoil enhances dissolution				X											
2.1.02.05.0A	High-level waste glass cracking				X											
2.1.02.06.0A	High-level waste glass recrystallization				X											
2.1.02.07.0A	Radionuclide release from gap and grain boundaries				X											
2.1.02.08.0A	Pyrophoricity from defense spent nuclear fuel			X	X											
2.1.02.09.0A	Chemical effects of void space in waste package			X	X											
2.1.02.10.0A	Organic/cellulosic materials in waste			X	X											
2.1.02.11.0A	Degradation of cladding from waterlogged rods				X											
2.1.02.12.0A	Degradation of cladding prior to disposal				X											
2.1.02.13.0A	General corrosion of cladding				X											
2.1.02.14.0A	Microbially influenced corrosion (MIC) of cladding				X											
2.1.02.15.0A	Localized (radiolysis enhanced) corrosion of cladding				X											
2.1.02.16.0A	Localized (pitting) corrosion of cladding				X											
2.1.02.17.0A	Localized (crevice) corrosion of cladding				X											
2.1.02.18.0A	Enhanced corrosion of cladding from dissolved silica				X											
2.1.02.19.0A	Creep rupture of cladding				X											
2.1.02.20.0A	Internal pressurization of cladding				X											
2.1.02.21.0A	Stress corrosion cracking (SCC) of cladding				X											

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
2.1.02.22.0A	Hydride cracking of cladding				X											
2.1.02.23.0A	Cladding unzipping				X											
2.1.02.24.0A	Mechanical impact on cladding				X											
2.1.02.25.0A	Defense spent nuclear fuel cladding				X											
2.1.02.25.0B	Naval spent nuclear fuel cladding				X											
2.1.02.26.0A	Diffusion-controlled cavity growth in cladding				X											
2.1.02.27.0A	Localized (fluoride enhanced) corrosion of cladding				X											
2.1.02.28.0A	Grouping of defense spent nuclear fuel waste types into categories				X											
2.1.02.29.0A	Flammable gas generation from defense spent nuclear fuel				X											
2.1.03.01.0A	General corrosion of waste packages	X		X												
2.1.03.01.0B	General corrosion of drip shields	X		X												
2.1.03.02.0A	Stress corrosion cracking (SCC) of waste packages	X	X	X												
2.1.03.02.0B	Stress corrosion cracking (SCC) of drip shields	X	X	X												
2.1.03.03.0A	Localized corrosion of waste packages	X		X												
2.1.03.03.0B	Localized corrosion of drip shields	X		X												
2.1.03.04.0A	Hydride cracking of waste packages	X		X												
2.1.03.04.0B	Hydride cracking of drip shield	X		X												
2.1.03.05.0A	Microbially influenced corrosion (MIC) of waste packages	X		X												
2.1.03.05.0B	Microbially influenced corrosion (MIC) of drip shields	X		X												
2.1.03.06.0A	Internal corrosion of waste packages prior to breach	X		X												
2.1.03.07.0A	Mechanical impact on waste packages		X													
2.1.03.07.0B	Mechanical impact on drip shields		X													
2.1.03.08.0A	Early failure of waste packages	X	X													
2.1.03.08.0B	Early failure of drip shields	X	X													
2.1.03.09.0A	Copper corrosion in engineered barrier system	X														
2.1.03.10.0A	Advection of liquids and solids through cracks in the waste package	X	X	X												
2.1.03.10.0B	Advection of liquids and solids through cracks in the drip shield	X	X	X												
2.1.03.11.0A	Physical form of waste package and drip shield	X	X	X							X					
2.1.04.01.0A	Flow in backfill			X												
2.1.04.02.0A	Chemical properties and evolution of backfill		X	X	X											
2.1.04.03.0A	Erosion or dissolution of backfill		X	X	X											
2.1.04.04.0A	Thermal-mechanical effects of backfill		X								X					
2.1.04.05.0A	Thermal-mechanical properties and evolution of backfill		X	X	X											
2.1.04.09.0A	Radionuclide transport in backfill				X											
2.1.05.01.0A	Flow through seals (access ramps and ventilation shafts)					X										
2.1.05.02.0A	Radionuclide transport through seals					X	X									
2.1.05.03.0A	Degradation of seals					X	X									

