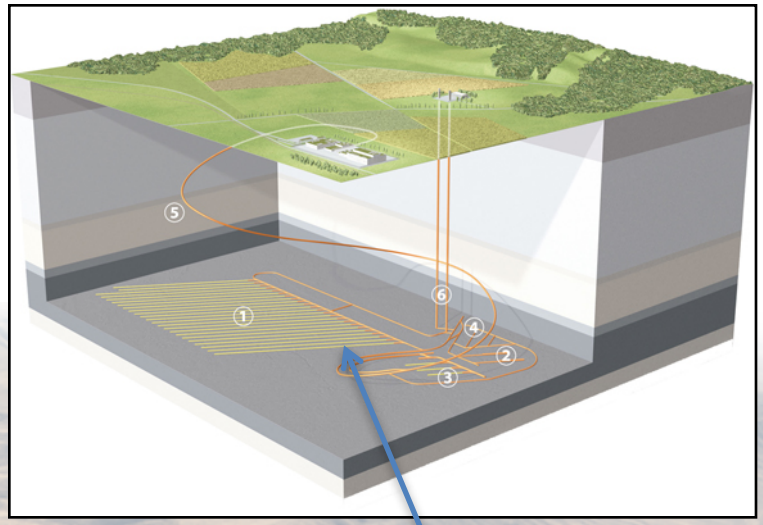
An Overview of Radioactive Waste Disposal Research Activities Linked to International Underground Research Laboratories

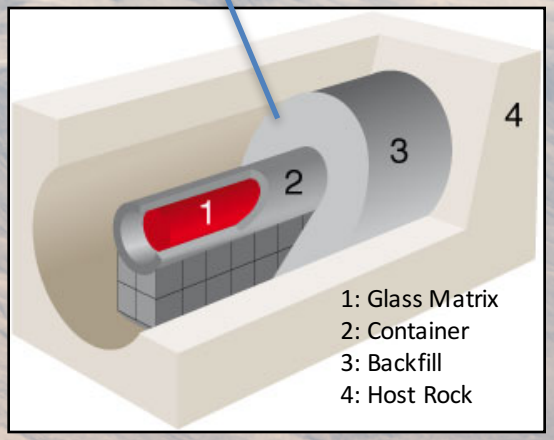
Jens Birkholzer
Lawrence Berkeley National Laboratory

GSA 2016, Denver, Colorado

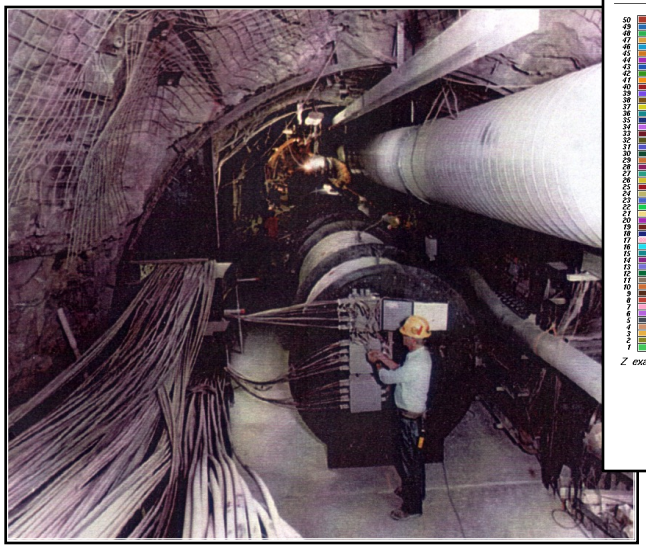
R&D Needs for Mined Geologic Disposal

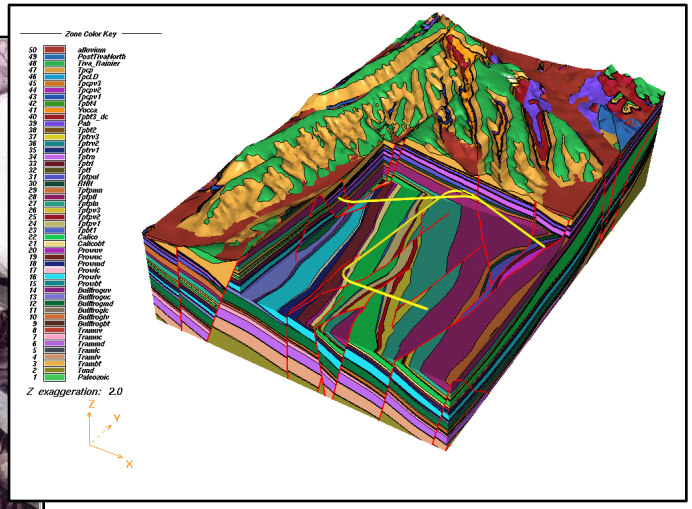
- **Understanding Geologic Disposal Safety**
  - Characterize geologic and hydrogeologic conditions
  - Evaluate near-field perturbations
  - Understand barrier integrity over time
  - Predict radionuclide transport
  - Demonstrate integrated system behavior





Dedicated Underground Research Laboratories





Yucca Mountain

Stripa Mine

Project	Where	Timeline	
Lyons Mine (Project Salt Vault)	USA		URL and SNF demo
Asse Mine	Germany		LLW/ILW currently in remediation
Stripa Mine	Sweden		
Climax Mine	USA		Former nuclear testing; SNF demo
G-Tunnel	USA		Former nuclear testing
Fanay-Augeres	France		Former uranium mine
HADES-URF*	Belgium		
Konrad**	Germany		Being developed as a repository
Grimsel Test Site	Switzerland		
AECL URL (Lac du Bonnet)*	Canada		
Gorleben**	Germany		Operations curtailed 2012
WIPP**	USA		URL testing for heat-generating waste
Amelie	France		Former potash mine
Tono Mine	Japan		
Kamaishi Mine	Japan		
Tournemire Tunnel	France		Former rail tunnel
Aspo HRL*	Sweden		
Olkiluoto Research Tunnel	Finland		Developed for LLW/ILW investigations
Mont Terri	Switzerland		Former highway tunnel
Pecs**	Hungary		Former uranium mine
ESF (Yucca Mountain)**	USA		
Busted Butte*	USA		
Bure URL (Meuse/Haute Marne)**	France		
Morsleben**	Germany		LLW/ILW repository 1981-1998
Mizunami URL*	Japan		
ONKALO**	Finland		
Horonobe URL*	Japan		
Korea UG Research Tunnel*	Rep. of Korea		

Timeline: ←1960 ←1970 ←1980 ←1990 ←2000 ←2010

NOTE: Timelines accurate to approx. ±3 years.

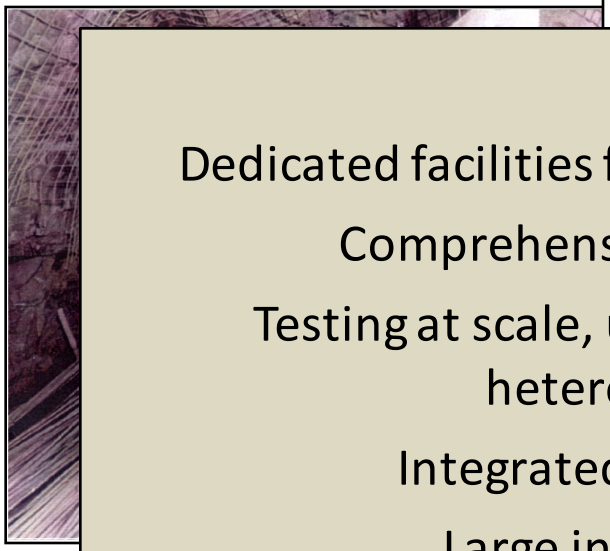
Salt
Crystalline
Tuff
Plastic clay
Argillaceous
Other sedimentary

* Purpose-built, generic
** Purpose-built, site-specific
(Generic pre-existing URLs have no marks)

NOT SHOWN: Early U.S. URLs (Avery Island, CSM Mine, etc.) and more recent U/G investigations in the Czech Republic, Canada, and elsewhere.

