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Practical Considerations for Feature, Event, and Process (FEP) Analysis

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Performance and Risk Assessment Community of Practice (P&RA CoP) Webinar

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Outline

- **FEP Analysis Overview**
  - FEP analysis supplements scenario development, PA modeling, and the safety case
  - FEP analysis for Deep Geologic Disposal of Spent Nuclear Fuel (SNF) and High-Level Radioactive Waste (HLW)
  - FEP Analysis for Near Surface Disposal of Low-Level Waste (LLW) and Intermediate Level Waste (ILW)

- **FEP Analysis Approaches**
  - Traditional Bottom-Up
  - Top-Down, Bottom-Up for LLW/ILW Disposal

What is a FEP?

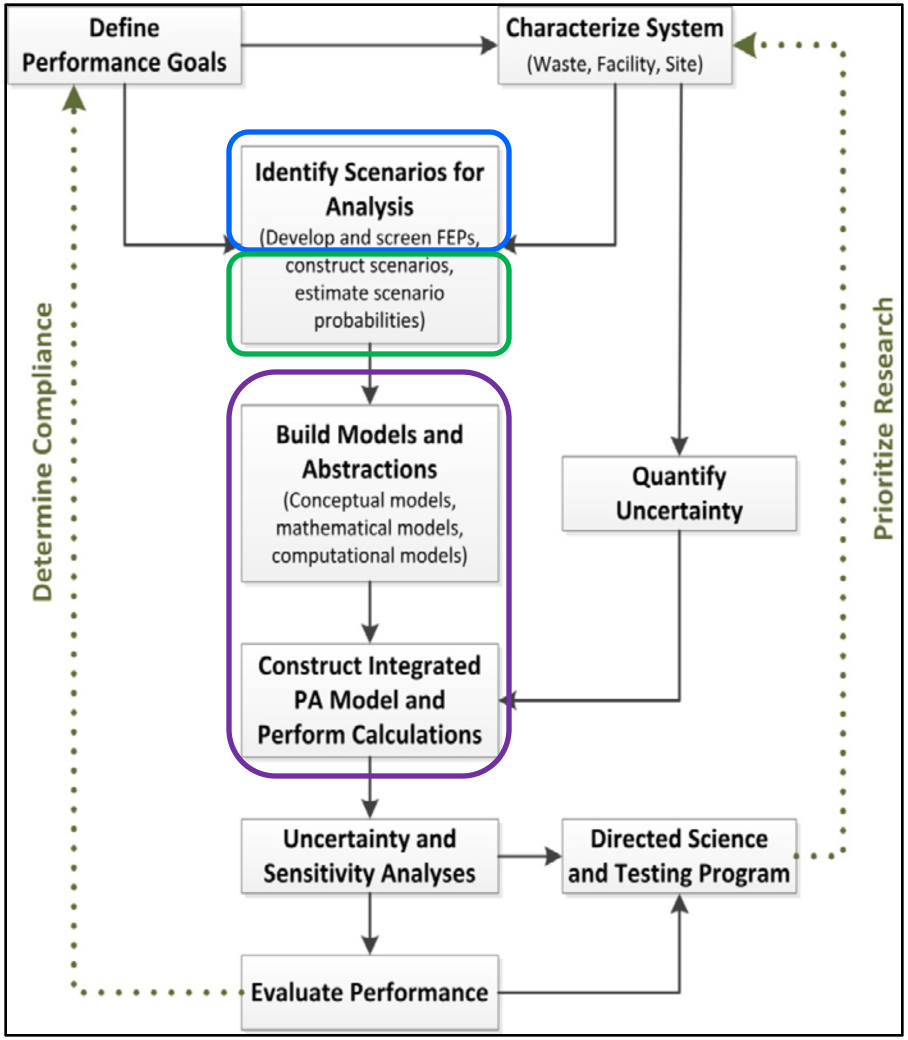
- **Feature**
  - An *object, structure, or condition* that has a potential to affect repository system performance (NRC 2003, Section 3)
- **Event**
  - A natural or human-caused *phenomenon* that has a potential to affect repository system performance and that occurs <u>during an interval that is short</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**
  - A repository is comprised of engineered and natural *features*
  - A FEP typically is a *process* or *event* <u>acting upon or within</u> a *feature*
  - FEPs can be defined at various levels of detail

What is FEP Analysis?

