Used Fuel Disposition Campaign

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

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Outline

- **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?

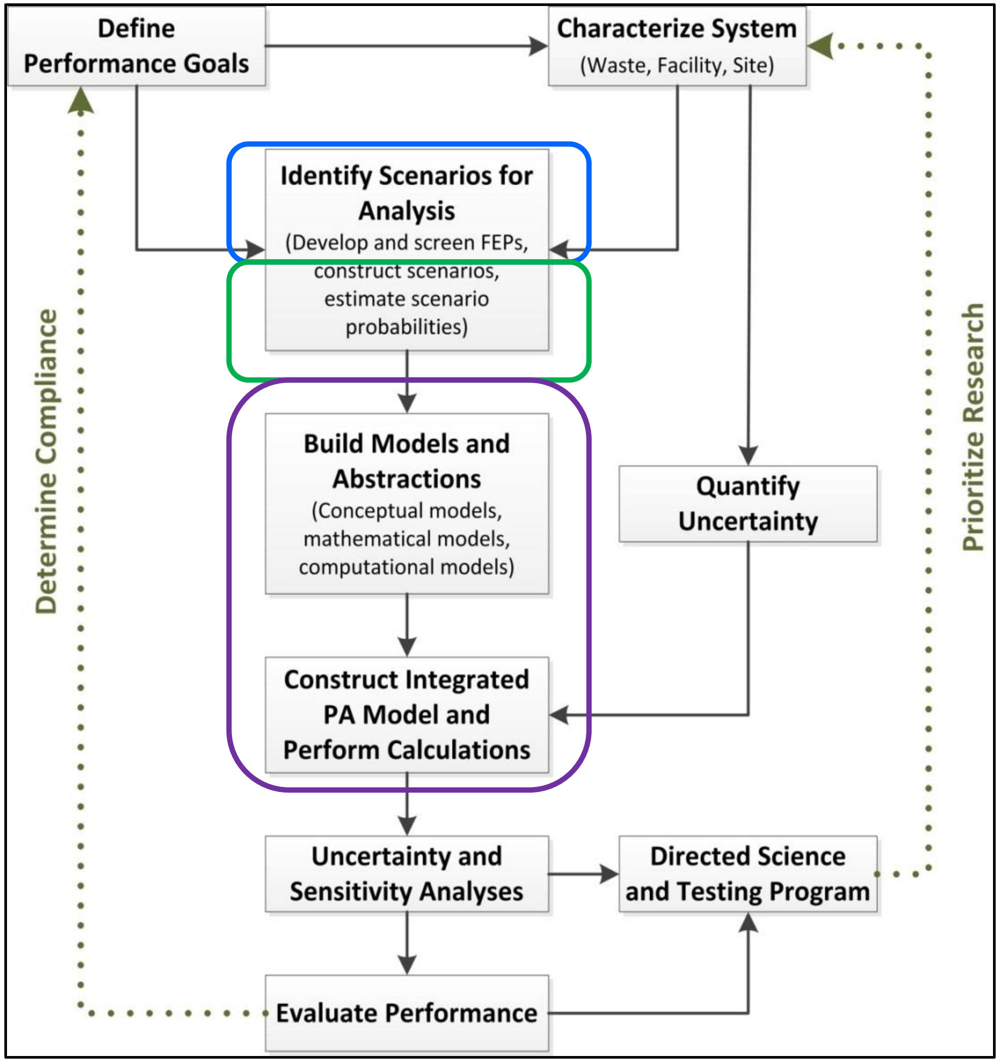
- **Feature**
  - An *object, structure, or condition* that has a potential to affect repository system performance (NRC 2003, Section 3)
- **Event**
  - A natural or human-caused *phenomenon* that has a potential to affect repository system performance and that occurs <u>during an interval that is short</u> 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 <u>during all or a significant part</u> of the period of performance (NRC 2003, Section 3)
- **A "FEP" generally encompasses a single phenomenon**
  - Typically a FEP is a *process* or *event* <u>acting upon</u> 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



Formal FEP Analysis - Objectives

- **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

FEP Analysis - History

- 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)

FEP Analysis - History

- 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

FEP Identification – Considerations

- **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)"*

FEP Identification – Considerations

- **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.*

FEP Screening – Considerations

- **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 <u>important</u> FEPs are <u>included</u> 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*

