SAND2015-7371PE

# Joint US-German Activities on the FEP Catalogue and Scenario Development

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6th US/German Workshop on Salt Repository Research, Design, and Operation

Hotel Pullman Dresden Newa

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Federal Ministry for Economic Affairs and Energy

NNSA National Nuclear Security Administration

U.S. DEPARTMENT OF ENERGY

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# Outline

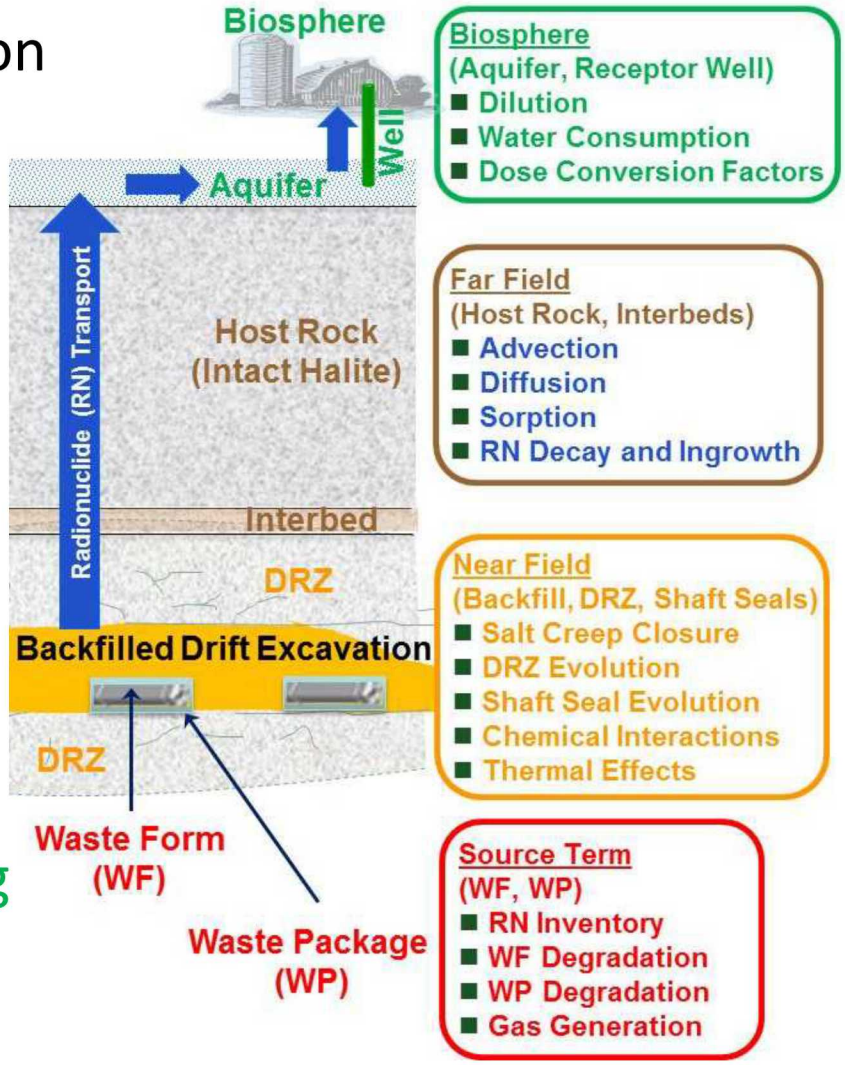
- Objectives / Motivation
- Feature, Event, and Process (FEP) Analysis Overview / Review
- Update on Collaborative Results
  - Populate FEP Matrix
  - NEA Participation
- Future Work
- Participants
  - SNL: Geoff Freeze, David Sevougian, Michael Gross, Christi Leigh
    - DOE Used Fuel Disposition (UFD) Campaign
    - Waste Isolation Pilot Plant (WIPP)
  - GRS: Jens Wolf, Jörg Mönig, Dieter Buhmann
    - Vorläufige Sicherheitsanalyse Gorleben (VSG)

# 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
    - Can support site selection
  - Promote dialogue of experts to review FEP analysis approaches
    - Adopted FEP Matrix approach
- NEA Salt Club
  - Produce a FEP Catalogue for use by all NEA Salt Club members
    - Countries with potential interest in salt repositories
  - Consistency with the pending update to the NEA International FEP Database

