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Fuel Cycle Technologies

Used Fuel Disposition (UFD) Features, Events, and Processes (FEPs) for Generic Disposal System Evaluations (GDSE)

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UFD Overview

- **Objectives/Mission**
  - Develop computational models, validated by experiment, for the evaluation of disposal system performance in a variety of generic disposal concepts and environments
- **FY10 Accomplishments**
  - Features, Events, and Processes (FEPs):
    - *Identification of potentially relevant FEPs*
    - *Initial collection of information to evaluate relevant FEPs*
    - *Collaborative effort at SNL, LLNL, LBNL, ANL, LANL*
    - *Collaboration with NEAMS Waste IPSC*
  - Generic Disposal System Evaluations (GDSE):
    - *Development of simplified generic performance assessment (PA) models for clay, salt, granite, and deep borehole disposal*
    - *Collaborative effort at SNL, ANL, LANL*

UFD Disposal System Alternatives

- **8 preliminary repository environment categories**
  - combinations of concept and geologic setting

Group	Disposal Concept / Geologic Setting	Description	Current R&D
1	Surface Storage	Long-term interim storage at reactors or at centralized sites	UFD-Storage
2	Shallow Disposal	e.g., near-surface disposal, LTHLW sites (Depths <= 100 m)	
3	Mined Geologic Disposal (Hard Rock, Unsaturated)	Granite/crystalline or tuff (Depths > 100 m)	UFD-NS, EBS
4	Mined Geologic Disposal (Hard Rock, Saturated)	Granite/crystalline or tuff (Depths > 100 m)	UFD-GDSE, NS
5	Mined Geologic Disposal (Clay/Shale, Saturated)	Clay/shale (Depths > 100 m)	UFD-GDSE, NS, EBS
6	Mined Geologic Disposal (Salt, Saturated)	Bedded or domal salt (Depths > 100 m)	UFD-GDSE, NS, EBS
7	Deep Borehole Disposal	Granite/crystalline (Depths~ 1000 m)	UFD-GDSE, NS
8	Other	Sub-seabed, carbonate formations, etc.	N/A

* GDSE=Generic Disposal System Evaluations, NS=Natural Systems, EBS=Engineered Barrier Systems

UFD Disposal System Alternatives

- **6 preliminary waste form / inventory categories**

Group	Waste Form Type	Description	Current R&D
1	Used Nuclear Fuel (UNF)	e.g., Commercial, DOE-Owned, HTGR	UFD-GDSE, EBS
2	High-Level Waste (HLW) Glass	Current (e.g., borosilicate) and future (e.g., no minor actinides)	WF
3	High-Level Waste (HLW) Glass Ceramic / Ceramic	Current (glass bonded sodalite) and future (e.g., from electrochemical processing)	WF
4	High-Level Waste (HLW) Metal Alloy	From electrochemical or aqueous reprocessing, cermets	WF
5	Lower Than HLW (LTHLW)	Class A, B, and C, and GTCC	
6	Other	Molten salt, electro-chemical refining waste, etc.	N/A

* GDSE=Generic Disposal System Evaluations, WF = Waste Form Campaign, EBS=Engineered Barrier Systems

UFD Disposal System Alternatives

- **35 potential disposal system alternatives**
  - *7 repository environments x 5 waste forms (excluding "other" categories)*

  – **20 alternatives initially considered by GDSE**
    - ***Mined and Deep disposal of UNF (and HLW)***

  – **4 alternatives initially considered by Storage**
    - ***Storage of UNF (and HLW)***

  – 2 alternatives initially considered by LLW
    - *Storage and shallow disposal of LTHLW*