Demonstration

- **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

Demonstration – SNF/HLW FEP Identification

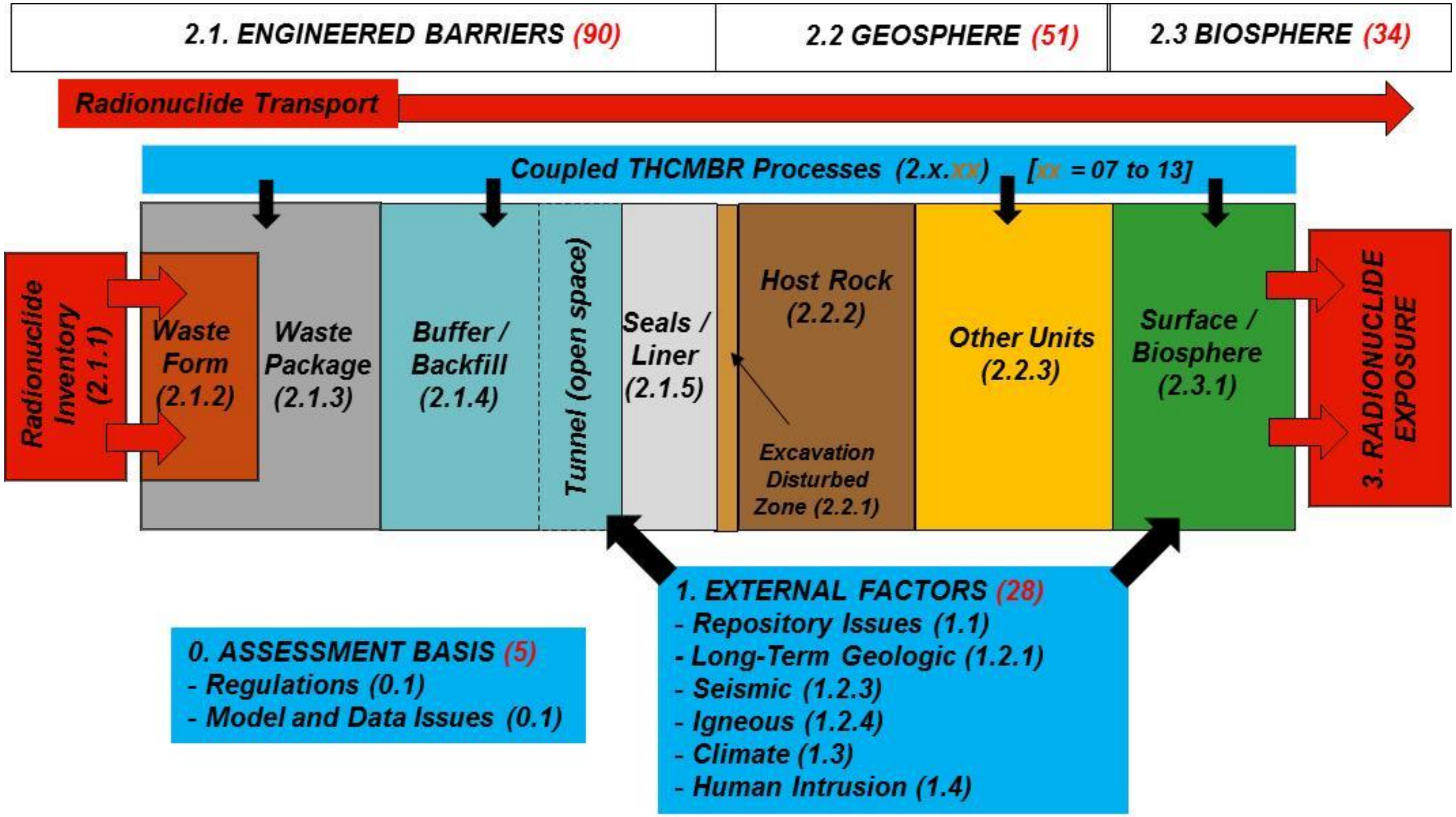
- **NEA FEP list is the basis for many SNF/HLW FEP lists**
  - *comprehensive NEA FEP list from NEA FEP database (NEA 2006) contains ~2000 FEPs from 10 international programs in 6 countries*

