Exceptional service in the national interest

FEP Catalogue and Database

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Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)

6th NEA Salt club Meeting
Washington, DC
September 6, 2016

Outline

- **NEA Salt Club Benefits from FEP Catalogue**

- **Update on Collaborative Results**
    - New Structure/Organization for FEPs and their Associated Processes
    - Salt FEP Database

- **Future Work**

- **Participants**
    - **SNL: Geoff Freeze, David Sevougian, Michael Gross, Kris Kuhlman, Christi Leigh**
        - **DOE Used Fuel Disposition (UFD) Campaign**
        - **Waste Isolation Pilot Plant (WIPP)**
    - **GRS: Jens Wolf, Dieter Buhmann, Jörg Mönig**
        - **Gorleben (VSG) – domal salt**
        - **KOSINA – bedded salt**

NEA Salt Club Benefits from SNL/GRS FEPs Collaboration

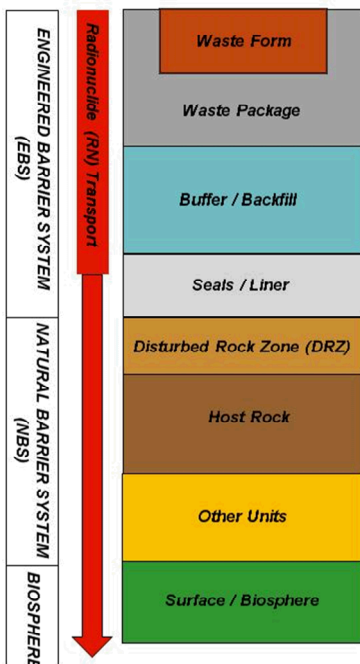- **Produce a FEP Catalogue for use by all Salt Club members**
  - Relevant FEPs for disposal of heat-generating waste (SNF and HLW) in salt
    - Applicable to all potential salt concepts and sites
    - Can support site selection

- **Adopted FEP Matrix approach**
  - Restructured FEP list to improve transparency and reduce redundancy
  - Considering consistency with the pending update to the NEA International FEP Database
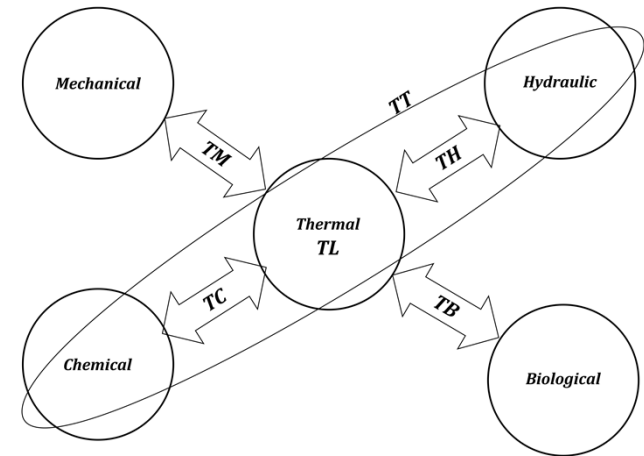
FEP Matrix

Each **Matrix Cell** contains all individual FEPs related to the "Process/Event" acting upon or within the "Feature"

	Characteristics, Processes, and Events		Characteristics	Processes												Events					
				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
Glossary / Definitions			CP	TM	TH	TC	TB	TT	TL	RA	LG	CL	HP	OP	NC	EF	SM	IG	HE	OE
Waste and Engineered Features																				
(WF) Waste Form and Cladding																				
(WP) Waste Package and Internals																				
(BB) Buffer/Backfill																				
(MW) Mine Workings																				
(SP) Seals/Plugs																				
Geosphere Features																				
(HR) Host Rock																				
(OU) Other Geologic Units																				
Surface Features																				
(BP) Biosphere																				
System Features																				
(RS) Repository System																				

Coupled THCMBR Processes and Events

Features / Components

Radionuclide (RN) Transport

- Waste Form
- Waste Package
- Buffer / Backfill
- Seals / Liner
- Disturbed Rock Zone (DRZ)
- Host Rock
- Other Units
- Surface / Biosphere

ENGINEERED BARRIER SYSTEM (EBS)

NATURAL BARRIER SYSTEM (NBS)

BIOSPHERE

Summary of FEP Matrix Approach

- **Two-dimensional FEP organizational structure:**
  - Matrix Rows = Feature (and Component) Categories
  - Matrix Columns = Process and Event Categories