Long History of Underground Observatories for Nuclear Waste Disposal R&D

Dedicated Underground Research Laboratories



Characteristics:

Dedicated facilities for observation and controlled experiments

Comprehensive characterization and monitoring

Testing at scale, under in situ conditions, in complex and heterogeneous subsurface systems

Integrated imaging, analysis, and modeling

Large interdisciplinary research groups

Objectives:

Improve process understanding

Test simulation capabilities

Prototype advanced imaging/monitoring methods

Evaluate engineered barrier materials and designs

Demonstrate integrated system behavior

Project		
Lyons Mine (Project Salt Vault)		
Asse Mine		
Stripa Mine		
Climax Mine		
G-Tunnel		
Fanay-Augeres		
HADES-URF*		
Konrad**		
Grimsel Test Site		
AECL URL (Lac du Bonnet)*		
Gorleben**		
WIPP**		
Amelie		
Tono Mine		
Kamaishi Mine		
Tournemire Tunnel		
Aspo HRL*		
Olkiluoto Research Tunnel		
Mont Terri		
Pecs**		
ESF (Yucca Mountain)**		
Busted Butte*		
Bure URL (Meuse/Haute Marne		
Morsleben**		
Mizunami URL*		
ONKALO**	Finland	(Generic pre-existing URLs have no marks)
Horonobe URL*	Japan	
Korea UG Research Tunnel*	Rep. of Korea	

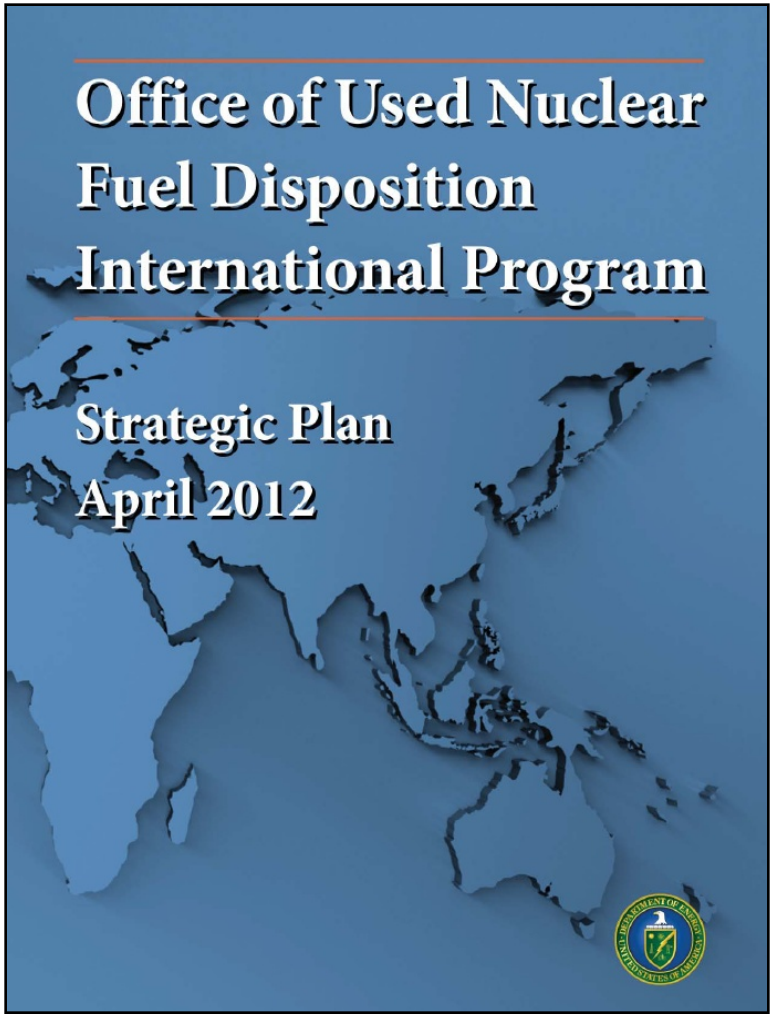
NOT SHOWN: Early U.S. URLs (Avery Island, CSM Mine, etc.) and more recent U/G investigations in the Czech Republic, Canada, and elsewhere.

Observatories for Nuclear Waste Disposal R&D

BERKELEY LAB

U.S. DOE - Strategic Plan for International Collaboration

- Yucca Mountain was so unique with respect to design and geologic environment that overlap with international R&D was quite limited in the past
- With the need for addressing alternative disposal designs and geologic environments, DOE views international collaboration as a very beneficial strategy of advancing disposal R&D
- A strategic decision was made in 2012 to advance international collaboration in disposal research, with particular focus on participation and active R&D associated with underground research laboratories



Current Collaboration in International Partnerships

Multinational Initiatives

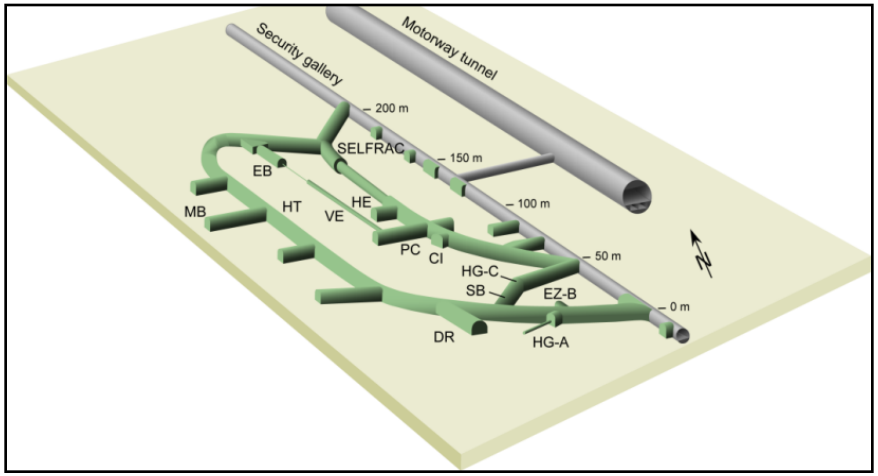
- **Mont Terri Project**
  - *Participate in experiments at Mont Terri clay URL in Switzerland*
- **DECOVALEX Project**
  - *Participate in model comparison initiative for several URL related tasks in different host rocks*
- **Colloid Formation and Migration Project (2012-2015)**
  - *Participate in colloid research at Grimsel granite URL in Switzerland*
- **SKB Task Forces**
  - *Participate in crystalline rock research centered around Äspö HRL in Sweden and Onkalo URL in Finland*
- **FEBEX DP**
  - *Participate in FEBEX dismantling project, which will analyze bentonite-rock behavior after 17 years of heating*
- **Nuclear Energy Agency (NEA)**
  - *Thermochemical Database Project*
  - *Salt Club*
  - *Clay Club*

