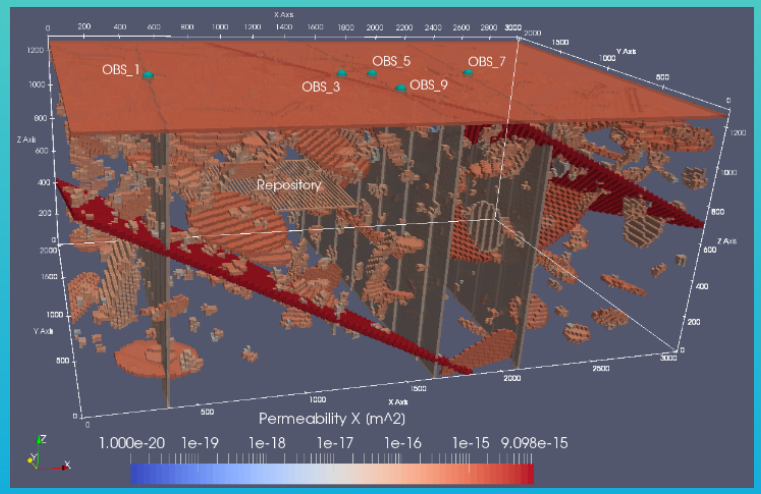


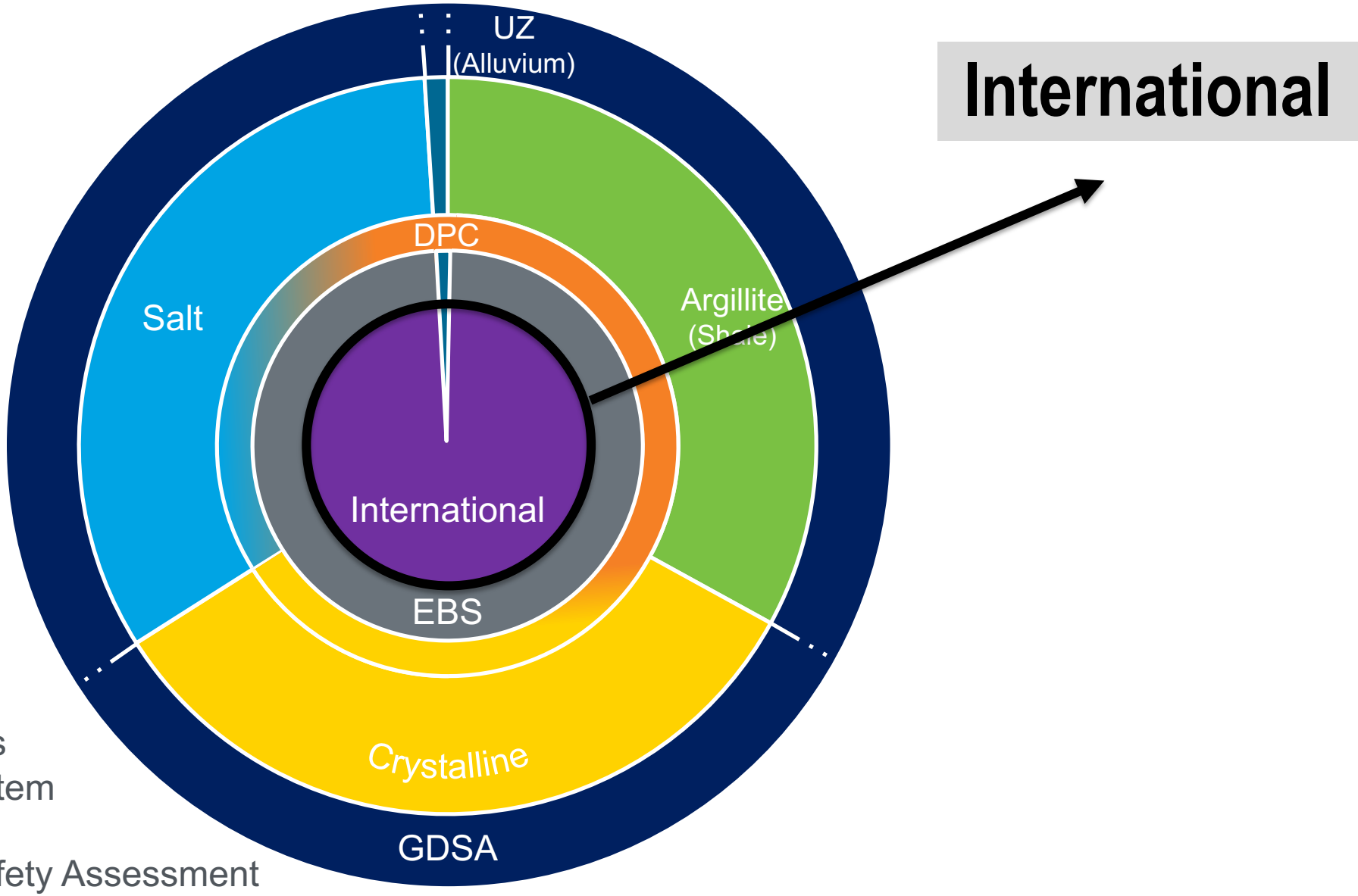
Prioritization of International Activities