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
2.1.06.01.0A	Chemical effects of rock reinforcement and cementitious materials in engineered barrier system		X	X				X								
2.1.06.02.0A	Mechanical effects of rock reinforcement materials in engineered barrier system		X													
2.1.06.04.0A	Flow through rock reinforcement materials in engineered barrier system		X	X			X									
2.1.06.05.0A	Mechanical degradation of emplacement pallet	X	X													
2.1.06.05.0B	Mechanical degradation of invert	X	X		X											
2.1.06.05.0C	Chemical degradation of emplacement pallet	X		X												
2.1.06.05.0D	Chemical degradation of invert		X	X				X								
2.1.06.06.0A	Effects of drip shield on flow	X	X	X												
2.1.06.06.0B	Oxygen embrittlement of drip shields	X	X	X												
2.1.06.07.0A	Chemical effects at engineered barrier system component interfaces	X		X	X											
2.1.06.07.0B	Mechanical effects at engineered barrier system component interfaces	X	X		X											
2.1.07.01.0A	Rockfall		X		X											
2.1.07.02.0A	Drift collapse	X	X	X	X											
2.1.07.04.0A	Hydrostatic pressure on waste package		X													
2.1.07.04.0B	Hydrostatic pressure on drip shield		X													
2.1.07.05.0A	Creep of metallic materials in the waste package		X													
2.1.07.05.0B	Creep of metallic materials in the drip shield		X													
2.1.07.06.0A	Floor buckling	X	X		X											
2.1.08.01.0A	Water influx at the repository						X									
2.1.08.01.0B	Effects of rapid influx into the repository			X												
2.1.08.02.0A	Enhanced influx at the repository						X									
2.1.08.03.0A	Repository dryout due to waste heat						X									
2.1.08.04.0A	Condensation forms on roofs of drift (drift-scale cold traps)			X			X									
2.1.08.04.0B	Condensation forms at repository edges (repository-scale cold traps)			X			X									
2.1.08.05.0A	Flow through invert				X											
2.1.08.06.0A	Capillary effects (wicking) in engineered barrier system			X			X									
2.1.08.07.0A	Unsaturated flow in the engineered barrier system			X	X											
2.1.08.09.0A	Saturated flow in the engineered barrier system			X	X											
2.1.08.11.0A	Repository resaturation due to waste cooling			X			X									
2.1.08.12.0A	Induced hydrologic changes in invert			X	X											
2.1.08.14.0A	Condensation on underside of drip shield			X			X									
2.1.08.15.0A	Consolidation of engineered barrier system components	X	X	X	X											
2.1.09.01.0A	Chemical characteristics of water in drifts			X	X			X								
2.1.09.01.0B	Chemical characteristics of water in waste package			X	X											
2.1.09.02.0A	Chemical interaction with corrosion products			X	X											
2.1.09.03.0A	Volume increase of corrosion products impacts cladding			X	X											
2.1.09.03.0B	Volume increase of corrosion products impacts waste package	X		X	X											