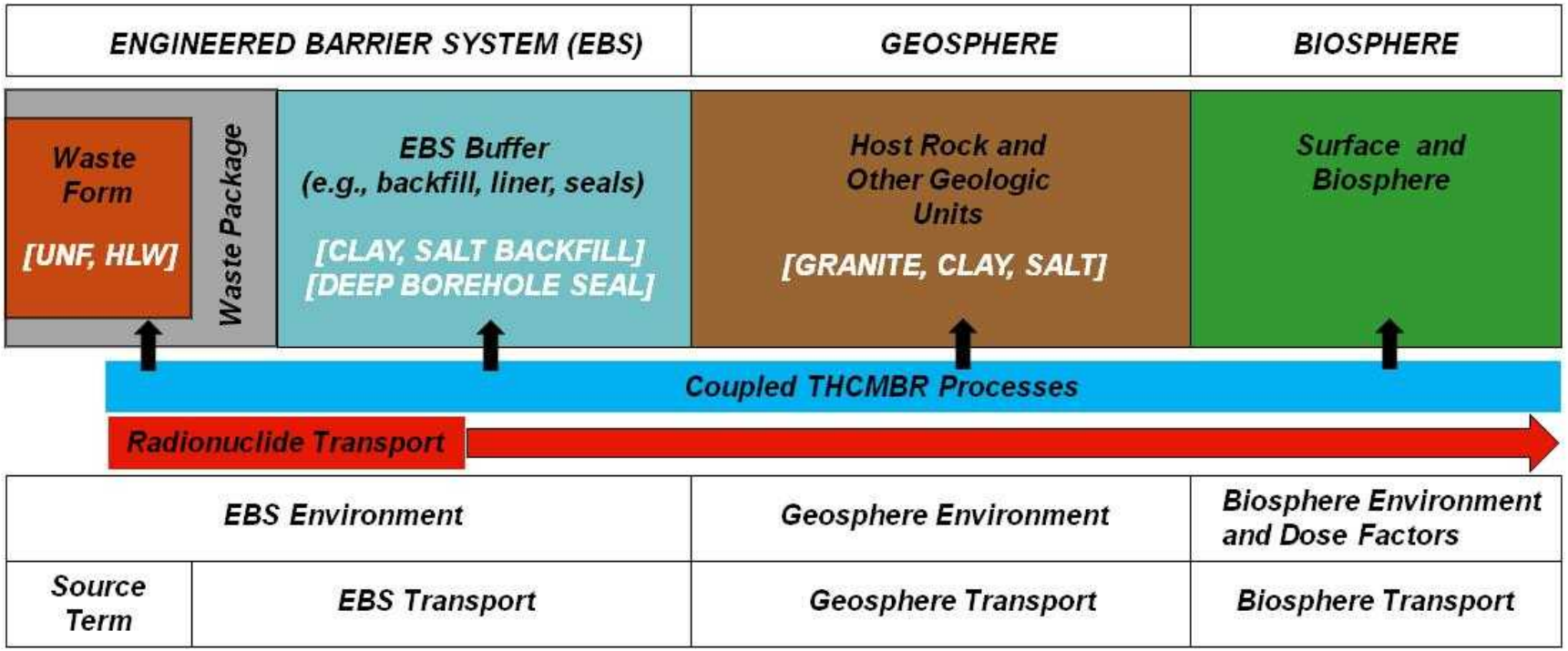
  – 9 alternatives not initially considered
    - *Mined and Deep disposal of LTHLW - "implicit" in UNF and HLW*
    - *Shallow disposal of UNF and HLW – not expected*

UFD GDSE Overview

- **20 potential disposal system alternatives initially considered**
  - 5 repository environments x 4 waste form types (1 UNF and 3 HLW)
  - encompassed by 4 GDSE conceptual models
- **4 GDSE conceptual models developed**
  - Mined Geologic Disposal – Granite / hard rock
  - Mined Geologic Disposal – Clay / Shale
  - Mined Geologic Disposal – Salt
  - Deep Borehole Disposal – Granite / hard rock
    - *Initial focus is on saturated host rock. Effects of desaturation, oxidizing conditions, and/or unsaturated flow pathways to be evaluated later.*
- **All conceptual models can accommodate inventory and degradation representative of UNF and/or HLW waste form types**

UFD GDSE Overview

- **1D schematic of generic disposal system domains and phenomena**
  - Common to all 4 GDSE conceptual models



