Used Fuel Disposition Campaign

THM Modeling of the Mont Terri FE Heater Test and DECOVALEX Studies

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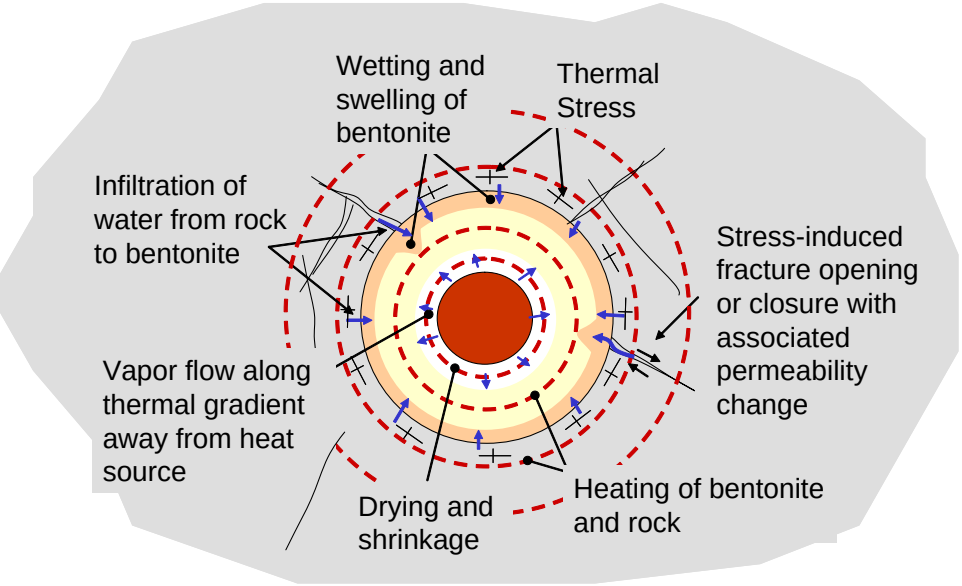
Lawrence Berkeley National Laboratory

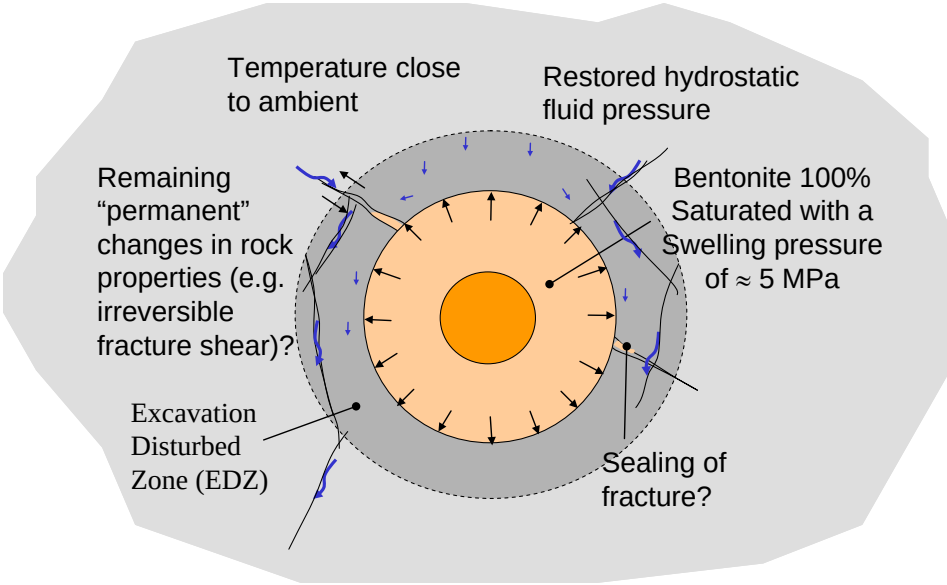
UFD WG Meeting in Las Vegas
Argillite & Crystalline Disposal WP
June 4-6, 2014