- **Thermal-centric organization of the processes and process coupling**

- **FEP Identification "Numbering" Scheme**
  - Developed a new alpha-numeric identification scheme indicating where a FEP is mapped in the FEP Matrix (row and column)
    - More descriptive than strictly numeric identifiers
    - Can still be traced to NEA Database numbering

Describes/catalogs the physical-chemical properties of a feature or component

- BB.02.CP.01   Backfill Materials (Characteristic FEP)
- BB.02.TM.01   Mechanical Effects on Backfill or from Backfill
- BB.02.TM.02   Thermal-Mechanical Effects on Backfill or from Backfill
- HR.02.TH.01   Flow Through the DRZ
- SP.02.TC.01   Chemical Interaction of Groundwater with Shaft Seals

Full FEP Matrix

Characteristics, Processes, and Events / Features / Components	Characteristics	Processes											Events					
		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
Glossary / Definitions	CP	TM	TH	TC	TB	TT	TL	RA	LG	CL	HP	OP	NC	EF	SM	IG	HE	OE
Waste and Engineered Features																		
(WF) Waste Form and Cladding																		
(01) SNF and Cladding																		
(02) Vitrified HLW																		
(05) Other HLW																		
(06) Metal Parts from Reprocessing																		
(WP) Waste Package and Internals																		
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(01) Drift/Tunnel/Room Supports																		
(02) Liners																		
(03) Open Excavations/Gaps																		
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(01) Overlying / Adjacent Units (including Caprock, Aquifers)																		
(02) Underlying Units																		
Surface Features																		
(BP) Biosphere																		
(01) Natural Surface and Near-Surface Environment																		
(02) Flora and Fauna																		
(03) Humans																		
(04) Food and Drinking Water																		
(05) Dwellings and Other Man-Made Surface Features/Materials																		
System Features																		
(RS) Repository System																		
(01) Assessment Basis																		
(02) Preclosure/Operational																		
(03) Other Global																		

U.S.
~200 UFD Bedded Salt FEPs
(Sevougian et al. 2012)

- Modified from generic FEPs (Freeze et al. 2011) to be more salt-specific
- Derived from NEA FEP Database (1999, 2006)
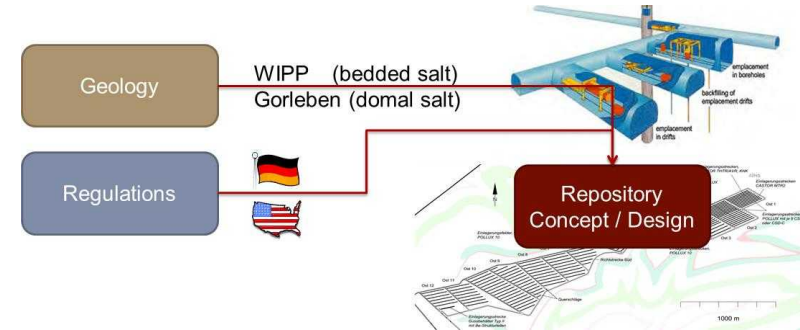- Cross-checked against WIPP FEP catalogue (DOE 2009)

Germany
~100 Gorleben VSG FEPs
(Wolf et al. 2012a,b)

- Derived from NEA FEP Database (1999, 2006)
- Specific to a salt dome in Northern Germany

Combined Salt FEPs (2015)

- **25 Examples of matrix-based FEPs:**
  - Derived from initial US and German FEPs
  - Focus on FEPs which emphasize differences between bedded and domal salt

- **Screening occurs at the "associated process" level**

Table 3-1. Screening decisions for HR.02.TH.01 - Flow Through the DRZ.

ID	Description of Associated Process	Screening Decision	
		Bedded Salt	**Domal Salt**
A	**Single-phase flow** (saturated and/or unsaturated)	Evaluate	Included
B	**Multi-phase flow** (e.g., gas/liquid)	Included	Evaluate
C	**Fracture flow and/or matrix flow.**	Evaluate	Evaluate
D	**Evolution of flow pathways** through the DRZ, especially by healing/ sealing of the DRZ	Likely Included	Likely Included

- **Extensive Documentation in Sevougian et al. (2015)**
  - FEP Descriptions
  - Preliminary, generic screening
- **Many more FEPs still to be created**

Recent Developments (2016)

- **FEPs matrix redesigned at a joint meeting in DC in February to be generally applicable to any mined concept, i.e., any host rock**
  - By changing the features/components (rows of the matrix) to be more general, e.g.,
    - "Bedded or domal salt" component under the Host Rock (HR) feature changed to "Emplacement Unit(s)"
    - "Pressurized brine reservoir(s)" component under the Other Geologic Units (OU) feature changed to "Underlying Units"
  - By changing the various individual FEPs which appear in the FEPs matrix cells to be less "salt-centric" and more general