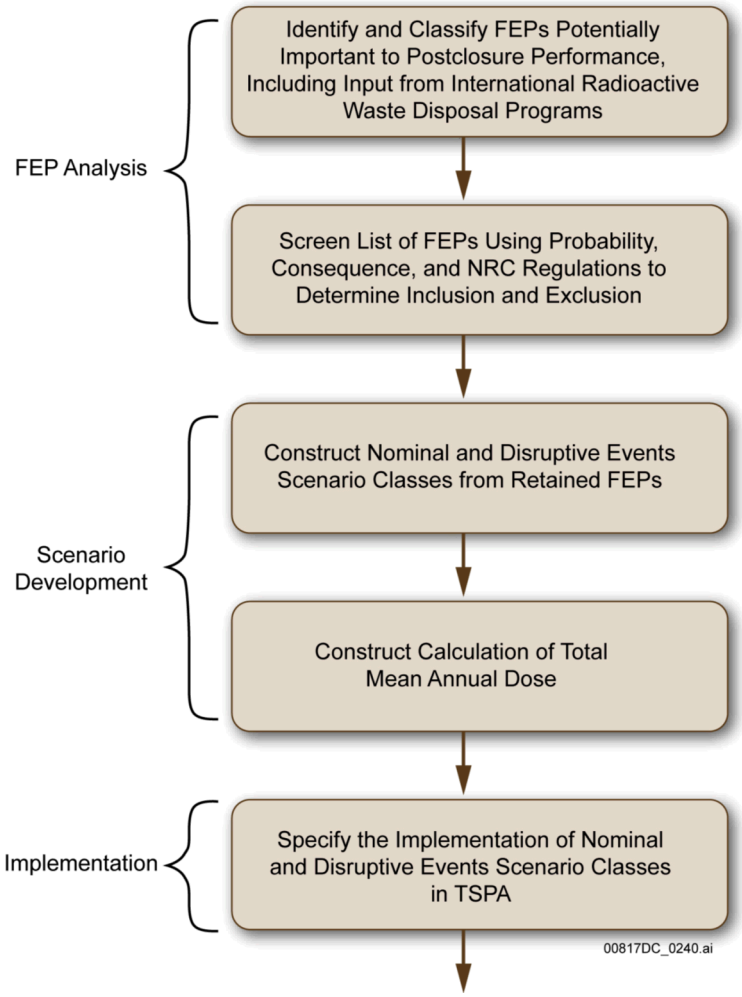
UFD GDSE Overview

- **Initial development of GDSE models based on:**
  - Informal identification of key disposal system components
    - *Concept (engineered barrier system (EBS) with some combination of waste form, waste package, backfill, and seals)*
    - *Geologic Setting (granite, clay/shale, or salt host rock)*
  - Informal specification of key phenomena
    - *Source Term (waste form degradation, solubility, and mobilization)*
    - *Environment (temperature, chemistry – reducing/oxidizing, solubility)*
    - *Radionuclide Transport (simplified THC processes – advection, diffusion, sorption)*

- **FY11 plans for GDSE models:**
  - Refinement of conceptual models informed by FEP analysis
  - Generic parameterization of FEPs/phenomena, including uncertainty quantification