# FEP Analysis Overview

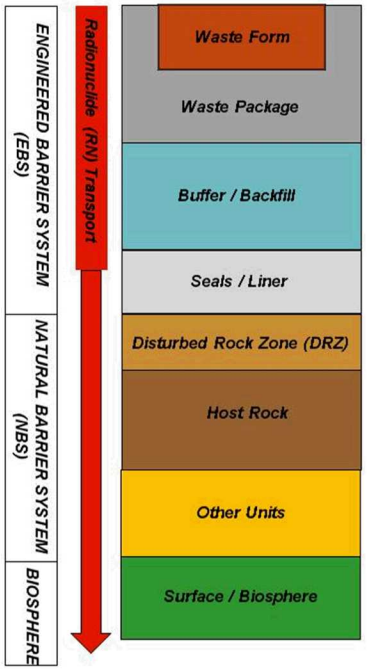
- A FEP is a Process or Event acting upon or within Feature(s)
- FEP Identification
  - Develop and classify a comprehensive list of FEPs potentially relevant to long-term repository performance
- FEP Screening
  - Specify a subset of important FEPs that individually, or in combination, that contribute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



# FEP Matrix Overview

- Two-dimensional FEP organizational structure to guide FEP identification and screening
  - Matrix Rows = Feature (and Component) Categories
  - Matrix Columns = Process and Event Categories
- Related FEPs are grouped by Matrix Cell (or by Row or Column)
  - Matrix Cell contains all FEPs related to the “Process/Event” acting upon or within the “Feature”
- 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 mapped to NEA Database numbering for traceability

# FEP Matrix




Coupled THCMBR Processes and Events

| Characteristics, Processes, and Events / Features and 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 |
| **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 Matrix

| Characteristics, Processes, and Events / Features and Components | (CP) Characteristics | Processes: (TM) Mechanical and Thermal-Mechanical | (TH) Hydrologic and Thermal-Hydrologic | (TC) Chemical and Thermal-Chemical | (TB) Biological and Thermal-Biological | (TT) Transport and Thermal-Transport | (TR) Thermal | (RA) Radiological | (LG) Long-Term Geologic | (CL) Climatic | (HP) Human Activities (long timescale) | (OP) Other | Events: (NC) Nuclear Criticality | (EF) Early Failure | (SM) Seismic | (IG) Igneous | (HE) Human Activities (short timescale) | (OE) Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Waste and Engineered Barriers Region** | | | | | | | | | | | | | | | | | | |
| **(WF) Waste Form and Cladding** | | | | | | | | | | | | | | | | | | |
| • Commercial SNF & Cladding | | | | | | | | | | | | | | | | | | |
| • Commercial HLW Glass | | | | | | | | | | | | | | | | | | |
| • Naval SNF & Cladding | | | | | | | | | | | | | | | | | | |
| • Defense SNF & Cladding | | | | | | | | | | | | | | | | | | |
| • Defense HLW | | | | | | | | | | | | | | | | | | |
| • Other | | | | | | | | | | | | | | | | | | |
| **(WP) Waste Package and Internals** | | | | | | | | | | | | | | | | | | |
| • Commercial SNF | | | | | | | | | | | | | | | | | | |
| • Commercial HLW | | | | | | | | | | | | | | | | | | |
| • Naval SNF | | | | | | | | | | | | | | | | | | |
| • Defense SNF | | | | | | | | | | | | | | | | | | |
| • Defense HLW | | | | | | | | | | | | | | | | | | |
| • Other Packages | | | | | | | | | | | | | | | | | | |
| **(BB) Buffer/Backfill** | | | | | | | | | | | | | | | | | | |
| • Waste Package Buffer | | | | | | | | | | | | | | | | | | |
| • Tunnel/Drift/Room Backfill | | | | | | | | | | | | | | | | | | |
| **(MW) Emplacement Tunnels/ Drifts and Mine Workings** | | | | | | | | | | | | | | | | | | |
| • Open Excavations | | | | | | | | | | | | | | | | | | |
| • Drift Support | | | | | | | | | | | | | | | | | | |
| • Liners | | | | | | | | | | | | | | | | | | |
| • Other | | | | | | | | | | | | | | | | | | |
| **(SP) Seals/Plugs** | | | | | | | | | | | | | | | | | | |
| • Drift/Panel Seals/Closures | | | | | | | | | | | | | | | | | | |
| • Shaft Seals | | | | | | | | | | | | | | | | | | |
| • Plugged Boreholes | | | | | | | | | | | | | | | | | | |
| **Geosphere and Natural Barriers Region** | | | | | | | | | | | | | | | | | | |
| **(HR) Host Rock (Repos. Horizon)** | | | | | | | | | | | | | | | | | | |
| • Bedded or Domal Salt | | | | | | | | | | | | | | | | | | |
| • Disturbed Rock Zone | | | | | | | | | | | | | | | | | | |
| • Interbeds and Seams | | | | | | | | | | | | | | | | | | |
| **(OU) Other Geologic Units** | | | | | | | | | | | | | | | | | | |
| • Aquifer(s) | | | | | | | | | | | | | | | | | | |
| • Unsaturated Zone | | | | | | | | | | | | | | | | | | |
| • Pressurized Brine Reservoir(s) | | | | | | | | | | | | | | | | | | |
| **Surface Region** | | | | | | | | | | | | | | | | | | |
| **(BP) Biosphere** | | | | | | | | | | | | | | | | | | |
| • Natural Surface and Near-Surface Environment | | | | | | | | | | | | | | | | | | |
| • Flora and Fauna | | | | | | | | | | | | | | | | | | |
| • Humans | | | | | | | | | | | | | | | | | | |
| • Food and Drinking Water | | | | | | | | | | | | | | | | | | |
| • Dwellings and Man-Made Surface Features/Materials | | | | | | | | | | | | | | | | | | |
| **System Region** | | | | | | | | | | | | | | | | | | |
| **(RS) Repository System** | | | | | | | | | | | | | | | | | | |
| • Assessment Basis | | | | | | | | | | | | | | | | | | |
| • Pre-closure and Operational | | | | | | | | | | | | | | | | | | |
| • 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

