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Features, Events, and Processes (FEPs) Development Activities

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Verantwortung für Generationen / Responsibility for Generations DBE TEC DBE TECHNOLOGY GmbH

PTKA Project Management Agency Karlsruhe Karlsruhe Institute of Technology

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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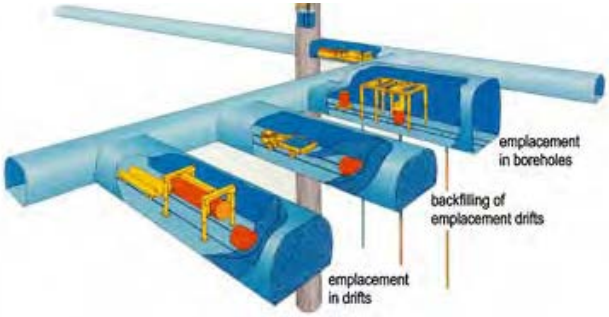
Outline

- Joint U.S.-German Objectives / Motivation
  - SNL: Geoff Freeze, S. David Sevougian, Michael Gross, Christi Leigh
    - DOE Used Fuel Disposition (UFD) Campaign
  - GRS: Jens Wolf, Jörg Mönig, Dieter Buhmann
    - Vorläufige Sicherheitsanalyse Gorleben (VSG)
- Collaborative Results to Date
  - FEP Matrix and Documentation Template
  - New FEPs: bedded salt vs. domal salt FEPs
- Future Work