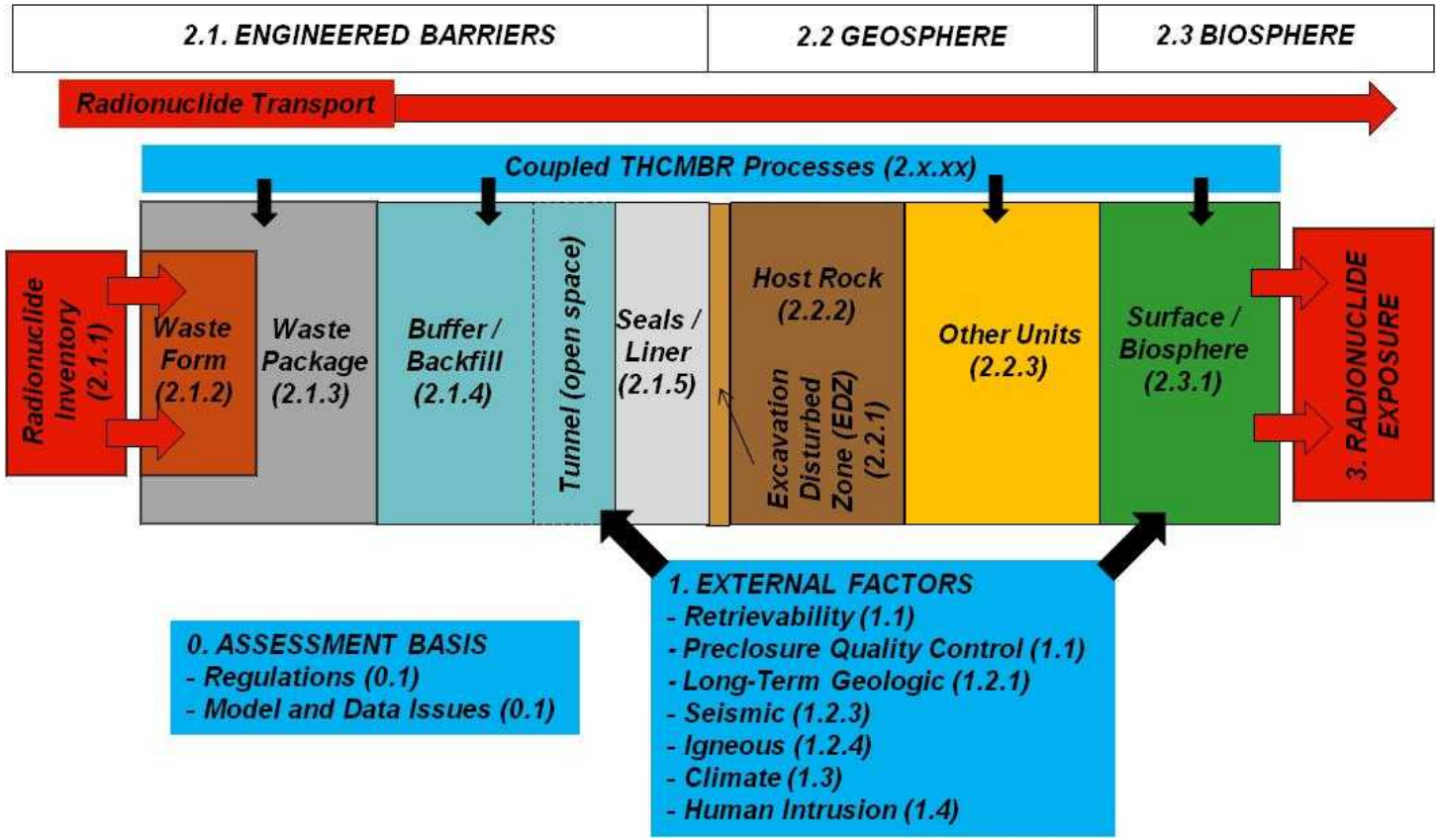
UFD FEP Analysis

- **FEP analysis consists of:**
  - FEP Identification and Categorization
  - FEP Evaluation and Screening
  - Scenario Development and Implementation in a GDSE/PA Model
  - Iteration
- **Preliminary identification and categorization of potentially relevant UFD FEPs**
  - Based on NEA International FEP Database
    - *Includes granite, clay, and salt concepts from 10 different national programs*
  - Follows Yucca Mountain Project FEP analysis methodology
    - *Comprehensiveness, level of detail*



UFD FEP Identification

- **Identified and categorized 208 preliminary UFD FEPs**
  - Generic features applicable to all 20 GDSE disposal system alternatives
  - FEPs describe the coupled thermal-hydrologic-chemical-mechanical-biological-radiological (THCMBR) processes and events acting upon the features



UFD FEP Evaluations

- **208 UFD FEPs need to be evaluated for all 4 GDSE conceptual models**
  - Evaluations are done in collaboration with other activities
    - *UFD: Natural Systems, EBS, Storage*
    - *FCR&D WF Campaign*
  - Evaluations (and conceptual models) are dynamic
    - *Evolve as new information (data, designs, model results, socio-political input) becomes available*
  - Current FEP evaluations are limited to collection of existing information
    - *Preliminary evaluations/data collection initiated for 104 FEPs in FY10*
    - *Can be used to inform preliminary FEP screening for GDSE models*
    - *Ongoing collection of information may include experimental work*
    - *Examples provided on subsequent slides*

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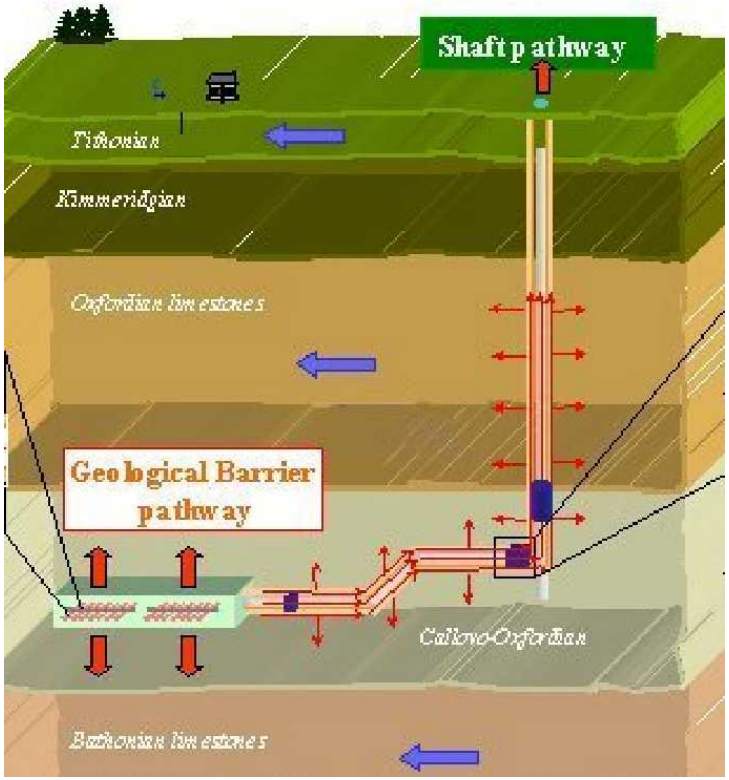
UFD FEP Evaluations – Waste Forms (ANL)