- **FEP analysis is part of a broader performance assessment (PA) methodology that supports:**
  - Scenario Development
  - Implementation in a PA Model
  - Safety Case and Safety Functions

- **FEP analysis includes the following steps:**
  - FEP (Phenomena) Identification
  - FEP (Phenomena) Screening

Performance Assessment Methodology



FEP Analysis for SNF/HLW Disposal

- **Long history of FEP analysis, starting in the early to mid-1980s**
  - Backup slides provide references
- **FEP analysis is promoted by international organizations for deep geologic disposal of SNF/HLW**
  - International Atomic Energy Agency (IAEA) (IAEA 1983; 2011)
  - Nuclear Energy Agency (NEA) (NEA 1992; 2012)
- **FEP analysis is used in all advanced repository programs for deep geologic SNF/HLW repositories**
  - U.S.
    - Waste Isolation Pilot Plant (WIPP) (DOE 1996; 2009)
    - Yucca Mountain Project (YMP) (BSC 2005; SNL 2008; Freeze and Swift 2010)
    - DOE-NE Used Fuel Disposition Campaign (UFD) (Freeze et al. 2010; 2011)
  - NEA International FEP Database (NEA 1999; 2006)
    - Sweden, Switzerland, Belgium, U.K., Canada, US (WIPP)
  - Other Countries
    - Germany, Japan, Finland, France, South Korea, Spain, Netherlands

FEP Analysis for LLW Disposal

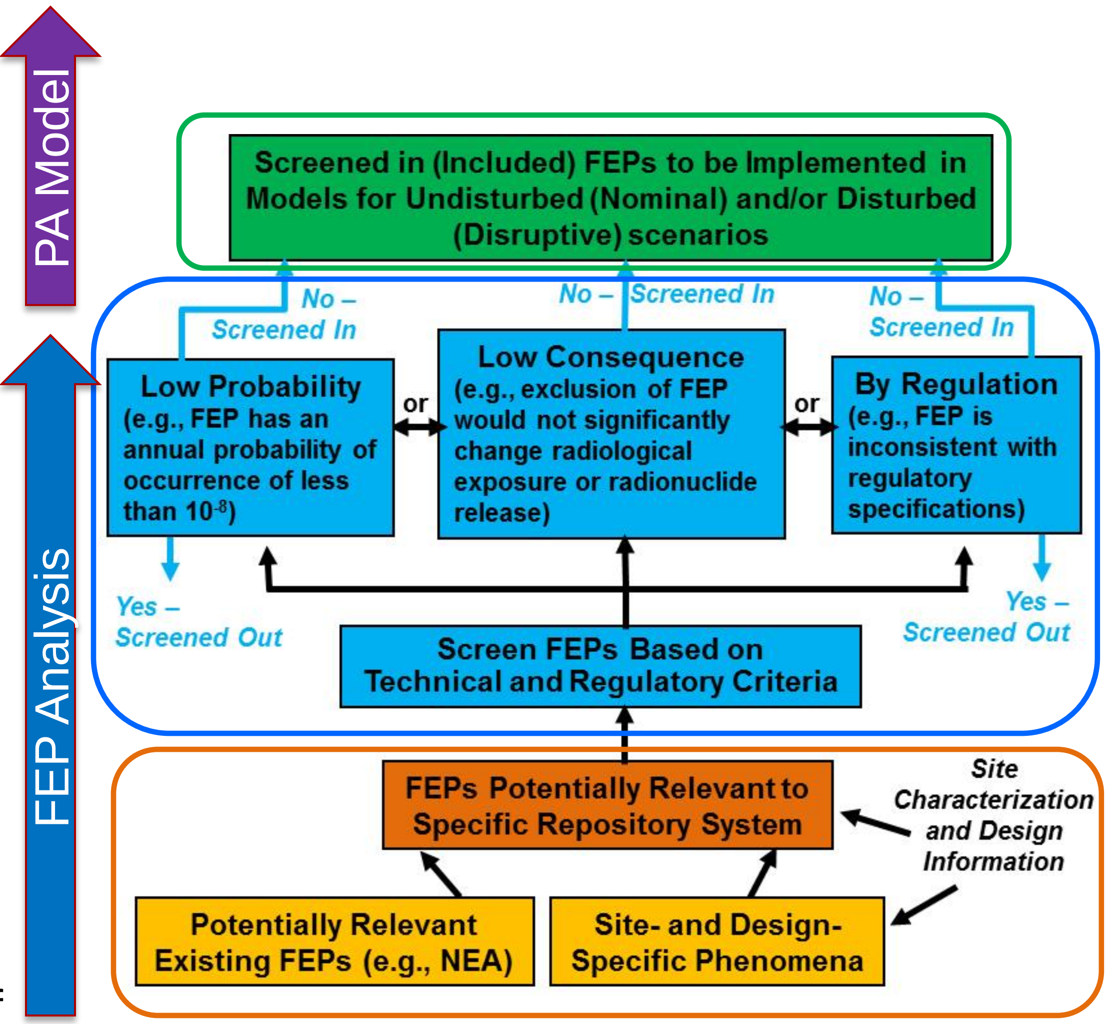
- **FEP analysis has been undertaken for near surface and borehole disposal of LLW (and ILW)**
  - General Lists, originating from NEA International FEP Database for SNF/HLW
    - IAEA Improvement of Safety Assessment Methodologies (ISAM) for Near Surface Disposal Facilities FEP List (IAEA 2004)
    - DOE-NE UFD LLW (Jones 2011)
  - Project-Specific Lists
    - U.S.: Greater Confinement Disposal (GCD) Facility (Guzowski and Newman 1993)
    - U.S.: Clive UT LLW Disposal Facility (Tauxe 2012)
    - U.K.: Drigg LLW Repository (Phifer 2011; www.llwrsite.com)
    - Canada: Ontario Power Generation (OPG) Deep Geologic Repository (DGR) for LLW/ILW (Garisto et al. 2009; www.nwmo.ca/dgr)