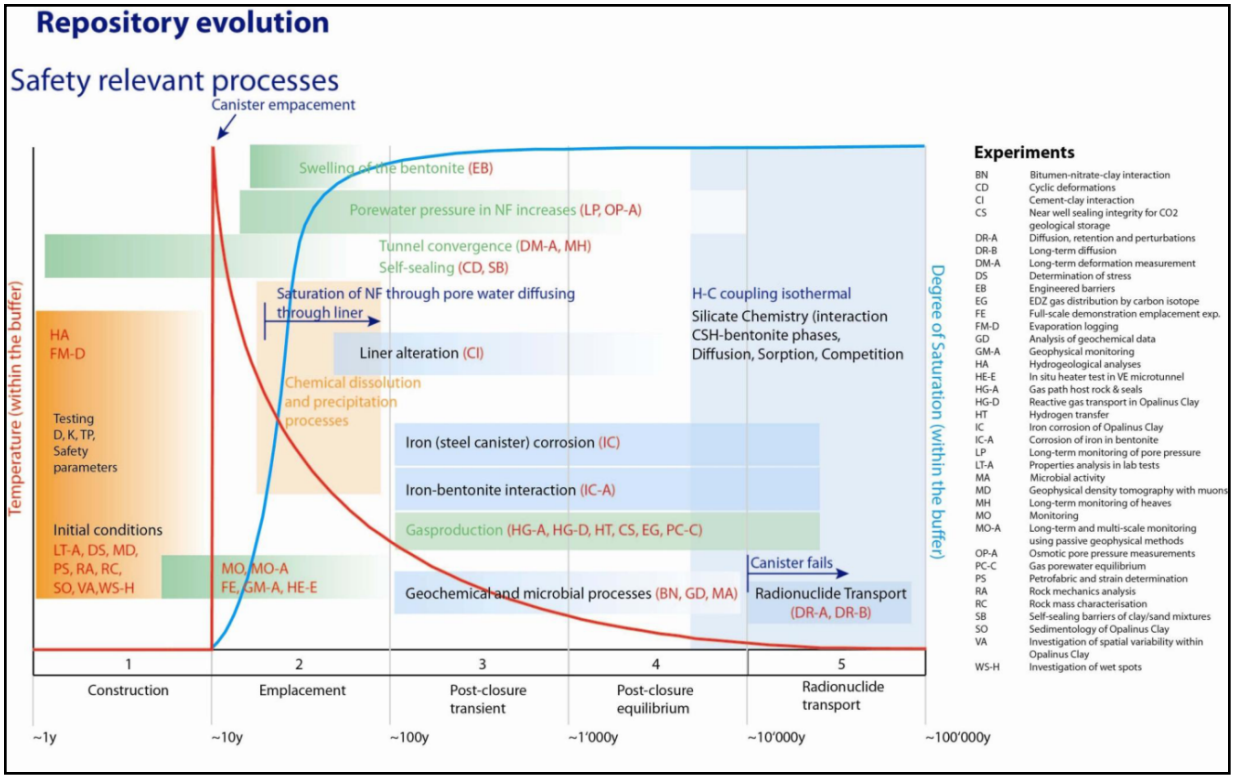
Bilateral Agreements

- **US-China**
  - *Bilateral Civil Nuclear Energy Cooperative Action Plan (BCNECAP) with working group in Spent Fuel Storage and Repository Science*
- **US-Germany benchmarking study for salt**
  - *Participate in model comparison for TM behavior of domal and bedded salt*
- **US-Republic of Korea (ROK)**
  - *KAERI Underground Research Tunnel (KURT), experiments in crystalline rock*
  - *Joint Fuel Cycle Study (JFCS), information exchange in used fuel disposal*
- **Other Potential Opportunities**
  - *Explore use of existing Memorandum of Understanding (MoU) between DOE and Spain (ENRESA), France (ANDRA), Japan (JNEAP) and Belgium*

Mont Terri Project

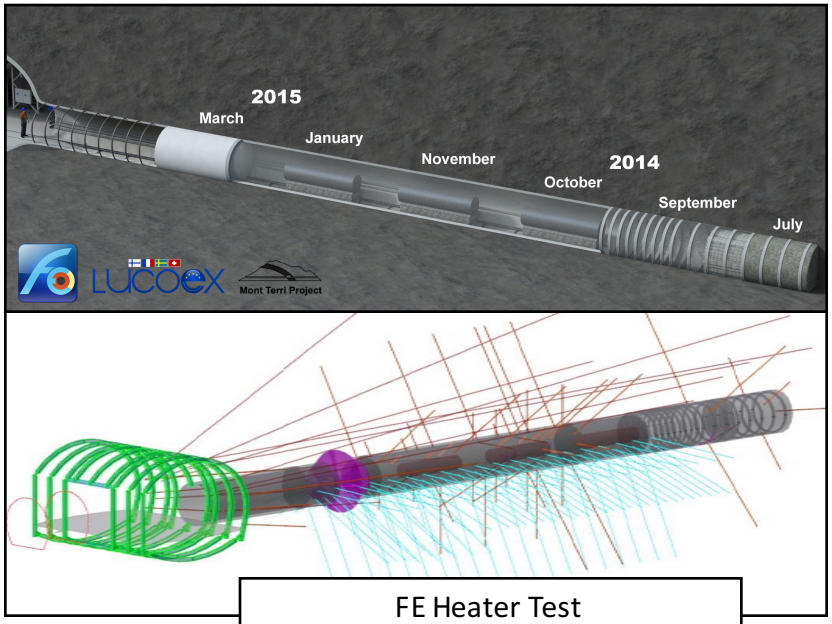
- International research project for hydrogeological, geochemical, and geotechnical studies in a clay/shale formation
- Access to experimental data from one URL, with many past, ongoing and future experiments addressing various FEPs
- URL is situated near the town of St Ursanne in Northwestern Switzerland
- Opportunity to participate directly in international research groups that conduct, analyze, and model experiments
- Opportunity for conducting own experiments