Coupled THM Processes and Nuclear Waste Disposal

Short-Term THM Disturbance (0 to 1000 years)



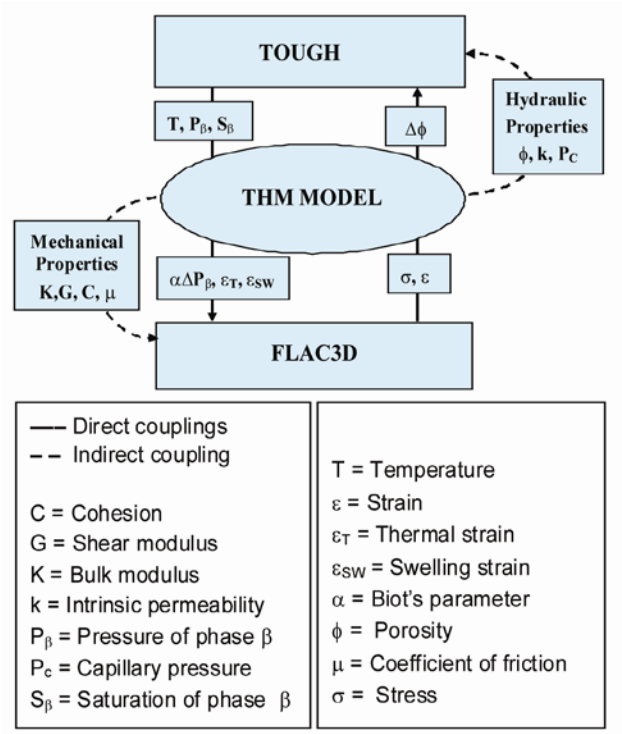
Long-Term Impact (10,000 to 100,000 years)



- Are strongest during the early time (excavation, waste emplacement and thermal peak), but may cause permanent changes that could have a significant impact on the long-term performance.
- Are complex but can be analyzed with advanced numerical modeling supported by lab and field experiments.

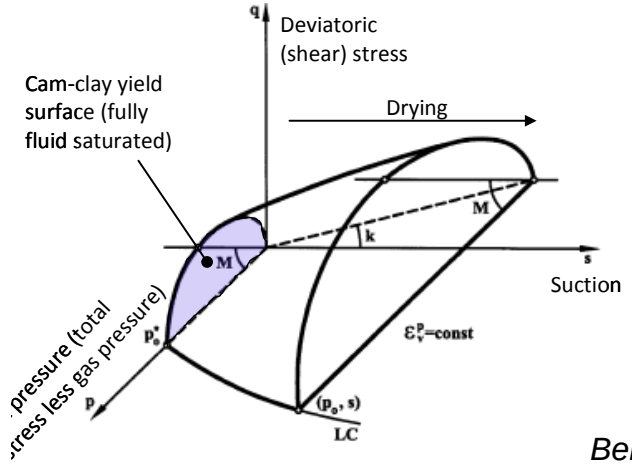
Recent UFD THM Model Developments (TOUGH-FLAC, BBM and BExM)

TOUGH-FLAC



1) Barcelona Basic Model (BBM)

A constitutive model for thermo-elasto-plastic behavior of unsaturated soils (bentonite)

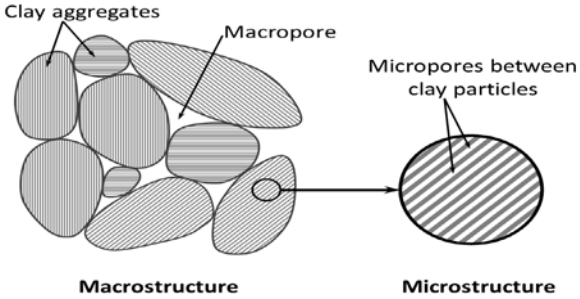


Bentonite block stored at different relative humidity (Teodori et al 2011)

- Shear strength and stiffness depends on saturation (or suction)
- Wetting-induced swelling or collapse strains

2) Barcelona Expansive Model (BExM)