- **Used Nuclear Fuel (UNF)**
  - Basis for evaluating degradation of commercial LWR fuels (UOX and MOX) is extensive
    - *Data are available from worldwide sources to assess degradation of UOX fuel matrix and release of gap and grain-boundary inventories*
    - *UOX and MOX matrix degradation processes are well understood and depend on the redox conditions in the disposal environment*
  - Basis for evaluating degradation of DOE-owned fuels and advanced reactor fuels in less mature
- **High-Level Waste (HLW)**
  - Basis for evaluating degradation of HLW glass is extensive
    - *Data are available from worldwide sources on processes controlling hydrolysis and dissolution of glass network*
    - *The important environmental factors (T, pH, dissolved silica) are likely to be controlled by the waste form and EBS*
  - Basis for evaluating ceramics (e.g., glass bonded sodalite) and metal alloys (e.g., SS 15Zr) is less extensive

UFD FEP Evaluations – Clay (LBNL)

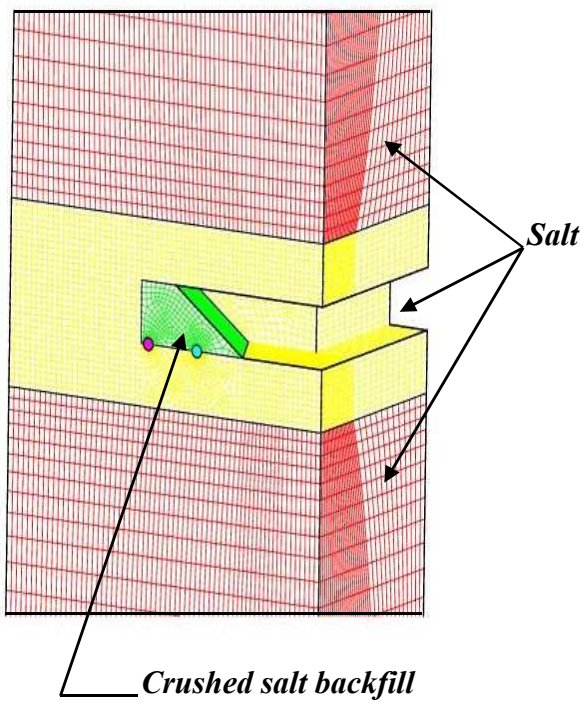
- **Bentonite Backfill**
  - Rehydration and swelling to close gaps
  - Interaction of swelling stress and EDZ
  - Erosion and piping
  - Dissolution and precipitation
- **Excavation Disturbed Zone (EDZ) and Near-Field Clay**
  - Enhanced fracturing in EDZ due to changes in stress and saturation
  - Formation of long-range connected transport pathways through EDZ
  - Mitigation of extent of fractures and transport pathways through self-sealing



from Bauer et al. (2003)

UFD FEP Evaluations – Salt (SNL)

- **Thermal-Mechanical (TM) Effects in EBS and Near Field**
  - Large deformation salt creep behavior
  - Compaction of crushed salt backfill
  - Temperature dependent material properties



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UFD FEP Evaluations – Granite (LANL)

- **Hydrology and Radionuclide Transport in Far Field (Geosphere)**
  - Advection through fractures and heterogeneous domains
  - Characterization of fracture networks and connectivity
  - Matrix diffusion – exchange between fractures and surrounding rock matrix
  - Sorption
  - Colloid-facilitated transport

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Interfaces Between UFD GDSE Models and NEAMS Waste IPSC Models

- **UFD GDSE Model Timeline**
- **Short time horizon (2-3 yrs)**
  - Simplified generic system models (i.e., PA-fidelity)
  - Current computing capabilities
  - Minimal multi-physics coupling
  - Sufficient for scoping studies and high-level comparison of options
- **Intermediate time horizon (~5 yrs)**
  - More advanced system models developed in parallel with NEAMS Waste IPSC
- **Long time horizon (~10 yrs)**
  - Mature models based on NEAMS Waste IPSC experience

- **R&D and FEP Evaluations**
  - Informs process and PA model development

- **NEAMS Waste IPSC Timeline**
- **Long time horizon (~ 10 yrs)**
  - Fully coupled multi-physics (THCMBR) models from first principles (i.e., high-fidelity)
  - PA-fidelity system model abstracted from high-fidelity model
  - Advanced high-performance computing capabilities
  - Models capable of detailed analyses of a range of disposal options, sufficient for licensing