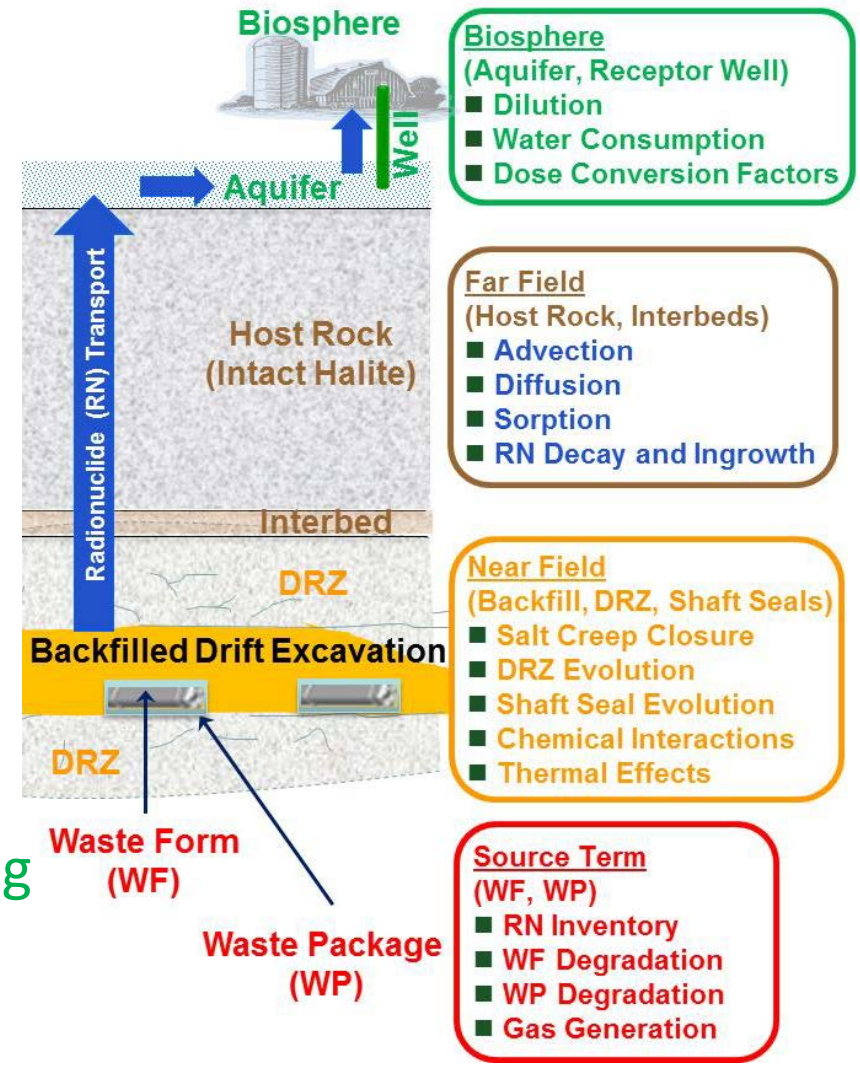
Objectives / Motivation

- U.S. – German collaboration to produce a common FEP list
  - Identify relevant FEPs for disposal of heat-generating waste (SNF and HLW) in salt
    - Applicable to all potential salt concepts and sites
  - Refine existing FEP identification and screening approaches
- Salt Club
  - Produce a FEP Catalogue for use by all NEA Salt Club members
    - Countries with potential interest in salt repositories
    - Documentation of screening decisions
  - Inform the pending update to the NEA International FEP database



FEP Analysis

- A FEP is a Process or Event acting upon or within Feature(s)
- FEP Identification
  - Develop and classify a comprehensive list of FEPs potentially relevant to long-term repository performance
- FEP Screening
  - Specify a subset of important FEPs that individually, or in combination, that contribute to long-term repository performance
- Scenario Development and Screening
  - Identify and screen scenarios (i.e., combinations/sequences of FEPs)
    - Nominal/reference, disruptive



Salt FEP Identification

- US: ~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 as part of "FEP Matrix" approach (Freeze et al. 2014a,b)
  - Initial US and German FEPs mapped to FEP Matrix to eliminate redundancies
  - 5 example matrix-based FEPs created to test approach

FEP Matrix

- Two-dimensional FEP organizational structure
  - Matrix Rows = Feature (and component) Categories
  - Matrix Columns = Process and Event Categories
- Matrix Cell contains all FEPs related to the "Process/Event" acting upon or within the "Feature"
- Related FEPs are grouped by Matrix Cell (or by Row or Column)
  - Not distributed among various locations as in the NEA-based hierarchical list

Coupled THCMBR Processes and Events

Features \ 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
Waste and Engineered Barriers Region																	
Waste Form and Cladding																	
• Commercial SNF & Cladding																	
• Commercial HLW Glass																	
• Naval SNF & Cladding																	
• Defense SNF & Cladding																	
• Defense HLW																	
• Other																	
Waste Package and Internals																	
• Commercial SNF																	
• Commercial HLW																	
• Naval																	
• Defense SNF																	
• Defense HLW																	
• Other Packages																	
Buffer/Backfill																	
• Waste Package Buffer																	
• Tunnel/Drift/Room Backfill																	
Emplacement Tunnel/Drift and Mine Workings																	
• Open Excavations																	
• Drift Support																	
• Liners																	
• Other																	
Seals/Plugs																	
• Drift/Panel Seals/Closures																	
• Shaft Seals																	
• Plugged Boreholes																	
Geosphere / Natural Barrier Region																	
Host Rock (Repository Horizon)																	
• Bedded or Domal Salt																	
• Disturbed Rock Zone																	
• Interbeds / Seams																	
Other Geologic Units																	
• Aquifer(s)																	
• Unsaturated Zone																	
• Pressurized Brine Reservoir(s)																	
Surface Region																	
Biosphere																	
• Natural Surface and Near-Surface Environment																	
• Flora and Fauna																	
• Humans																	
• Food & Drinking Water																	
• Dwellings and Man-Made Surface Features/Materials																	
System Region																	
Repository System																	
• Assessment Basis																	
• Preclosure/Operational																	
• Other Global																	

Feature Categories

FEP Matrix

- All FEPs relevant to the Buffer/Backfill "feature"
  - Some are broadly applicable to both
  - Some are specific to the Buffer "component" or Backfill "component"
- All Thermal-Mechanical FEPs relevant to Buffer/Backfill and Emplacement Tunnels/Drifts