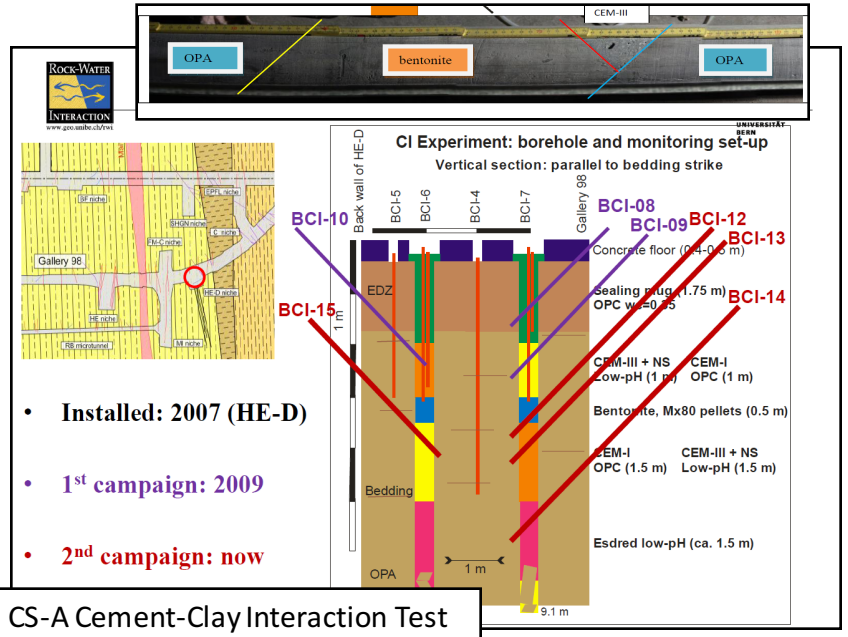


Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

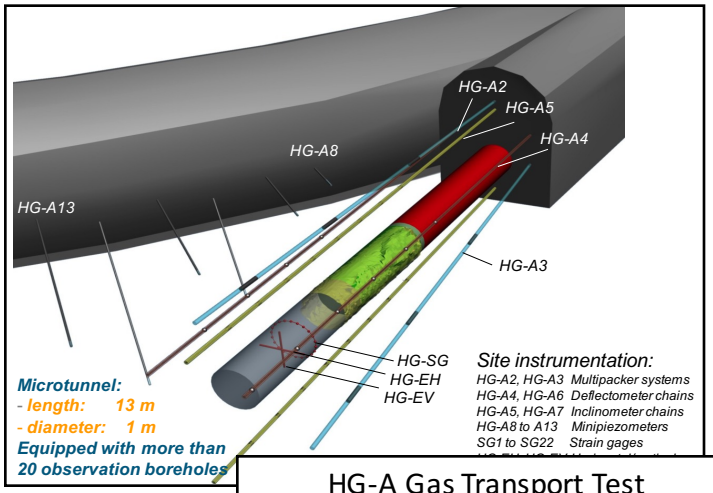
Selected Mont Terri Experiments and Activities



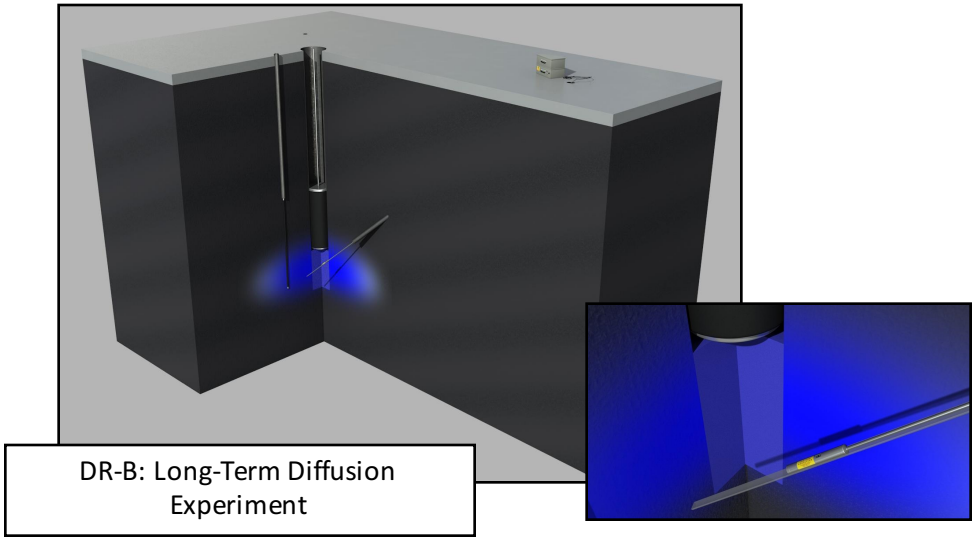
FE Heater Test



CS-A Cement-Clay Interaction Test



HG-A Gas Transport Test

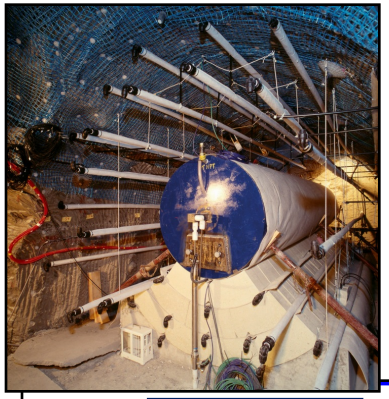


DR-B: Long-Term Diffusion Experiment

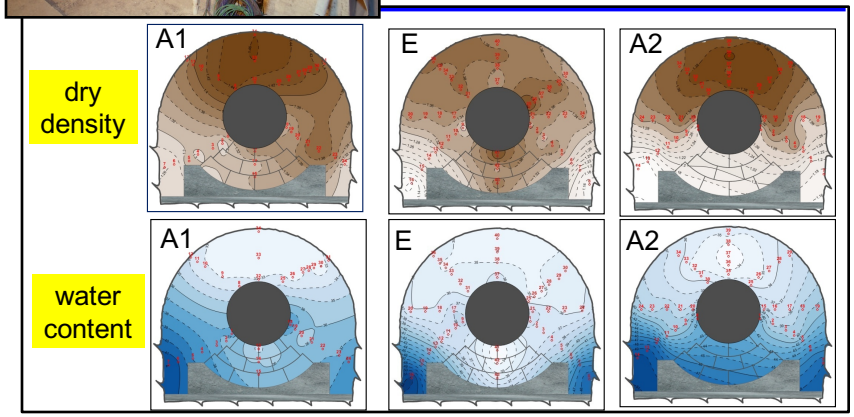
DECOVALEX Model Comparison Project

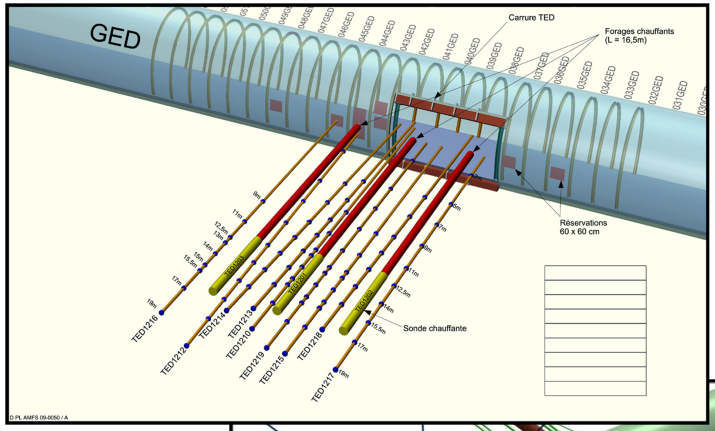
- **DECOVALEX was established in 1992, and has been active since, in several project stages**
  - The objective is to achieve a better understanding and improved modeling of the effects of coupled (T-H-M-C) processes in nuclear waste repositories
  - Past DECOVALEX activities have included several international programs and research tasks with focus on clay and granite repositories
  - New DECOVALEX Phase has just started, with a kick-off meeting in Berkeley (DECOVALEX 2019)