FEP Analysis for LLW Disposal

- **381 DOE UFD LLW FEPs (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 ISAM Co-ordinated Research Project (IAEA 2004)
    - Greater Confinement Disposal Facility (Guzowski et al. 1993)
    - Ontario Power Generation (OPG) Deep Repository for LLW/ILW (Garisto et al. 2009)
    - SNF/HLW Deep Borehole Disposal (Brady et al. 2009)
    - Drigg Low Level Waste Repository (Phifer 2011)
  - Differences from SNF/HLW FEPs are:
    - more LLW FEPs related to proximity to surface
      - *surficial events and processes (e.g., subsidence, erosion, surficial transport)*
      - *human intrusion*
    - more LLW FEPs related to additional EBS features
      - *engineered covers, disposal units (e.g., concrete vaults)*
      - *underlying layers (e.g., drains, geomembranes, etc.)*

FEP Analysis – Traditional Bottom-Up Approach

- **Scenario Development**
  - The included FEPs define the range of possible future states (i.e., scenarios) of the system
- **FEP Screening**
  - The specification of a subset of <u>important</u> FEPs that individually, or in combination with other FEPs, contribute to long-term performance
- **FEP Identification**
  - Development and classification of a list of FEPs that that capture the entire range of phenomena <u>potentially relevant</u> to the long-term performance of the repository system

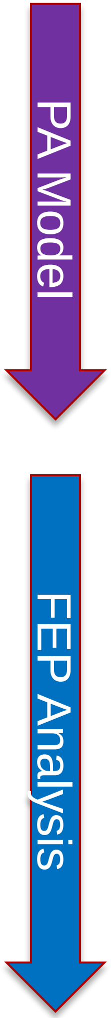


FEP Analysis – Traditional Bottom-Up Approach
Pros and Cons

- **Results in a large number of FEPs**
  - NEA FEP Database (NEA 2006) is the basis for most FEP lists
    - NEA FEP list contains ~2000 FEPs from 10 international programs in 6 countries
    - DOE UFD LLW FEP list contains 381 FEPs
- **Difficult to uniquely categorize and screen**
  - Considerable redundancy and overlap in the large number of NEA FEPs
  - Screening of overlapping FEPs leads to situations where individual FEPs are partially included and partially excluded
    - Application of quantitative screening criteria not always possible
- **Time consuming and costly**
  - Acceptable for a large national repository program
  - Cost prohibitive for smaller LLW sites
- **Helps to demonstrate comprehensiveness of the FEP list**
  - Although comprehensiveness can never be "proven"