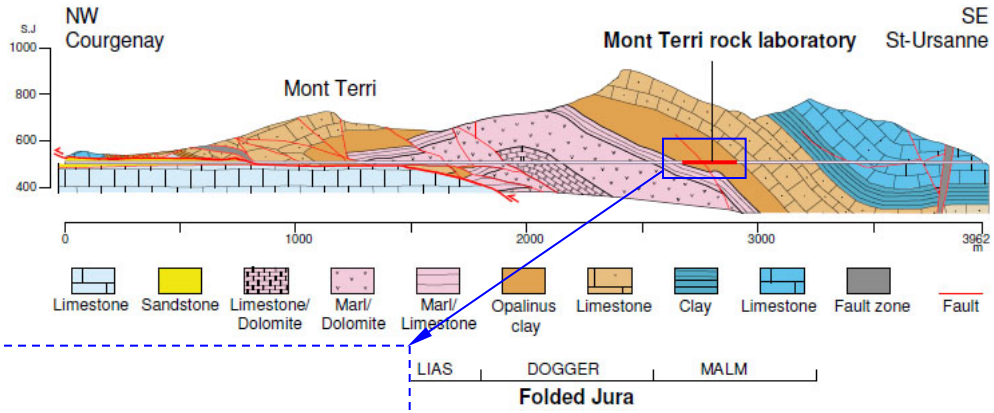
- Micro- and macro-structure
- Proper modeling of fluid flow through macro pores and their changes with stress and saturation
- Provides a link for coupling mechanics with chemistry



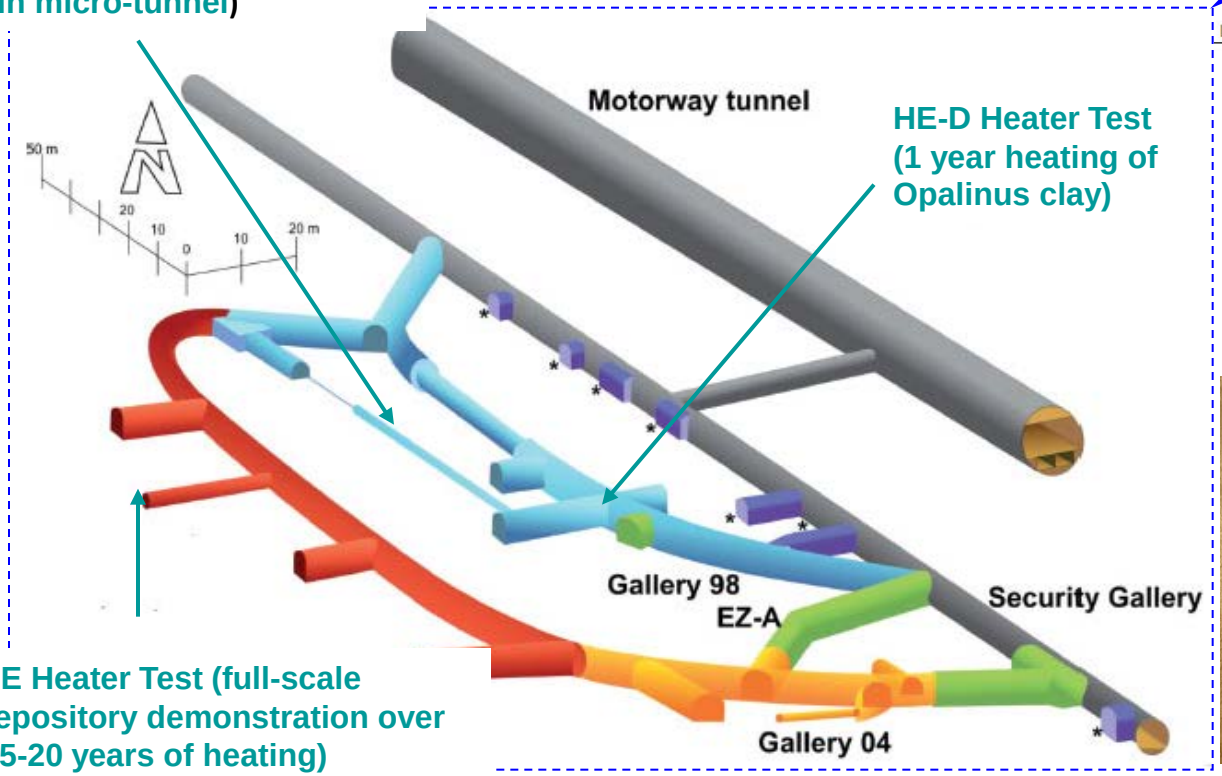
Model Validation Against Field Experiments

