Prioritization of International Activities and Moving Forward: Disposal Research 5-Year Plan

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International Disposal Research Activities: Tapping into Multinational Initiatives and Individual Collaborations

Multinational Initiatives

• Cooperative research partnerships, often requiring formal participation agreements
• Examples with active research focus include DECOVALEX Project, Mont Terri Project, SKB Task Forces, FEBEX-DP Project, and HotBENT Project
• Other examples with focus on information exchange are provided by Nuclear Energy Agency (NEA) or certain European Union Projects

Bilateral Collaborations

• Informal or formal research collaboration with individual organizations
• A prominent current example is the comprehensive collaboration on salt disposal with German organizations
International Collaboration Activities with Experimental Focus

Key R&D Issues
- Near-Field Perturbation
- Engineered Barrier Integrity
- Flow and Radionuclide Transport
- Demonstration of Integrated System Behavior

International

Salt

Argillite/Mudstone

Crystalline

Gas Migration

EBS

TSDE (Asse)

BEDRICH

LTDE

CFM

GREET

BRIE

FEBEX & HotBENT

Gas Migration

2019 Status

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2019 Status
Motivation and Prioritization

Scientific and Technical Benefits

• Tap into global knowledge, stay abreast of science advances, and gain access to international datasets and experiments
• Test and validate advanced process-modeling and experimental tools
• Understand research needs arising from critical (and sometimes surprising) issues related to “real” rocks and sites
• Leverage resources and share cost of science campaigns, in particular large experimental projects

Other Benefits

• Build valuable relationships and re-establish the U.S. disposal research program as a committed international partner
• Work towards a common set of disposal best practices and lessons learned (e.g., risk communication and site selection)
• Attract and build a new generation of “waste disposal” scientists

Prioritization Principles

• Prioritize international R&D activities based on key issues, technical merit, relevance to safety, and cost/benefit
• Emphasize active R&D participation and access to experiments in underground research laboratories (URLs)
• Balance portfolio across host rocks, repository designs, and key R&D areas
Integration with Campaign Research Roadmapping Exercises

- **2010-2012**: Roadmap Workshops to identify high-priority research needs for campaign
- **2012**: International collaboration workshop to discuss priority research activities related to international URLs
- **2019**: Roadmap Update to review existing R&D activities, assess priority levels, and brainstorm remaining research needs (fully integrated with international activities planning)

Continuous Re-Evaluation in Annual Campaign Working Group Meetings

- Assess emerging or changing research needs (e.g., gas pressure buildup, seal performance, interfacial processes, etc.)
- Consider changing campaign priorities (e.g., higher thermal limits)
- Assess or create new international opportunities (e.g., DECOVALEX-2023)
- Revise international portfolio
Integration Among Disposal Research Activities

Spent Fuel and Waste Science and Technology (FY21)

Disposal Research

- Argillite Disposal R&D
- Crystalline Disposal R&D
- Salt Disposal R&D
- Geologic Disposal Safety Assessment
- Direct Disposal of Dual Purpose Canisters
- International Collaborations Disposal Research
- Engineered Barrier System R&D
- Inventory and Waste Form Characteristics and Performance
- Technical Support for Underground Research Laboratory Activities

Planning & Coordination

Host-rock Investigations

Cross-cutting Investigations
Integration Among Disposal Research Activities

Generic and International Research

Planning & Coordination

Generic and International Research

Integrated Planning of Activities
During the first few years, DOE participated in international R&D efforts that had been planned years earlier.

Since then, DOE has been actively involved in planning of new projects together with the international community, achieving more integration.