FEP Analysis – Top-Down Reality

- **PA Model Implementation**
  - Apply “favored” code to simulate “inherent” scenarios and FEPs
- **Scenario Development and FEP Screening**
  - Included scenarios and FEPs are phenomena that are represented by the conceptual/numerical models in the selected code
    - e.g., waste degradation/source term, flow and transport
  - FEP screening and exclusion is not systematic or comprehensive
    - Guided by expert judgment and experience rather than a formalized process
- **FEP Identification**
  - Provides a bottom-up audit of included FEPs and scenarios
    - Supports demonstration of comprehensiveness of FEP list
    - Confirms adequacy of capabilities in “favored” code
    - Identifies new FEPs to be implemented through alternate code, code modification, and/or parameter adjustment

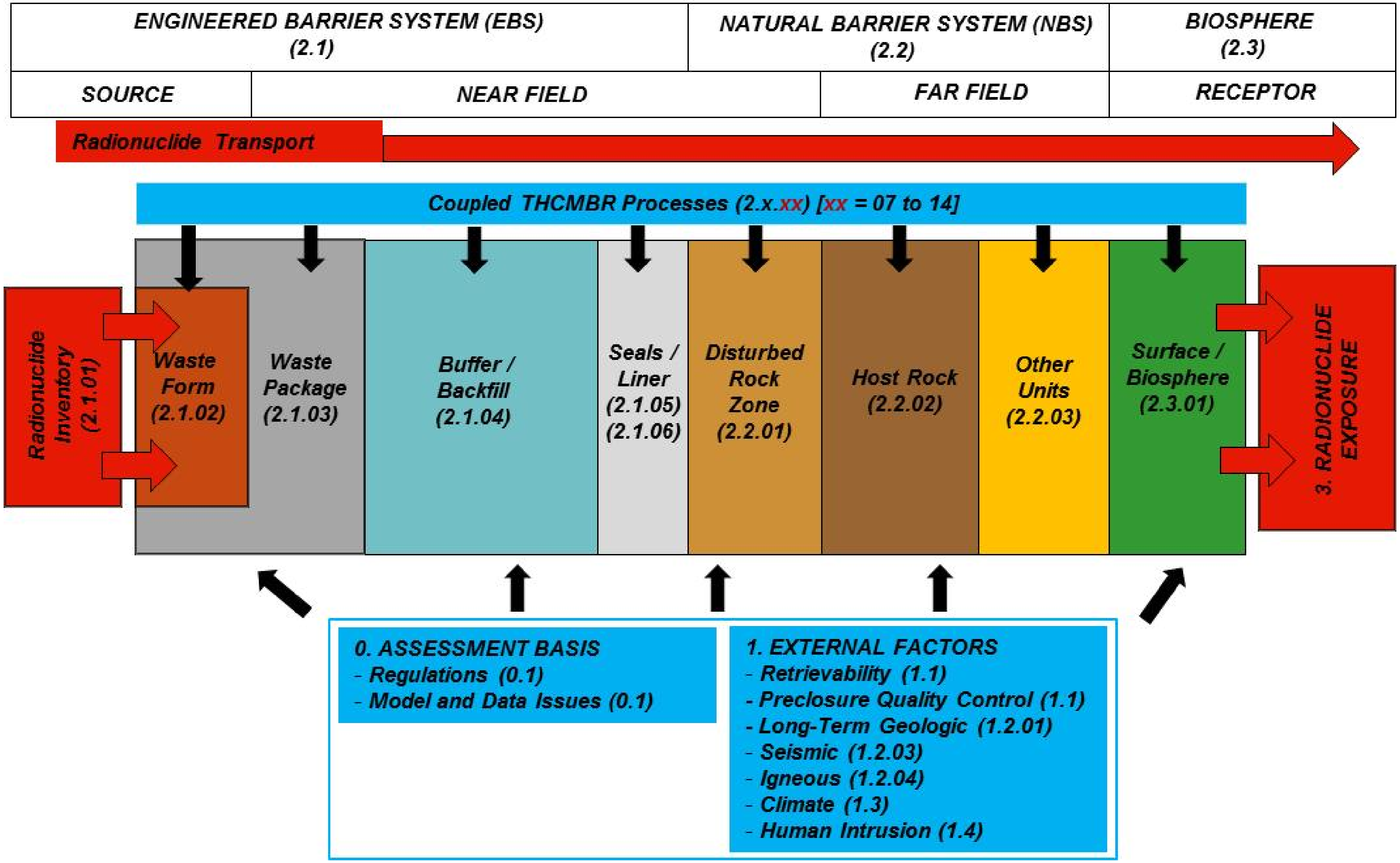


FEP Analysis – Top-Down, Bottom-Up Approach
Pros and Cons

- **Top-down development of phenomena models, scenarios and FEPs**
  - Provides efficient organization/mapping of phenomena
  - Level of effort can be commensurate with project scope and budget
    - Level of detail (fewer broad scenarios/FEPs vs. many detailed scenarios/FEPs)
    - Rigor level must meet expectation of regulators
- **Bottom-up FEP identification**
  - Provides a check on comprehensiveness of scenarios/FEPs
    - Use an existing FEP list as an audit
  - Supports systematic documentation of FEP screening

FEP Analysis – Top-Down, Bottom-Up Approaches

- **Top-Down from General NEA SNF/HLW FEP Database Categories**
  - Features must be adapted for LLW



FEP Analysis – Top-Down, Bottom-Up Approaches

- **Top-Down from FEP Matrix**
  - Freeze et al. (2013)
  - Matrix Rows = Features
  - Matrix Columns = Process / Events
  - Matrix Cell contains all FEPs related to the "Process/Event" acting upon or within the "Feature"
    - e.g., hydro processes in the backfill