Mont Terri (Switzerland) field experiments in Opalinus Clay

Horizontal emplacement



HE-E Heater Test (3 years heating of bentonite-rock in micro-tunnel)



HE-D Heater Test (1 year heating of Opalinus clay)

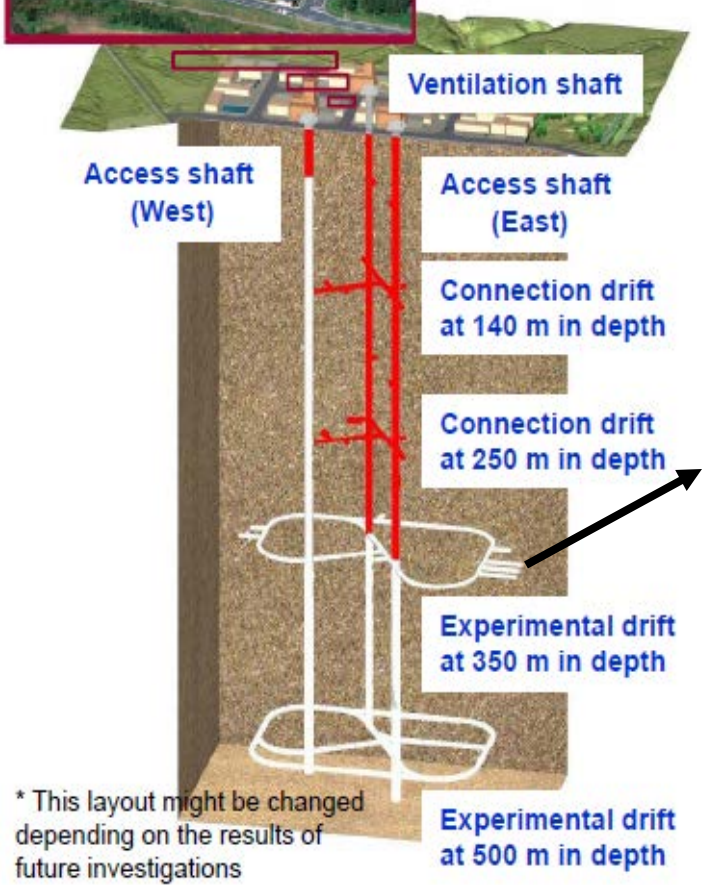
FE Heater Test (full-scale repository demonstration over 15-20 years of heating)

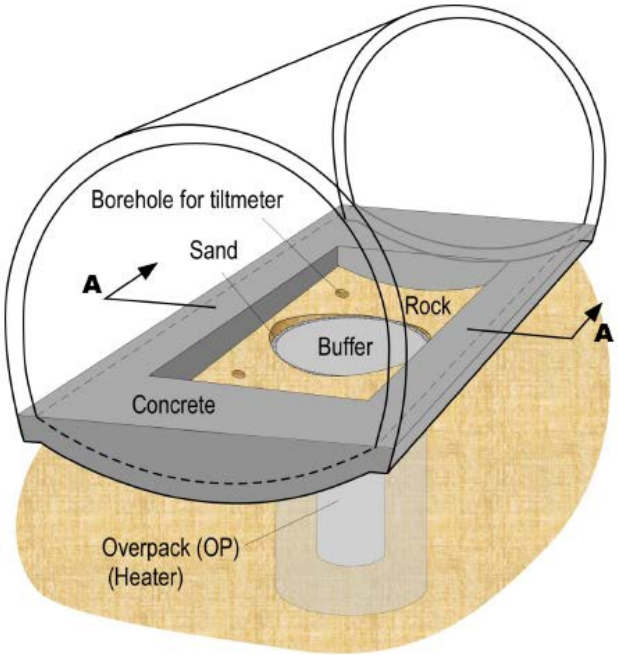
View of FE-tunnel showing Opalinus Clay beddings

