U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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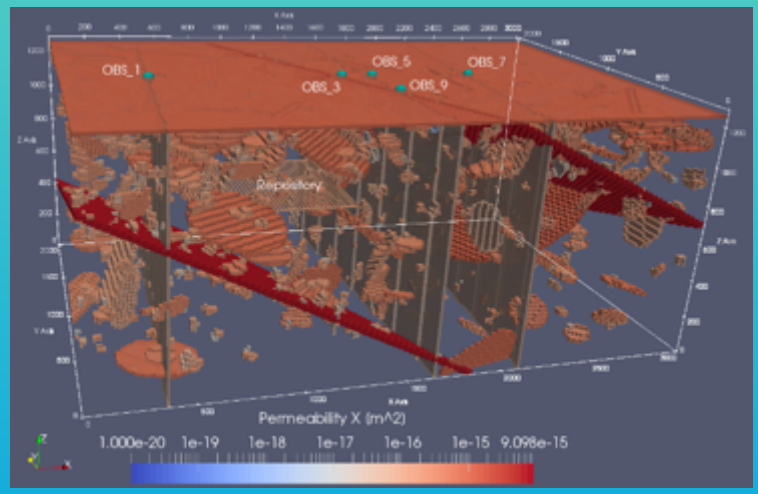
Spent Fuel and Waste Science and Technology (SFWST)



U.S. Nuclear Waste Technical Review Board
Fall 2020 Board Meeting
December 02-03, 2020
Virtual Meeting

Ed Matteo, Principal Member of Technical Staff, Sandia National Laboratories

LianGe Zheng, Staff Scientist, Nuclear Energy and Waste Program Head, Lawrence Berkeley National Laboratory

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Overview

- Knowledge and Capability Gaps
- Research Priorities
- Engineered Barrier Systems(EBS) Research relative to other SFWST research areas
- Summary of Current EBS Research
- High Temperature Studies of Bentonite (HotBENT) Deep-Dive
  (LianGe Zheng, LBNL)

R&D Priorities are determined by Knowledge Gaps

- Knowledge Gaps in understanding of fundamental processes
  - Integrity of Repository Seals
    - Drift and shaft seals
    - Degradation evolution, esp. permeability evolution
  - Processes at material interfaces
    - Engineered materials and Disturbed Rock Zone (DRZ)
    - Waste Package materials, buffer, and host rock
  - Coupled processes
    - Chemo-mechanics
    - Thermal-Hydrologic-Mechanical-Chemical (THMC)
    - Multi-phase flow
    - Multi-scale phenomenon
    - Linking microstructural scale to continuum scale
  - Esp. attention on cementitious materials and bentonite

Knowledge and Capability Gaps

- Knowledge Gaps in Process models
  - Cement models for evolution plugs and liners
    - Chemo-mechanical coupling
    - Fracture models/representations
  - Modelling Saturation/Re-saturation of Cementitious Materials and Bentonite
    - Fracture models/representations
  - Bentonite buffer
    - Thermal-Hydrologic-Mechanical-Chemical (THMC) model refinement
- Filling these gaps can:
  - Impact representation of seal representation in GDSA, or at least improve confidence in permeability/porosity values for engineered seals esp. at interfaces
  - Improve understanding of near field geochemistry

GDSA = Geologic Disposal Safety Assessment

How are EBS Knowledge Gaps Prioritized?

High Impact R&D Topics	High-Priority R&D Activities	Medium-High-Priority R&D Activities
High Temperature Impacts	D-1, D-4, I-4, I-6, I-16*, E-11, S-5	I-2, I-3, I-7, E-10
Buffer and Seal Studies	I-4, E-9, E-17*, A-8, C-15*	I-2, I-3, I-7, A-4, C-6, C-8, C-11
Coupled Processes (Salt)	S-1, S-3, S-4, I-12, I-13	I-14, S-2, S-7, S-8, S-11*
Gas Flow in the EBS	I-6, I-8, I-18*	I-9, P-17*
Criticality	D-1, D-3, D-4, D-5	
Waste Package Degradation	C-16*, P-12	E-4*, E-6
In-Package Chemistry	E-14*	E-2, E-20, P-15*, P-16*
Generic PA Models		P-1, P-2, P-4, P-11*, P-13*, P-14
Radionuclide Transport		C-11*, C-13*, C-14*, P-15*, P-16*
DFN Issues		I-21*, C-1, C-17*
GDSA Geologic Modeling		O-2, O-3
THC Processes in EBS		E-3

Activity Designator Legend:

A – Argillite
C – Crystalline
S – Salt
D – Dual Purpose Canisters
E – Engineered Barrier System
I – International
O – Other
P – Performance Assessment
* – indicates Gap Activity

2019 Roadmap Update: High-Priority R&D Activities

High Priority R&D Activities	
A-08	Evaluation of ordinary Portland cement (OPC)
C-15*	Design improved backfill and seal materials
C-16*	Development of new waste package concepts and models for evaluation of waste package performance for long-term disposal
D-01	Probabilistic post-closure DPC criticality consequence analyses Task 1 - Scoping Phase Task 2 - Preliminary Analysis Phase Task 3 - Development Phase
D-03	DPC filler and neutron absorber degradation testing and analysis
D-04	Coupled multi-physics simulation of DPC postclosure (chemical, mechanical, thermal-hydraulic) including processes external to the waste package.
D-05	Source term development with and without criticality
E-09	Cement plug/liner degradation
E-11	EBS High Temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.
E-14*	In-Package Chemistry
E-17*	Buffer Material by Design

High Priority R&D Activities	
I-04	Experiment of bentonite EBS under high temperature, HotBENT
I-06	Mont Terri FS Fault Slip Experiment
I-08	DECOVALEX-2019 Task A: Advective gas flow in bentonite
I-12	TH and THM Processes in Salt: German-US Collaborations (WEIMOS)
I-13	TH and THM Processes in Salt: German-US Collaborations (BENVASIM)
I-16*	New Activity: DECOVALEX Task on Salt Heater Test and Coupled Modeling
I-18*	New Activity: Other potential DECOVALEX Tasks of Interest: Large-Scale Gas Transport
P-12	WP Degradation Model Framework
S-01	Salt Coupled THM processes, hydraulic properties from mechanical behavior (geomechanical)
S-03	Coupled THC advection and diffusion processes in Salt, multi-phase flow processes and material properties in Salt
S-04	Coupled THC processes in Salt, Dissolution and precipitation of salt near heat sources (heat pipes)
S-05	Borehole-based Field Testing in Salt

Activity Designator Legend:

A – Argillite

C – Crystalline

S – Salt

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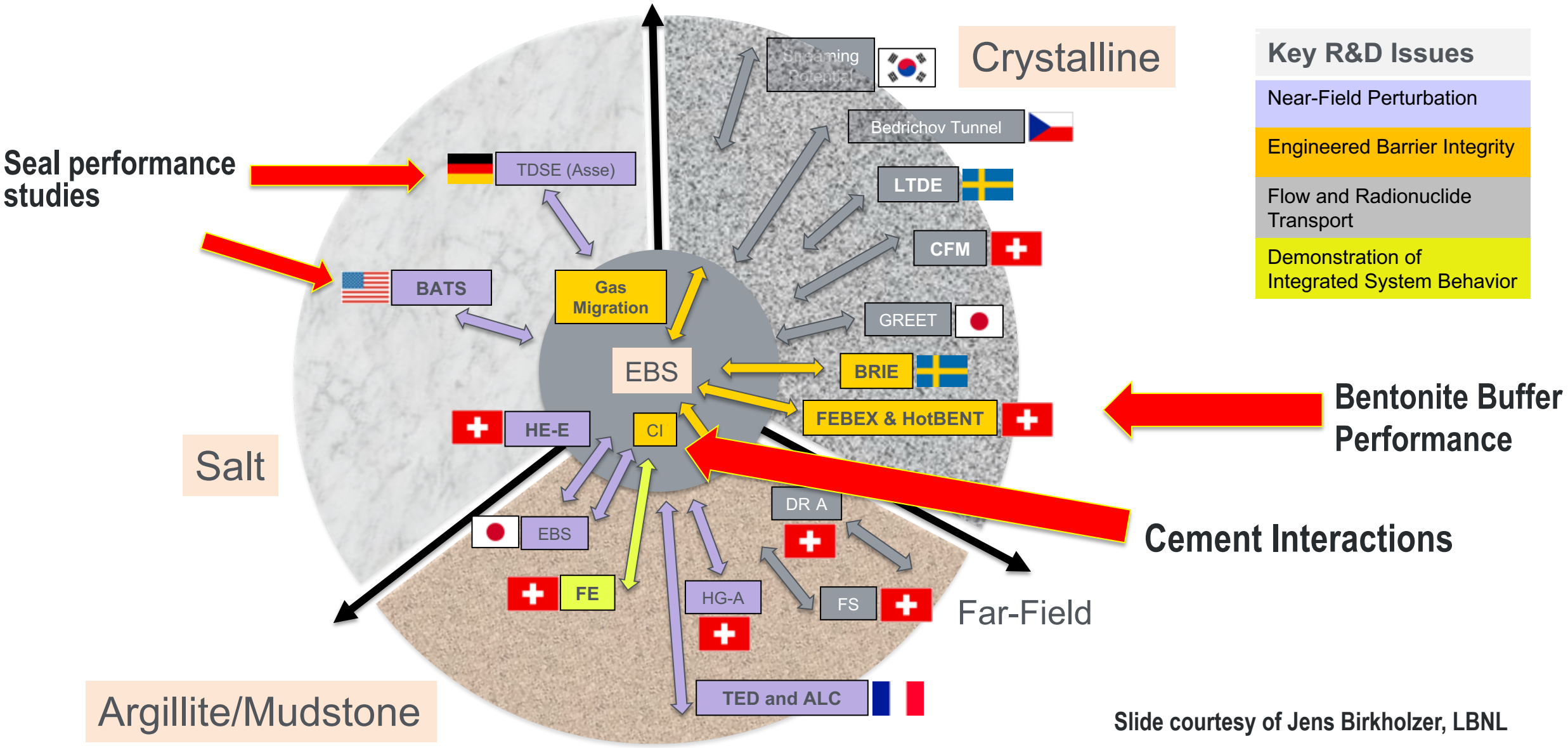
Knowledge and Capability Gaps also Crosscut with the International Field Test Portfolio and Host Media



