



Used Fuel Disposition Campaign

Features, Events, and Processes (FEPs) Analysis for Radioactive Waste Disposal: Rationale And Application



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■ **FEP Analysis – Rationale**

- Overview
- Considerations

■ **FEP Analysis – Application**

- DOE-NE Used Fuel Disposition (UFD) SNF/HLW Deep Disposal
- DOE-NE Used Fuel Disposition (UFD) LLW Shallow Disposal

Overview – What are FEPs?

■ Feature

- An *object, structure, or condition* that has a potential to affect repository system performance (NRC 2003, Section 3)

■ Event

- A natural or human-caused *phenomenon* that has a potential to affect repository system performance and that occurs during an interval that is short compared to the period of performance (NRC 2003, Section 3)

■ Process

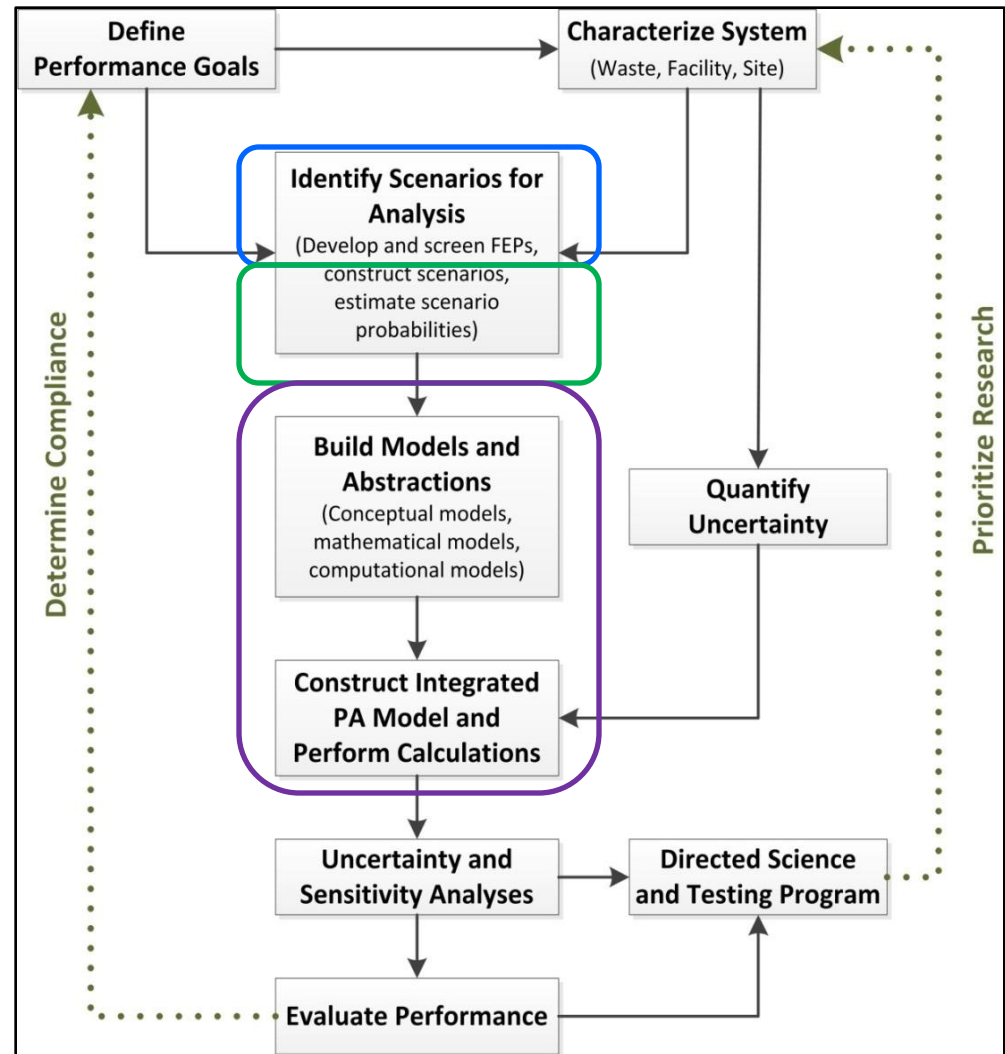
- A natural or human-caused *phenomenon* that has a potential to affect repository system performance and that occurs during all or a significant part of the period of performance (NRC 2003, Section 3)

