Supplement of

The role of international collaboration in the United States geologic disposal research program

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The Role of International Collaboration in the United States Geologic Disposal Research Program

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Spent Nuclear Fuel and High-Level Waste (HLW) Storage Sites

DOE HLW Sites

Spent Nuclear Fuel Facilities

DOE HLW Sites
In 2010, the United States discontinued all activities focused on unsaturated fractured tuff formation as the geologic disposal option for spent fuel and high-level radioactive waste.

A new DOE disposal research program was initiated to provide a sound technical basis for alternative disposal options across clay, crystalline, and salt rocks.

To date, no regulatory framework exists for alternative disposal sites, and only generic (site-independent) disposal research can be conducted.
DOE's Office of Spent Fuel and Waste Disposition: Mission

R&D on Viable Geologic Disposal Options in the US
- Increase confidence in the robustness of multiple generic disposal concepts in the US
- Develop the science and engineering tools needed to support disposal concept implementation
- Evaluate potential for direct disposal of dual-purpose canisters

R&D on Extended Storage and Large-Scale Transport
Support the technical basis for evaluating:
- Extended storage of used nuclear fuel
- Fuel retrievability and transportation after extended storage
- Transportation of high-burnup used nuclear fuel

Implementation of Federal Consolidated Interim Storage

CONSENT-BASED SITING PROCESS
for Federal Consolidated Interim Storage of Spent Nuclear Fuel

Exploring the background, fundamentals, rules, and more associated with DOE's consent-based siting process
Prior to 2010, repository development in unsaturated fractured tuff was so unique with respect to design and geologic environment that overlap with international R&D was quite limited.

Since the U.S. programs focus shifted to a wide range of other repository designs and host rock environments, there has been a lot more alignment with the international disposal world.

A strategic decision was made in 2012 to significantly advance international collaboration in geologic disposal research.
The U.S. International Collaboration Program: Benefits and Principles

**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

**Scientific and Technical Benefits**

- Tap into global knowledge, stay abreast of science advances, 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 program as a committed international partner
- Work towards a common set of disposal best practices and lessons learned
- Attract, develop and retain a new generation of “waste disposal” scientists
Multinational Initiatives

- Cooperative research partnerships, often requiring formal participation agreements
- Examples with active research focus: DECOVALEX Initiative, Mont Terri Project, Grimsel Test Site Projects, SKB Task Forces, etc.
- Other examples with focus on information exchange and data base development are provided, for example, by Nuclear Energy Agency (NEA) (e.g., Clay, Salt Club, and Crystalline Clubs)

Bilateral Collaborations

- Informal or formal research collaboration with individual organizations
- A prominent example is the comprehensive collaboration on salt disposal between U.S. and German organizations
# Multinational Initiatives with Focus on Underground Research Labs

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Host Rock</th>
<th>URL</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DECOVALEX</strong>&lt;br&gt;DEvelopment of COupled models and their VALidation against Experiments Project</td>
<td>Multiple</td>
<td>Multiple</td>
<td>• Long-term international model comparison initiative&lt;br&gt;• <strong>Multiple modeling tasks</strong> with validation against experiments</td>
</tr>
<tr>
<td><strong>Mont Terri Project</strong></td>
<td>Argillite</td>
<td>Mont Terri, Switzerland</td>
<td>• <strong>Multiple experiments</strong> are conducted and evaluated collaboratively&lt;br&gt;• Access to data and results from past and ongoing experiments</td>
</tr>
<tr>
<td><strong>SKB Task Forces</strong>&lt;br&gt;SKB = Swedish Nuclear Fuel and Waste Management</td>
<td>Crystalline</td>
<td>Äspö Hard Rock Lab, Sweden</td>
<td>• Collaborative modeling of <strong>multiple tasks</strong>&lt;br&gt;• Focus on flow and transport in fractured rock and engineered barrier system</td>
</tr>
<tr>
<td><strong>Colloid Formation and Migration Project (CFM)</strong></td>
<td>Crystalline</td>
<td>Grimsel Test Site (GTS), Switzerland</td>
<td>• Long-term project with several test phases&lt;br&gt;• Investigation of colloid formation, colloid migration, and radionuclide transport</td>
</tr>
<tr>
<td><strong>FEBEX-DP</strong>&lt;br&gt;Full-Scale Engineered Barrier Experiment - Dismantling Proj.</td>
<td>Crystalline EBS Focus</td>
<td>GTS, Switzerland</td>
<td>• Dismantling and characterization of full-scale heater test after 18 years of heating&lt;br&gt;• Collaborative analysis of data and samples</td>
</tr>
<tr>
<td><strong>HotBENT</strong></td>
<td>Crystalline EBS Focus</td>
<td>GTS, Switzerland</td>
<td>• Conduct a full-scale high-temperature heater test at 200°C maximum temperature</td>
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</table>
International URLs with U.S. Participation (plus WIPP facility for salt)