- **New organization and formulation of individual FEPs by using a more logical structure for associated processes**
  - Eliminates some redundancy among FEPs (e.g., some of the old feature-related FEPs can be combined with old process-related FEPs)
  - Allow for an easier initial completeness check for each FEPs matrix cell
  - Screening (i.e., inclusion/exclusion in PA model and/or scenario development) continues to be managed at the associated process level, rather than the higher FEPs level

New RN Transport FEPs and Associated Processes

- **New transport FEPs organization:**
  - Organized primarily by material phase
  - Other organizational structures could be considered but this one seems reasonably complete from a model-building perspective

- **For any set of FEPs, the level of "discretization" of both FEPs and associated processes is somewhat arbitrary:**

  - Strive for a reasonable level of discretization as might be conceived when building a process model or a PA model, but not too highly discretized
  - Competing "goals": completeness for licensing (i.e., greater discretization) but more "rolled-up" (i.e., less discretization) for model building.

RS.00.TT.01 Transport of Dissolved Radionuclides in the Liquid Phase
  A. Advection
  B. Dispersion
  C. Diffusion
  D. Matrix Diffusion
  E. Intra-aqueous Complexation
  F. Isotopic Dilution (mixing of radioisotopes and stable isotopes)
  G. Dilution by Mixing of Groundwaters

RS.00.TT.02 Interaction of Dissolved Radionuclides with Stationary Phases (Rock Matrix, Fracture Surfaces)
  A. Reversible/Irreversible Physical Sorption
  B. Surface Complexation
  C. Ion Exchange
  D. Precipitation/Dissolution

RS.00.TT.03 Interaction of Dissolved Radionuclides with other Mobile Phases (Colloids, Gas Phase)
  A. Reversible/Irreversible Physical Sorption
  B. Surface Complexation
  C. Ion Exchange
  D. Precipitation/Dissolution
  E. Partitioning

RS.00.TT.04 Coupled Process Effects on Transport of Dissolved Radionuclides

RS.00.TT.05 Transport of Radionuclides in the Gas Phase
  A. Advection
  B. Diffusion

RS.00.TT.06 Formation of Colloids
  A. Intrinsic Colloids*
  B. Pseudo-colloids*

RS.00.TT.07 Transport of Radionuclides on Colloids
  A. Advection of Colloids
  B. Dispersion of Colloids
  C. Diffusion of Colloids
  D. Matrix Diffusion of Colloids
  E. Stability/Flocculation of Colloids (mechanical stability, chemical stability)
  F. Filtration of Colloids (physical filtration, electrostatic filtration)
  G. Dilution by Mixing of Groundwaters

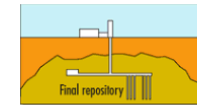**RS.00.TT.08 Interaction of Colloids with Other Phases (Rock Matrix, Fracture Surfaces)**
  A. Reversible/Irreversible Physical Sorption of Colloid Particles onto Stationary Phases
  B. Sorption of Colloids at Air-Water Interface

*FEPs .07 and .08 may need to be screened separately for intrinsic vs. pseudo-colloids

SaltFEP Database Project

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SaltFEP Database Project

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Username:
grs_wolf

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Welcome to the SaltFEP Database Project

To use the salt FEP database you must be registered. Registration is for documenta

SaltFEP (Database of Features, Events, and Processes (FEP) in Salt) is a joint proje relevant to potential repository sites in a salt formation.

This database is developed from an international data base of OECD-NEA and natio radioactive waste in final repositories in salt.

Project Funding

Bundesministerium
für Wirtschaft
und Energie

Details

MARCH 2016

Actual work focuses on the development of the data base and implementation into

JANUARY 2016

January 2016 A preliminary version of the SaltFEP database homepage has been di

FEBRUARY 01 TO FEBRUARY 04, 2016

February 01 to February 04, 2016 A meeting at Washington, DC was held with San

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We have currently 1 other member(s) online:
grs_wolf (Wolf)