Examples of international research leadership and active engagement:

- Joint planning & execution of HotBENT field test with NAGRA and others.
- Leading the THMC modeling of HotBENT Lab Experiment in SKB EBS Task Force.
- Chairing the international DECOVALEX Project and thus coordinating its research emphasis.
- Coordinating use of the BATS salt heater test at WIPP (Waste Isolation Pilot Plant) as a modeling task in the international DECOVALEX 2023 project.
- Coordinating performance assessment benchmarking exercises (salt, crystalline) as a modeling task in DECOVALEX 2023.
Examples of Prioritization and Integrated Planning: High Temperature Effects

Fundamentals of Physico-Chemical Alterations
- Laboratory imaging/characterization of heated samples
- Detailed coupled processes modeling of individual components

Barrier System Behavior
- Laboratory or in situ testing of barrier systems
- Validation of predictive process models for system behavior
- Predictions of engineered and natural barrier perturbations
- Optimization studies (e.g., alternative backfill materials)

Performance Assessment
- Include high temperature effects in performance assessment models
- Determine scenarios and parameters with significant impact on high-temperature repository performance
- Conduct performance assessment for different thermal designs
International Experiments: Long-Term Planning & Coalition Building & Execution

Timeline Towards HotBENT:

• **2013**: discussions with international partners about high-temperature research needs

• **2015**: joint paper with NAGRA about research status/needs, including *in situ* test

• **2016**: international coalition building and first HotBENT planning meeting (five partners; NAGRA leadership)

• **2018**: official HotBENT partnership (five full & four associated partners)

• **Since 2019**: preparation and installation of *in situ* test

• **2021**: HotBENT heaters will be turned on and run for 10 to 20 years
Examples of Prioritization and Integrated Planning: Gas Migration in Clay-Based Materials

Step 1: Basic process understanding

- In-Situ LASGIT Experiment at Åspö Hard Rock Lab in DECOVALEX-2023

Step 2: Full-scale behavior and predictive modeling

- Laboratory Experiments in DECOVALEX-2019

Step 3: Testing of a gas permeable seal

- In-Situ Gas Permeable Seal Test (GAST) at Grimsel Test Site
Examples of Prioritization and Integrated Planning: Site Selection, Comparison and Characterization

Best Practices and Lessons Learned

Germany: is currently in early stages of site selection with broad range of host rocks

Switzerland: has narrowed its selection to three regions, which are compared in a formal process. Detailed characterization is ongoing.

Canada: has narrowed its search from initially 22 areas to two sites. Detailed characterization is ongoing.

Sweden: has finalized its site selection and site characterization process. Waiting for permission to construct.

Site Characterization Methods

Characterization of flowing fractures in deep borehole at COSC Project, Sweden

Fault characterization studies at Mont Terri, Switzerland
Summary

• Active collaboration with international programs is a central and fully integrated element of DOE’s disposal research program

• International research activities have been extremely beneficial to the Disposal Research Campaign:
  – Improving science base, reducing uncertainty, and building confidence in alternative geologic disposal options
  – Testing new advanced process-modeling and monitoring tools
  – Shared cost for large expensive experiments
  – Information and knowledge exchange in terms of best practices, state of the art simulation and monitoring methods, R&D priorities elsewhere

• Prioritization of international activities is conducted via integrated, open, and frequent planning efforts across the campaign

• Various opportunities exist for expansion of international disposal research activities
Content of Report (332 pages):