- **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*

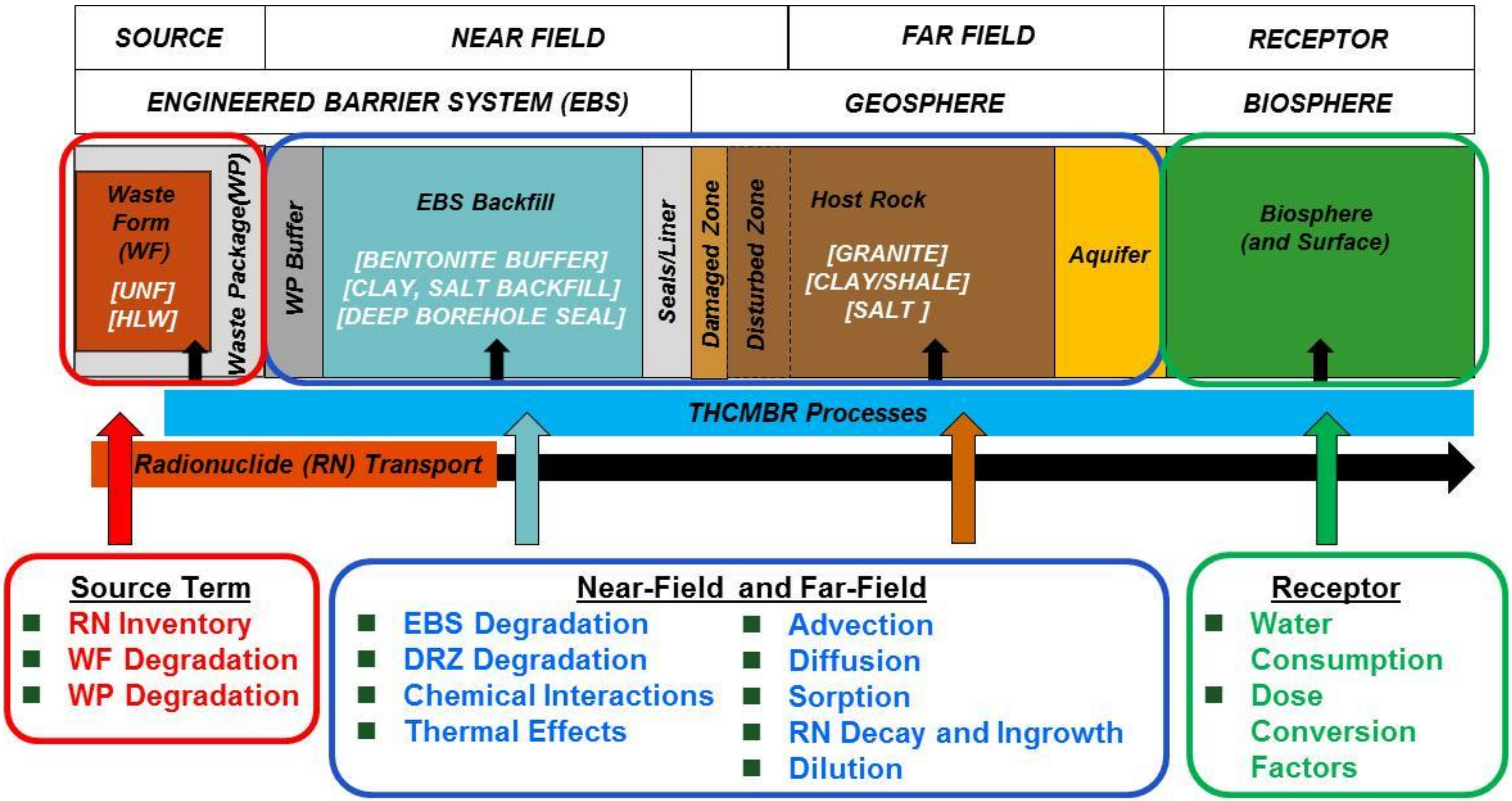
Demonstration – SNF/HLW FEP Identification

- 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



Demonstration – SNF/HLW FEP Identification

- UFD key phenomena



Demonstration – SNF/HLW FEP Identification

- **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	- Drift collapse - Degradation/consolidation of EBS components - Plugging of flow pathways - Formation of corrosion products - Water ponding [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]	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)		