Slide courtesy of Jens Birkholzer, LBNL

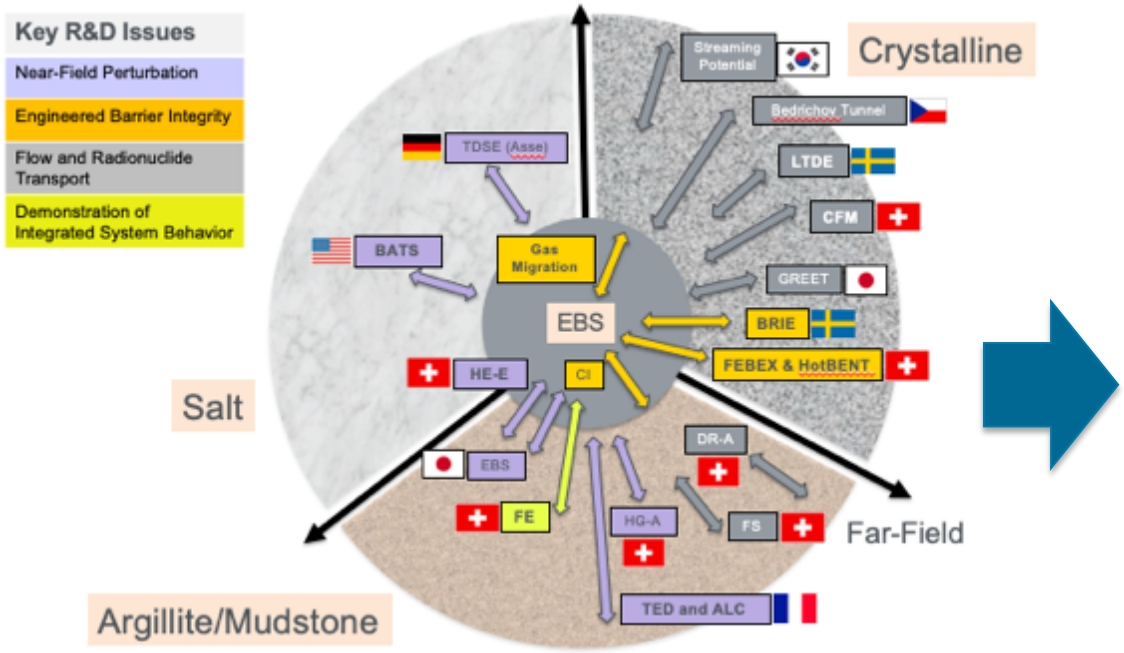
High Priority EBS Activities

#	Description	Purpose	Crosscut	SFWST EBS Activity	Int'l Tie-in
E-09	Cement plug/liner degradation	***Understanding mineralogic alteration and permeability evolution in seals and liners***	***Argillite***	Experimentally verified cement-geomaterial 3D model development in PFLOTRAN	EBS Task Force Task Cement Task
A-08	Evaluation of Ordinary Portland Cement (OPC)		***Salt***	Seals in Salt	BATS Heater Test in Salt RANGERS Project
E-11	EBS High Temperature Geochemistry/ Mineralogy	***Understanding mineralogic alteration at buffer/waste package interface***	***Crystalline and Argillite***	Hydrothermal Experiments examining host, buffer, and canister materials interaction/evolution at elevated temperature	HotBENT

High Priority EBS Activities (cont.)

#	Description	Purpose	Crosscut	SFWST EBS Activity	Int'l Tie-in
E-03	TH/THC Processes in EBS	***Understand transport and permeability evolution in seals, buffer, and backfill***	***Argillite and Crystalline***	Various Bentonite Studies -chemical controls -molecular scale -bench scale -drift scale	FEBEX activities DECOVALEX 2023 • Task B: Modeling Advection of Gas in Clays (MAGIC) • Task C: THM Modeling of the FE Experiment • Task E: Brine Availability Test in Salt (BATS)
I-08	Advective gas flow in bentonite				
			Salt →		
I-04	Experiments of Bentonite at High Temperature	***Understand transport and permeability evolution in seals, buffer, and backfill***	***Argillite and Crystalline***	Benchtop High Temp Bentonite Column Test	HotBENT
E-10	High Temperature Behavior			Modelling Support of HotBENT and Benchtop Tests	EBS Task Force Column Test

EBS Involvement with International Activities



- FEBEX
  - Two-stage heater test with bentonite block buffer in the Grimsel granodiorite
  - Engineered Barrier System Task Force Task 9 (completed March 2020)
- DECOVALEX 2023 Task B, Task C, Task E
- Engineered Barrier System Task Force New Tasks
  - Cement-Bentonite Interactions
  - HotBENT Column Test at LBNL
- RANGERS
  - shaft and drift performance study in collaboration with Germany
- HotBENT Field Test
  - High temperature bentonite field test

FEBEX = Full-scale Engineered Barriers EXperiment

DECOVALEX = Development of Coupled models and their Validation against Experiments

RANGERS = Entwicklung eines Leitfadens zur Auslegung und zum Nachweis von geo-technischen Barrieren für ein HAW Endlager in Salzformationen

HotBENT = High Temperature Effects on Bentonite Buffers

Priority R&D – A Forward Look

- Continued participation in International EBS Studies
  - Continued participation in EBS Task Force, DECOVALEX, HotBENT, etc.
  - Collaboration with German partners in salt investigations of seal performance
  - Other emerging collaborative URL-based activities
- Improved understanding of fracture development in EBS materials, esp. cementitious materials and bentonite
  - Leverage tools for fracture representation from Crystalline or Geologic Disposal Safety Assessment (GDSA) work packages
  - Meshless methods for fracture representation
- Next generation materials, including cementitious materials
  - 21st century materials for are evolving towards a decarbonized energy infrastructure
  - Availability of supplemental cementitious materials (e.g. fly ash)
  - New materials, e.g. cements /binders with lower carbon intensity

SFWST EBS Research Teams

Lawrence Berkeley National Laboratory

L. Zheng, L. Lammers, P. Fox, C. Chang, H. Xu, S. Borglin, M. Whittaker, C. Chou, C. Tournassat, N. Subramanian, Y. Wu, P. Nico, B. Gilbert, T. Kneafsey

Los Alamos National Laboratory

F. Caporuscio, K.B. Sauer, M.J. Rock

Sandia National Laboratories

E.N. Matteo, T. Dewers, S. Gomez, T. Hadgu

Vanderbilt University

C. Gruber, A. Taylor, D.S. Kosson

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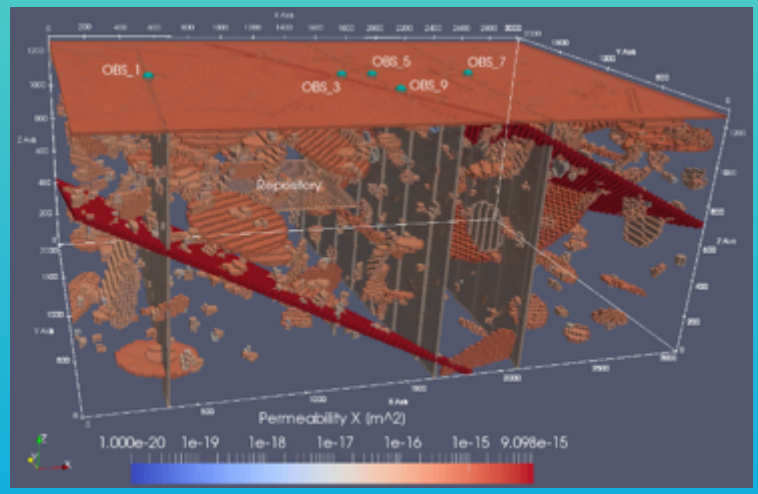

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LianGe Zheng
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Energy Geoscience Division
Lawrence Berkeley National Laboratory

Motivation

- Gap to be addressed: understanding of fundamental processes, especially coupled Thermal-Hydrologic-Mechanical-Chemical (THMC) processes in Engineered Barrier System (EBS) and interfacial areas under high temperature.
- A particular motivation: evaluating the thermal limit of a repository.