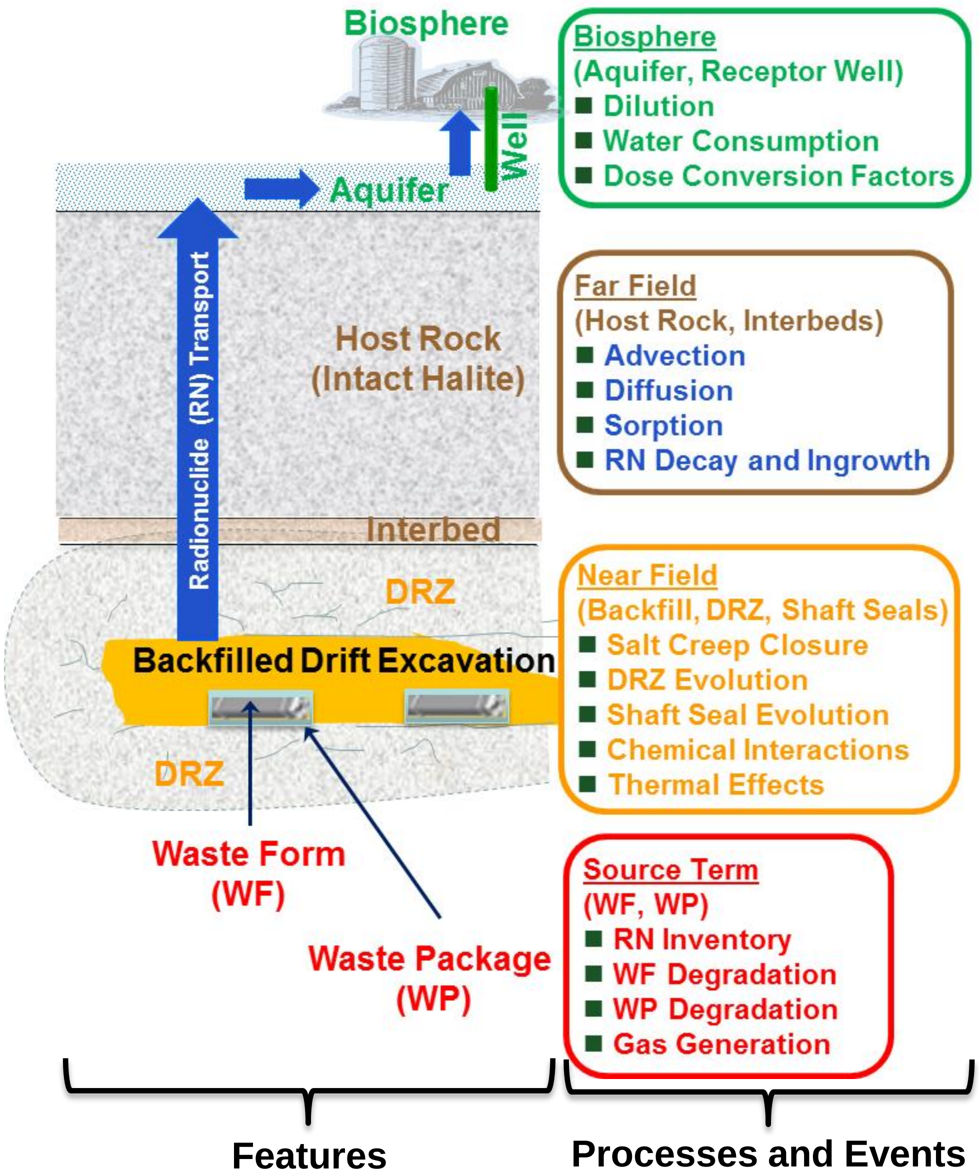
Processes and Events

Features

Characteristics, Processes, and Events / Features		Processes											Events					
	Characteristics	Mechanical and Thermal-Mechanical	Hydrological and Thermal-Hydrologic	Chemical and Thermal-Chemical	Biological and Thermal-Biological	Transport and Thermal-Transport	Thermal	Radiological	Long-Term Geologic	Climatic	Human Activities (Long Timescale)	Other	Nuclear Criticality	Early Failure	Seismic	Igneous	Human Activities (Short Timescale)	Other
Waste and Engineered Features																		