Clays and Mudstones

- Mont Terri, Switzerland
- Horonobe, Japan
- Bure, France

Crystalline

- Äspö Hard Rock Lab, Sweden
- Mizunami, Japan

- Grimsel Test Site, Switzerland
International Activities Involving Field Experiments (Since 2012)

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

Salt
- Argillite
- Far-Field
- Crystalline

Engineered barrier integrity, near-field perturbation, flow and radionuclide transport, and integrated system behavior and performance assessment.
Can waste package and bentonite buffer temperature safely be raised to 200°C, without causing performance relevant alteration and damage in barrier behavior?

**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 Efforts Are Integrated Into DOE Priority Research: Understanding High Temperature Effects

Can waste package and bentonite buffer temperature safely be raised to 200°C, without causing performance relevant alteration and damage in barrier behavior?

- Long-term demonstration experiment at 100 °C
- Exploratory simulations for 200 °C: THMC modeling
- High-temperature laboratory testing at 200 °C
- Long-term demonstration experiment at 200 °C
- Performance assessment of 200 °C repository
International Efforts Are Integrated Into DOE Priority Research: Understanding Gas Migration in Clay-Based Materials

Step 1: Basic process understanding
- Clay Aggregates
  - Moisture induced stress with liquid saturation

Step 2: Full-scale behavior and predictive modeling
- Effective stress based on maximum phase-pore-pressure
- In-Situ NSC Test at Bure URL in DECOVALEX 2027
- Laboratory Experiments in DECOVALEX 2019
- In-Situ LASGIT Experiment at Åspö Hard Rock Lab in DECOVALEX 2023

Step 3: Testing of a gas permeable seal
- Testing of a gas permeable seal
International Collaboration in Disposal Research Five-Year Plan (2020)

**Ongoing Activities**
- Continue **participation within international R&D** in URLs for a range of geologic systems
- Pursue a **more active role in conducting experimental work** in international URLs (e.g., HotBENT)
- Contribute to **integration and confidence building** for safety assessment models (e.g., DECOVALEX task)
- Continued assessment and integration of **new international opportunities**: e.g., Sealing Elements

**New Directions**
- Utilize international activities for **workforce development in disposal science**
- Develop best practices and technologies for **site selection and characterization**
Stimulating Student Interest:
- Seminars Series
- Summer Courses

Creating the Pipeline:
- Undergraduate/Graduate Intern Program at National Labs
- Opportunities of Time Abroad with International Collaborators

Advancing the Pipeline:
- Dedicated Post-Doc at National Labs (e.g., the HotBENT post-doc)
- Opportunities of Time Abroad with International Collaborators

Special focus on underrepresented communities and minority-serving universities
International Collaboration in Site Selection and Characterization

Best Practices and Lessons Learned

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

Switzerland: has just down selected from three siting regions to one.

Canada: has narrowed its search from initially 22 areas to two sites.

Sweden: has finalized its site selection and site characterization process.

Site Characterization Methods

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

Fault characterization studies at Mont Terri, Switzerland
• Active collaboration with international programs is a central and fully integrated element of United States Disposal Research Program

• International research activities have been extremely beneficial:
  – 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

• We are always interested in additional opportunities for expansion of our international disposal research activities (e.g., best practices in site selection, EURAD-2 collaboration)
Thank You!

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Second International DECOVALEX Coupled Processes Symposium

November 14-16, 2023; Troyes, France

Coupled thermo-hydro-mechanical-chemical (THMC) processes in geological systems are critically important to the performance and safety assessment of geologic disposal systems for radioactive waste and spent nuclear fuel. Understanding of such processes is also essential for a number of other subsurface engineering processes, including mining, geothermal exploration, geological carbon sequestration, energy storage, and oil and gas production.

The Second International DECOVALEX Symposium on Coupled Processes in Radioactive Waste Disposal and Subsurface Engineering Applications invites you to the beautiful city of Troyes, France on November 14-16, 2023. This in-person symposium is jointly hosted by ANDRA, Lawrence Berkeley National Laboratory, and the DECOVALEX project - an international collaboration for advancing the understanding and numerical simulation of coupled THMC processes in a geological system.

This open symposium will feature internationally recognized keynote speakers and researchers focusing on coupled processes, including computational methods, lab experiments, and in situ tests. The symposium will also provide exciting insights from the current phase of the DECOVALEX project, referred to as DECOVALEX-2023.

https://2023-decovalex-coupled-processes-symposium.lbl.gov/home