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
2.1.09.03.0C	Volume increase of corrosion products impacts other engineered barrier system components	X	X	X	X											
2.1.09.04.0A	Radionuclide solubility, solubility limits, and speciation in the waste form and engineered barrier system				X											
2.1.09.05.0A	Sorption of dissolved radionuclides in the engineered barrier system				X											
2.1.09.06.0A	Reduction-oxidation potential in waste package	X		X	X											
2.1.09.06.0B	Reduction-oxidation potential in drifts	X		X	X											
2.1.09.07.0A	Reaction kinetics in waste package	X		X	X											
2.1.09.07.0B	Reaction kinetics in waste drifts	X		X	X											
2.1.09.08.0A	Diffusion of dissolved radionuclides in engineered barrier system				X											
2.1.09.08.0B	Advection of dissolved radionuclides in engineered barrier system				X											
2.1.09.09.0A	Electrochemical effects in engineered barrier system	X		X												
2.1.09.10.0A	Secondary phase effects on dissolved radionuclide concentrations				X											
2.1.09.11.0A	Chemical effcts of waste-rock contact			X	X											
2.1.09.12.0A	Rind (chemically altered zone) forms in near field		X	X	X		X	X								
2.1.09.13.0A	Complexation in engineered barrier system			X	X											
2.1.09.15.0A	Formation of true (intrinsic) colloids in engineered barrier system			X	X											
2.1.09.16.0A	Formation of pseudo-colloids (natural) in engineered barrier system			X	X											
2.1.09.17.0A	Formation of pseudo-colloids (corrosion products) in engineered barrier system	X		X	X											
2.1.09.18.0A	Formation of microbial colloid in engineered barrier system			X	X											
2.1.09.19.0A	Sorption of colloids in engineered barrier system			X	X											
2.1.09.19.0B	Advection of colloids in engineered barrier system				X											
2.1.09.20.0A	Filtration of colloids in engineered barrier system				X											
2.1.09.21.0A	Transport of particles larger than colloids in engineered barrier system				X											
2.1.09.21.0B	Transport of particles larger than colloids in saturated zone				X			X		X						
2.1.09.21.0C	Transport of particles larger than colloids in unsaturated zone				X			X								
2.1.09.22.0A	Colloid sorption at the air-water interface				X			X		X						
2.1.09.23.0A	Stability of colloids in engineered barrier system			X	X											
2.1.09.24.0A	Diffusion of colloids in engineered barrier system				X											
2.1.09.25.0A	Formation of colloids (waste-form) by coprecipitation in engineered barrier system			X	X											
2.1.09.26.0A	Gravitational settling of colloids in engineered barrier system				X											
2.1.09.27.0A	Coupled effects on radionuclide transport in engineered barrier system	X	X	X	X											
2.1.09.28.0A	Deliquescence on waste package outer surface	X		X												
2.1.09.28.0B	Deliquescence on drip shield outer surface	X		X												
2.1.10.01.0A	Microbial activity in engineered barrier system	X		X	X											
2.1.11.01.0A	Heat generation in engineered barrier system	X	X	X	X											
2.1.11.02.0A	Non-uniform heat distribution in engineered barrier system	X	X	X	X											
2.1.11.03.0A	Exothermic reactions in engineered barrier system			X	X											
2.1.11.05.0A	Thermal expansion/stress of in-package engineered barrier system components	X	X		X											

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)																
Tracking No	**FEP Title**	**ENG1**	**ENG2**	**ENG3**	**ENG4**	**UZ1**	**UZ2**	**UZ3**	**SZ1**	**SZ2**	**Dir1**	**Dir2**	**Dos1**	**Dos2**	**Dos3**	**TSPAI**
2.1.11.06.0A	Thermal sensitization of waste packages	X	X													
2.1.11.06.0B	Thermal sensitization of drip shields	X	X													
2.1.11.07.0A	Thermally expansion/stress of in-drift engineered barrier system components		X	X	X											
2.1.11.08.0A	Thermal effects on chemistry and microbial activity in engineered barrier system			X												
2.1.11.09.0A	Thermal effects on flow in the engineered barrier system			X			X									
2.1.11.09.0B	Thermally-driven flow (convection) in waste packages			X	X											
2.1.11.09.0C	Thermally-driven flow (convection) in drifts			X			X									
2.1.11.10.0A	Thermal effects on transport in engineered barrier system				X											
2.1.12.01.0A	Gas generation (repository pressurization)	X		X	X											
2.1.12.02.0A	Gas generation (He) from waste form decay			X	X											
2.1.12.03.0A	Gas generation (H2) from waste package corrosion	X		X												
2.1.12.04.0A	Gas generation (CO2, CH4, H2S) from microbial degradation	X		X	X											
2.1.12.06.0A	Gas transport in engineered barrier system	X		X	X											
2.1.12.07.0A	Effects of radioactive gases in engineered barrier system				X											
2.1.12.08.0A	Gas explosions in engineered barrier system	X		X	X											
2.1.13.01.0A	Radiolysis	X		X	X											
2.1.13.02.0A	Radiation damage in engineered barrier system	X	X	X	X											
2.1.13.03.0A	Radiological mutation of microbes	X		X	X											
2.1.14.15.0A	In-package criticality (intact configuration)				X											X
2.1.14.16.0A	In-package criticality (degraded configurations)				X											X
2.1.14.17.0A	Near-field criticality				X											X
2.1.14.18.0A	In-package criticality resulting from a seismic event (intact configuration)				X											X
2.1.14.19.0A	In-package criticality resulting from a seismic event (degraded configurations)				X											X
2.1.14.20.0A	Near-field criticality resulting from a seismic event				X											X
2.1.14.21.0A	In-package criticality resulting from rockfall (intact configuration)		X		X											X
2.1.14.22.0A	In-package criticality resulting from rockfall (degraded configurations)		X		X											X
2.1.14.23.0A	Near-field criticality resulting from rockfall		X		X											X
2.1.14.24.0A	In-package criticality resulting from an igneous event (intact configuration)				X											X
2.1.14.25.0A	In-package criticality resulting from an igneous event (degraded configurations)				X											X
2.1.14.26.0A	Near-field criticality resulting from an igneous event				X											X
2.2.01.01.0A	Mechanical effects of excavation and construction in the near field		X				X				X					
2.2.01.01.0B	Chemical effects of excavation and construction in the near field			X			X	X								
2.2.01.02.0A	Thermally-induced stress changes in the near-field		X				X	X								
2.2.01.02.0B	Chemical changes in the near field from backfill		X				X	X								
2.2.01.03.0A	Changes in fluid saturations in the excavation disturbed zone		X	X			X									
2.2.01.04.0A	Elemental solubility in excavation disturbed zone				X											
2.2.01.05.0A	Radionuclide transport in the excavation disturbed zone				X			X								
2.2.03.01.0A	Stratigraphy					X	X	X	X	X	X					