Summary

- **FEP Analysis**
  - FEP list is reasonably mature
  - FEP evaluations are ongoing
    - *Will inform GDSE model conceptualization and parameterization*
- **GDSE Model Capabilities**
  - 4 conceptual models (granite, clay, salt, deep borehole)
  - Provide insights at a generic level
  - Facilitate comparisons among generic concepts, for example
    - *compare different EBS designs with same geosphere and biosphere*
    - *compare the same stylized treatment of human intrusion or disruptive events in different concepts*
  - Identify important features, processes, and sources of uncertainty in various disposal concepts, for example
    - *diffusion vs. advection*
    - *waste form lifetime vs. EBS transport time vs. geosphere transport time*
    - *impact of variability in waste package failure times*

- **Backup Slides**

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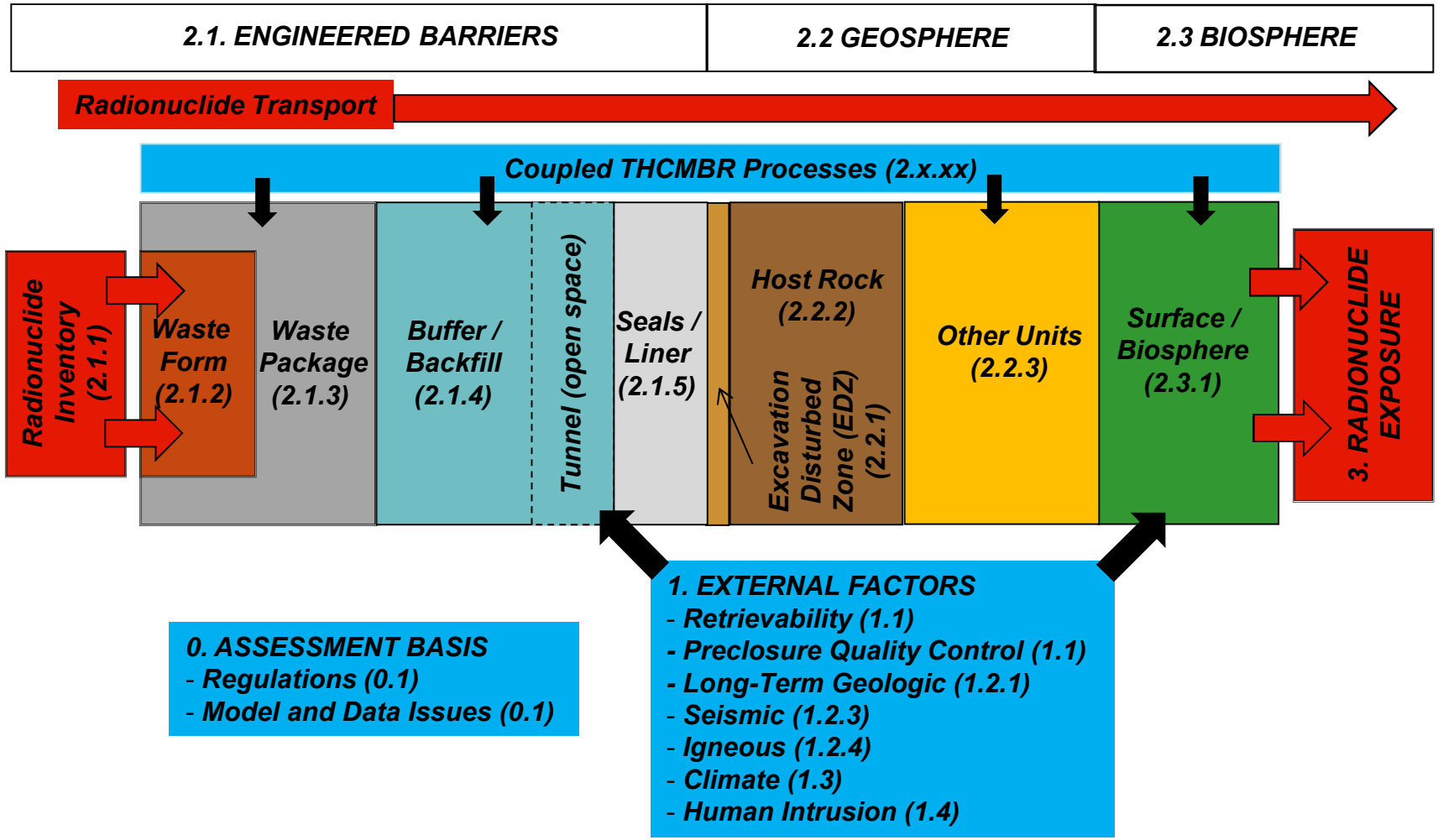
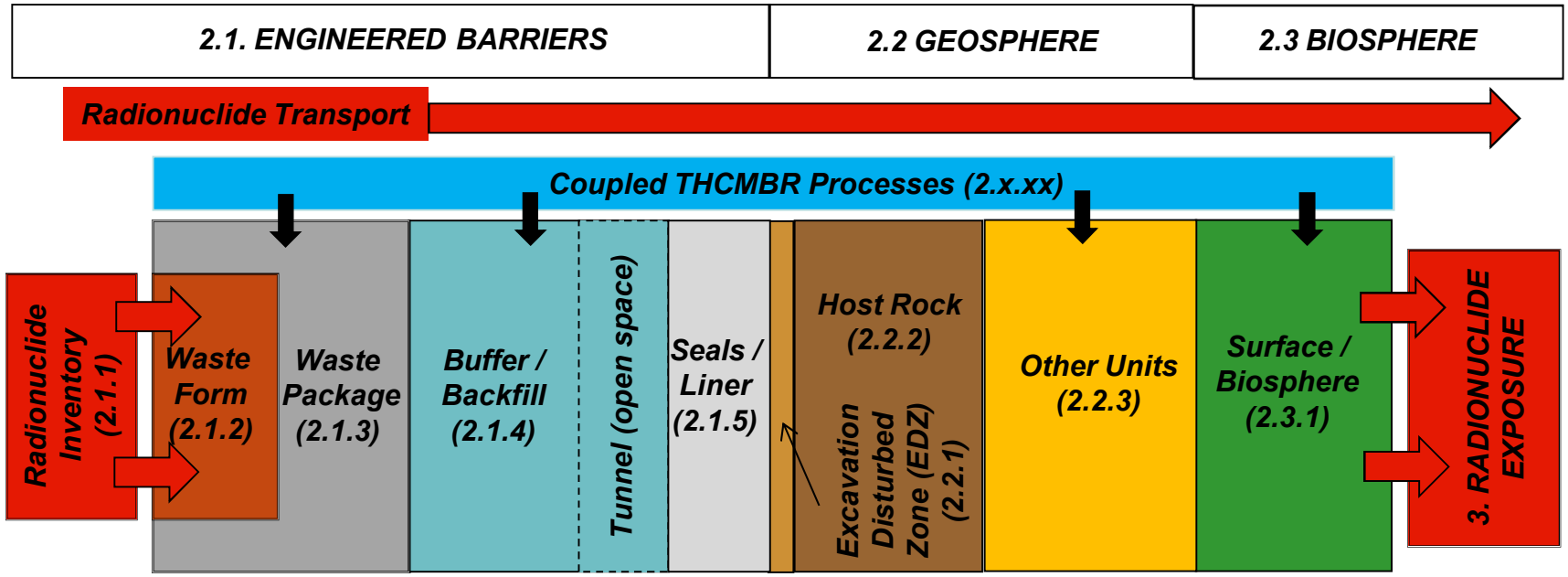
UFD FEP Evaluations – UNF Waste Forms (ANL)