Features \ Characteristics, Processes, and Events		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
Buffer/Backfill	2.1.04.00a 2.1.04.00b	2.1.04.01a 2.1.07.01a	2.1.04.01b 2.1.08.03 2.1.08.07b 2.1.08.08c	2.1.04.01c 2.1.09.06 2.1.09.13c 2.1.11.13c	2.1.09.13c 2.1.11.13d	2.1.09.51c 2.1.09.52c 2.1.09.53c 2.1.09.54c 2.1.09.55c 2.1.11.14b	2.1.04.01d	2.1.13.02c					2.1.14.02a	2.1.03.01b	1.2.03.01b	1.2.04.01b	1.4.02.01b 1.4.11.01b	
• Waste Package Buffer	2.1.04.00a	2.1.11.09a	2.1.04.01b	2.1.04.01c		2.1.09.51c 2.1.09.52c	2.1.04.01											
• Tunnel/Drift/Room Backfill	2.1.04.00b	2.1.07.03 2.1.11.08	2.1.04.01b	2.1.09.03		2.1.09.51c 2.1.09.52c	2.1.11.02c 2.1.11.03											
Emplacement Tunnels/Drifts and Mine Workings	2.1.04.00c	2.1.07.02 2.1.07.08a 2.1.11.09b 2.1.12.01d	2.1.08.08d 2.1.11.10b 2.1.12.01e 2.1.12.02	1.09.04 2.1.09.11b 2.1.11.13e 2.1.12.01f	2.1.10.01d 2.1.11.13f	2.1.09.53d 2.1.09.54d 2.1.09.55d 2.1.11.14c	2.1.11.02d 2.1.11.04 2.1.11.05	2.1.13.01b 2.1.11.04 2.1.11.05					2.1.14.02b	2.1.03.01c	1.2.03.01c	1.2.04.01c	1.4.02.01c 1.4.11.01c	
• Open Excavations			2.1.08.07c	2.1.09.10														
• Tunnel/Drift Support	2.1.04.00d 2.1.06.01		2.1.08.05	2.1.06.01a 2.1.09.07		2.1.09.62a												
• Liners	2.1.04.00d 2.1.06.01		2.1.08.05	2.1.06.01a 2.1.09.07		2.1.09.62a												
• Other	2.1.04.00d 2.1.06.01			2.1.09.07 2.1.09.08b														

FEP Matrix

- Characteristic FEPs
  - FEPs containing properties and parameter values that describe a feature or component
    - Only one Characteristic FEP per feature/component
    - No screening for Characteristic FEPs

Features \ Characteristics, Processes, and Events		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
Buffer/Backfill	2.1.04.00a 2.1.04.00b	2.1.04.01a 2.1.07.01a	2.1.04.01b 2.1.08.03 2.1.08.07b 2.1.08.08c	2.1.04.01c 2.1.09.06 2.1.09.13c 2.1.11.13c	2.1.09.13c 2.1.11.13d	2.1.09.51c 2.1.09.52c 2.1.09.53c 2.1.09.54c 2.1.09.55c 2.1.11.14b	2.1.04.01d	2.1.13.02c					2.1.14.02a	2.1.03.01b	1.2.03.01b	1.2.04.01b	1.4.02.01b 1.4.11.01b	
• Waste Package Buffer	2.1.04.00a	2.1.11.09a	2.1.04.01b	2.1.04.01c		2.1.09.51c 2.1.09.52c	2.1.04.01											
• Tunnel/Drift/Room Backfill	2.1.04.00b	2.1.07.03 2.1.11.08	2.1.04.01b	2.1.09.03		2.1.09.51c 2.1.09.52c	2.1.11.02c 2.1.11.03											
Emplacement Tunnels/Drifts and Mine Workings	2.1.04.00c	2.1.07.01b 2.1.07.02 2.1.07.08a 2.1.11.09b 2.1.12.01d	2.1.08.06 2.1.08.08d 2.1.11.10b 2.1.12.01e 2.1.12.02	2.1.09.012. 1.09.04 2.1.09.11b 2.1.11.13e 2.1.12.01f	2.1.10.01d 2.1.11.13f	2.1.09.53d 2.1.09.54d 2.1.09.55d 2.1.11.14c	2.1.11.02d 2.1.11.04 2.1.11.05	2.1.13.01b 2.1.11.04 2.1.11.05					2.1.14.02b	2.1.03.01c	1.2.03.01c	1.2.04.01c	1.4.02.01c 1.4.11.01c	
• Open Excavations			2.1.08.07c	2.1.09.10														
• Tunnel/Drift Support	2.1.04.00d 2.1.06.01		2.1.08.05	2.1.06.01a 2.1.09.07		2.1.09.62a												
• Liners	2.1.04.00d 2.1.06.01		2.1.08.05	2.1.06.01a 2.1.09.07		2.1.09.62a												
• Other	2.1.04.00d 2.1.06.01			2.1.09.07 2.1.09.08b														