Impact R&D Topics	High-Priority R&D Activities
High Temperature Impacts	D-1, D-4, I-4, I-6, I-16*, E-11, S-5
Buffer and Seal Studies	I-4, E-9, E-17*, A-8, C-15*
Coupled Processes (Salt)	S-1, S-3, S-4, I-12, I-13
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In-Package Chemistry	E-14*
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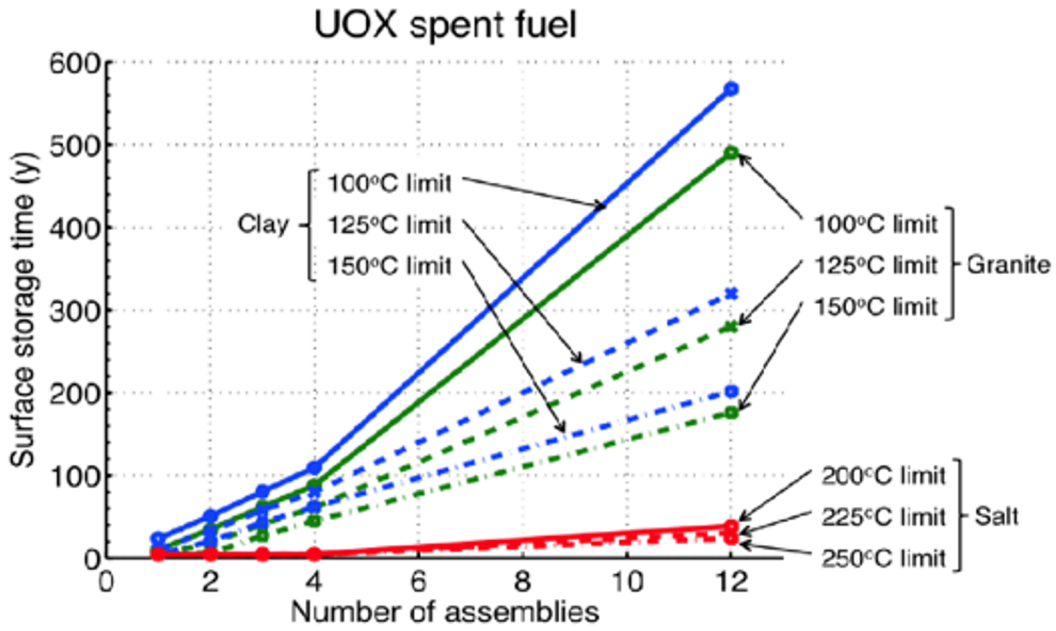
Radionuclide Transport	
DFN Issues	
GDSA Geologic Modeling	
THC Processes in EBS	

EBS high temp experimental data collection- To evaluate high temperature mineralogy /geochemistry changes.

Cement plug/liner degradation

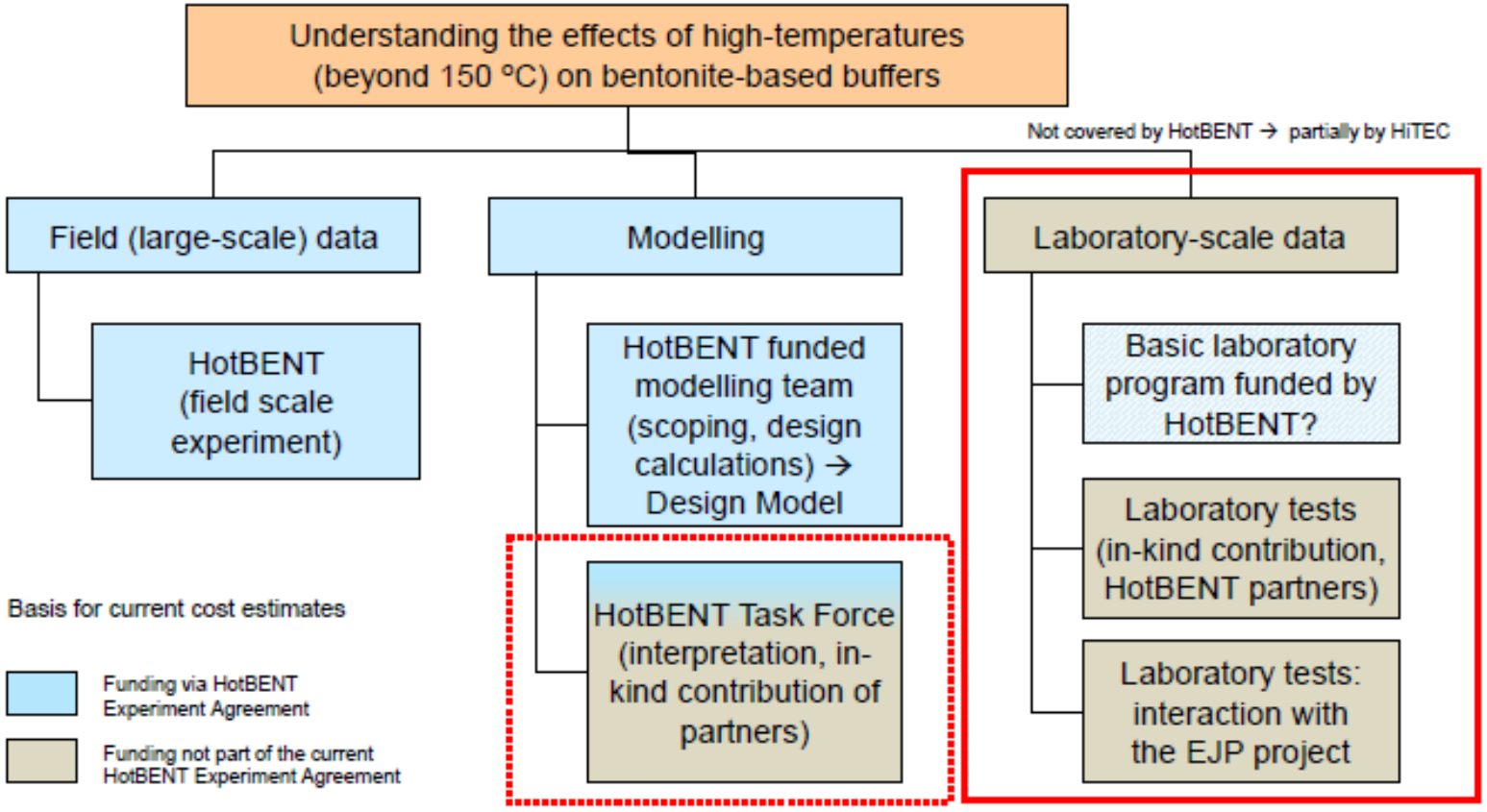


(Greenberg et al., 2012)

An Overview of the International Project HotBENT

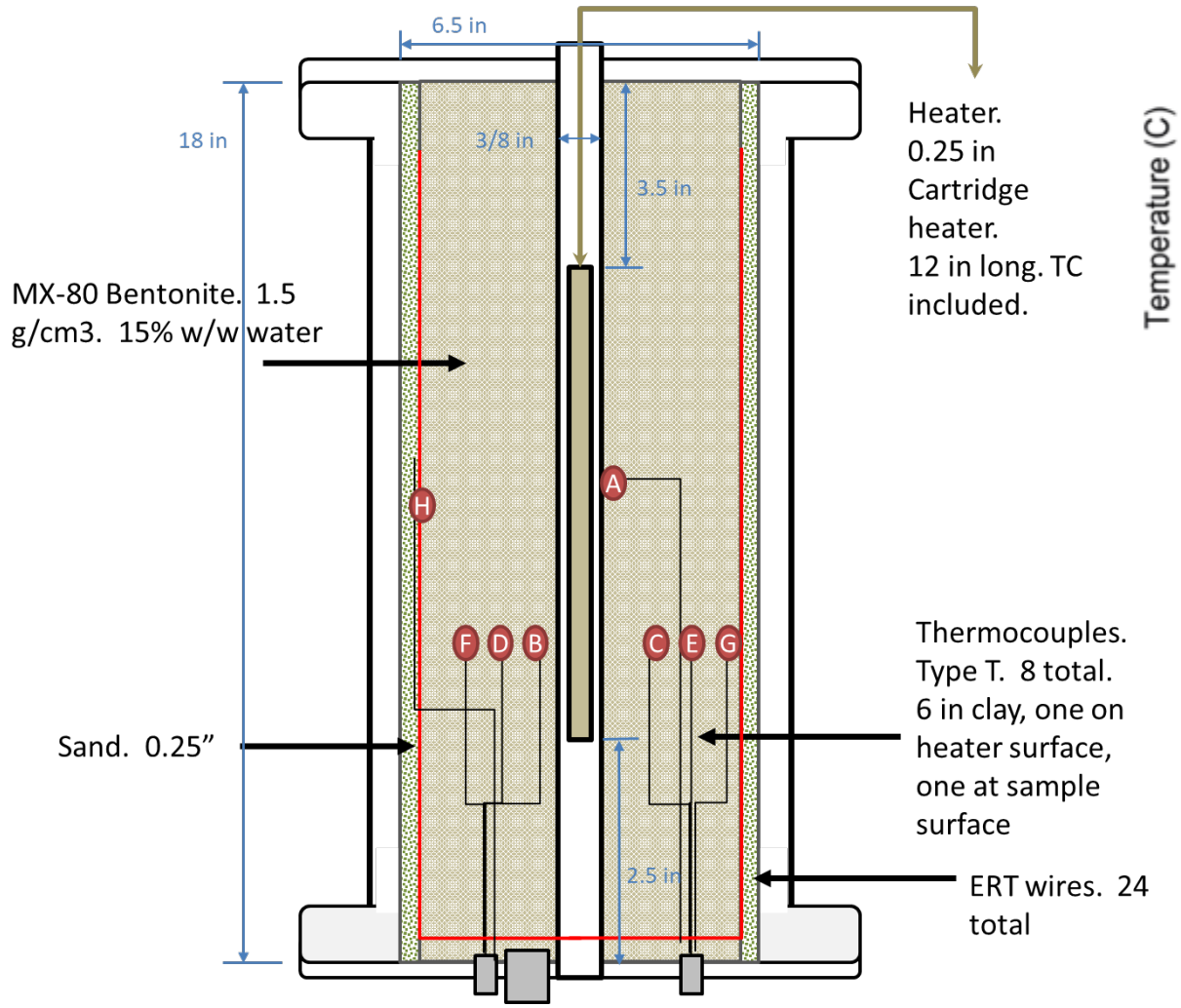
- Inspired by the coupled THMC modeling under high temperature in SFWST (e.g. Zheng et al., 2015; Vomvoris et al., 2015)