Waste Form and Cladding																		
Waste Package and Internals																		
Buffer/Backfill																		
Emplacement Tunnels/Drifts and Mine Workings																		
Seals/Plugs																		
Geosphere Features																		
Host Rock (Repository Horizon)																		
Other Geologic Units (non-Repository Horizon)																		
Surface Features																		
Biosphere																		
System Features																		
Repository System																		

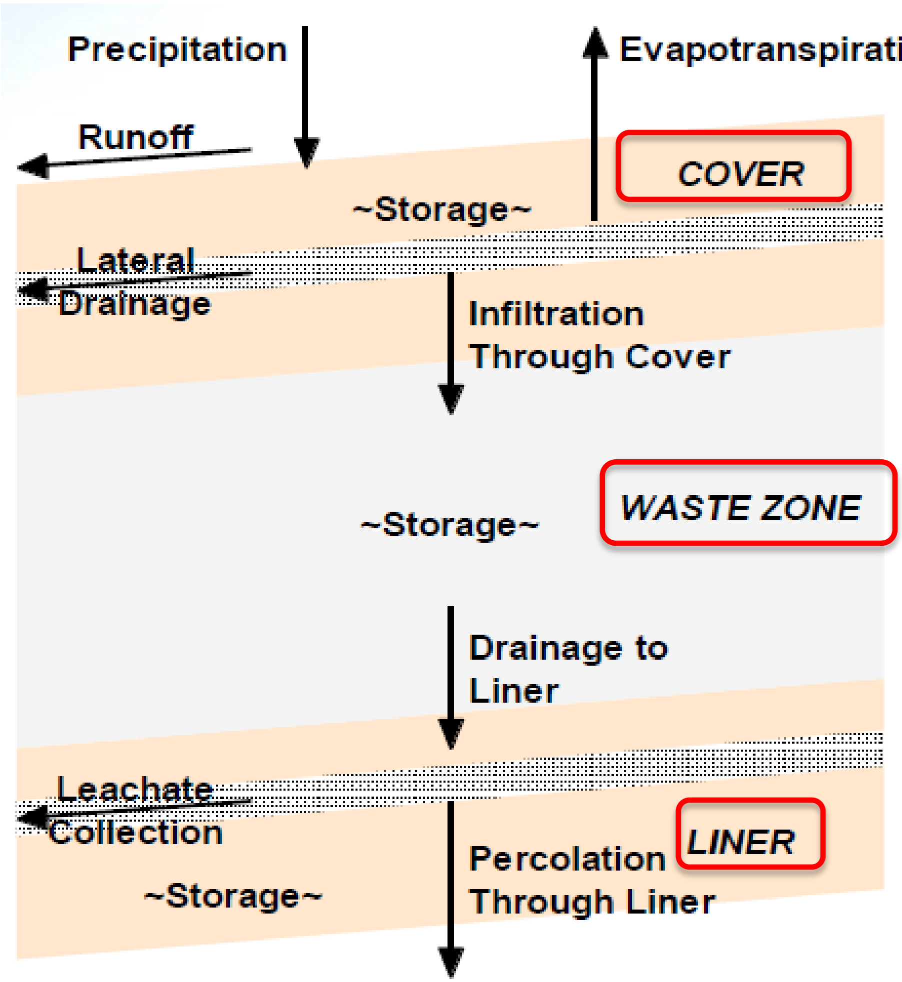
FEP Analysis – Top-Down, Bottom-Up Approaches