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)																
Tracking No	**FEP Title**	**ENG1**	**ENG2**	**ENG3**	**ENG4**	**UZ1**	**UZ2**	**UZ3**	**SZ1**	**SZ2**	**Dir1**	**Dir2**	**Dos1**	**Dos2**	**Dos3**	**TSPAI**
2.2.03.02.0A	Rock properties of host rock and other units		X			X	X	X	X	X						
2.2.06.01.0A	Seismic activity changes porosity and permeability of rock						X	X	X							X
2.2.06.02.0A	Seismic activity changes porosity and permeability of faults						X		X							X
2.2.06.02.0B	Seismic activity changes porosity and permeability of fractures						X	X	X							X
2.2.06.03.0A	Seismic activity alters perched water zones						X									X
2.2.06.04.0A	Effects of subsidence						X									
2.2.06.05.0A	Salt creep															X
2.2.07.01.0A	Locally saturated flow at bedrock/alluvium contact					X										
2.2.07.02.0A	Unsaturated ground water flow in geosphere					X	X									
2.2.07.03.0A	Capillary rise in the unsaturated zone						X									
2.2.07.04.0A	Focusing of unsaturated flow (fingers, weeps)					X	X									
2.2.07.05.0A	Flow in the unsaturated zone from episodic infiltration					X	X									
2.2.07.06.0A	Episodic or pulse release from repository				X		X									
2.2.07.06.0B	Long-term release of radionuclides from the repository				X			X		X			X			
2.2.07.07.0A	Perched water develops						X	X								
2.2.07.08.0A	Fracture flow in the unsaturated zone						X	X								
2.2.07.09.0A	Matrix imbibition in the unsaturated zone						X									
2.2.07.10.0A	Condensation zone forms around drifts			X			X									
2.2.07.11.0A	Resaturation of geosphere dryout zone			X			X									
2.2.07.12.0A	Saturated ground water flow in the geosphere								X				X			
2.2.07.13.0A	Water-conducting features in the saturated zone								X	X			X			
2.2.07.14.0A	Chemically-induced density effects on ground water flow								X	X			X			
2.2.07.15.0A	Advection and dispersion in the saturated zone								X	X			X			
2.2.07.15.0B	Advection and dispersion in the unsaturated zone						X	X								
2.2.07.16.0A	Dilution of radionuclides in ground water								X	X			X			
2.2.07.17.0A	Diffusion in the saturated zone									X			X			
2.2.07.18.0A	Film flow into the repository			X			X									
2.2.07.19.0A	Lateral flow from Solitario Canyon fault enters drifts						X									
2.2.07.20.0A	Flow diversion around repository drifts						X									
2.2.07.21.0A	Drift shadow forms below repository						X									
2.2.08.01.0A	Chemical characteristics of groundwater in saturated zone								X	X			X	X	X	
2.2.08.01.0B	Chemical characteristics of groundwater in unsaturated zone			X				X						X	X	
2.2.08.03.0A	Geochemical interactions and evolution in the saturated zone								X	X						
2.2.08.03.0B	Geochemical interactions and evolution in the unsaturated zone						X	X								
2.2.08.04.0A	Re-dissolution of precipitates directs more corrosive fluids to waste packages			X			X									
2.2.08.05.0A	Diffusion in the unsaturated zone							X								
2.2.08.06.0A	Complexation in the saturated zone									X			X		X	
2.2.08.06.0B	Complexation in the unsaturated zone							X		X						