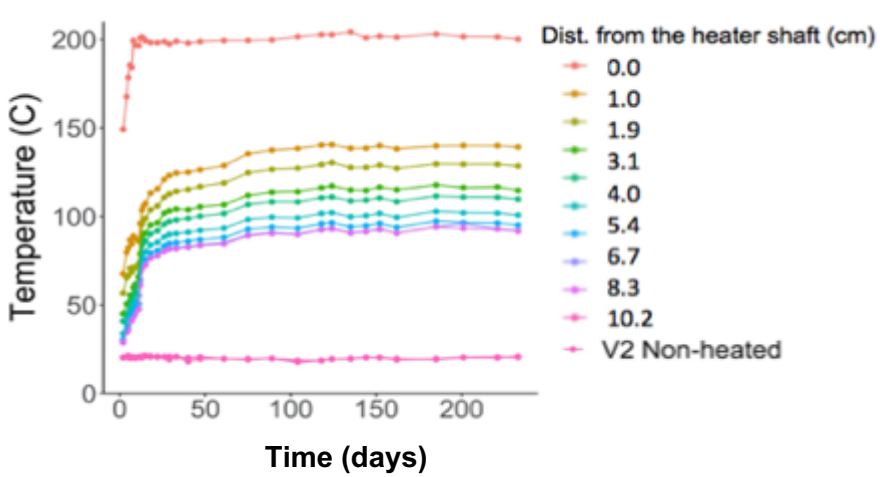
- Currently SFWST is involved in three activities:
  - High temperature column experiments on bentonite (LBNL)
  - A field scale test at Grimsel, Switzerland
  - A modeling platform

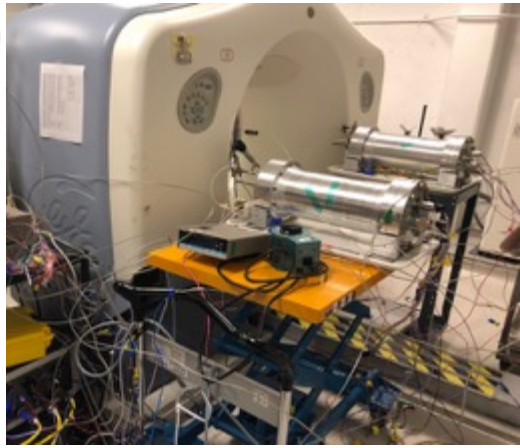


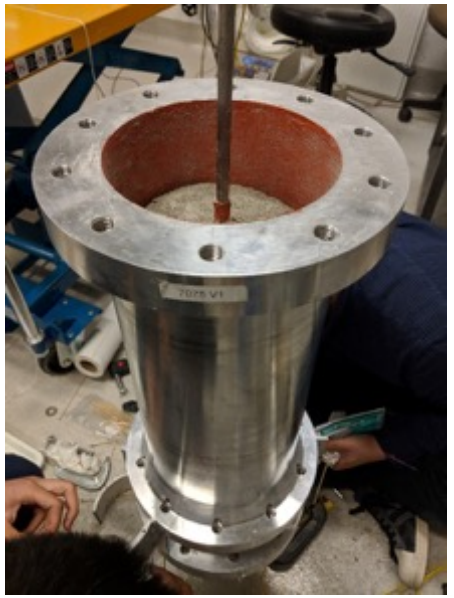
(Kober, 2020)

High Temperature Column Experiment on Bentonite









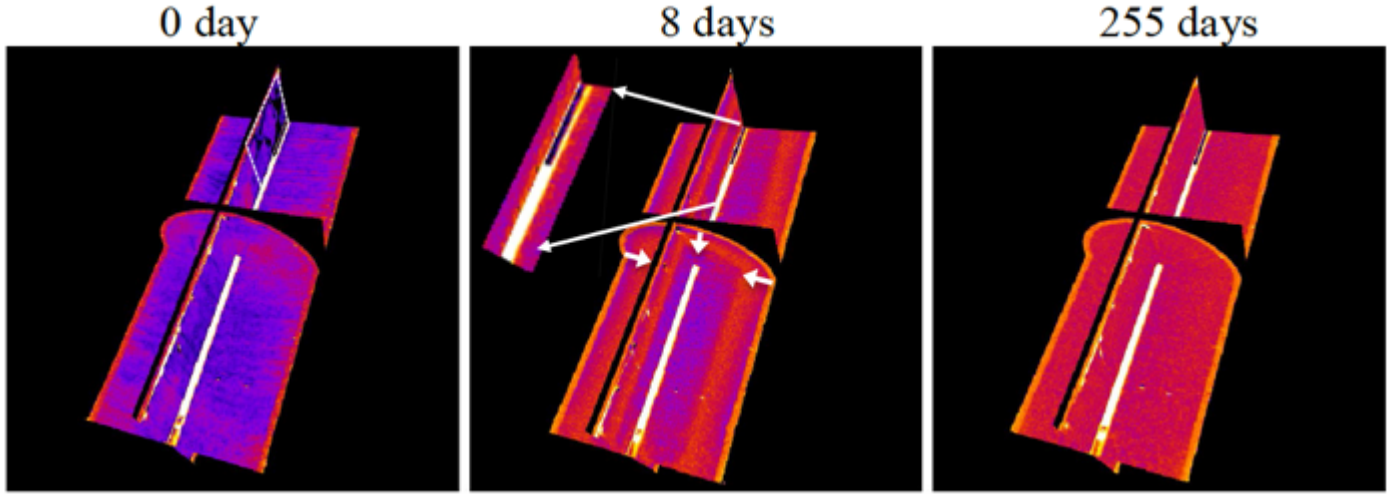
Average for inlet and outlet pressure has been 120 psi (8.3 bars). Flow is 0.11 mL/min.
After the bentonite was flooded for 1 day, heater was turned on at 150 °C.
After a week the temperature at the heater was maintained at 200 °C

Electrical Resistivity Tomography (ERT) array

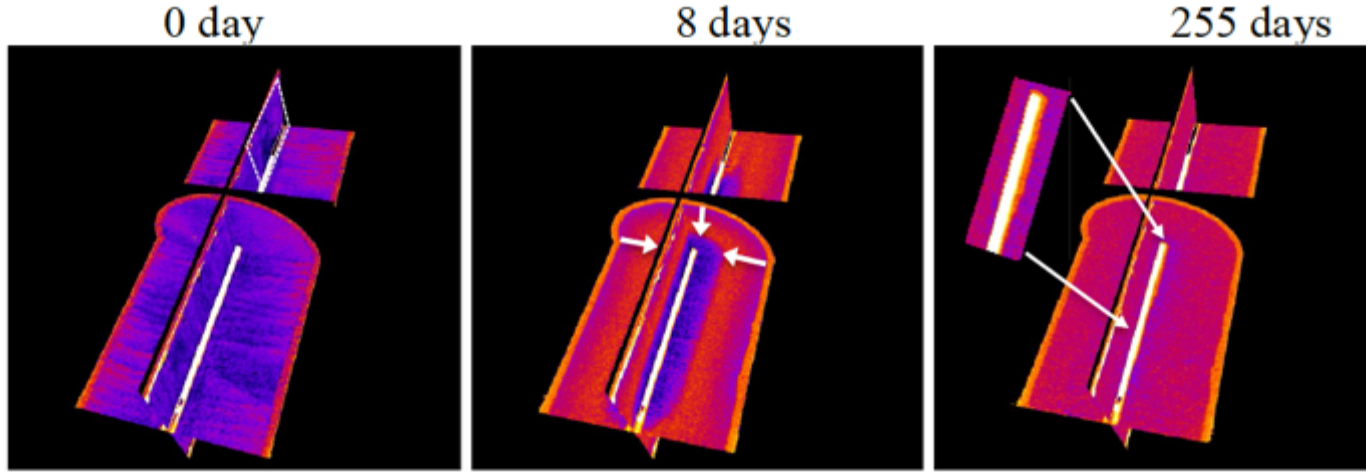
High Temperature Column Experiment on Bentonite

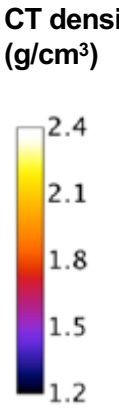
❖ Hydration Process

Non-heated



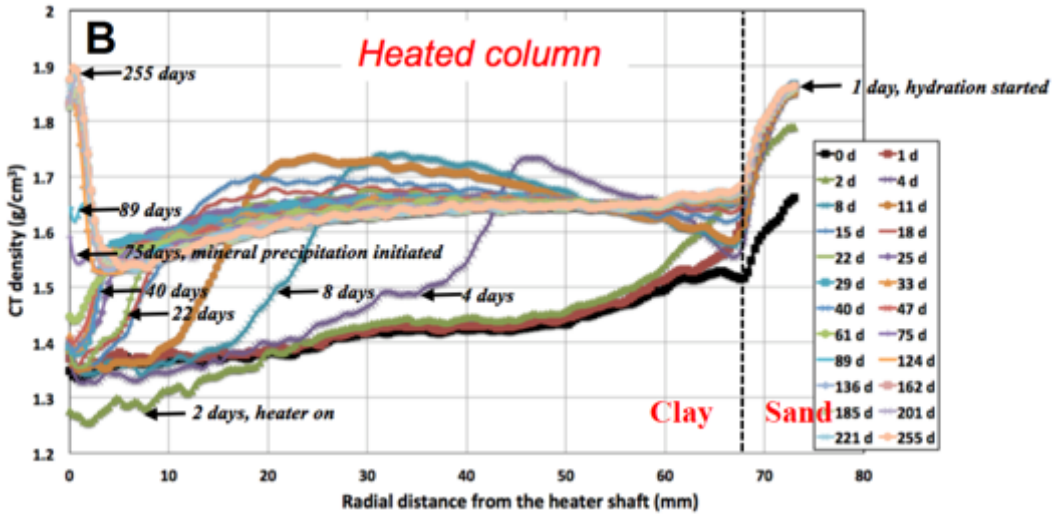
Heated





The column tests and CT images show coupled processes of:
Hydration;