FEP Matrix

Characteristics, Processes, and Events / Features / Components		Processes													Events					
	Characteristics	Mechanical and Thermal-M	Hydrological and Thermal-H	Chemical and Thermal-C	Biological and Thermal-B	Transport and Thermal-T	Thermal	Radiological	Long-Term Geologic	Climatic	Human Activities	Other	Nuclear Criticality	Early Failure	Seismic	Igneous	Human Activities	Other		
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Waste and Engineered Features																				
(WF) Waste Form and Cladding	1	1	3																	
(01) SNF and Cladding				1																
(02) Vitrified HLW				1																
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(04) Metal Parts from Reprocessing																				
(WP) Waste Package and Internals	1																			
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(03) Other HLW																				
(04) Metal Parts																				
(BB) Buffer/Backfill	1	1																		
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September 6, 2016

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Future Work

- **Salt FEP Catalogue**
  - Continuation of matrix-based FEP identification and documentation
  - Both countries are in a pre-site-selection stage
    - Generic FEPs only, hard to screen without a site or design
  - Filling out the entire matrix with fully described FEPs requires significant resources
    - Maybe just identify FEP names?
  - Advanced electronic FEP Database
- **NEA Participation**
  - Need to identify "Product" for Salt Club
  - Complete NEA FEP Database beta testing

Acknowledgements

Supported by:

Questions?

Backup Slides

New TH FEPs and Associated Processes

- **FEPs themselves (e.g., HR.00.TH.01) tend to be formulated around driving *forces* or "loading"**

- **Associated processes tend to formulated as *responses* to the driving forces**

- **First six FEPs do not specifically include temperature (heat or energy) effects**

- **Last FEP (.07) includes coupled thermal-hydrological flow processes:**

  - technically brine-inclusion decrepitation and/or migration could go here, too

HR.00.TH.01 Pressure-driven Darcy flow in fractures and porous media
    A. Pressure-driven flow of liquid (wetting) phase
    B. Pressure-driven flow of gas (non-wetting) phase
    C. Flow of any additional phases (e.g., hydrocarbons)
    D. Pressure-driven flow between fractures and matrix (local non-equilibrium)

HR.00.TH.02 Capillarity-dominated Darcy flow
    A. Wicking and absorption (i.e., infiltration without gravity)
    B. Vapor barrier (i.e., reduction in relative liquid permeability at low saturation)
    C. Immiscible phase interaction and displacement
    D. Trapping, discontinuous blobs, or viscous fingering in non-wetting phase

HR.00.TH.03 Gravity- and density-dominated flow
    A. Free convection due to density variation (temperature and salinity effects)
    B. Infiltration, imbibition, and drainage
    C. Dripping and ponding

HR.00.TH.04 Adsorption-dominated flow (water held by electrostatic, van der Waals, and hydration forces)
    A. Thin-film flow below residual saturation (i.e., near liquid dryout)
    B. Hygroscopy (equilibration of solid phase with humidity)
    C. Immobile water in nano-pores or small-aperture fractures

HR.00.TH.05 Diffusion and dispersion in miscible phases
    A. Vapor diffusion in air phase
    B. Dissolved gas diffusion in liquid phase

HR.00.TH.06 Non-Darcy flow in fractures and porous media
    A. High Reynolds number gas or liquid flow in large-aperture fractures
    B. Erosion or sedimentation (i.e., non-chemical plugging) of fractures and flowpaths
    C. Threshold gradient flow in low-permeability matrix
    D. Decrepitation, creation (during reconsolidation), and migration of fluid inclusions

HR.00.TH.07 Thermal-Hydrological effects
    A. Convection and conduction of energy via liquid phase
    B. Convection of energy via vapor (i.e., heat pipe)
    C. Fluid density and viscosity changes due to temperature (e.g., thermal expansion of brine)
    D. Phase changes (i.e., condensation, boiling, freezing, and sublimation)
    E. Release of water from hydrated minerals during heating

New Associated Processes for TC FEPs

- **Set of TC FEPs has not yet been redefined (as was the case with TH and TT FEPs)**

- **Associated processes for any C or TC FEPs were designed as a comprehensive list that might be applicable to any feature/component:**

  (A) Speciation
  (B) Oxidation/reduction processes, reaction kinetics
  (C) Dissolution, reaction kinetics
  (D) Precipitation, inclusion in secondary phase, reaction kinetics
  (E) Formation and filtration of colloids
  (F) Effect of sorption
  (G) Solubility of radionuclides and other species
  (H) Thermal-chemical interactions with WP/MW/BB/seal
      components, including chemical effects on fluid density
  (I) Thermal-chemical interaction with corrosion products,
      including effects on fluid density
  (J) Thermal-chemical Interaction with intruding fluids, including
      effects on fluid density
  (K) Interaction with gas phase
  (L) Osmotic stress and osmotic binding