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
2.2.08.07.0A	Radionuclide solubility limits in the saturated zone									X			X			
2.2.08.07.0B	Radionuclide solubility limits in the unsaturated zone							X						X		
2.2.08.07.0C	Radionuclide solubility limits in the biosphere														X	
2.2.08.08.0A	Matrix diffusion in the saturated zone								X	X						
2.2.08.08.0B	Matrix diffusion in the unsaturated zone						X	X								
2.2.08.09.0A	Sorption in the saturated zone									X						
2.2.08.09.0B	Sorption in the unsaturated zone							X								
2.2.08.10.0A	Colloidal transport in the saturated zone									X			X		X	
2.2.08.10.0B	Colloidal transport in the unsaturated zone							X		X						
2.2.08.11.0A	Groundwater discharge to surface with the reference biosphere												X	X	X	
2.2.08.12.0A	Chemistry of water flowing into the drift			X												
2.2.08.12.0B	Chemistry of water flowing into the waste package	X		X												
2.2.09.01.0A	Microbial activity in the saturated zone								X	X						
2.2.09.01.0B	Microbial activity in the unsaturated zone						X	X								
2.2.10.01.0A	Repository-induced thermal effects on flow in the unsaturated zone			X		X	X	X								
2.2.10.02.0A	Thermal convection cell develops in saturated zone								X	X						
2.2.10.03.0A	Natural geothermal effects on flow in the saturated zone								X							
2.2.10.03.0B	Natural geothermal effects on flow in the unsaturated zone						X									
2.2.10.04.0A	Thermo-mechanical stresses alter characteristics of fractures near repository		X	X			X									
2.2.10.04.0B	Thermo-mechanical stresses alter characteristics of faults near repository		X	X			X			X						
2.2.10.05.0A	Thermo-mechanical stresses alter characteristics of rocks above and below the repository		X	X		X	X									
2.2.10.06.0A	Thermo-chemical alteration in the unsaturated zone (solubility, speciation, phase changes, precipitation/dissolution)			X				X								
2.2.10.07.0A	Thermo-chemical alteration of the Calico Hills unit						X	X								
2.2.10.08.0A	Thermo-chemical alteration in the saturated zone (solubility, speciation, phase changes, precipitation/dissolution)								X	X						
2.2.10.09.0A	Thermo-chemical alteration of the Topopah Spring basal vitrophyre						X	X								
2.2.10.10.0A	Two-phase bouyant flow/heat pipes						X									
2.2.10.11.0A	Natural air flow in unsaturated zone					X	X									
2.2.10.12.0A	Geosphere dry-out due to waste heat					X	X									
2.2.10.13.0A	Repository-induced thermal effects on flow in the saturated zone								X							
2.2.10.14.0A	Mineralogic dehydration reactions		X				X	X								
2.2.11.01.0A	Gas effects in the saturated zone						X		X	X						
2.2.11.02.0A	Gas effects in the unsaturated zone						X	X	X							
2.2.11.03.0A	Gas transport in geosphere			X			X	X		X						
2.2.12.00.0A	Undetected features in the unsaturated zone					X	X	X								
2.2.12.00.0B	Undetected features in the saturated zone								X	X			X			
2.2.14.09.0A	Far-field criticality				X			X		X						X