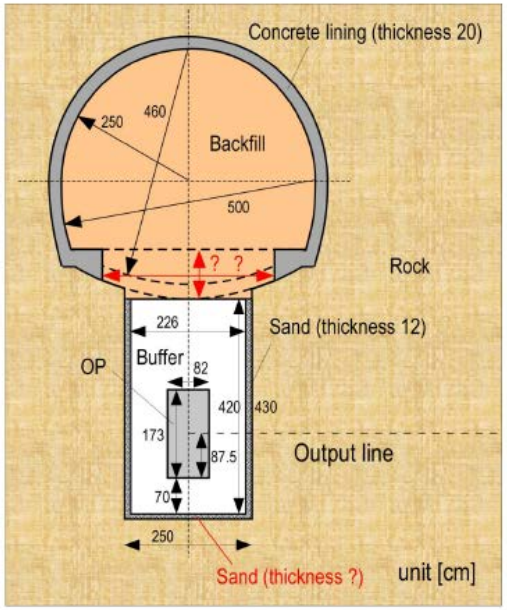
Model Validation Against Field Experiments

Horonobe (Japan) EBS experiment in siliceous mudstone

Vertical emplacement, tunnel backfill, buffer







A-A section

FY14 Plan and Beyond

DECOVALEX-2015 Project (DEvelopment of COupled models and their VALidation against EXperiments in nuclear waste isolation)

- **Task B1: Modeling the Mont Terri (Switzerland) HE-E Experiment in Opalinus Clay**
  - Step 1a: HE-D in situ heating of Opalinus Clay (completed November, 2013)
  - Step 1b: Bentonite laboratory THM experiments for processes understanding and parameter determination (completed, May 30, 2014)
  - Step 2: HE-E predictive modeling (May 2014 – Oct 2014).
  - Step 3: HE-E Interpretative modeling (Nov 2014 – April 2015).

- **Task B2: Modeling the Horonobe (Japan) EBS Experiment in siliceous mudstone**
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Mont Terri Project Full-Scale Emplacement (FE Experiment)

- **Benchmark modeling of experiment** with comparison to the results of international modeling teams (Completed, April 2014)
- **Model prediction and design of experiment** (Preliminary prediction complete, final results to be report before start of heating December 2014)