- International Opportunities and Strategic Considerations
- Multinational Cooperative Initiatives
- Bilateral Collaboration Opportunities
- Selection of International Collaboration Activities
- Disposal Research Activities Associated with International Collaborations
## International - Acronyms and Abbreviations (1)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ALC</td>
<td>Full-scale Emplacement Experiment</td>
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<tr>
<td>BATS</td>
<td>Brine Availability Test in Salt</td>
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<td>BRIE</td>
<td>Bentonite Rock Interaction Experiment</td>
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<td>CFM</td>
<td>Colloid Formation and Migration Project</td>
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<tr>
<td>CI</td>
<td>Cement Clay Interaction Experiment</td>
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<tr>
<td>COSC</td>
<td>Collision Orogeny in the Scandinavian Caledonides</td>
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<tr>
<td>DECOVALEX</td>
<td>DEvelopment of COupled Models and their VALidation Against EXperiments</td>
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<td>DOE</td>
<td>Department of Energy, USA</td>
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<tr>
<td>DR-A</td>
<td>Diffusion, Retention, and Perturbation Experiment</td>
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<td>EB</td>
<td>Engineered Barrier</td>
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<tr>
<td>EBS</td>
<td>Engineered Barrier System</td>
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<td>FE</td>
<td>Full-scale Emplacement Experiment</td>
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<td>FEBEX</td>
<td>Full-scale Engineered Barrier Experiment</td>
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<td>FEBEX-DP</td>
<td>FEBEX Dismantling Project</td>
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<tr>
<td>FS</td>
<td>Faults Slip Hydro-Mechanical Characterization Experiment</td>
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<tr>
<td>FY</td>
<td>Fiscal Year</td>
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<tr>
<td>GAST</td>
<td>Gas-Permeable Seal Test</td>
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<td>GREET</td>
<td>Groundwater REcovery Experiment in a Tunnel</td>
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<td>HE-E</td>
<td><em>In Situ</em> Heater Experiment in Micro-tunnel</td>
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<td>HG-A</td>
<td>Gas Path through Host Rock Experiment</td>
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<td>KURT</td>
<td>KAERI Underground Research Tunnel, Republic of Korea</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>LASGIT</td>
<td>Large-scale Gas Injection Test</td>
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<td>LTDE</td>
<td>Long-Term Sorption Diffusion Experiment</td>
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<td>NAGRA</td>
<td>Swiss waste management organization</td>
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<td>NEA</td>
<td>Nuclear Energy Agency</td>
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<td>SFWST</td>
<td>Spent Fuel and Waste Science &amp; Technology</td>
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<td>SKB</td>
<td>Swedish Nuclear Fuel and Waste Management, Sweden</td>
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<td>TSDE</td>
<td>Thermal Simulation for Drift Experiment</td>
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<td>TED</td>
<td>Thermal Experiment</td>
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<tr>
<td>THMC</td>
<td>Thermo-hydro-mechanical-chemical</td>
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<tr>
<td>URL</td>
<td>Underground Research Laboratory</td>
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<td>WIPP</td>
<td>Waste Isolation Pilot Plant, New Mexico, USA</td>
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Moving Forward: Disposal Research 5-Year Plan

David C. Sassani, Sandia National Laboratories, National Technical Director, Spent Fuel and Waste Science and Technology (SFWST) Campaign

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Outline

- Program Planning Introduction
  - Overview and challenges
  - Completed prioritization efforts and Disposal Research coverage

- Disposal Research Five-year Plan
  - Purpose and structure
  - R&D priorities
  - Integration example from FY21 planning

- Summary and Conclusions
Generic Disposal Concepts and Program Planning

- Provide a sound technical basis for multiple viable disposal options in the US
  - Spent nuclear fuel (SNF)
    - Commercial
    - DOE-managed
  - High-level nuclear waste (HLW) glass

- Increase confidence in the robustness of generic disposal concepts

- Develop the science and engineering tools needed to support disposal concept implementation

### Planning Challenges:
- Wide range of geologic disposal concepts
- Constrain the generic R&D most important for each
- Define complete enough for generic D&D
- Utilize vast international experience
- Integrate cross-cutting aspects clearly
Planning Prioritization Drivers, Previous Efforts, and Disposal Research Coverage

- **Driving Forces**
  - Program Direction
  - Generic nature of R&D studies
    - Provide bases and capabilities applicable to broad concepts
    - GDSA capabilities in multiple geologic disposal concepts
  - International investigations including site-specific work

- **Completed prioritization efforts**
  - Used Fuel Disposition Roadmap (2012)
    - Generated from FY10 through FY12
  - Roadmap Update (2019)
    - Started in FY17 reassessment

- **Disposal Research Coverage**
Purpose and Utility

- Strategic guide to the work within the DR R&D technical areas (i.e., the control accounts)
  - Concise consolidated plan report for Disposal Research Program
  - Provides thrust topics in each DR technical area
- Living document to be updated annually based on
  - Program Direction
  - Technical progress
  - Enhanced knowledge