- **DECOVALEX 2019 Tasks from Different URLs (examples)**

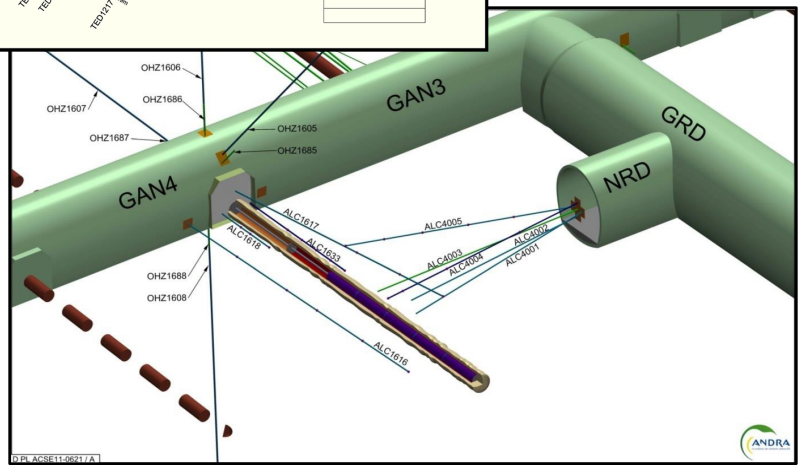


Bentonite Homogenization



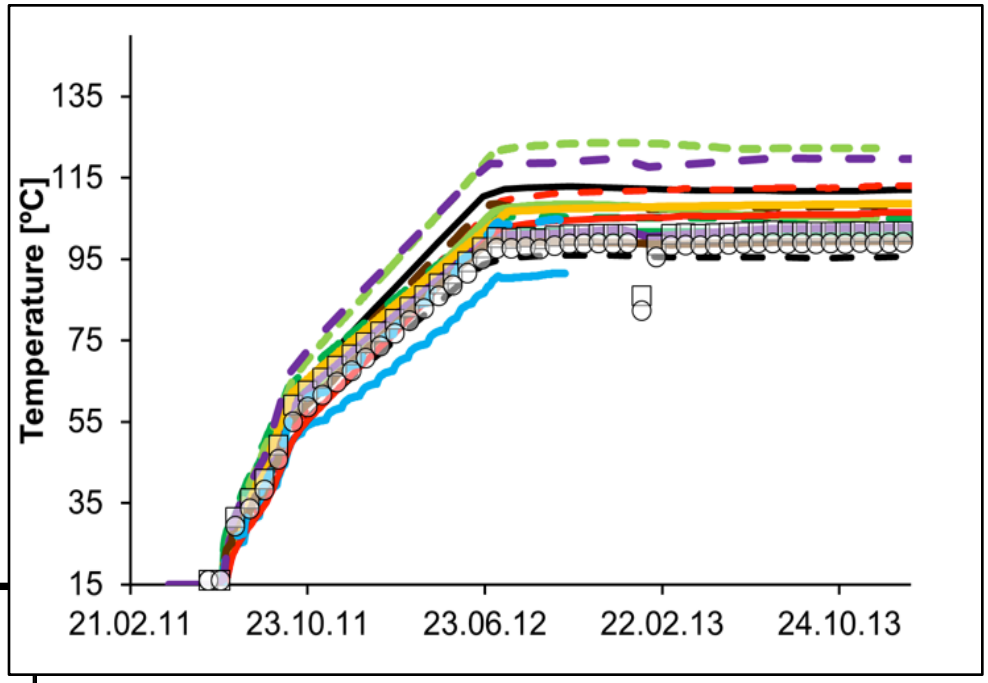


Upscaling Heater Tests



DECOVALEX Characteristics

Advanced experiments

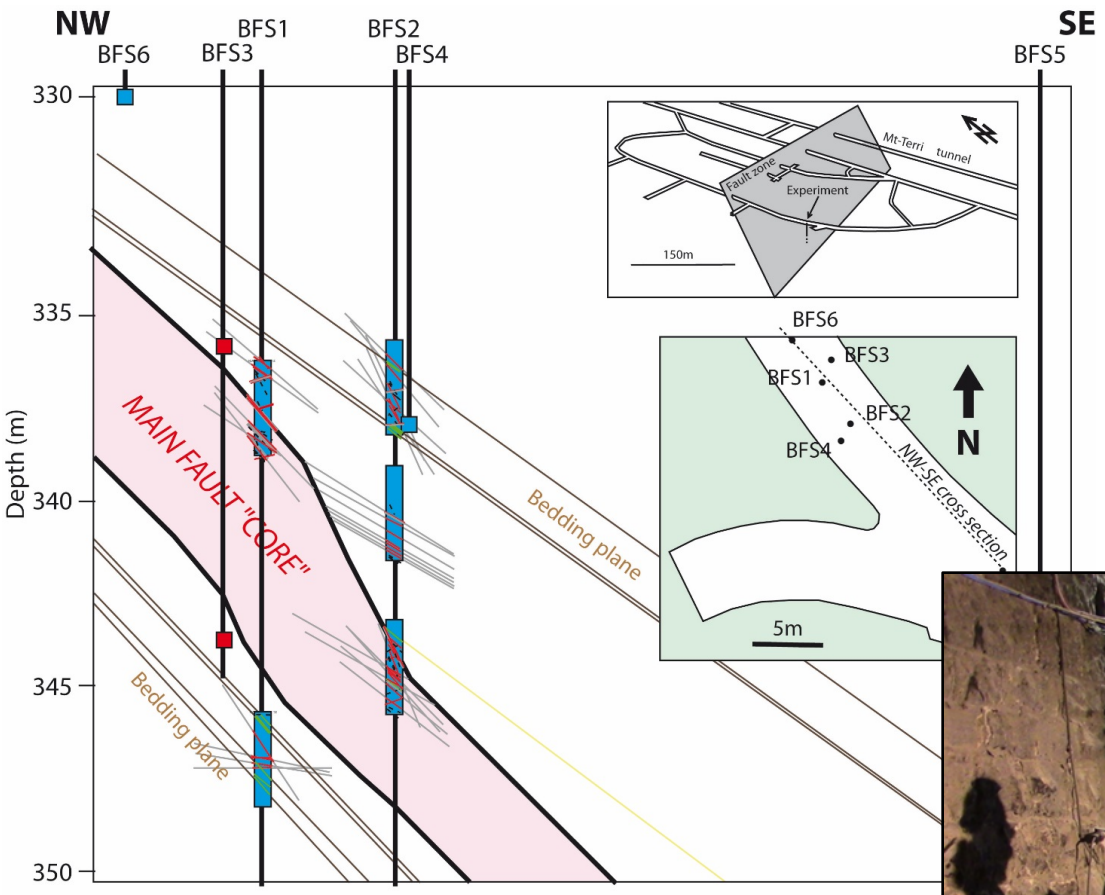


Detailed comparison with data

Team	Person	F.O.	Country	Code
BGR	Wang Xuerui	BGR	Germany	OpenGeoSys
CAS	Pengzhi Pan	CAS	China	EPCA3D
LBNL	Jonny Rutqvist	DOE	USA	TOUGH-FLAC
ENSI	Bastian Graupner	ENSI	Switzerland	OpenGeoSys
CNSC	Son T. Nguyen	IRSN	Canada/France	COMSOL
JAEA	Keisuke Maekawa	JAEA	Japan	THAMES
KAERI	Changsoo Lee	KAERI	South Korea	FLAC
CNWRA	Chandrika Manepally	NRC	USA	FLAC-xFlo