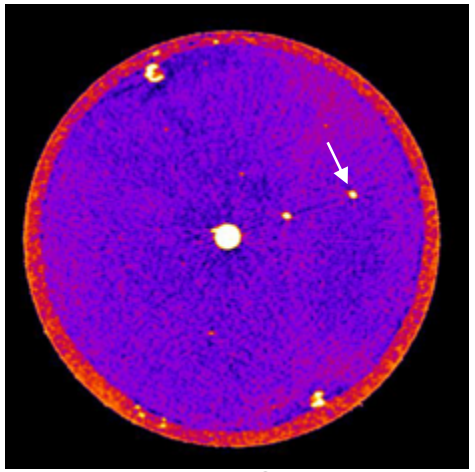
- Clay swelling;
- Heating dehydration;
- Mineral precipitation.



High Temperature Column Experiment on Bentonite

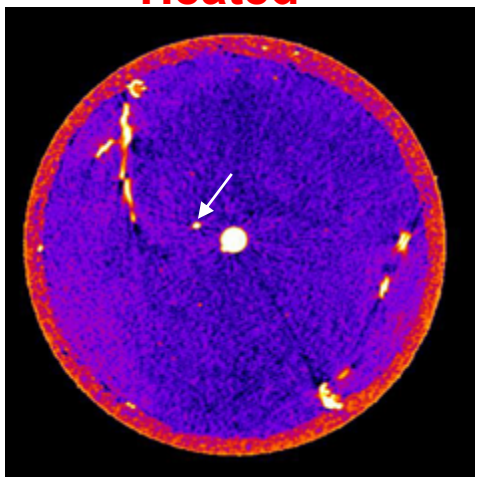
❖ Deformation

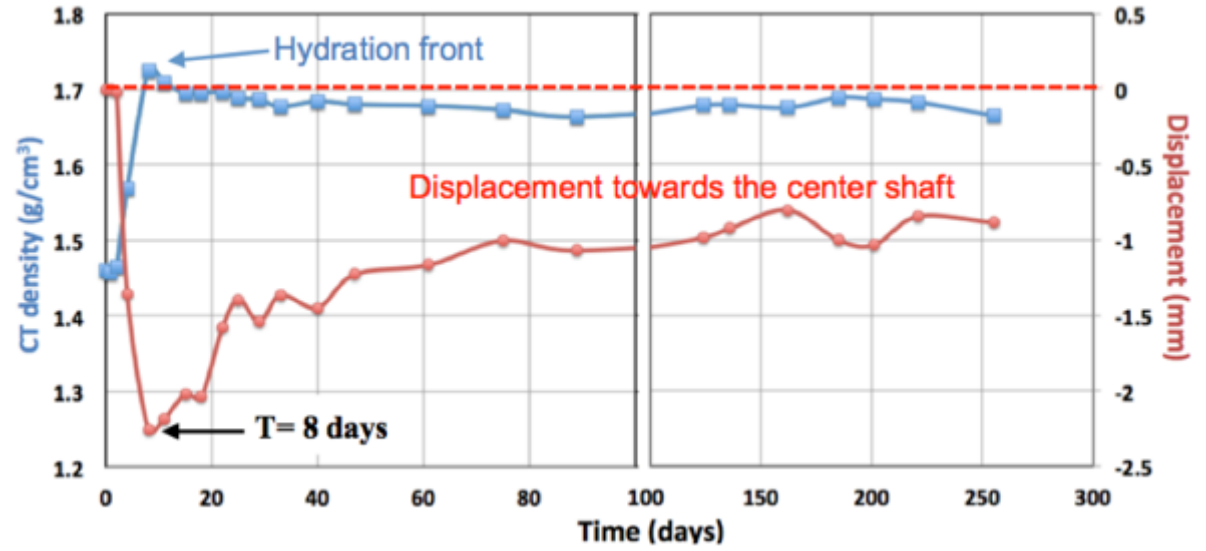
Non-heated

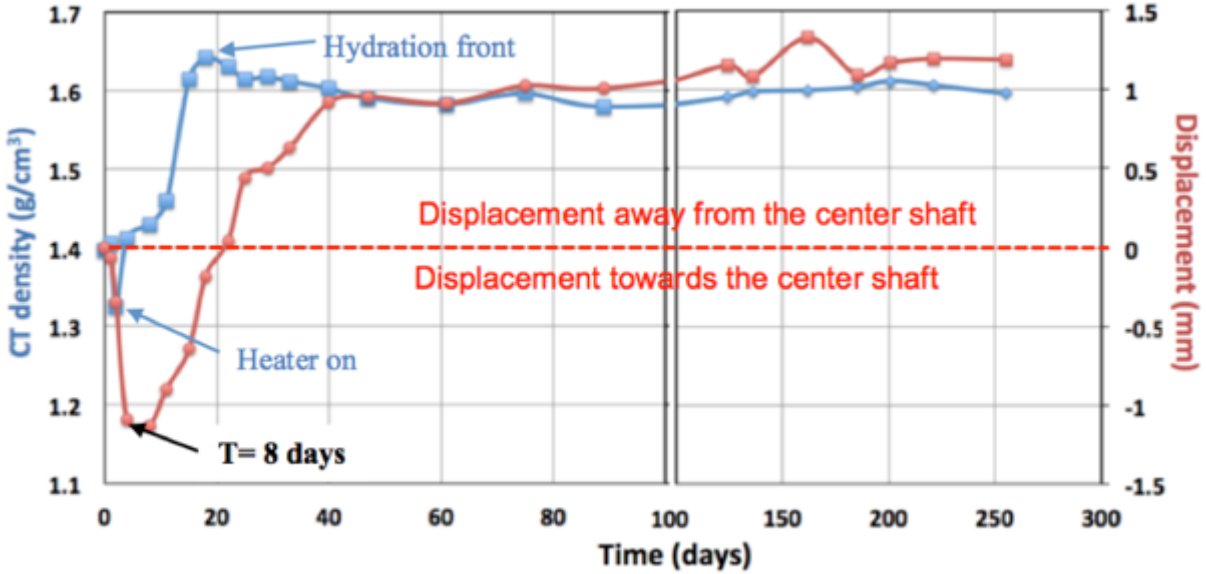


2D time-lapse CT images

Heated





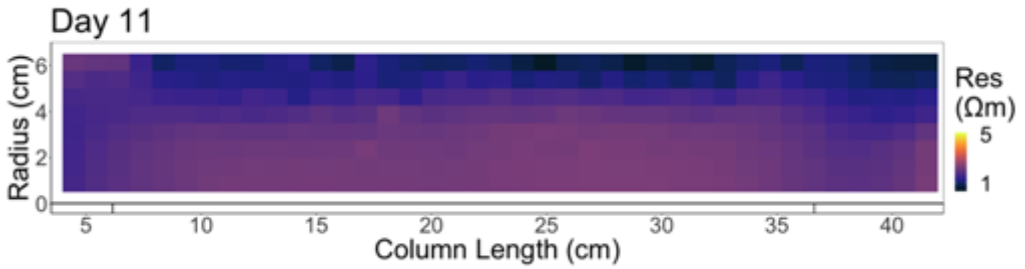


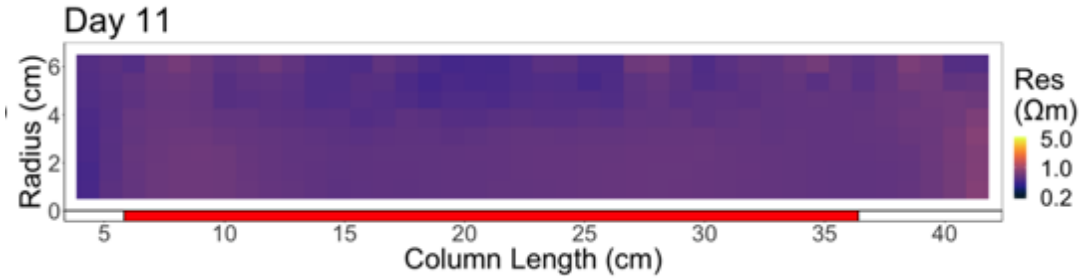
High Temperature Column Experiment on Bentonite