U.S. Nuclear Waste Technical Review Board, Fact Finding Meeting
November 4-5, 2020

Jens Birkholzer
Senior Scientist
Director Energy Geosciences Division
Lawrence Berkeley National Laboratory
Berkeley, California

R&D Priorities in Disposal Research

- Host rocks are wedges of the pie.
- Partial circles are cross-cuts.
- Extent of circle indicates interfaces between host rocks and cross-cuts.



UZ = Unsaturated Zone
DPC = Dual Purpose Canisters
EBS = Engineered Barrier System
SNF = Spent Nuclear Fuel
GDSA = Geologic Disposal Safety Assessment

International Collaboration as Central Element of Disposal Research

Scientific and Technical Benefits

- Tap into global knowledge, stay abreast of science advances, and gain access to international datasets and experiments
- Improve domestic science base, reduce uncertainties, and build confidence
- 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

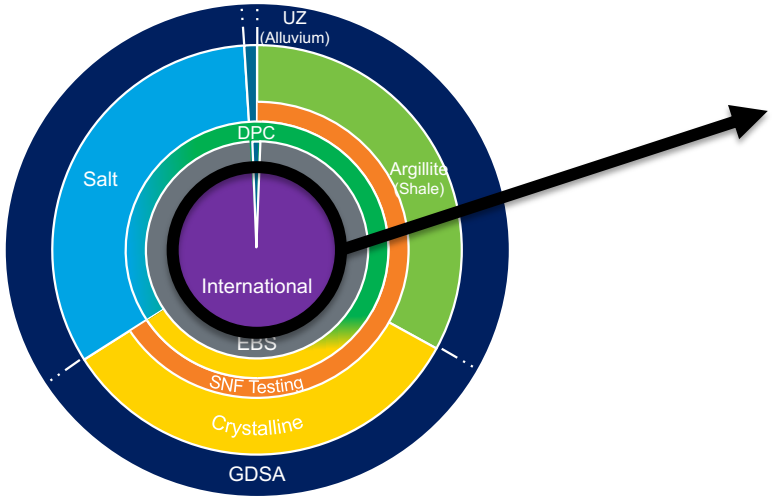
Other Benefits

- 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, for example with regards to public outreach, engagement, and risk communication related to 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 case, and cost/benefit
- Focus on collaboration opportunities for active R&D participation
- Emphasize access to experiments in underground research laboratories (URLs)
- Balance portfolio across host rocks, repository designs, and key R&D areas

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 NEA or certain European Union Projects

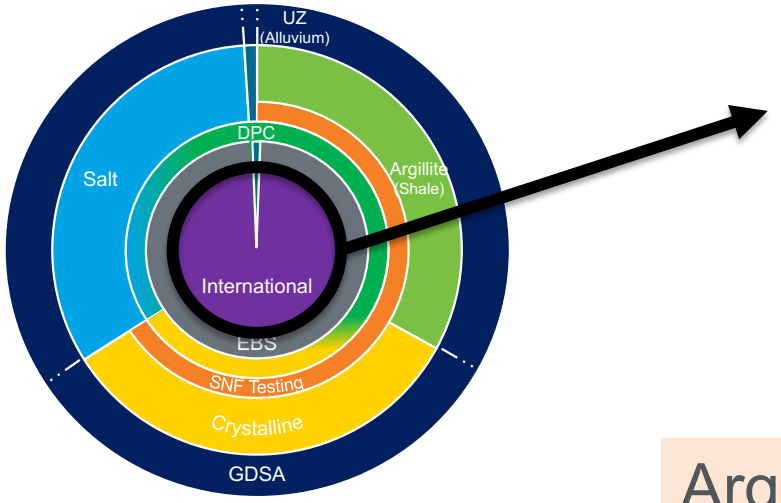
Bilateral Collaborations

- 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



Salt

Crystalline

Streaming Potential

Bedrichov Tunnel

TSDE (Asse)