- **Initial evaluations focused on commercial LWR fuels (UOX and MOX) and DOE-owned fuels**
  - Few relevant data for evaluating degradation of advanced reactor fuels
- **Basis for evaluating degradation of LWR fuels is extensive**
  - Data are available from worldwide sources to assess degradation of UOX fuel matrix and release of gap and grain-boundary inventories
  - The UOX and MOX matrix degradation processes are well understood and depend on the redox conditions in the disposal environment
  - UOX Degradation models have been developed for oxidizing and reducing environments
- **Basis for evaluating DOE-owned fuels is less mature**
  - N Reactor uranium metal fuel degrades rapidly under aqueous oxidizing and reducing conditions

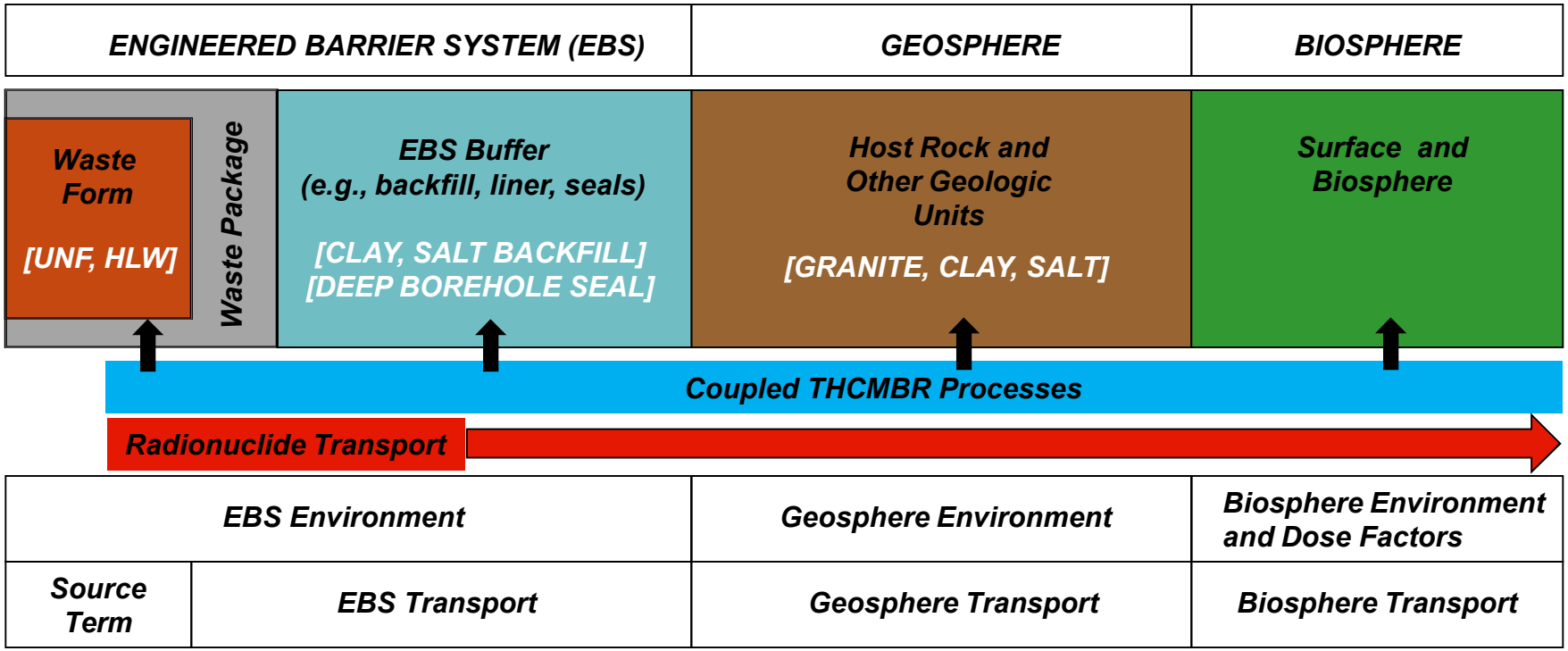
UFD FEP Evaluations – HLW Waste Forms (ANL)

- **Initial evaluations focused on current HLW waste forms and similar materials that are baseline waste forms for advanced processing of used fuels**
- **Basis for evaluating degradation of HLW glass is extensive**
  - Data are available from worldwide sources on processes controlling hydrolysis and dissolution of glass network
    - *disagreements concerning long-term extrapolation of degradation rates*
  - The important environmental factors (T, pH, dissolved silica) are likely to be controlled by the waste form and EBS
- **Basis for evaluating ceramics (e.g., glass bonded sodalite) and metal alloys (e.g., SS 15Zr) is less extensive**
  - Metal alloy waste form degradation will depend on the redox conditions and halide ion concentration in the disposal settings


2.1. ENGINEERED BARRIERS
2.2 GEOSPHERE
2.3 BIOSPHERE
Radionuclide Transport
Coupled THCMBR Processes (2.x.xx)
Radionuclide Inventory (2.1.1)
Waste Form (2.1.2)
Waste Package (2.1.3)
Buffer / Backfill (2.1.4)
Tunnel (open space)
Seals / Liner (2.1.5)
Host Rock (2.2.2)
Excavation Disturbed Zone (EDZ) (2.2.1)
Other Units (2.2.3)
Surface / Biosphere (2.3.1)
3. RADIONUCLIDE EXPOSURE
0. ASSESSMENT BASIS
- Regulations (0.1)
- Model and Data Issues (0.1)
1. EXTERNAL FACTORS
- Retrievability (1.1)
- Preclosure Quality Control (1.1)
- Long-Term Geologic (1.2.1)
- Seismic (1.2.3)
- Igneous (1.2.4)
- Climate (1.3)
- Human Intrusion (1.4)



EBS Environment		Geosphere Environment	Biosphere Environment and Dose Factors
Source Term	EBS Transport	Geosphere Transport	Biosphere Transport



Schematic of Model Components