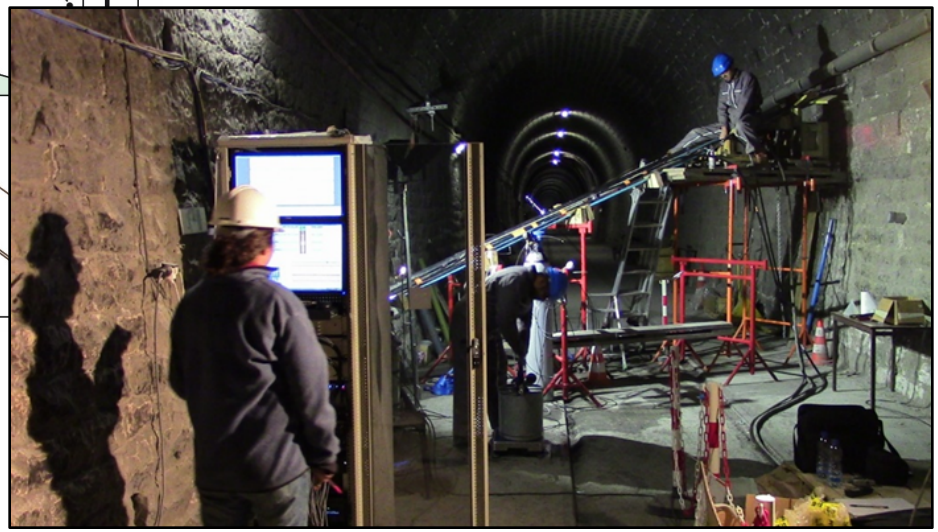
Various teams with various models

DECOVALEX Fault Slip Task: An Open Invitation



DECOVALEX 2019

www.decovalex.org



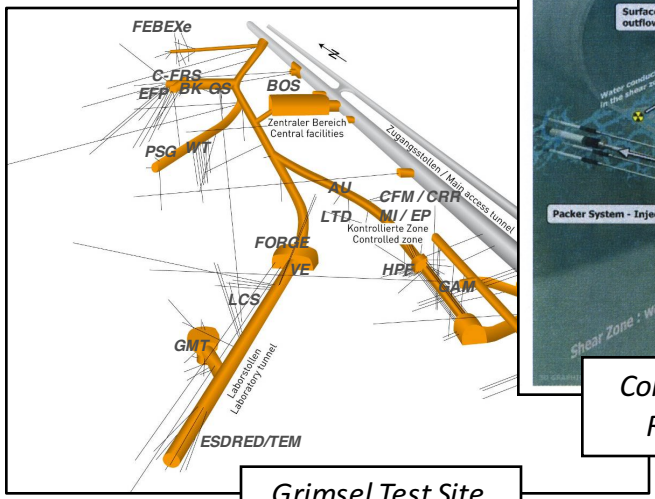
FS Experiment at Mont Terri

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

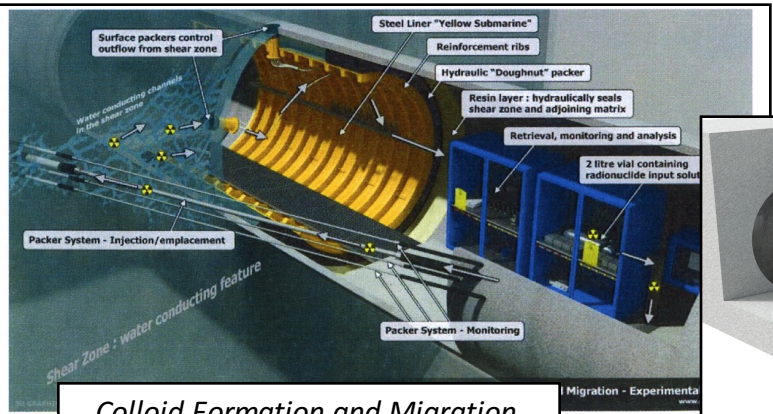
Contact:
Jens Birkholzer, jtbirkholzer@lbl.gov
Alex Bond, alexbond@quintessa.org

BERKELEY LAB

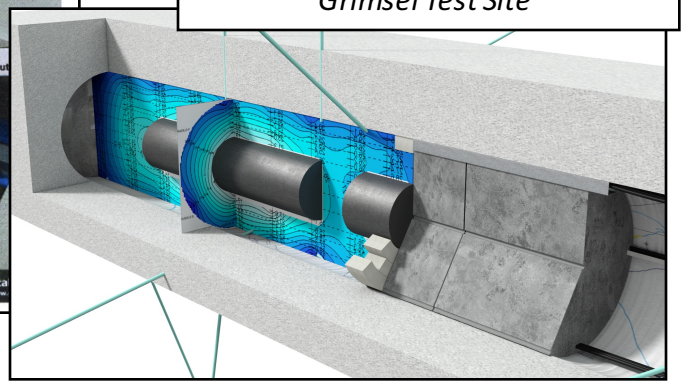
Other Collaboration Examples



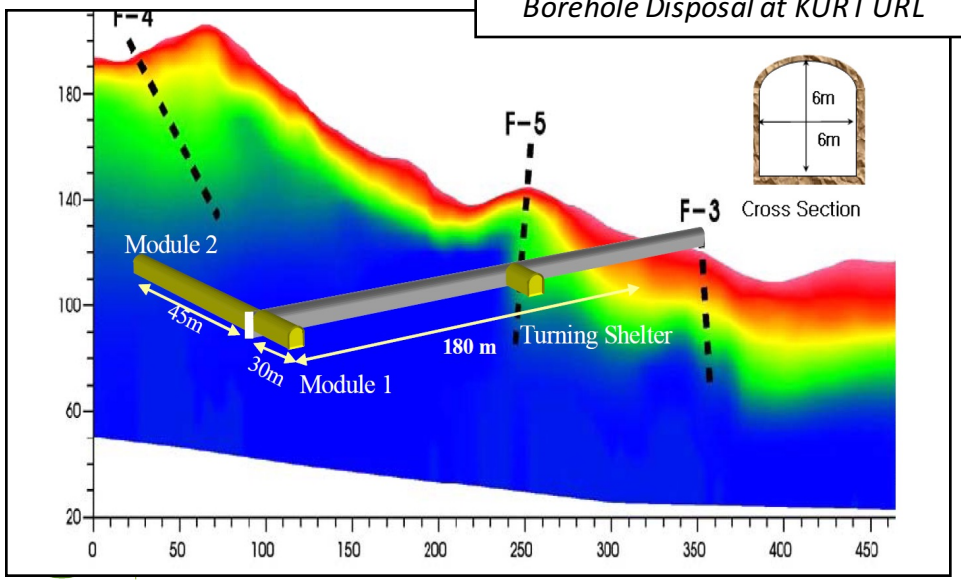
Grimsel Test Site



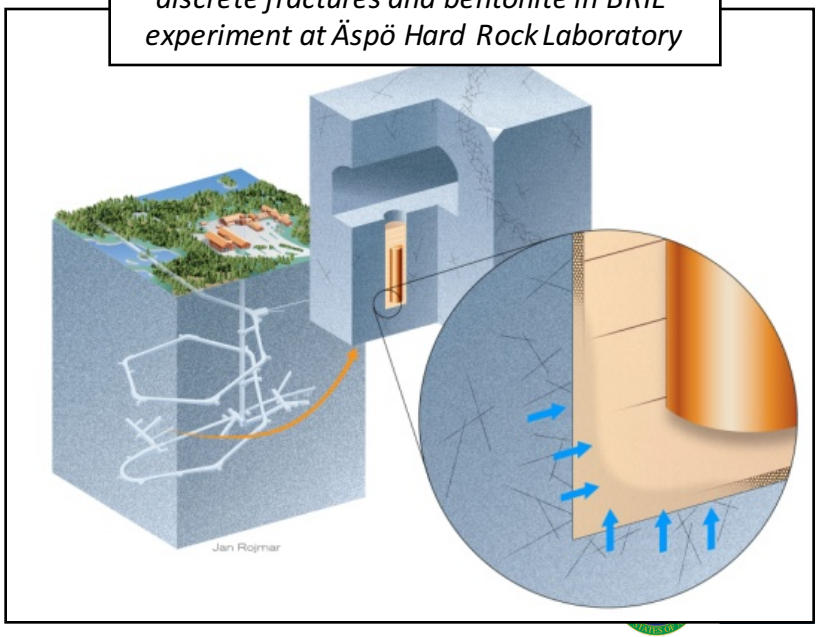
Colloid Formation and Migration Research at Grimsel Test Site