# FEP Matrix

| Features and Components / Characteristics, Processes, and Events | (CP) Characteristics | (TM) Mechanical and Thermal-Mechanical | (TH) Hydrologic and Thermal-Hydrologic | (TC) Chemical and Thermal-Chemical | (TB) Biological and Thermal-Biological | (TT) Transport and Thermal-Transport | (TR) Thermal | (RA) Radiological | (LG) Long-Term Geologic | (CL) Climatic | (HP) Human Activities (long timescale) | (OP) Other | (NC) Nuclear Criticality | (EF) Early Failure | (SM) Seismic | (IG) Igneous | (HE) Human Activities (short timescale) | (OE) Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Waste and Engineered Barriers Region** | | | | | | | | | | | | | | | | | | |
| **(WF) Waste Form and Cladding** | | | | | | | | | | | | | | | | | | |
| • Commercial SNF & Cladding | | | | | | | | | | | | | | | | | | |
| • Commercial HLW Glass | | | | | | | | | | | | | | | | | | |
| • Naval SNF & Cladding | | | | | | | | | | | | | | | | | | |
| • Defense SNF & Cladding | | | | | | | | | | | | | | | | | | |
| • Defense HLW | | | | | | | | | | | | | | | | | | |
| • Other | | | | | | | | | | | | | | | | | | |
| **(WP) Waste Package and Internals** | | | | 1 | | | | | | | | | | | | | | |
| • Commercial SNF | | | | | | | | | | | | | | | | | | |
| • Commercial HLW | | | | | | | | | | | | | | | | | | |
| • Naval SNF | | | | | | | | | | | | | | | | | | |
| • Defense SNF | | | | | | | | | | | | | | | | | | |
| • Defense HLW | | | | | | | | | | | | | | | | | | |
| • Other Packages | | | | | | | | | | | | | | | | | | |
| **(BB) Buffer/Backfill** | | | | | | | | | | | | | | | | | | |
| • Waste Package Buffer | | | | | | | | | | | | | | | | | | |
| • Tunnel/Drift/Room Backfill | 1 | 2 | | | | 2 | | | | | | | | | | | | |
| **(MW) Emplacement Tunnels/ Drifts and Mine Workings** | | | 1 | | | | | | | | | | | | | | 1 | |
| • Open Excavations | | | | | | | | | | | | | | | | | | |
| • Drift Support | | | | | | | | | | | | | | | | | | |
| • Liners | | | | | | | | | | | | | | | | | | |
| • Other | | | | | | | | | | | | | | | | | | |
| **(SP) Seals/Plugs** | | | | | | | | | | | | | | | | | | |
| • Drift/Panel Seals/Closures | | | | | | | | | | | | | | | | | | |
| • Shaft Seals | | 1 | | 1 | | | | | | | | | | | | | | |
| • Plugged Boreholes | | | | | | | | | | | | | | | | | | |
| **Geosphere and Natural Barriers Region** | | | | | | | | | | | | | | | | | | |
| **(HR) Host Rock (Repos. Horizon)** | | 1 | | | | | | | | | | 1 | | | | | | |
| • Bedded or Domal Salt | 1 | | | | | 2 | | | | | | | | | | | | |
| • Disturbed Rock Zone | 1 | 1 | 1 | | | 2 | | | | | | | | | | | | |
| • Interbeds and Seams | 1 | | | | | 2 | | | | | | | | | | | | |
| **(OU) Other Geologic Units** | | | | | | | | | | | | | | | | | | |
| • Aquifer(s) | | | | | | | | | | | | | | | | | | |
| • Unsaturated Zone | | | | | | | | | | | | | | | | | | |
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| **Surface Region** | | | | | | | | | | | | | | | | | | |
| **(BP) Biosphere** | | | | | | | | | | | | | | | | | | |
| • Natural Surface and Near-Surface Environment | | | | | | | | | | | | | | | | | | |
| • Flora and Fauna | | | | | | | | | | | | | | | | | | |
| • Humans | | | | | | | | | | | | | | | | | | |
| • Food and Drinking Water | | | | | | | | | | | | | | | | | | |
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| **System Region** | | | | | | | | | | | | | | | | | | |
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| • Assessment Basis | | | | | | | | | | | | | | | | | | |
| • Pre-closure and Operational | | | | | | | | | | | | | | | | | | |
| • Other Global | 1 | | | | | | | | | | | | | | | | | |