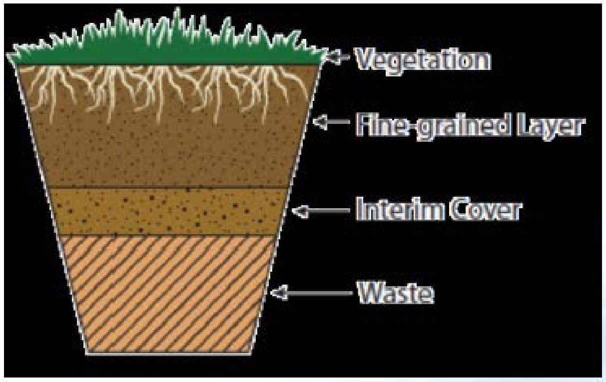
- **Top-Down from Specific Repository Phenomena**
  - Example here is SNF/HLW Repository in Bedded Salt



FEP Analysis – Top-Down, Bottom-Up Approaches

- **Top-Down from Specific Repository Phenomena**
  - Example here is Generic Near-Surface Facility (from Seitz 2014)

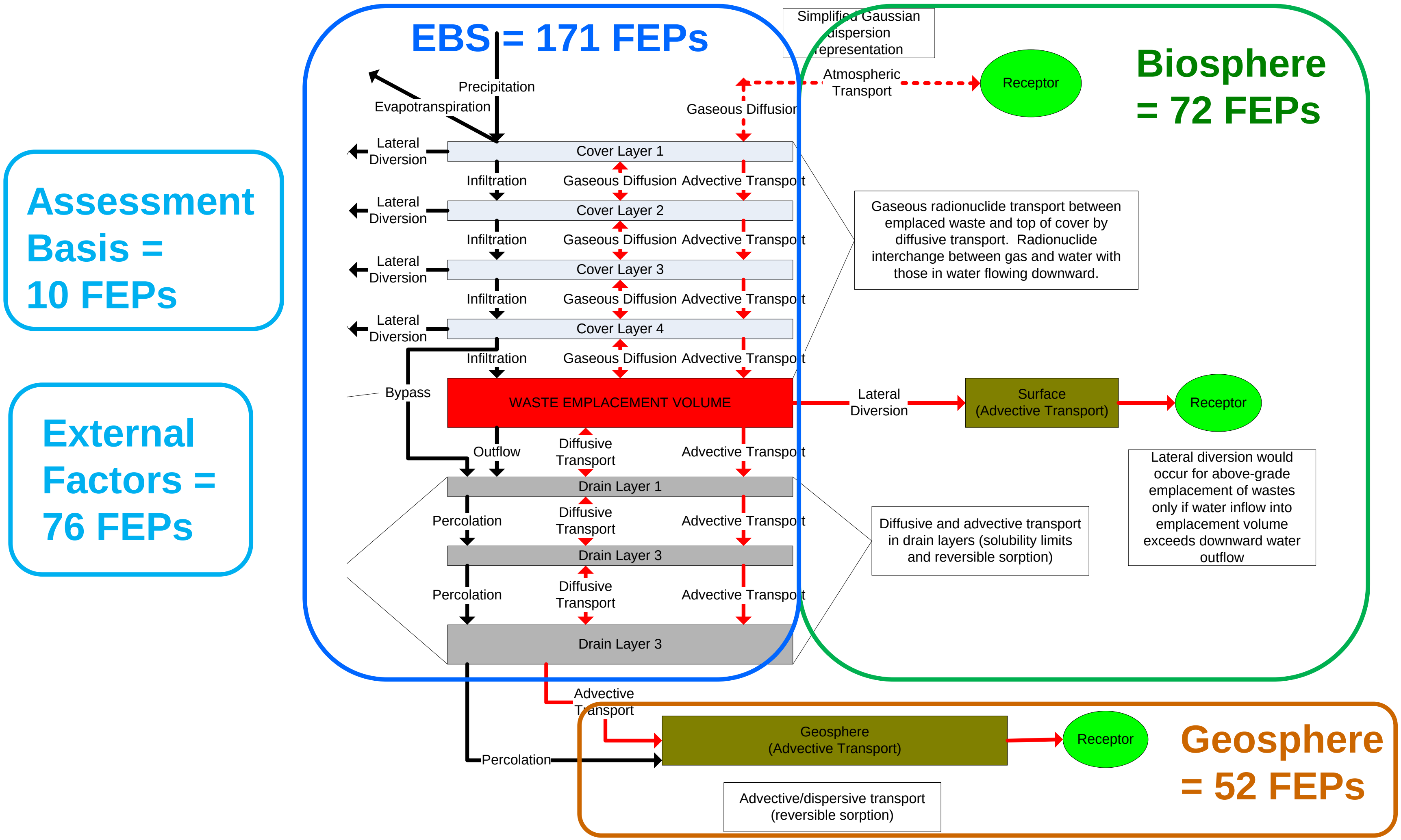




Features in red
Processes in black

FEP Analysis – Top-Down, Bottom-Up Approaches

- **Bottom-Up Audit using UFD LLW list (381 FEPs)**



FEP Analysis – Top-Down, Bottom-Up Approaches

- **Specific FEP from UFD LLW list**

FEP Number	FEP Title	FEP Description	FEP Screening (Included / Excluded)	Disposal Option (Near Surface / Borehole)	Basis for Exclusion
2.1.05.02	Engineered Covers and Their Degradation Processes	FEPs related to the performance of engineered cover materials above the emplaced waste vaults, trenches, etc. such as: - soil layers - rock armoring - low permeability layers (earthen materials, geotextiles, geomembranes) - drainage layers - side slopes / side fill Degradation processes include: - embrittlement, cracking - loss of ductility - movement - hydrostatic pressure - swellling corrosion products - chemical effect of water on polymeric materials - Fracturing of near field rock (such as by initial stresses during excavation, ice sheet loading/unloading or seismic activity) with subsequent impact on containers already compromised by other degradation mechanisms. Gas pressure may enhance cracking in the excavation disturbed zone.	Included		

Jones (2011) did preliminary screening for two generic designs

FEP Analysis – Top-Down, Bottom-Up Approaches

- **Bottom-Up Audit using IAEA LLW FEP list (IAEA 2004)**
  - Specific FEP