FEBEX Dismantling Project at Grimsel Test Site



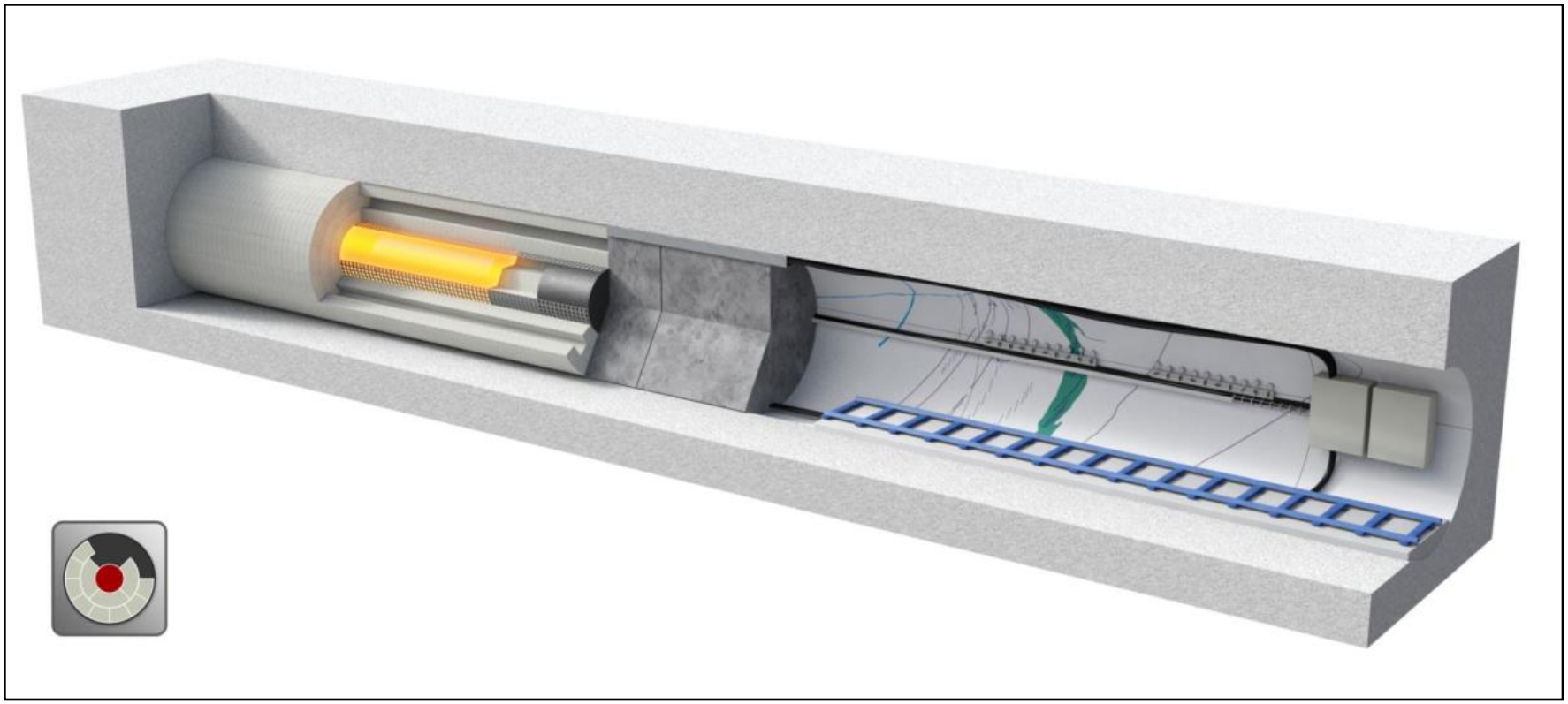
Collaboration Regarding Deep Borehole Disposal at KURT URL



SKB Task Forces: Water exchange between discrete fractures and bentonite in BRIE experiment at Äspö Hard Rock Laboratory

Planning for New Opportunities: HotBENT

A planned collaboration project, led by NAGRA, to conduct a joint experiment integrated with lab and modeling studies to evaluate buffer behavior at 150°C to 200°C



Subsurface Observatories…. Build Science Communities

DECOVALEX Meeting at Mont Terri

Yucca Mountain Field Trip

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

BERKELEY LAB

Summary and Conclusions

- Active collaboration with international programs, initiatives, or projects is beneficial to DOE's disposal research program, providing access to decades of experience gained in various disposal environments
- DOE has pursued various avenues for international collaboration and has joined formal collaborative R&D agreements with international partners
- Focus is on partnerships that allow "active" R&D collaboration in underground research laboratories

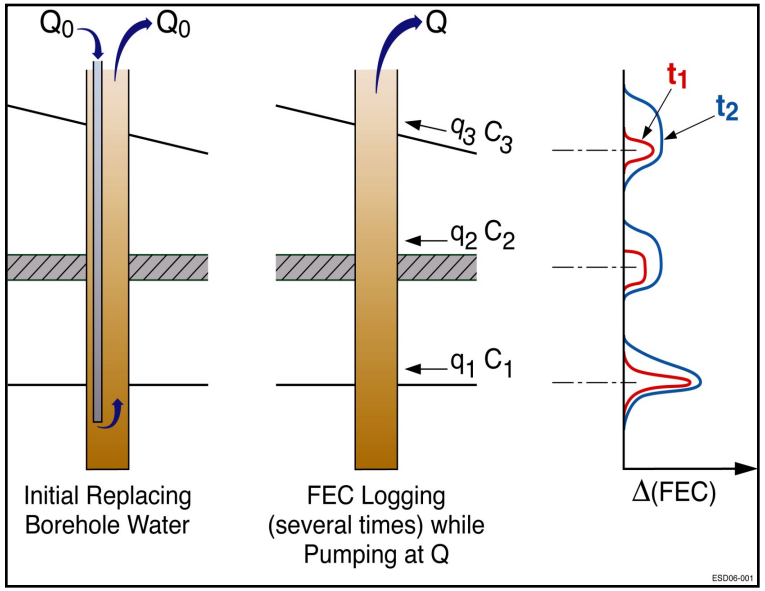
- ➢ Improved understanding of near-field perturbation, engineered barrier integrity, and RN transport
- ➢ Testing of advanced computational tools against experimental data at scale
- ➢ Collaboration with international partners builds science communities and provides opportunities for learning