■ A “FEP” generally encompasses a single phenomenon

- Typically a FEP is a *process or event* acting upon a feature

Overview – What is FEP Analysis?

- Formal FEP analysis for performance assessment (PA) of disposal systems consists of the systematic implementation of the following steps:
 - FEP Identification
 - FEP Screening
- FEP analysis supports:
 - Scenario Development
 - Implementation in a PA Model
- These steps are performed and refined over multiple iterations as part of a broader PA methodology



■ FEP Identification - Comprehensiveness of the FEP List

- Have we thought of everything?
 - A comprehensive set of FEPs (i.e., a FEP List) captures all of the phenomena that are potentially relevant to the long-term performance of a disposal system
 - Formal FEP analysis provides objective evidence that all potentially relevant FEPs have been addressed

■ FEP Screening - Completeness of the PA Model

- Are all important phenomena represented in the PA Model?
 - From the comprehensive set of all potentially relevant FEPs, a subset of important FEPs can be identified that define the range of possible future states (i.e., scenarios) of the disposal system
 - Formal FEP analysis provides a structure to ensure that all important FEPs are captured in the PA model

- Early (mid 1980's) FEP lists were generic
 - IAEA (IAEA 1983)
 - US NRC (Cranwell et al. 1990)
 - NEA (NEA 1992)

- More recent (1990's) project-specific FEP lists and analyses are contained in the NEA FEP Database (NEA 1999, NEA 2006)
 - Canada – AECL (Goodwin et al. 1994)
 - Switzerland – NAGRA (NAGRA 1994)
 - USA – DOE WIPP (DOE 1996)
 - Sweden – SKI and SKB (Chapman et al. 1995; Miller et al. 2002)
 - UK – HMIP (Miller and Chapman 1993)
 - Belgium – SCK-CEN (Bronders et al. 1994)

- Additional project specific FEP lists not contained in the NEA FEP database
 - 1990s (summarized in NEA 1999)
 - Netherlands – ECN/RIVM/RGD (Prij 1993)
 - Spain – ENRESA (ENRESA 1995)
 - 2000s
 - NEA – Clay (Mazurek et al. 2003)
 - South Korea – KAERI (Hwang et al. 2006)
 - USA – DOE YMP (BSC 2005; SNL 2008; Freeze and Swift 2010)
 - USA – DOE NE (Freeze et al. 2010; Freeze et al. 2011)
 - USA – DOE NE (Jones 2011) LLW

■ Comprehensiveness

- Must develop a FEP list that can be demonstrated to cover the entire range of potentially relevant phenomena at a sufficient level of detail
 - *There is some value in starting with an existing or generic FEP list and then trying to enhance the list based on site- and design-specific considerations*
- Comprehensiveness of a FEP list cannot be proven with absolute certainty. However, confidence can be gained through a combination of systematic reviews (both top-down and bottom-up), audits, comparisons with other FEP lists, and examination of multiple categorization schemes.
 - *“... it is impossible to exhaustively identify all possible FEPs and interactions within a complex and evolving system. It is possible, however, to list a range of broadly-defined FEPs that might be relevant to consider in safety assessments. This is the aim of the International FEP List - to be comprehensive in a broad sense rather than in a detailed sense. (NEA 1999)”*