Plan Structure: Thrust Topics in each DR Technical Area for

- The near term => 1- to 2-year timeframe
  - The present DR R&D portfolio with modest modifications
- The longer term => 3- to 5-year timeframe
  - Vision of where the DR R&D is heading (w/o major Program changes)
- Implemented by executing the work and revising the plan each year
  - First revision will add report on progress for short term thrusts and bases for revised prioritization
Disposal Research (DR) Technical Area Thrust Topics

- **Argillite Disposal R&D**
  - Near-Term Thrust Topics (Next 1- to 2-year period)
    - Elucidation of the coupled thermal, hydrologic, mechanical, and chemical (THMC) processes affecting repository performance and
    - Development of multi-fidelity approaches for integration of process models into the GDSA Framework
  - Longer-Term Thrust Topics (Next 3- to 5-year period)
    - Simplifying the representations of THMC processes occurring from within the EBS
    - International collaborations with inputs on field testing and process understanding

- **Crystalline Disposal R&D**
  - Near-Term Thrust Topics
    - Flow and transport in fractures, including matrix diffusion
    - Improved representation of coupled THM processes affecting fracture transmissivity
  - Longer-Term Thrust Topics
    - Performance of candidate buffer materials under a range of disposal conditions
Disposal Research (DR) Technical Area Thrust Topics (Continued)

- **Salt Disposal R&D**
  - Near-Term Thrust Topics
    - Effect of heat-generating waste
    - Evolution of engineered barriers in salt
    - Model development
  - Longer-Term Thrust Topics
    - Additional heated borehole tests (beyond BATS)
    - Integration of models into GDSA Framework

- **Geologic Disposal Safety Assessment**
  - Near-Term Thrust Topics
    - Advanced simulation capability
    - Uncertainty and sensitivity analysis
    - Workflow
    - Repository systems analysis
    - Geologic modeling
  - Longer-Term Thrust Topics
    - Incorporation of newer models from host-rock investigations for additional FEP
    - Refined representations of EBS and geologic features
Direct Disposal of Dual-Purpose Canisters (July 2020)

- **Near-Term Thrust Topics**
  - Probabilistic Post-Closure DPC Criticality Consequence Analyses
  - As-Loaded DPC Reactivity Margin Modeling
  - DPC Injectable Filler Testing and Analysis
  - Future DPC (Fuel/Basket) Modifications

- ** Longer-Term Thrust Topics**
  - Higher-fidelity GDSA Probabilistic Post-Closure DPC Criticality Consequence Model
  - Near Full-scale Demonstration of DPC Injectable Filler Testing and Analysis
  - Develop/Demonstrate Most Promising Future DPC (Fuel/Basket) Modifications
International Collaboration in Disposal Research (April 2019)

- **Near-Term Thrust Topics**
  - Continue participation within international R&D in underground research laboratories for a range of geologic systems
  - Continue assessment of **new international opportunities**
  - Pursue a **more active role in conducting experimental work** in international underground research laboratories
  - Contribute to integration and confidence building for Generic Disposal System Analysis

- **Longer-Term Thrust Topics**
  - Develop **best practices and technologies for site selection** and characterization
  - Utilize international activities for training/education of junior staff
Disposal Research (DR) Technical Area Thrust Topics (Continued)

- **Engineered Barrier System (EBS) R&D**
  - **Near-Term Thrust Topics**
    - Analysis of thermal, mechanical, and chemical processes that will influence performance of EBS designs for each host media
    - Understanding of bentonite buffer drying and re-saturation processes (i.e., thermal-hydrologic behavior)
  - **Longer-Term Thrust Topics**
    - a) International collaboration and URL studies for EBS performance and design materials (e.g., cement)

- **Online Waste Library (OWL) – Inventory and Waste Characterization**
  - **Near-Term Thrust Topics**
    - Provide Change Control and Release Control processes for OWL
    - Develop Glass Waste Degradation Expertise
  - **Longer-Term Thrust Topics**
    - Maintain OWL Inventory Content
    - Consider Additional Interface Capabilities for the GDSA Framework
Disposal Research (DR) Technical Area Thrust Topics (Continued)