LTDE

CFM

BATS

Gas Migration

GREET

EBS

BRIE

FEBEX & HotBENT

HE-E

CI

DR-A

EBS

FE

HG-A

FS

Far-Field

TED and ALC

Argillite/Mudstone

2019 Status

Integrated Planning of Priority R&D Topics and International Collaboration Opportunities

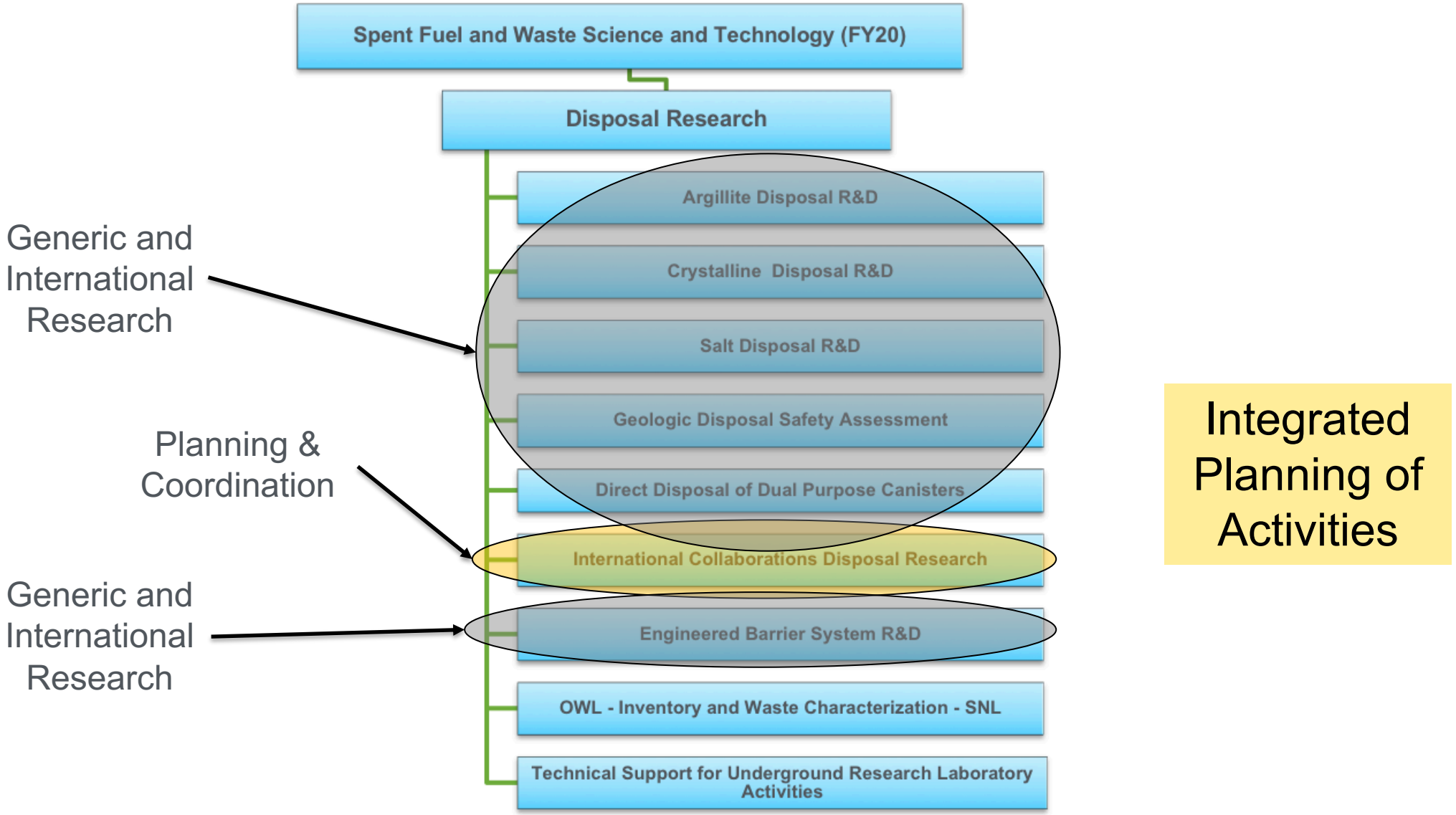
Integration with Campaign Research Roadmapping Exercises