FEP Identification Scheme

- Developed a "numbering" scheme consistent with FEP Matrix
  - Alpha-numeric identifiers indicate where a FEP is mapped in the FEP matrix (e.g., row and column)
    - More descriptive than strictly numeric identifiers
    - Can still be mapped to NEA Database FEP Numbers for traceability

- FEP matrix identifiers have the form: FF.CC.PE.nn

  where:

  FF = Feature

  CC = Component (sub-feature)

  PE = Process or Event category

  nn = sequential tracking number

FEP Identification Scheme

FF.CC.PE.nn

FF = Features:

- Waste Form: WF
- Waste Package: WP
- Buffer/Backfill: BB
- Mine Workings: MW
- Seals/Plugs: SP
- Host Rock: HR
- Other Geologic Units: OU
- Biosphere BI
- Repository System RS

CC = Components:

- Feature-level: 00
- Component-level (e.g. buffer, backfill, …): 01, 02, 03, ….

FEP Identification Scheme

FF.CC.PE.nn

PE = Process or Event category:

Characteristics:	CP	Processes
Mechanical and thermal-mechanical processes:	TM	
Hydrological and thermal-hydrological processes:	TH	
Chemical and thermal-chemical processes:	TC	
Biological and thermal-biological processes:	TB	
Transport and thermal-transport processes:	TT	
Thermal:	TR	
Radiological:	RA	
Long-Term Geologic:	LG	
Climatic:	CL	
Human Activities (Processes):	HP	
Other (Processes):	OP	
Nuclear Criticality:	NC	Events
Early Failure:	EF	
Seismic:	SM	
Igneous:	IG	
Human Activities (Events):	HE	
Other (Events):	OE	

FEP Documentation Template

0. FEP Name and Identifier
1. Definition
2. Description and Related FEPs
   - FEP Description may subdivide into “sub-parts” A, B, C, etc.

   2.1 General

   2.2 Concept Specific (e.g., bedded salt vs. domal salt)

   2.3 Properties and Parameter Values

   2.4 Related FEPs
3. Screening Decision (by sub-part)
4. Screening Justification (by sub-part)
5. Open Issues
6. References

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3. Screening Decision (by sub-part)
4. Screening Justification (by sub-part)
5. Open Issues
6. References

Matrix-Based FEPs – Issues for Bedded vs. Domal Salt

- Filling in the whole matrix with fully described FEPs needs a lot of resources
- “Product” for Salt Club
- Both countries are in a site selection process
- Develop new example matrix-based FEPs that highlight areas where there are differences between bedded salt and domal salt
- Improve template regarding screening decisions and screening justifications