❖ Geophysical Monitoring - Electrical Resistivity Tomography

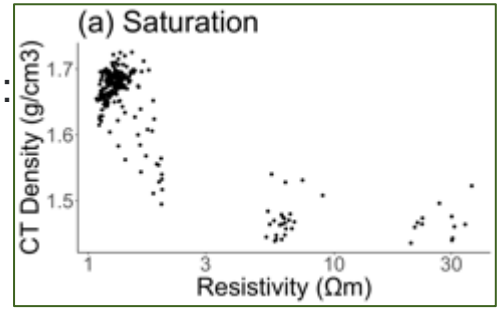
Non-heated ***Heated***

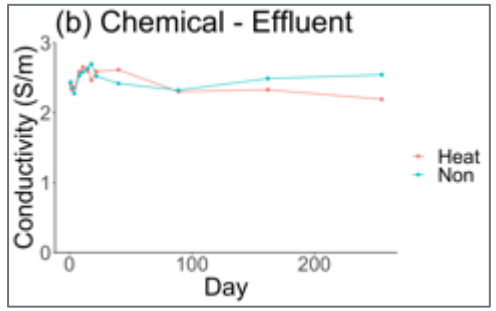
Time-lapse resistivity

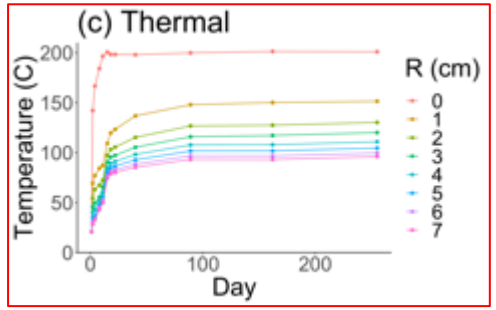




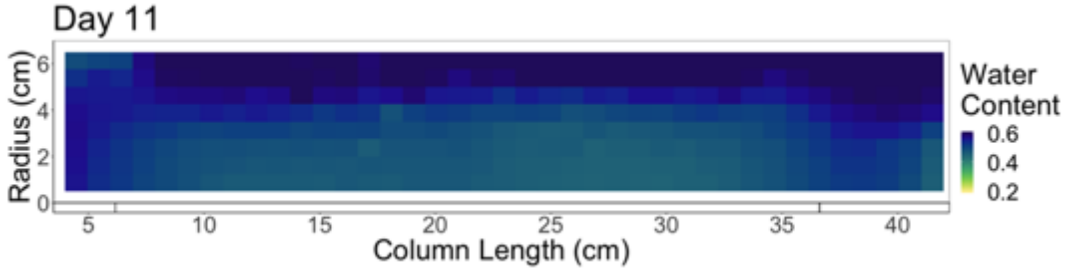
In situ petrophysical calibration: Resistivity = *f* (fluid saturation, chemistry, temperature)

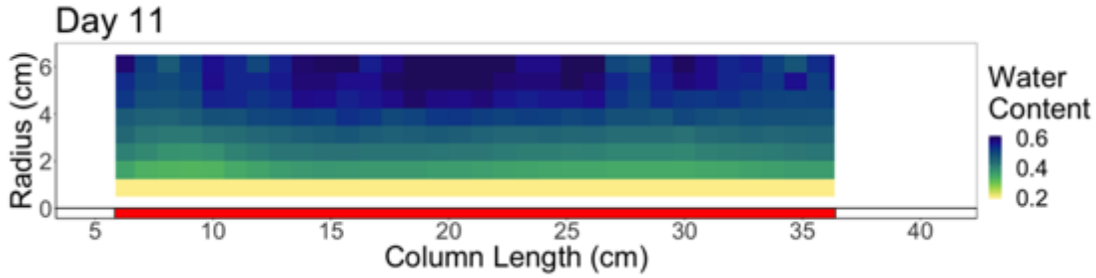






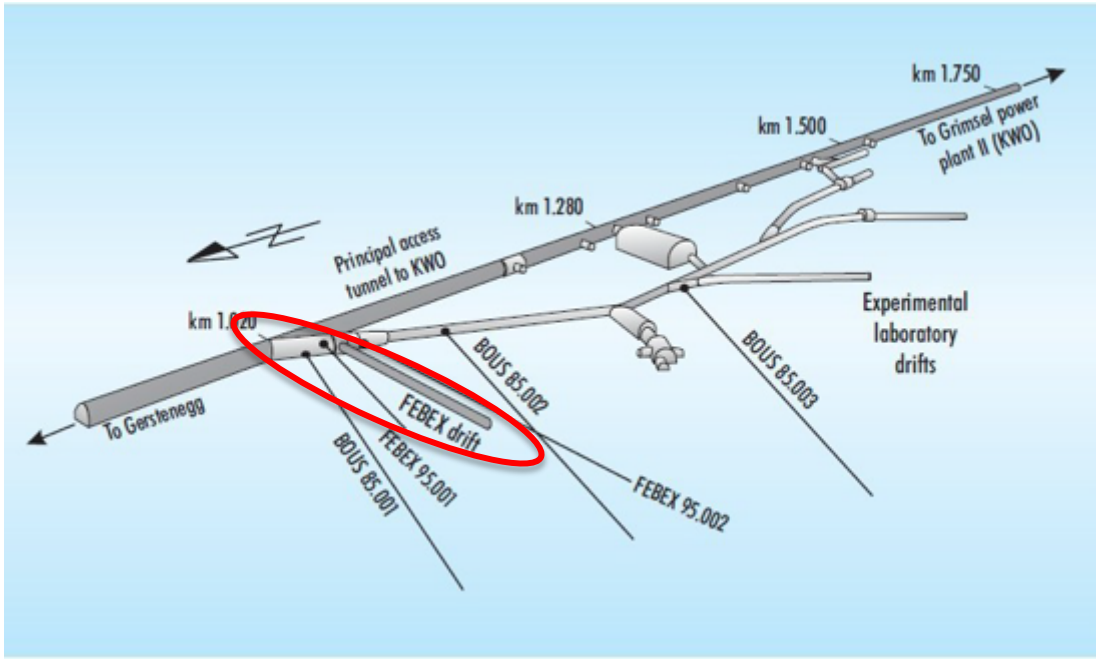
Fluid Infiltration Visualization





HotBENT Field Scale Experiment

❖Location

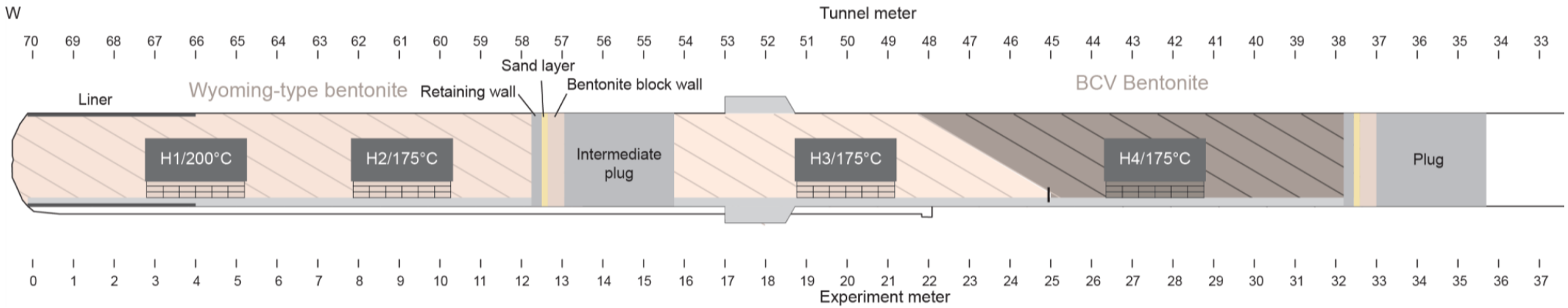


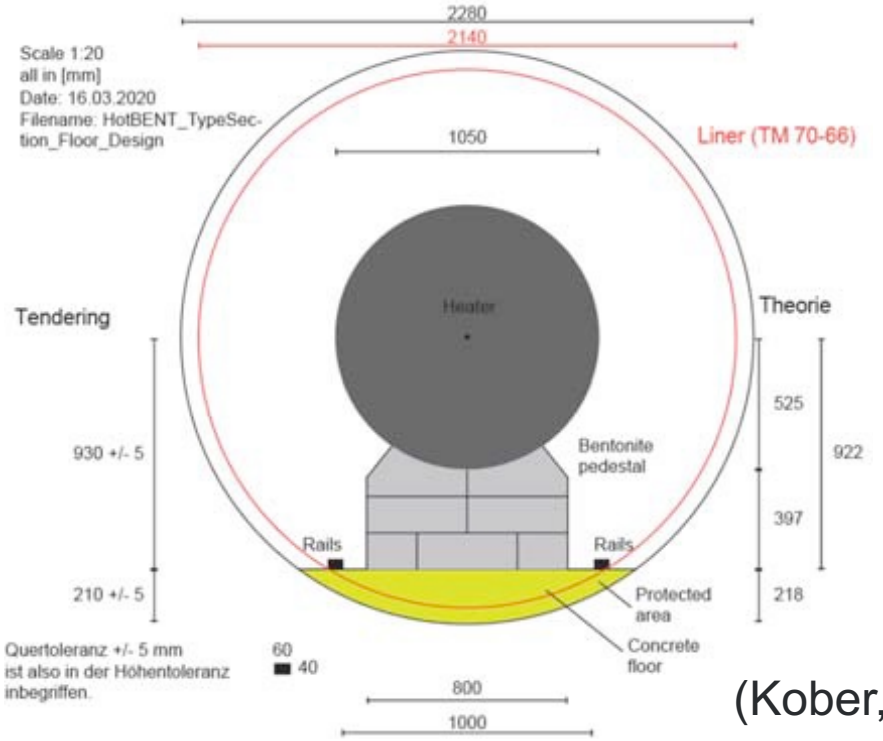
Participating organizations

NAGRA (Switzerland), **DOE**(USA), **NUMO** (Japan), **RWM** (UK), **SÚRAO** (Czech Republic), **NWMO** (Canada), **BGR** (Germany), **ENRESA (Spain), Obayashi (Japan)**