- **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 & revise 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 R&D needs and changing research needs (e.g., gas pressure buildup, seals 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



From Opportunistic Participation to Active Engagement

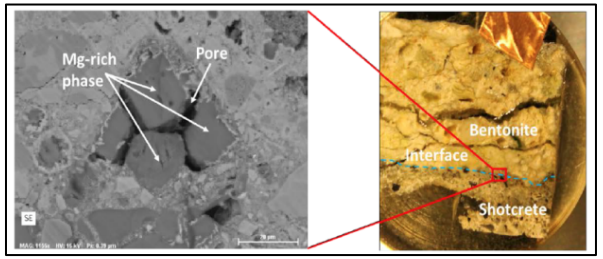
- **During the first few years, DOE participated in international R&D efforts that had been planned years earlier**
- **Since then, DOE has been actively involved in planning of new projects together with the international community, achieving more integration**
- **Examples of international research 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 Task Force
  - Chairing the international DECOVALEX Project and thus coordinating its research emphasis
  - Coordinating use of the salt heater test at WIPP 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 characterization of heated samples
- Detailed THMC modeling of individual components

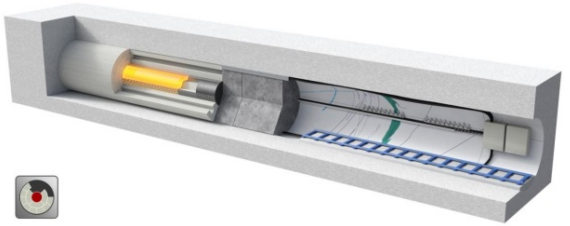
Micro-structural analysis



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)

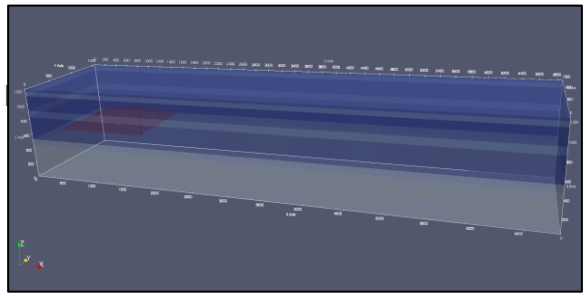
Lab and field experiments (HotBENT)



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

Performance assessment modeling



International Experiments: Long-Term Planning & Coalition Building & Execution

Timeline Towards HotBENT:

- **2013:** discussions with international partners about high-temperature research needs
- **2014:** discussions with NAGRA about the need for full-scale experiment
- **2015**: joint paper with NAGRA about research status/needs, including *in situ* test
- **2016**: international coalition building and first HotBENT planning meeting (five partners)
- **2018**: official HotBENT partnership (five full & four associated partners)
- **Since 2019:** preparation and installation of in situ test
- **2020:** HotBENT Modelling Platform kick-off
- **2021:** HotBENT heaters will be turned on and run for 10 to 20 years

ANS 2015 International High-Level Radioactive Waste Management Conference

April 12-16, 2015 · Charleston Marriott · Charleston, SC

"Real World Solutions for Achieving Disposal of Used Fuel and HLW through Integrated Management"

CALL FOR PAPERS – *Abstract deadline: September 2, 2014*

THMC behavior of clay-based barriers under high temperature – from laboratory to URL scale

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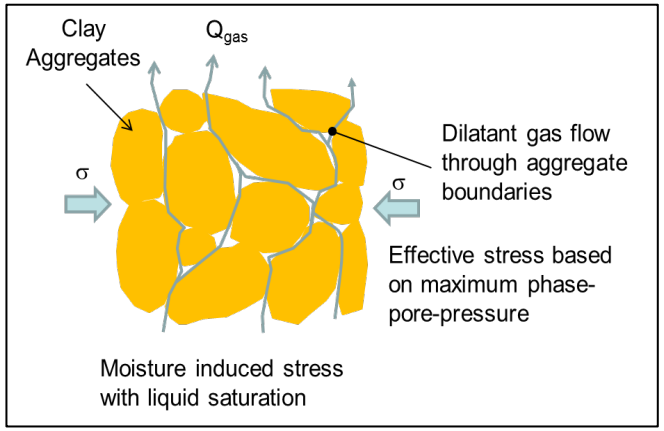
*** Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley CA, 94707, USA*