Example Matrix-Based FEP

- BB.02.TM.01 – Mechanical effects on Backfill or from Backfill

Features \ Characteristics, Processes, and Events		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
Buffer/Backfill	2.1.04.00a 2.1.04.00b	2.1.04.01a 2.1.07.01a	2.1.04.01b 2.1.08.03 2.1.08.07b 2.1.08.08c	2.1.04.01c 2.1.09.06 2.1.09.13c 2.1.11.13c	2.1.09.13c 2.1.11.13d	2.1.09.51c 2.1.09.52c 2.1.09.53c 2.1.09.54c 2.1.09.55c 2.1.11.14b	2.1.04.01d	2.1.13.02c					2.1.14.02a	2.1.03.01b	1.2.03.01b	1.2.04.01b	1.4.02.01b 1.4.11.01b	
• Waste Package Buffer	2.1.04.00a	2.1.11.09a	2.1.04.01b	2.1.04.01c		2.1.09.51c 2.1.09.52c	2.1.04.01											
• Tunnel/Drift/Room Backfill	2.1.04.00b	2.1.07.03 2.1.11.08	2.1.04.01b	2.1.09.03		2.1.09.51c 2.1.09.52c	2.1.11.02c 2.1.11.03											
Emplacement Tunnels/Drifts and Mine Workings	2.1.04.00c	2.1.07.01b 2.1.07.02 2.1.07.08a 2.1.11.09b 2.1.12.01d	2.1.08.06 2.1.08.08d 2.1.11.10b 2.1.12.01e 2.1.12.02	2.1.09.012. 1.09.04 2.1.09.11b 2.1.11.13e 2.1.12.01f	2.1.10.01d 2.1.11.13f	2.1.09.53d 2.1.09.54d 2.1.05.55d 2.1.11.14c	2.1.11.02d 2.1.11.04 2.1.11.05	2.1.13.01b 2.1.11.04 2.1.11.05					2.1.14.02b	2.1.03.01c	1.2.03.01c	1.2.04.01c	1.4.02.01c 1.4.11.01c	
• Open Excavations			2.1.08.07c	2.1.09.10														
• Tunnel/Drift Support	2.1.04.00d 2.1.06.01		2.1.08.05	2.1.06.01a 2.1.09.07		2.1.09.62a												
• Liners	2.1.04.00d 2.1.06.01		2.1.08.05	2.1.06.01a 2.1.09.07		2.1.09.62a												
• Other	2.1.04.00d 2.1.06.01			2.1.09.07 2.1.09.08b														

Screening decisions

- Included – FEP is almost certain to be included, independent of the type of salt site or specific site characteristics.
- Excluded – FEP that is almost certain to be screened, independent of the specific salt site
- Site-Specific – FEP requires a substantial amount of detailed information for a specific site evaluation
- Design-Specific – FEP requires detailed information for a specific repository design.
- Evaluate – FEPs are candidates for quantitative sensitivity analyses

Example Matrix-Based FEP

- BB.02.TM.01 – Mechanical effects on Backfill or from Backfill

ID	Description of Process	Screening Decision	
		Bedded Salt	Domal Salt
A	Compaction or Reconsolidation of Backfill	Included	
	(A_1) An eventual moisture content in backfill may increase the convergence rates (A_2) Internal pressure in a segment influences the convergence process		Included Included
B	Back-Stress from Backfill (B_1) The presence of backfill will generate mechanical loads on the drift walls, slowing convergence of the drifts. (B_2) The presence of backfill will generate mechanical loads on drift and borehole liners, and on the waste packages if the packages are placed directly on the floor of the emplacement drifts or (B_3) The presence of backfill will generate mechanical loads on the tops of waste containers if the containers are placed in short boreholes in the floor or ribs of a drift.	Included Evaluate Likely Excluded	Included Likely Excluded Likely Excluded
C	Non-Thermally-Induced Volume Changes (C_1) Swelling of corrosion products (C_2) Crushing of backfill grains	Likely Excluded Evaluate	Likely Included Evaluate
D	Roof Collapse	Likely Excluded	Likely Excluded