- Technical Support for Underground Research Laboratory Activities
  - Near-Term Thrust Topics
    - Operational
    - Passive monitoring
    - Cosmic radiation
  - Longer-Term Thrust Topics
    - Long-term data collection for both passive monitoring and cosmic radiation detection activities

- Knowledge Management (KM - in Campaign Management Control Account)
  - Near-Term Thrust Topics
    - Continued maintenance and development on KM Repository
    - Expand topical coverage for disposal programs and storage & transportation
  - Longer-Term Thrust Topics
    - Expand KM Repository efficacy to larger portions of the nuclear energy fuel cycle community
    - Consider developing training courses
FY 21 Updates SFWST Disposal Research R&D Campaign Structure (from PICS NE 1.08.01)

- **Integration** Within Disposal Research for Waste Forms (SNF)
  - With Storage and Transportation (S&T) R&D
  - With Integrated Waste Management (IWM) Campaign
  - Further…

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Integration of Waste Form Work

- Spent Fuel and Waste Science and Technology (FY21)
  - Disposal Research
    - Argillite Disposal R&D
    - Crystalline Disposal R&D
    - Salt Disposal R&D
    - Geologic Disposal Safety Assessment
    - Direct Disposal of Dual Purpose Canisters
    - International Collaborations Disposal Research
    - Engineered Barrier System R&D
    - Inventory and Waste Form Characteristics and Performance
    - Technical Support for Underground Research Laboratory Activities

- Inventory and Waste Form Characteristics and Performance
  - OWL - Inventory - SNL
  - Waste Form Testing, Modeling, and Performance - SNL
  - SNF Modeling and Testing - ANL
  - SNF Modeling and Testing - LANL
  - SNF Modeling and Testing International Collaborations - PNNL
  - SNF Degradation Testing - ORNL
  - Advanced Isotopic Measurements of HBU SNF - ORNL
  - Cladding Degradation Conceptual Model - PNNL
  - Cladding Degradation Conceptual Model - SNL
Visual Depiction of Disposal Research Host Rock and Cross-cutting Technical Areas

- Patterned Wedges: Host Rock Areas
- Colored Overlay Rings: Cross-cutting Areas
  - Shading indicates focus of Cross-cutting activities

- Host-rock Investigations
  - Argillite/shale
  - Crystalline
  - Salt

- Cross-cutting Investigations
  - International
  - Engineered Barrier System
  - Dual Purpose Canisters
  - Geologic Disposal Safety Assessment
  - Inventory/Waste Form
  - SNF testing
  - Finalize planning FY21
    - Initiating Testing?
  - Underground Research Laboratory

- Unsaturated Zone Activities (less mature)

DPC = Dual Purpose Canisters
EBS = Engineered Barrier System
GDSA = Geologic Disposal Safety Assessment
SNF = Spent Nuclear Fuel
Summary and Conclusions

- Generic Disposal Research R&D Planning/Prioritization has Multiple Drivers
  - Program Direction
  - Generic nature of R&D studies
  - GDSA capabilities in multiple geologic disposal concepts
  - International investigations including site-specific work

- Within the UFD/SFWST Campaign(s), Detailed Planning Activities Occurred
  - 2012 Roadmap - Based on Features, Events, and Processes
    - Prioritized both for Safety Importance and Knowledge State
  - 2019 Roadmap Update - Based on Campaign Activities (i.e., Technical Progress)
    - Prioritized both for Safety Importance and Updated Knowledge State

- Developed Disposal Research (DR) Five-year Plan for R&D Priorities in
  - Near term (1-2 years)
  - Longer term (3-5 years)
  - Integrating technical thrusts within Disposal Research R&D with
    - Storage & Transportation R&D and Integrated Waste Mgt (DOE NE-82)…and beyond
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