■ Level of Detail

- Must define FEPs at a level of detail that is broad enough to produce a systematically categorized, manageable number of FEPs (a few hundred), yet specific enough to provide the complexity required for screening and/or modeling
 - *“Is it helpful for modeling purposes to include additional FEPs at the next level down, in order to represent this FEP? If the answer is ‘no’, then the [FEP list] can be considered comprehensive at that level.” (Bailey et al. 1998)*
- There is no uniquely correct level of detail at which to define and/or aggregate FEPs. However, bounding cases can be defined:
 - *“too specific” - FEPs are narrowly defined, such that there are many independent FEPs, and it is impractical to develop specific screening decisions and/or submodels for each FEP.*
 - *“too broad” - FEPs are coarsely defined and it is difficult to isolate important issues for each FEP. Consequently, some important issues may get overlooked.*

■ Screening Criteria

- FEPs may be screened out (excluded from PA) by
 - Low probability - probability of occurrence during the time period of concern is less than an established (regulatory) threshold
 - Low consequence - effect (quantitative or qualitative) on a specified performance measure (e.g., dose, subsystem measure) is not measureable/observable/significant during the time period of concern
 - Try to avoid system-wide quantitative measures of significance (e.g., 1% change) – not all FEPs or subsystem domains affect the system equally
 - A FEP will generally have a more significant effect on a subsystem performance measure (e.g., groundwater flow rate, radionuclide sorption) than on a system performance measure (e.g., dose)
 - Subsystem-level effects on system-level performance may be masked by certain designs and/or combinations of input parameter values
 - Regulation - inconsistent or incompatible with the regulations
 - Physical reasonableness - not relevant or applicable to the specific repository design or site

FEP Screening – Considerations

- **FEPs should be evaluated one-by-one against screening criteria**
 - Screening criteria can be considered in any order
 - Screening should consider interactions between FEPs
 - *Risk Dilution: Ensure that FEP level of detail is appropriate and does not minimize importance and/or consequence of interactions*
 - Screening may be more inclusive during early iterations
 - Screening is site-, design-, and regulation-specific
- **If a FEP cannot be excluded, then it must be included**
 - Err on side of inclusion – there is no downside to including a non-important FEP in a PA Model, other than computational / implementation cost
- **Completeness**
 - Must demonstrate that all important FEPs are included in the PA Model
 - *Included FEPs: Are they appropriately included in the model?*
 - *Excluded FEPs: Do they have defensible rationale for exclusion?*

FEP Analysis – Reality?

■ Initiate PA Modeling with a “favored” flow and transport code

- Included FEPs
 - *processes that are “inherent” in the code*
 - *processes that can be approximated by input parameter manipulation*
- Excluded FEPs
 - *none (or a few) documented*
- Comprehensiveness of FEP List
 - *Can’t be demonstrated*
- Completeness of PA Model
 - *Can’t be demonstrated, even though it may be an accurate and precise solution of the code capabilities as applied to the “inherent” conceptual model*

■ Perform formal FEP analysis to guide the next PA iteration

- Supports demonstration of comprehensiveness of FEP list
- Supports demonstration of completeness of PA model
 - *Confirms adequacy of capabilities in “favored” code*
 - *Identifies new FEPs to be implemented through alternate code, code modification, and/or parameter adjustment*

- **Application of NEA FEPs for SNF and HLW to:**
 - DOE-NE Used Fuel Disposition (UFD) SNF/HLW Deep Disposal
 - DOE-NE Used Fuel Disposition (UFD) LLW Shallow Disposal

■ NEA FEP list is the basis for many SNF/HLW FEP lists

- *comprehensive NEA FEP list from NEA FEP database (NEA 2006) contains ~2000 FEPs from 10 international programs in 6 countries*

■ Yucca Mountain Project (YMP) list = 374 FEPs (SNL 2008)

- *~400 site- and design-specific phenomena considered in addition to ~2000 NEA FEPs*
- *NEA list contains many duplicate or redundant FEPs – e.g., same FEP listed in each of the 10 programs*
- *Categorization identified additional NEA FEPs that could be combined*