Demonstration – LLW FEP Identification

- **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)*

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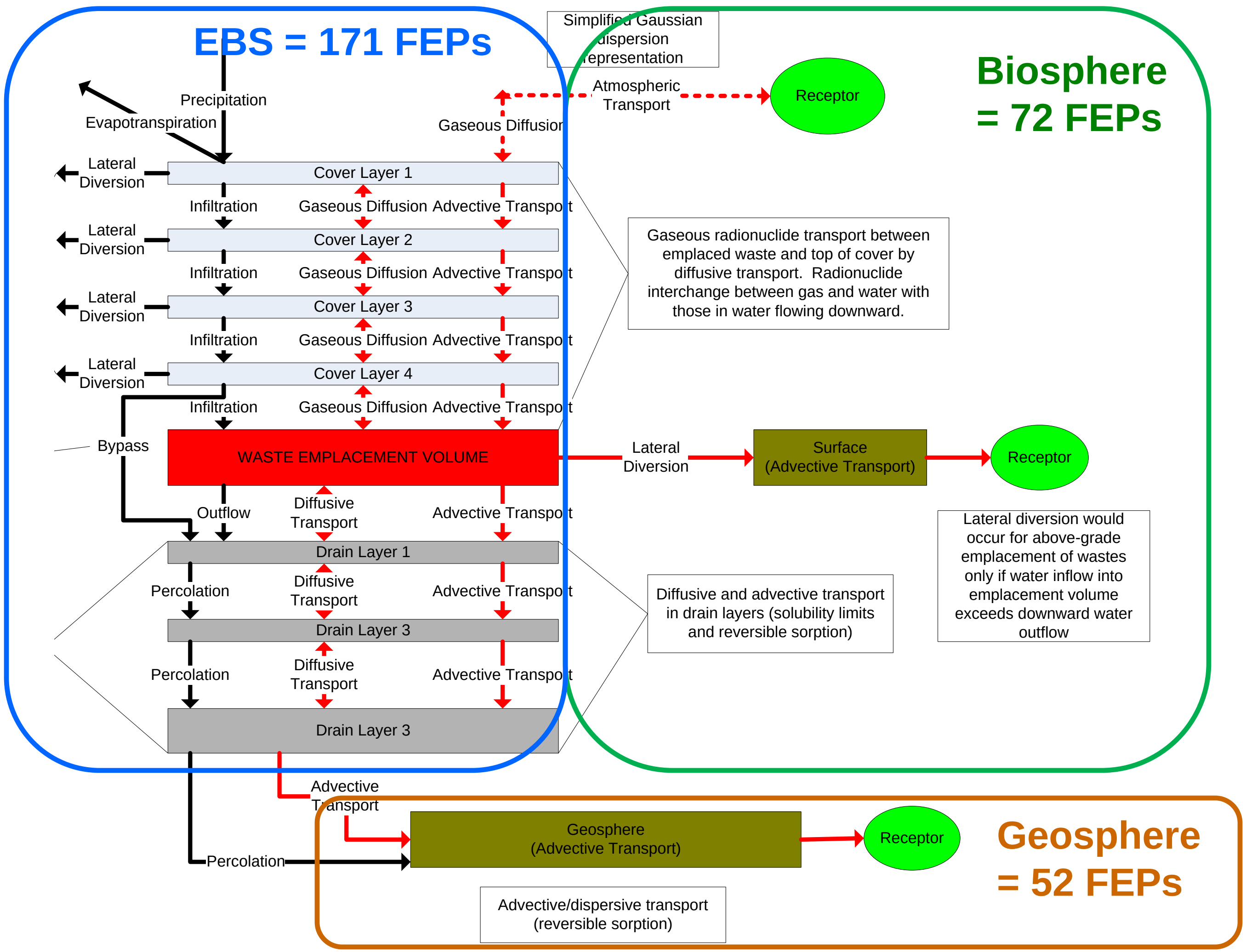
Demonstration – LLW FEP Identification

- **Preliminary UFD LLW list = 381 FEPs**

Assessment Basis = 10 FEPs

External Factors = 76 FEPs



Demonstration – LLW FEP Identification

- **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

Demonstration – LLW FEP Screening

- **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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