ABSTRACT

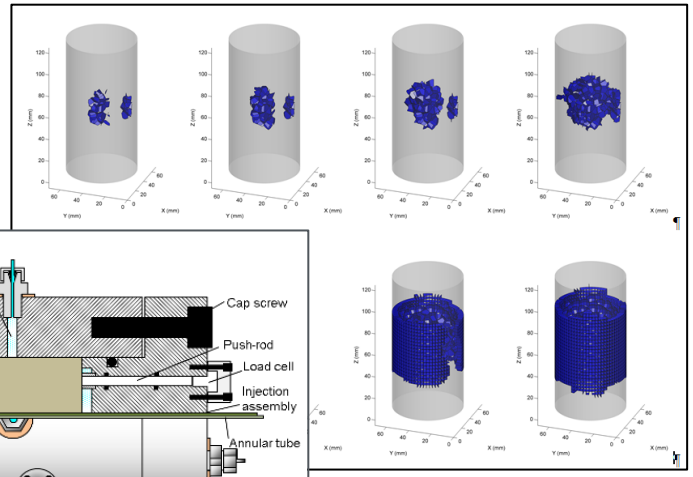
International disposal programs have been investigating if clay-based barriers can withstand temperatures higher than the 100 °C threshold for bentonite performance assumed in some advanced repository designs. For example, the United States disposal program is investigating the feasibility of direct geological disposal of large spent nuclear fuel canisters currently in dry storage.

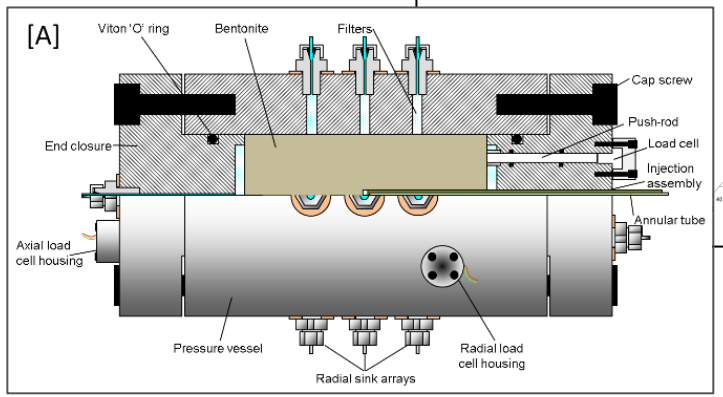
advanced repository designs. For example, the United States disposal program is investigating the feasibility of direct geological disposal of large spent nuclear fuel canisters currently in dry storage. These canisters typically hold as many as 32 PWR assemblies and recent designs hold even more, meaning that there is significant heat output associated with these canisters. Projections show that, by the year 2025, there will be more than 3,000 such canisters in use and that sometime before 2040 more than half of the spent nuclear fuel in the U.S. will be in

Examples of Prioritization and Integrated Planning: Gas Migration in Clay-Based Materials