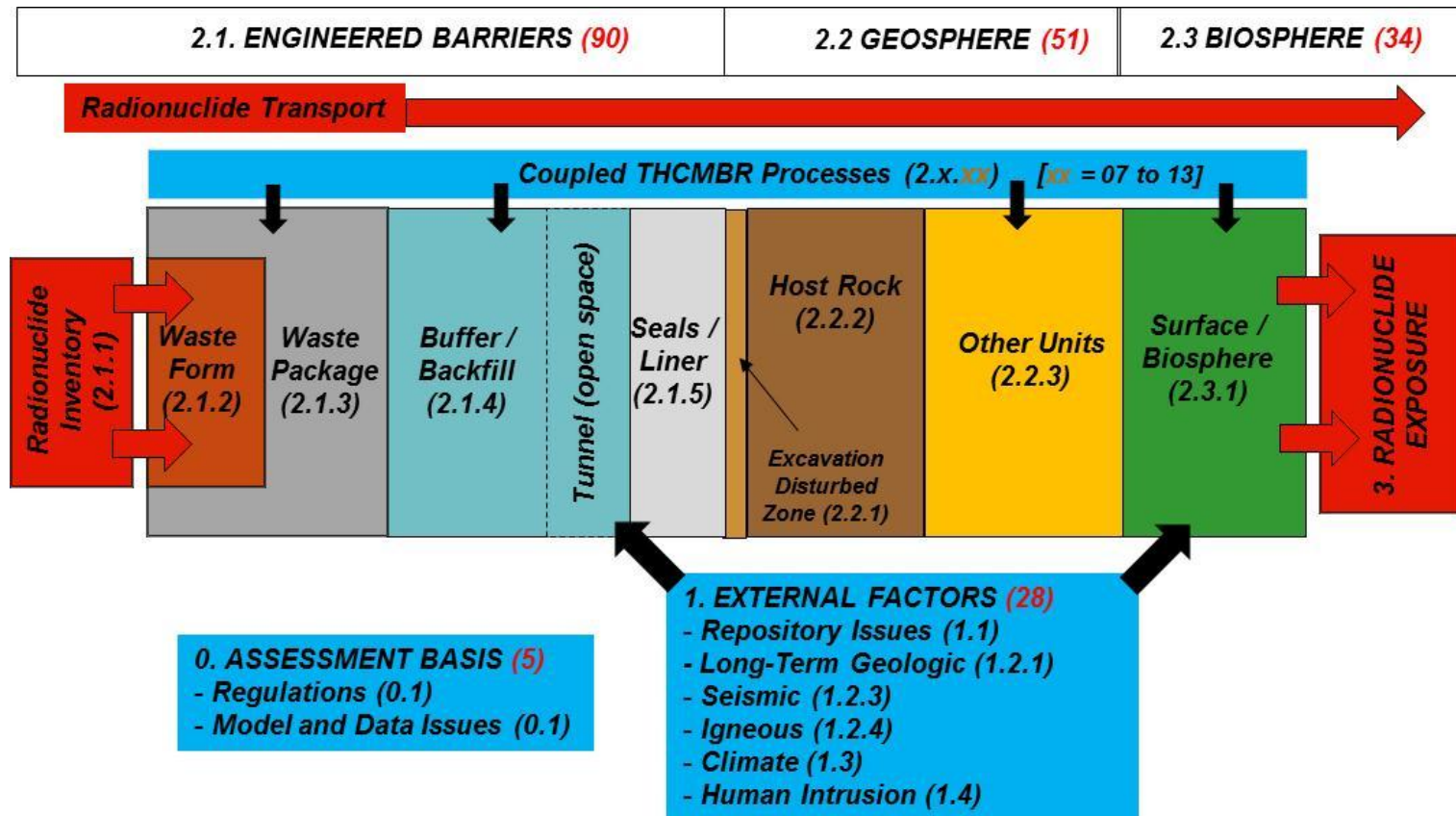
■ Preliminary UFD SNF/HLW list = 208 FEPs (Freeze et al. 2010, 2011)