HotBENT Field Scale Experiment

❖Design



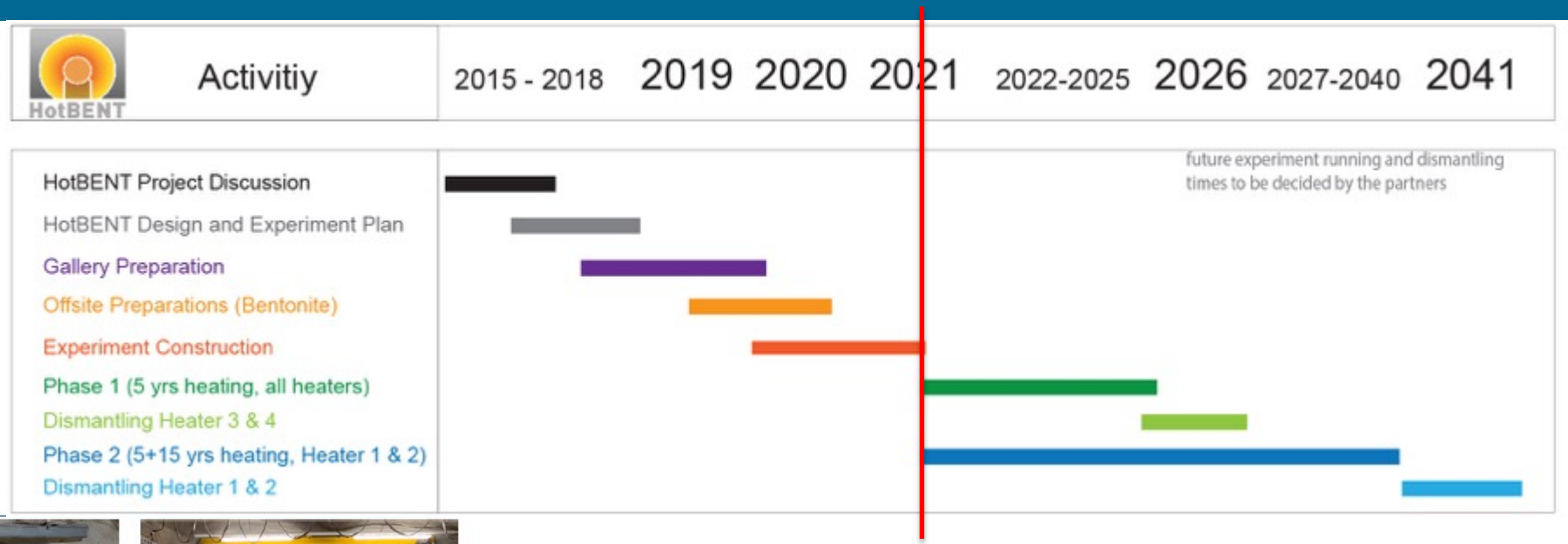


(Kober, 2020)

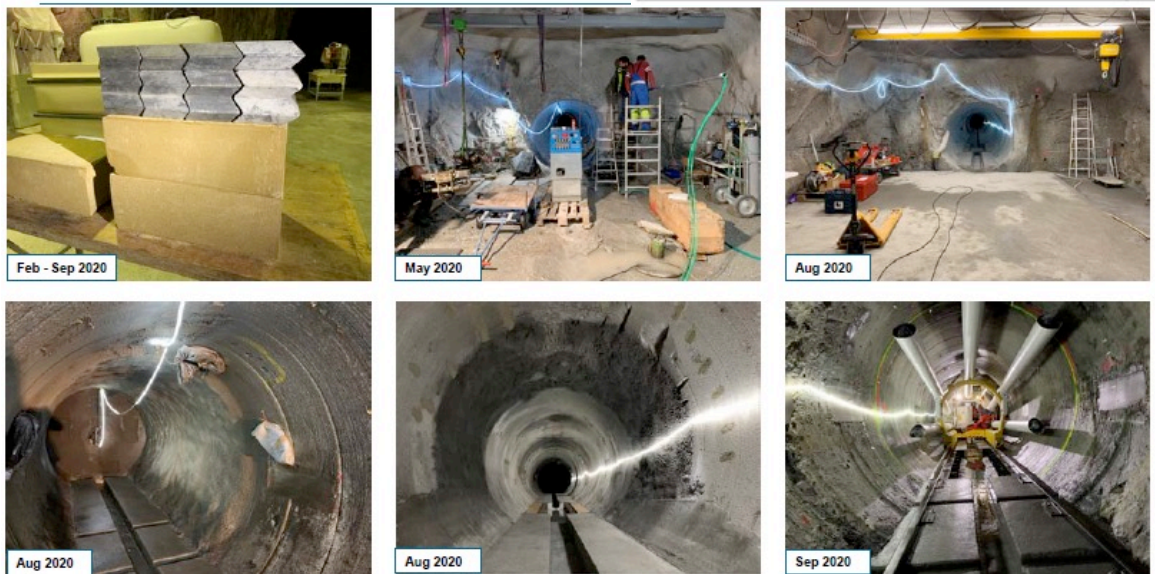
- **Four modules**
  - ✓ Differing in heating temperature, bentonite, time length and w/o concrete liner
- **Two experimental time lengths**
  - ✓ H3 and H4 will run for approximately 5 years
  - ✓ H1 and H2 will run up to 20 years
- **Two bentonites**
  - ✓ Wyoming (MX-80)
  - ✓ BCV (Czech Republic bentonite)
- **Two shapes**
  - ✓ Pedestals for the heaters made of highly compacted blocks, dry density > 1.7 g/cm^3
  - ✓ Granulated Bentonite Mixture (GBM), dry density >1.45 g/cm^3

HotBENT Field Scale Experiment

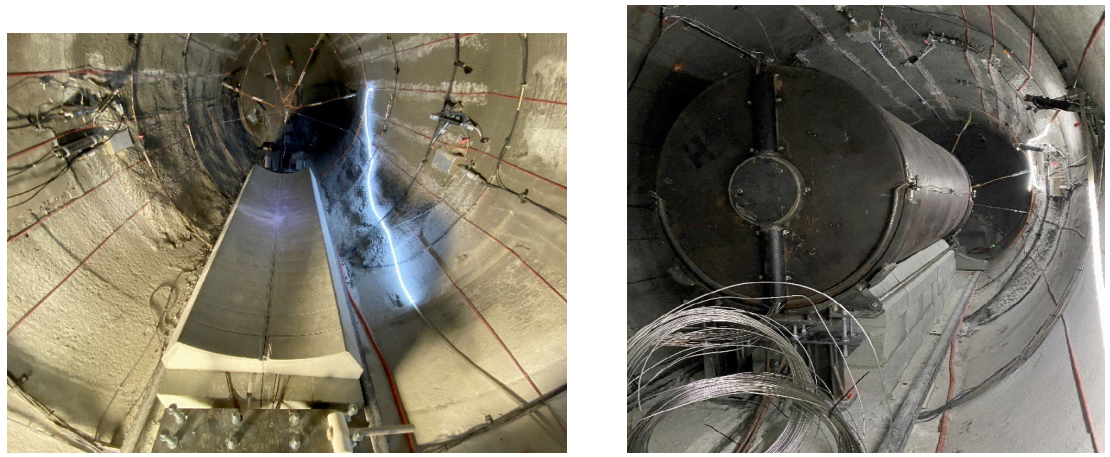
❖Timeline



Heating starts



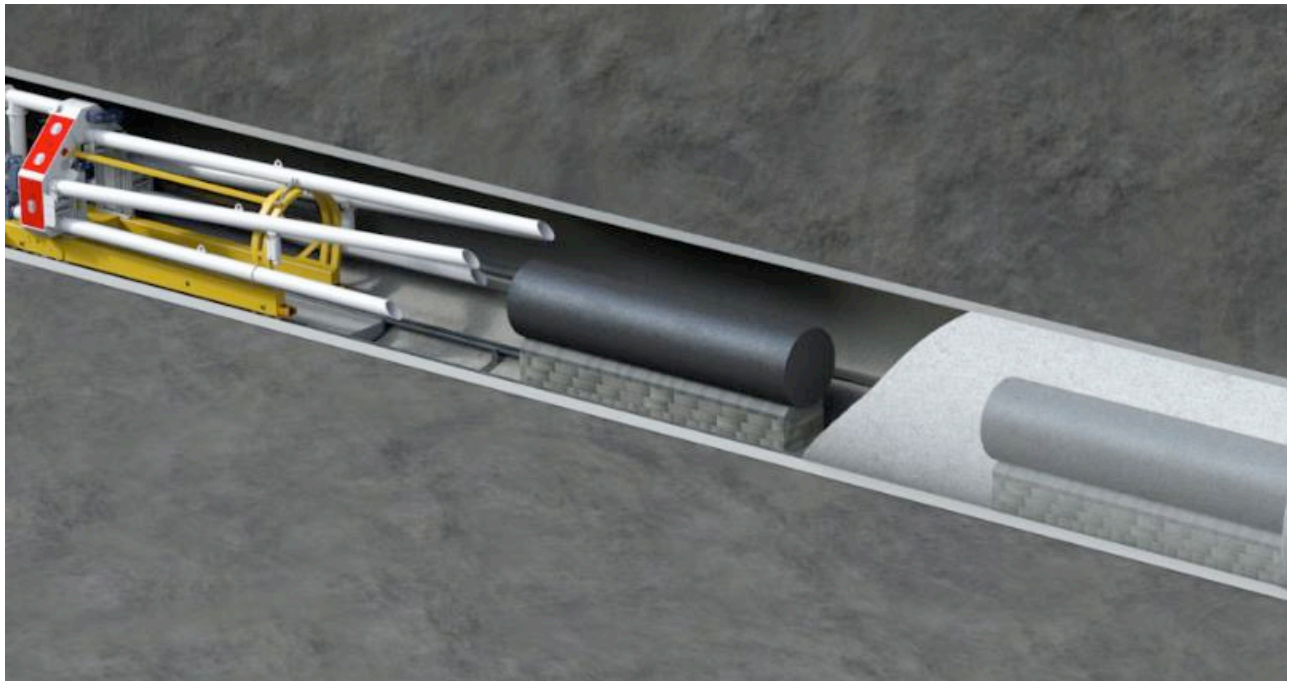
(Kober and Vomvoris, 2020)