FEP 2.1.05 Engineered barrier system characteristics and degradation processes
Definition: FEPs related to the design, physical, chemical, hydraulic etc. characteristics of the cavern/tunnel/shaft seals at the time of sealing and closure and also as they may evolve in the repository, including FEPs which are relevant specifically as cavern/tunnel/shaft seal and cap degradation processes. (Effect on hydrology / flow – change over time).
Comment: Cavern/tunnel/shaft seal and cap failure may result from gradual degradation processes, or may be the result of a sudden event. The importance is that alternative routes for groundwater flow and radionuclide transport may be created along the various layers and tunnels and/or shafts and associated EDZ (see FEP 2.2.01).
Key Concepts, examples, and related FEPs: **- Engineered caps (cover)** **- Cover degradation** **- Intrusion resistance caps** **- Cap materials: clay, concrete**

Conclusions

- **Practical FEP analysis can be performed at a level of effort commensurate with project scope and budget**
  - Supports scenario development, PA modeling, and the safety case
- **Top-down, bottom-up approach for LLW disposal**
  - Top-down scenario development, supplemented by bottom-up FEP analysis
    - Identify key scenarios
    - Build a top-down feature-based organizational structure (e.g., matrix)
    - Map key scenarios, FEPs/phenomena
    - Use existing FEP lists for audit

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Backup Slides

FEP Analysis for SNF/HLW Disposal

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- **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 for SNF/HLW Disposal

- **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)
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