## Combined Salt FEPs
(Freeze et al. 2014)
(Sevougian et al. 2015)

- 25 Matrix-based FEPs, derived from initial US and German FEPs
- Focus on FEPs which emphasize differences between bedded and domal salt

# Combined Salt FEPs (to date)

## Waste and Engineered Barrier FEPs (11)

Waste Package

- WP.00.TC.01 Gas Generation at Waste Packages

Backfill

- BB.02.CP.01 Backfill Materials
- BB.02.TM.01 Mechanical Effects on Backfill or from Backfill
- BB.02.TM.02 Thermal-Mechanical Effects on Backfill or from Backfill
- BB.02.TT.01 Advection of Dissolved Radionuclides in Backfill
- BB.02.TT.02 Diffusion/Dispersion of Dissolved Radionuclides in Backfill

Emplacement Drifts / Mine Workings

- MW.00.TH.01 Thermal-Hydrologic Effects of Gas in Emplacement Drifts / Boreholes
- MW.00.TM.01 Mechanical Response of Mine Workings to External Stress
- MW.00.HE.01 Human Intrusion into the Emplacement Drifts

Seals

- SP.02.TM.01 Mechanical Effects on Shaft Seals or from Shaft Seals
- SP.02.TC.01 Chemical Interaction of Groundwater with Shaft Seals

## System FEPs (1)

- RS.03.CP.01 Repository Design

# Combined Salt FEPs (to date)

## Geosphere and Natural Barrier FEPs (13)

Host Rock (General)

- HR.00.TM.01 Mechanical Effects on the Host Rock
- HR.00.OP.01 Alteration and Evolution of Flow Pathways in the Host Rock

Bedded or Domal Salt

- HR.01.CP.01 Stratigraphy and Properties of Bedded and Domal Salt
- HR.01.TT.01 Advection of Dissolved Radionuclides in Bedded or Domal Salt
- HR.01.TT.02 Diffusion/Dispersion of Dissolved Radionuclides in Bedded or Domal Salt

Disturbed Rock Zone (DRZ)