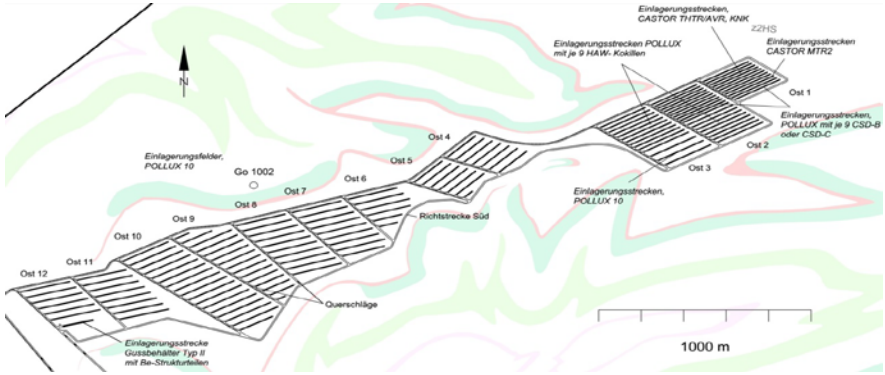
Matrix-Based FEPs – Issues for Bedded vs. Domal Salt

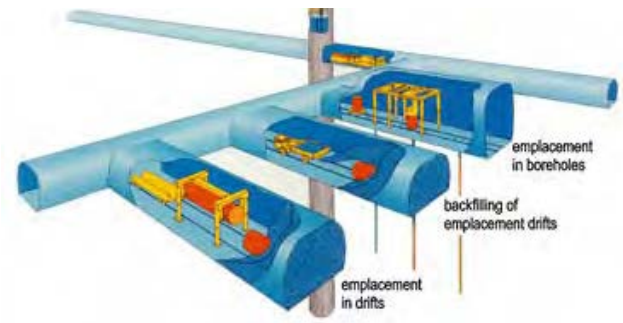
Geology

WIPP
Gorleben

Regulations

Repository Concept / Design





Matrix-Based FEPs – Issues for Bedded vs. Domal Salt

- 13 new example FEPs
  - HR.01.CP.01 Stratigraphy and Properties of Bedded and Domal Salt
  - HR.02.CP.01 Stratigraphy and Properties of Disturbed Rock Zone
  - HR.03.CP.01 Stratigraphy and Properties of Interbeds and Seams
  - RS.00.CP.01 Repository Design
  - WP.00.TC.01 Gas Generation at Waste Packages
  - MW.00.TH.01 Gas Generation in Emplacement Drifts
  - MW.00.HE.01 Human Intrusion into the Emplacement Drifts
  - SP.02.TM.01 Mechanical Effects on Shaft Sealing
  - HR.02.TM.01 Evolution of the DRZ
  - HR.00.OP.01 Alteration and Evolution of Flow Pathways in Host Rock
  - HR.00.TM.01 Mechanical Effects on Host Rock
  - HR.00.TT.01 Advection of Dissolved Radionuclides in Host Rock
  - HR.00.TT.02 Diffusion/Dispersion of Dissolved Radionuclides in Host Rock

Example Matrix-Based FEP

- HR.00.TT.01 Advection of Dissolved Radionuclides in Host Rock

ID	Description of Process	Screening Decision	
		Bedded Salt	Domal Salt
A	Advection of Dissolved Radionuclides	Included	Evaluate
B	Transport Through Fractures	Included	Evaluate
C	Channeling Flow	Likely Excluded	Likely Excluded
D	Viscous Fingering	Excluded	Excluded

Future Work

- Salt FEP Catalogue
  - FEP identification and documentation ongoing
    - Joint U.S.-German collaboration
    - Preamble completed
    - Focus on FEPs where there are differences between bedded and domal salt → Salt Club report
    - Schedule (???-2015?)
  - FEP screening process
    - FEPs vs. scenarios
- Two-Dimensional FEP Matrix Approach
  - Groups related FEPs in a single location (i.e., cell, row, or column)
  - Provides an intuitive alpha-numeric identification scheme
  - Supports safety assessment and safety case development by promoting easy searching of FEP Catalogue to find related issues
  - Present to NEA FEP Working Group in Oct 2014

Electronic FEP Database

- To be developed (future work?)
- e.g. Qt (C++ GUI library) / Postgres SQL / MySQL

Acknowledgement

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of Economics
and Energy

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

on the basis of a decision
by the German Bundestag

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