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
2.2.14.10.0A	Far-field criticality resulting from a seismic event				X			X		X						X
2.2.14.11.0A	Far-field criticality resulting from rockfall				X											X
2.2.14.12.0A	Far-field criticality resulting from an igneous event				X			X		X						X
2.3.01.00.0A	Topography and morphology					X					X			X		
2.3.02.01.0A	Soil type													X	X	
2.3.02.02.0A	Radionuclide accumulation in soils											X	X	X	X	
2.3.02.03.0A	Soil and sediment transport in the biosphere													X	X	
2.3.04.01.0A	Surface water transport and mixing													X	X	
2.3.06.00.0A	Marine features													X	X	
2.3.09.01.0A	Animal burrowing/intrusion														X	
2.3.11.01.0A	Precipitation					X								X	X	
2.3.11.02.0A	Surface runoff and flooding					X								X	X	
2.3.11.03.0A	Infiltration and recharge					X								X	X	
2.3.11.04.0A	Ground water discharge to surface outside the reference biosphere								X						X	
2.3.13.01.0A	Biosphere characteristics												X	X	X	
2.3.13.02.0A	Radionuclide alteration during biosphere transport														X	
2.3.13.03.0A	Effects of repository heat on biosphere					X										
2.3.13.04.0A	Radionuclde release outside the reference biosphere											X		X	X	
2.4.01.00.0A	Human characteristics (physiology, metabolism)														X	
2.4.04.01.0A	Human lifestyle												X	X	X	
2.4.07.00.0A	Dwellings														X	
2.4.08.00.0A	Wild and natural land and water use												X	X	X	
2.4.09.01.0A	Implementation of new agricultural practices or land use												X	X	X	
2.4.09.01.0B	Agricultural land use and irrigation												X	X	X	
2.4.09.02.0A	Animal farms and fisheries												X	X	X	
2.4.10.00.0A	Urban and industrial land and water use												X	X	X	
3.1.01.01.0A	Radioactive decay and ingrowth				X			X		X	X		X	X	X	
3.2.07.01.0A	Isotopic dilution							X		X			X	X		
3.2.10.00.0A	Atmospheric transport of contaminants											X		X	X	
3.3.01.00.0A	Contaminated drinking water, foodstuffs and drugs														X	
3.3.02.01.0A	Plant uptake														X	
3.3.02.02.0A	Animal uptake														X	
3.3.02.03.0A	Fish uptake														X	
3.3.03.01.0A	Contaminated non-food products and exposure														X	
3.3.04.01.0A	Ingestion														X	
3.3.04.02.0A	Inhalation														X	
3.3.04.03.0A	External exposure														X	
3.3.05.01.0A	Radiation doses														X	

Table A–1. Classification of Features, Events, and Processes per Integrated Subissue (continued)

Tracking No	FEP Title	ENG1	ENG2	ENG3	ENG4	UZ1	UZ2	UZ3	SZ1	SZ2	Dir1	Dir2	Dos1	Dos2	Dos3	TSPAI
3.3.06.00.0A	Radiological toxicity and effects														X	
3.3.06.01.0A	Repository excavation														X	
3.3.06.02.0A	Sensitization to radiation														X	
3.3.07.00.0A	Non-radiological toxicity and effects														X	
3.3.08.00.0A	Radon and radon daughter exposure														X	

Notations that refer to Integrated Subissues

ENG1 Degradation of engineered barriers
ENG2 Mechanical disruption of engineered barriers
ENG3 Quantity and chemistry of water contacting waste packages and waste forms
ENG4 Radionuclide release rates and solubility limits
UZ1 Climate and infiltration
UZ2 Flow paths in the unsaturated zone
UZ3 Radionuclide transport in the unsaturated zone
SZ1 Flow paths in the saturated zone
SZ2 Radionuclide transport in the unsaturated zone
Dir1 Volcanic disruption of waste packages
Dir2 Airborne transport of radionuclides
Dos1 Representative volume
Dos2 Redistribution of radionuclides in soil
Dos3 Biosphere characteristics