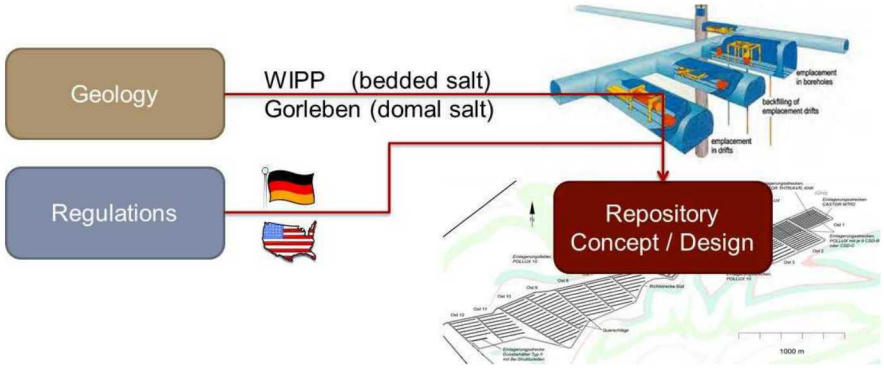
- HR.02.CP.01 Stratigraphy and Properties of the Disturbed Rock Zone in the Host Rock
- HR.02.TM.01 Mechanical Effects on the Evolution of the DRZ
- HR.02.TH.01 Flow Through the DRZ
- HR.02.TT.01 Advection of Dissolved Radionuclides in the Disturbed Rock Zone
- HR.02.TT.02 Diffusion/Dispersion of Dissolved Radionuclides in the Disturbed Rock Zone

Interbeds and Seams

- HR.03.CP.01 Stratigraphy and Properties of Interbeds and Seams in the Host Rock
- HR.03.TT.01 Advection of Dissolved Radionuclides in Interbeds and Seams
- HR.03.TT.02 Diffusion/Dispersion of Dissolved Radionuclides in the Interbeds and Seams

# Combined Salt FEPs

- 25 Matrix-based FEPs
  - Derived from initial US and German FEPs
  - Focus on FEPs which emphasize differences between bedded and domal salt




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


Sandia National Laboratories
Waste Isolation Pilot Plant

Generic Salt FEPs Catalogue, Volume II

Revision 0

June 22, 2015

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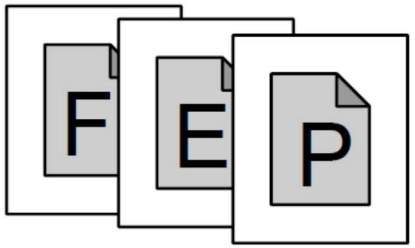
**Nuclear Regulatory and Support Services (NRSS)
***Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH

WBS 1.2.3.03.03.06
International R&D

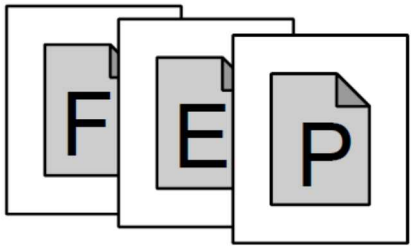
# NEA Participation – Salt Club

- Produce a FEP Catalogue for use by all NEA Salt Club members
  - Countries with potential interest in salt repositories
- Deliverable due at end of current Salt Club Mandate Period (2014-16)
  - Full Salt FEP Catalogue will not be complete
  - Deliverable content TBD




# NEA Participation – FEP Database

- US and German participation in the NEA FEP Task Group Meeting
  - Presentation of Salt FEPs Approach and Content
- Inform the pending update to the NEA International FEP database (completion date is TBD)
  - Existing NEA FEPs
  - Capability for user uploading of new FEP lists
- Currently beta testing web-based Version 0.3




# NEA Participation – Scenario Development

- US and German participation in the NEA Scenario Development Workshop (June 1-3, 2015) in Paris
  - Presentation of National approaches for FEP Analysis and Scenario Development, including comprehensiveness
  - Support development of an NEA Report on Scenario Development

# NEA Scenario Development Workshop

- Main outcomes / developments since NEA (2001)
  - Scenario development is an integral part of any safety case
  - Basic ideas are consistent in all discussed safety cases
    - Mixture of bottom-up and top-down approaches
    - Different classes of scenarios
    - Human intrusion → separate scenario category
    - What-if cases → robustness
  - Main efforts in the last decade
    - Comprehensiveness of scenarios
    - Traceability of decisions (regulatory expectations!)
    - Documentation in the safety case
  - Open issues
    - Communicating the role and choice of scenarios
    - Assigning probabilities to scenarios/FEPs

# Future Work

- Salt FEP Catalogue
  - Continuation of matrix-based FEP identification and documentation
  - Both countries are in a site selection process
    - Generic FEPs only, hard to screen
  - Filling out the entire matrix with fully described FEPs requires significant resources
    - Maybe just identify FEP names?
  - Electronic FEP Database under development → saltfep.org
- NEA Participation
  - Need to identify “Product” for Salt Club
  - Complete NEA FEP Database beta testing
  - Complete NEA Scenario Development documentation

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and Energy

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ENERGY | Nuclear Energy

on the basis of a decision
by the German Bundestag

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