- *Site- and design-specific YMP FEP list provides initial basis for generic UFD FEP list applicable to a range of disposal options*
- *Initial development (first iteration) of generic details results in smaller number of broader FEPs*

Used Fuel Disposition

Demonstration – SNF/HLW FEP Identification

- NEA hierarchical numbering system used to categorize 208 UFD FEPs by physical domains, features, processes, and external factors/events
- Generic system components applicable to range of deep disposal systems



Used Fuel Disposition

Demonstration – SNF/HLW FEP Identification

UFD key phenomena



■ Preliminary UFD FEPs – Example Listing for 1 of the 208 FEPs

- Broad description of FEP provided in the “Description” column
- Additional FEP detail provided in the “Associated Processes” column
- Traceability and comprehensiveness provided by the “Related FEP Number” and “Domain” columns
- Screening Decision is dependent on Disposal Option

UFD FEP Number	Description	Associated Processes	Related FEP Number	Domain	Disposal Options	Screening Decision
2.1.08.06	Alteration and Evolution of EBS Flow Pathways	<ul style="list-style-type: none"> - Drift collapse - Degradation/consolidation of EBS components - Plugging of flow pathways - Formation of corrosion products - Water ponding <p>[see also Evolution of Flow Pathways in WPs in 2.1.03.08, Evolution of Backfill in 2.1.04.01, Drift Collapse in 2.1.07.02, and Mechanical Degradation of EBS in 2.1.07.10]</p>	2.1.08.12.0A 2.1.08.15.0A 2.1.03.10.0A 2.1.03.11.0A 2.1.09.02.0A	EBS (FLOW)		

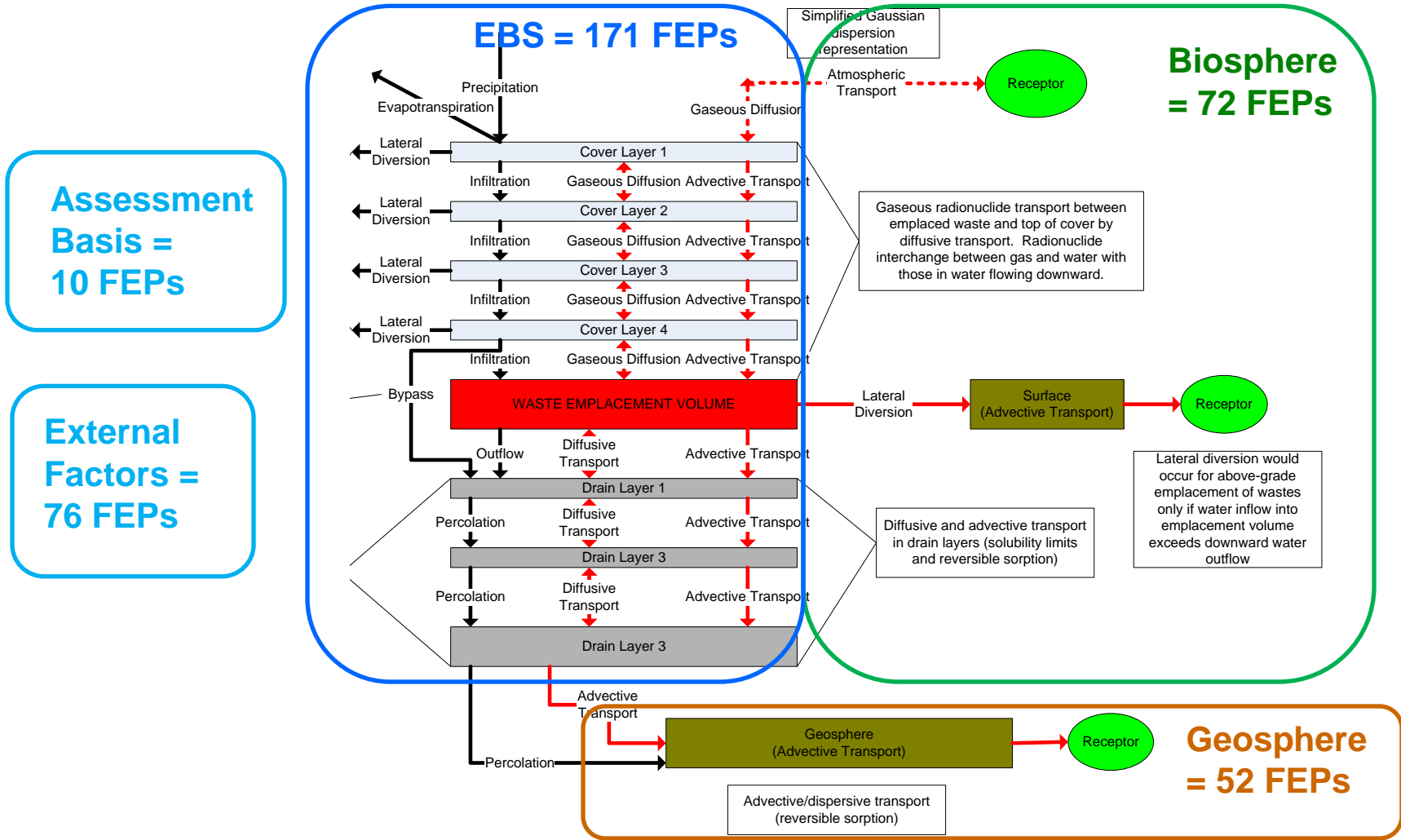
■ UFD LLW FEP list (Jones 2011)