October 30, 2020

HotBENT Field Scale Experiment

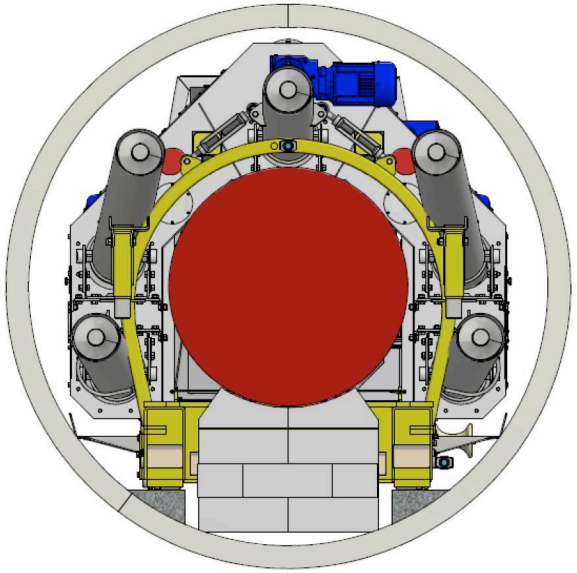
❖Installation



Computer animated picture of the auger unit during backfilling

(Kober, 2020)

Auger unit and heater on the block pedestal inside the galley



H1, Pictured on November 6, 2020

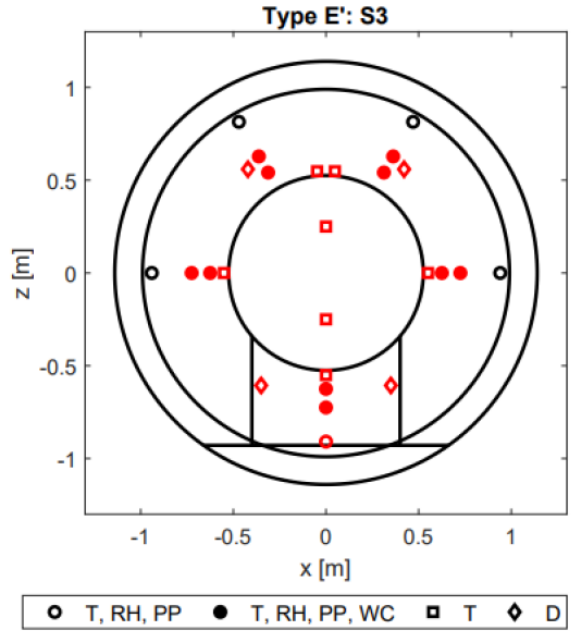
HotBENT Field Scale Experiment

❖ Instrumentation

Tunnel wall

Section E'
Measurements of:

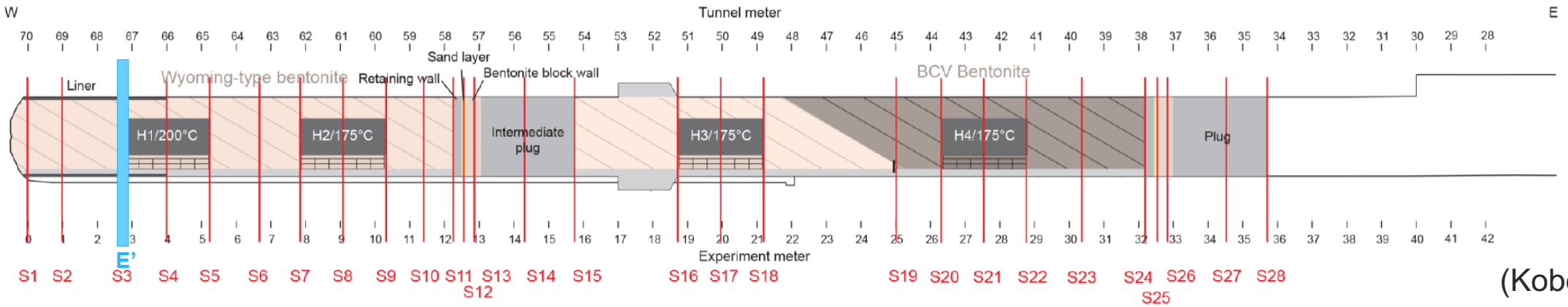
- Temperature (T)
- Pore pressure (PP)
- Relative humidity (RH)



Bentonite and heater

Section E'
Measurements of:

- Temperature (T)
- Pore pressure (PP)
- Relative humidity (RH)
- Total pressure (TP)
- Water content (WC)
- Displacement (D)



(Kober, 2020)

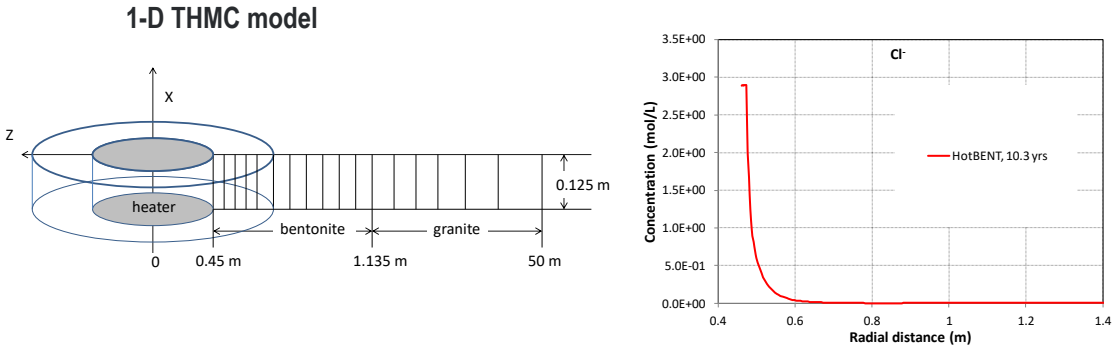
HotBENT Modeling Platform

❖Objective **Experiment informs Model** ⟺ **Model informs Experiment**

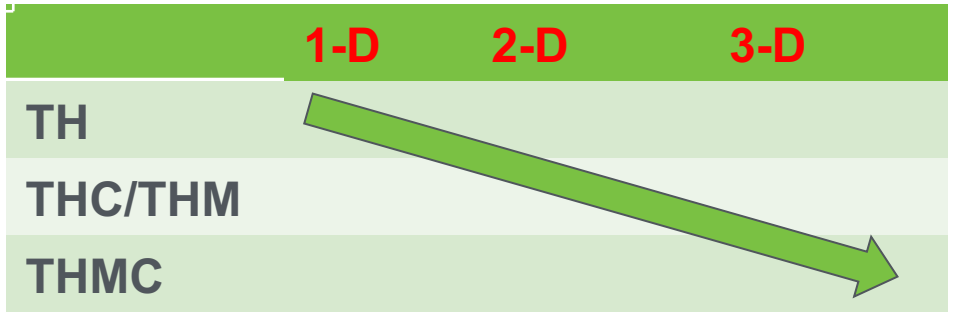
- Expedite data analysis and model updates for system understanding and decision support.
- Blind predictions as part of a model "validation" exercise
- Multiple modelling teams:
  - ➢ Alternative conceptual models => analyze conceptual uncertainties
  - ➢ Focus on different aspects of model/hypothesis/data/prediction
  - ➢ Enhanced insights from integrated/comparative analysis
  - ➢ Sharing of information and expertise in a collaborative environment

(Kober and Vomvoris, 2020)

SFWST supported HotBENT with scoping calculation and joined the modeling platform



LBNL's modeling goal: 3-D THMC model



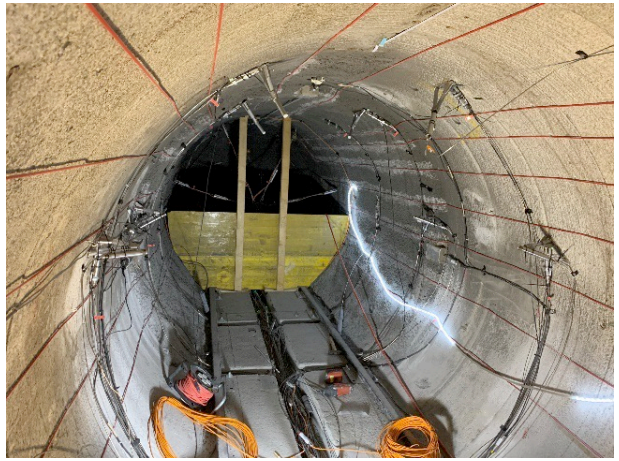
SNL's modeling goal: THMC process at interfacial areas

-Metal corrosion at metal-buffer material interfaces

Summary

- HotBENT project, composed of laboratory experiments, a field test, and numerical models, is ongoing.
- Heating of the four modules in the field test is expected to start around June 2021.
- It addresses several high priority R&D topics, improves particularly the understanding of coupled THMC process in EBS and interfacial areas under high temperature.
- It helps the study on the thermal limit of a repository.
- It increases the confidence of modeling EBS and crystalline host rock

HotBENT



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Thanks for your attention!

Questions?

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