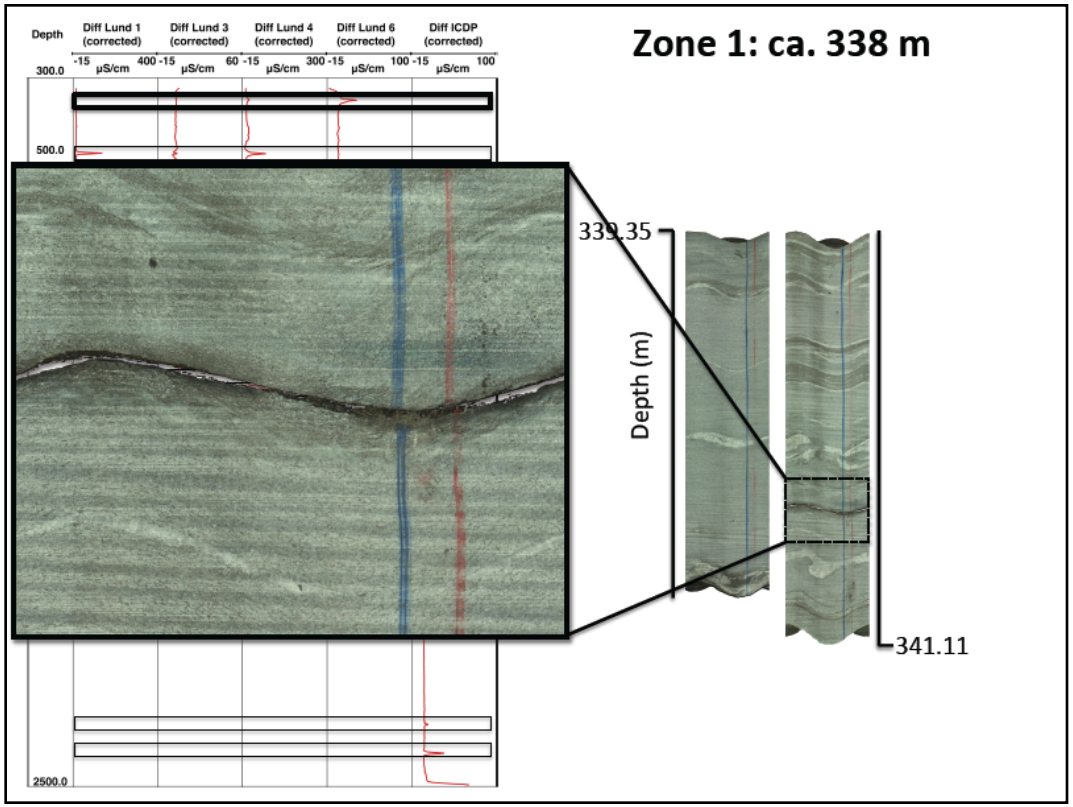
Backup

Borehole-Based Subsurface Observatories – COSC in Sweden

- COSC stands for "Collisional Orogeny in the Scandinavian Caledonides" and is a scientific deep drilling project in Sweden
- COSC-1 is a 2,500 m deep borehole in crystalline bedrock fully cored and available for pilot testing of characterization methods

Swedish and US researchers recently conducted a FEC logging campaign at COSC-1 to test capability for finding inflow zones

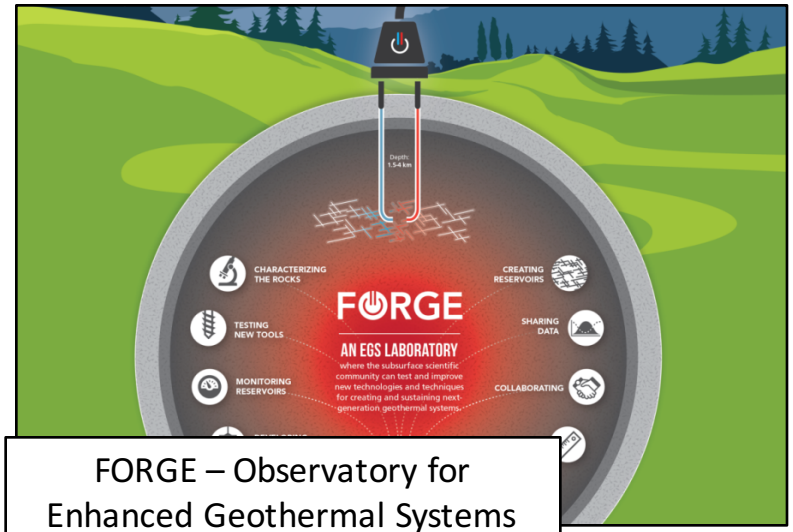




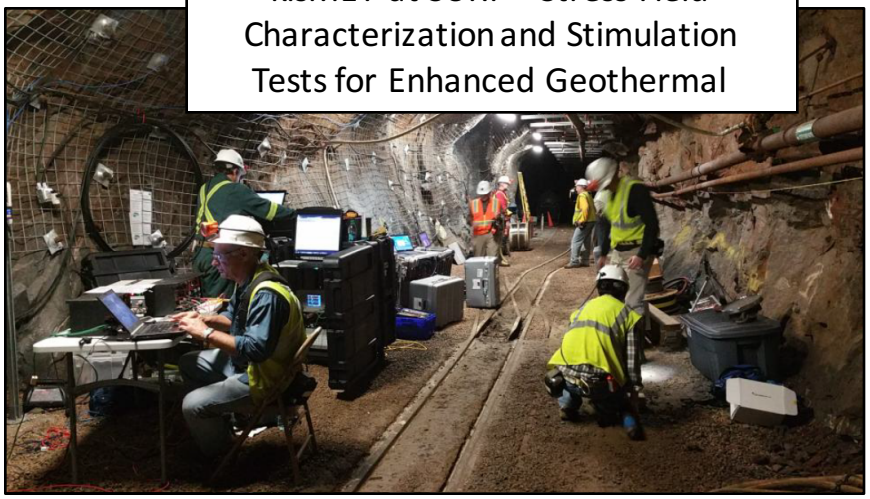
Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

BERKELEY LAB

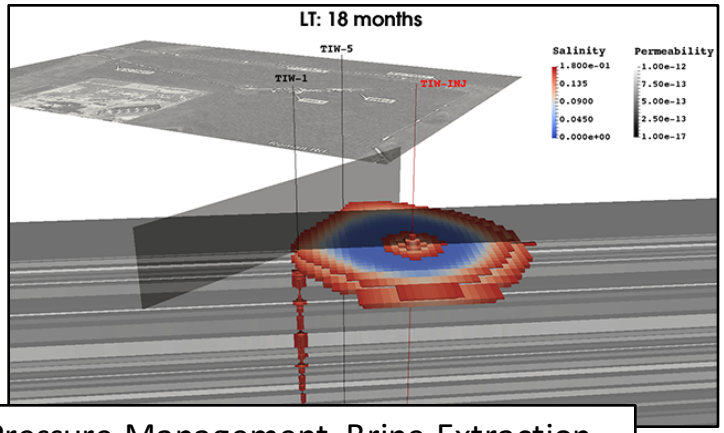
Subsurface Observatories in Other Communities



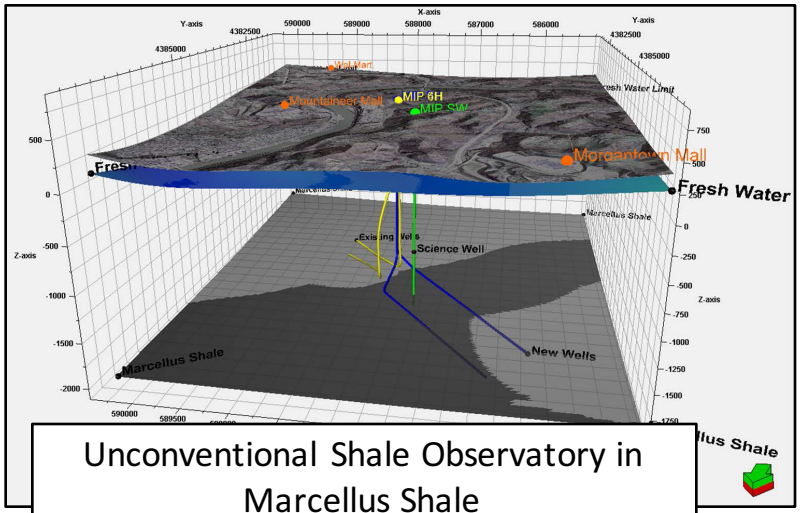
FORGE – Observatory for Enhanced Geothermal Systems



kisMET at SURF – Stress Field Characterization and Stimulation Tests for Enhanced Geothermal



Pressure Management, Brine Extraction and Desalination Pilot Test for CO_2 Storage



Unconventional Shale Observatory in Marcellus Shale

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

BERKELEY LAB