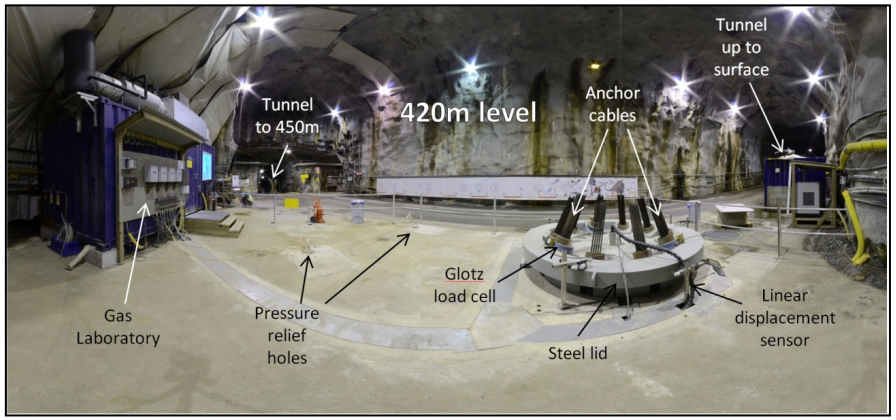
Step 1: Basic process understanding





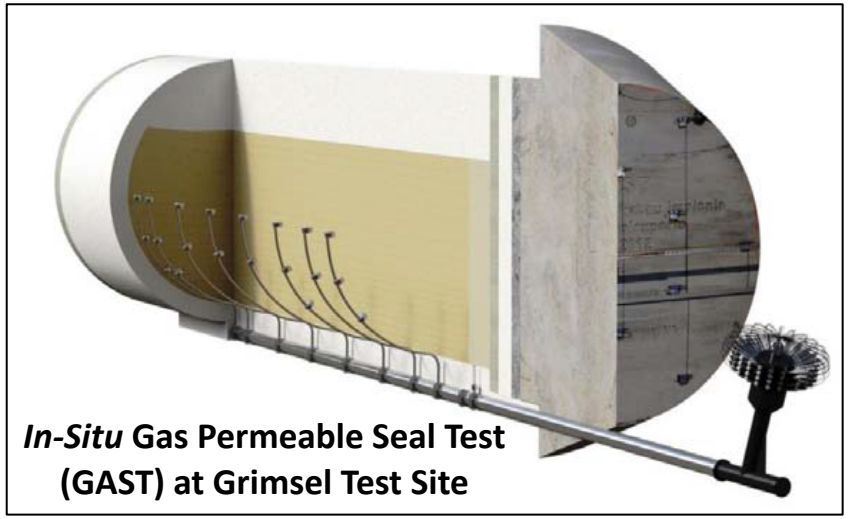
Laboratory Experiments in DECOVALEX-2019

Step 2: *Full-scale behavior and predictive modeling*



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

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

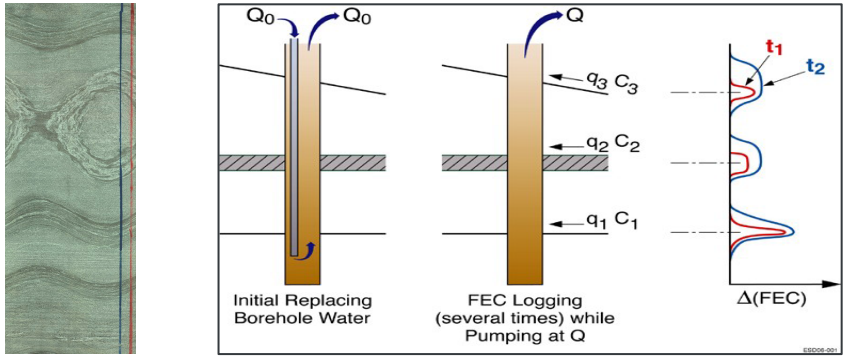
Germany: is currently in early stages of site selection with broad range of host rocks

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

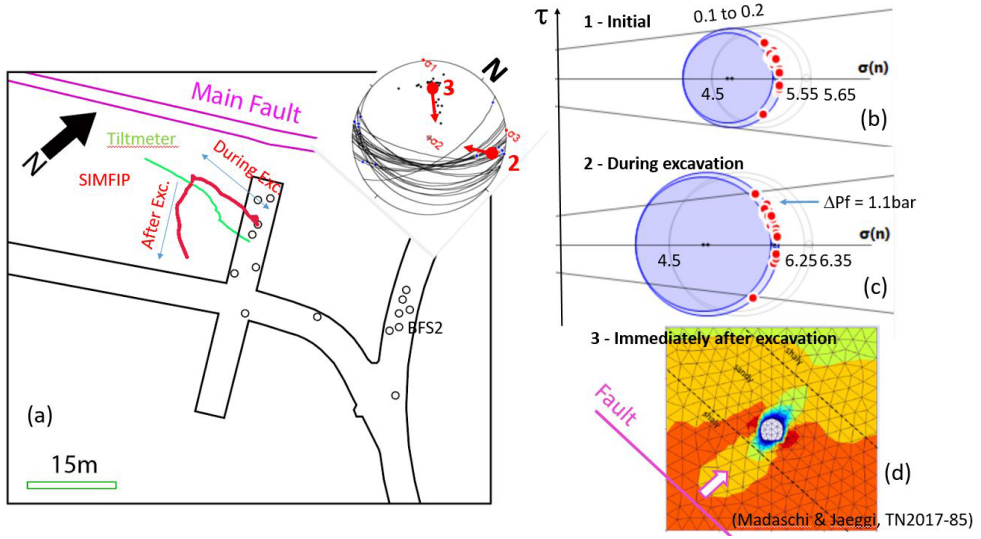
Canada: has narrowed its search from initially 22 areas to two sites. Detailed characterization is ongoing.