- Shallow (< 100 m depth) disposal concepts
 - *Near Surface Facility*
 - *Intermediate Depth Borehole*

- FEP sources (1194 total FEPs)
 - *UFD SNF/HLW FEPs (Freeze et al. 2011)*
 - *IAEA Co-ordinated Research Project (IAEA 2004)*
 - *Greater Confinement Disposal Facility (Guzowski et al. 1993)*
 - *Ontario Power Generation (OPG) Deep Geologic Repository for Low and Intermediate Level Waste (Garisto, et al. 2009)*
 - *SNF/HLW Deep Borehole Disposal (Brady et al. 2009)*
 - *Drigg Low Level Waste Repository (Phifer 2011)*

Demonstration – LLW FEP Identification

■ Preliminary UFD LLW list = 381 FEPs



■ Preliminary UFD LLW list = 381 FEPs

- More LLW FEPs (381 as compared to 208 for SNF/HLW) generally due to greater level of detail. Specific differences are:
 - **External Factors**
 - more LLW FEPs related to surficial events and processes (e.g., subsidence, erosion) and human intrusion
 - **EBS**
 - more LLW FEPs related to additional EBS components - engineered covers, disposal units (e.g., concrete vaults), underlying layers (e.g., drains, geomembranes, etc.)
 - more LLW FEPs related to proximity of EBS to surface - interactions with surficial processes, radionuclide releases to surface
 - **Biosphere**
 - more LLW FEPs related to surficial transport

- **Preliminary screening of 381 LLW FEPs for 2 generic designs (near surface and borehole)**
 - Excluded = 189
 - Low probability - qualitative
 - Low consequence - qualitative
 - Regulation – anticipated 10 CFR 61
 - Physical reasonableness - not relevant to near surface or borehole disposal
 - Not applicable to a generic model – site and/or design specific
 - Included = 192
 - Priority for implementation in LLW disposal PA model
 - Near-term (simple implementation)
 - Longer-term (complex implementation)

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