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

Site Characterization Methods



Characterization of flowing fractures at COSC, Sweden



Fault characterization studies at Mont Terri, Switzerland

Summary

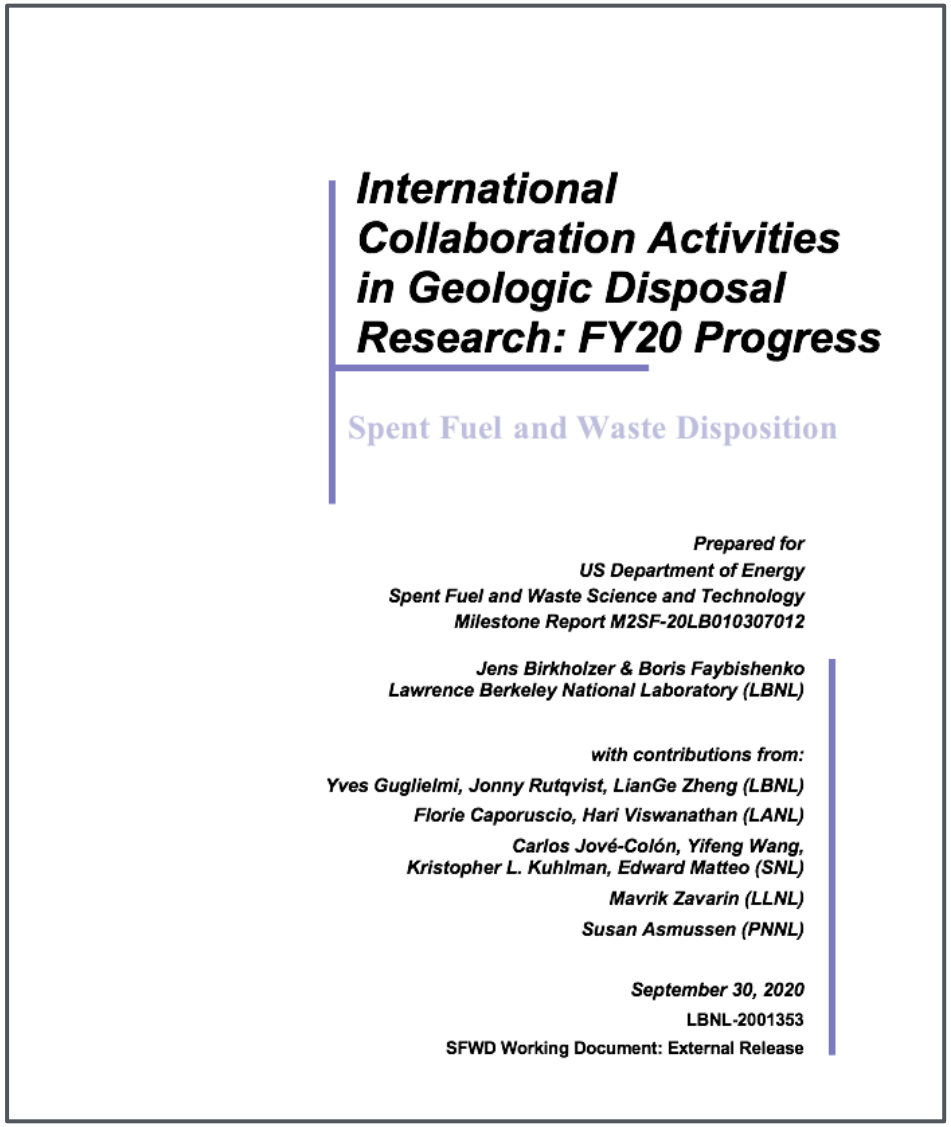
- **Active collaboration with international programs is a central and fully integrated element of DOE's disposal research program**
- **International research activities have been extremely beneficial to the SFWST Disposal Research Campaign:**
  - Improving science base, reducing uncertainty, and building 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**

Questions?

Reference: International Collaboration Report FY20

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 Collaboration Activities in Geologic Disposal Research: FY20 Progress

Spent Fuel and Waste Disposition

Prepared for
US Department of Energy
Spent Fuel and Waste Science and Technology
Milestone Report M2SF-20LB010307012

Jens Birkholzer & Boris Faybishenko
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Kristopher L. Kuhlman, Edward Matteo (SNL)
Mavrik Zavarin (LLNL)
Susan Asmussen (PNNL)

September 30, 2020
LBNL-2001353
SFWD Working Document: External Release

Acronyms and Abbreviations

ANDRA	National Radioactive Waste Management Agency, France
ALC	Full-scale Emplacement Experiment
BATS	Brine Availability Test in Salt
BGR	Federal Institute for Geosciences & Natural Resources, Germany
BMWi	Ministry for Economy and Labor, Germany
BRIE	Bentonite Rock Interaction Experiment
CFM	Colloid Formation and Migration Project
CI	Cement Clay Interaction Experiment
CIEMAT	Centro Investigaciones Energéticas Medioambientales y Tecnológicas, Spain
CNSC	Canadian Nuclear Safety Commission, Canada
CRIEPI	Central Research Institute of Electric Power Industry, Japan
DECOVALEX	DEvelopment of COupled Models and their VALidation Against EXperiments
DPC	Dual Purpose Canister
DOE	Department of Energy, USA
DR-A	Diffusion, Retention, and Perturbation Experiment
EB	Engineered Barrier
EBS	Engineered Barrier System
EDZ	Excavation Damage Zone (or Excavation Disturbed Zone)
ENRESA	National Radioactive Waste Corporation, Spain
ENSI	Swiss Federal Nuclear Safety Inspectorate, Switzerland
FANC	Federal Agency for Nuclear Control, Belgium
FE	Full-scale Emplacement Experiment

Acronyms and Abbreviations

FEBEX	Full-scale Engineered Barrier Experiment
FEBEX-DP	FEBEX Dismantling Project
FEPs	Features, Events, and Processes
FS	Faults Slip Hydro-Mechanical Characterization Experiment
GAST	Gas-Permeable Seal Test
GDSA	Geologic Disposal Safety Assessment
GREET	Groundwater REcovery Experiment in a Tunnel
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit, Germany
GTS	Grimsel Test Site, Switzerland
GWFTS	Groundwater Flow and Transport Task Force, Sweden
GREET	Groundwater Recovery Experiment
HE-E	*In Situ* Heater Experiment in Micro-tunnel
HG-A	Gas Path through Host Rock Experiment
HM	Hydro-mechanical
HMC	Hydro-mechanical-chemical
HRL	Hard Rock Laboratory
IRSN	Institut de Radioprotection et de Sûreté Nucléaire, France
JAEA	Japan Atomic Energy Agency, Japan
KAERI	Korea Atomic Energy Research Institute, Republic of Korea
KIT	Karlsruhe Institute of Technology, Karlsruhe, Germany
KURT	KAERI Underground Research Tunnel, Republic of Korea
LASGIT	Large-scale Gas Injection Test

Acronyms and Abbreviations

LTDE	Long-Term Sorption Diffusion Experiment
NAGRA	Swiss waste management organization
NBS	Natural Barrier System
NEA	Nuclear Energy Agency
NUMO	Nuclear Waste Management Organization of Japan
NWMO	Nuclear Waste Management Organization, Canada
PA	Performance Assessment
POSIVA	Nuclear Waste Management Organization, Finland
RWM	Radioactive Waste Management Limited, UK
SCK/CEN	Belgian Nuclear Research Centre, Belgium
SFWST	Spent Fuel and Waste Science & Technology
SKB	Swedish Nuclear Fuel and Waste Management, Sweden
SSM	Swedish Nuclear Waste Regulator
SURAO	Radioactive Waste Repository Authority, Czech Republic
swisstopo	Federal Office of Topography, Switzerland
TSDE	Thermal Simulation for Drift Experiment
TED	Thermal Experiment
THC	Thermo-hydro-chemical
THM	Thermo-hydro-mechanical
THMC	Thermo-hydro-mechanical-chemical
URL	Underground Research Laboratory
WIPP	Waste Isolation Pilot Plant, New Mexico, USA