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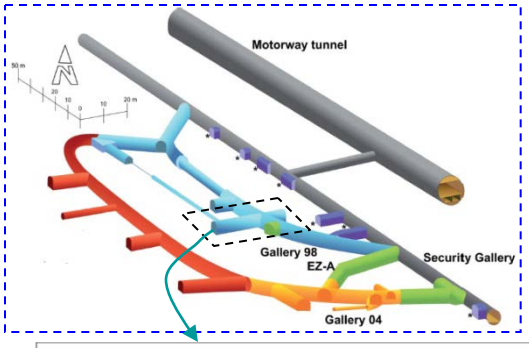
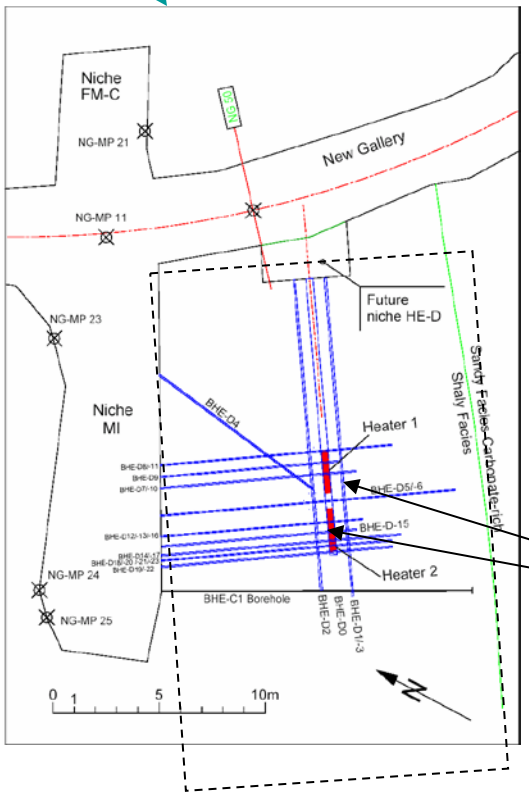
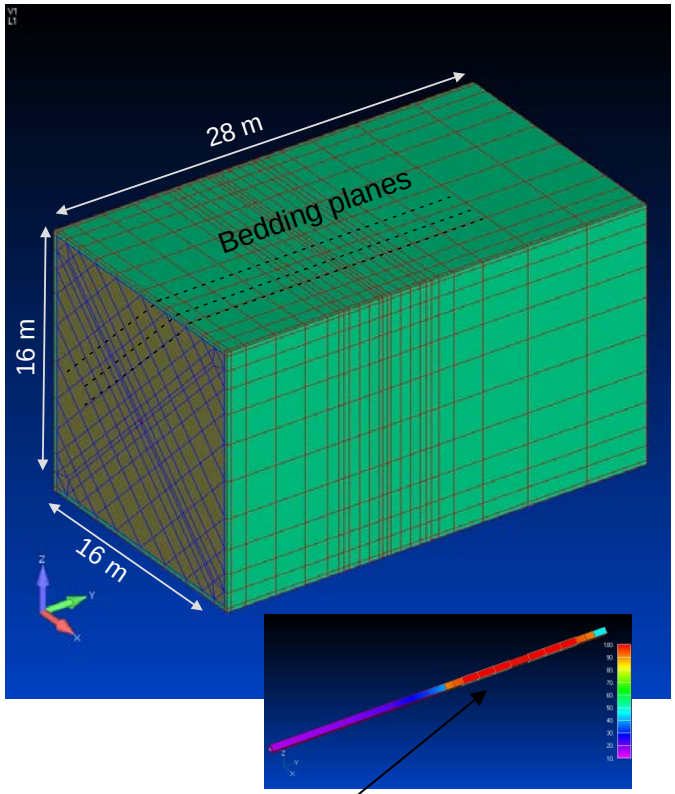
Mont Terri HE-D Experiment With In-Situ Heating of Opalinus Clay





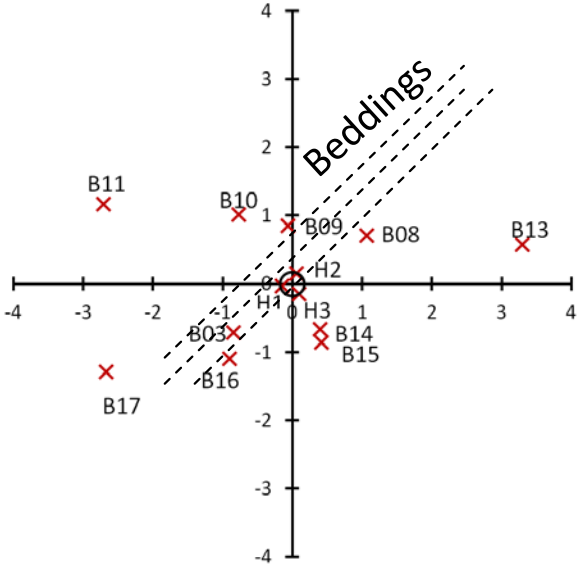
3D TOUGH-FLAC model



1 year heating of the Opalinus clay from a borehole

Comparison of modeled and observed

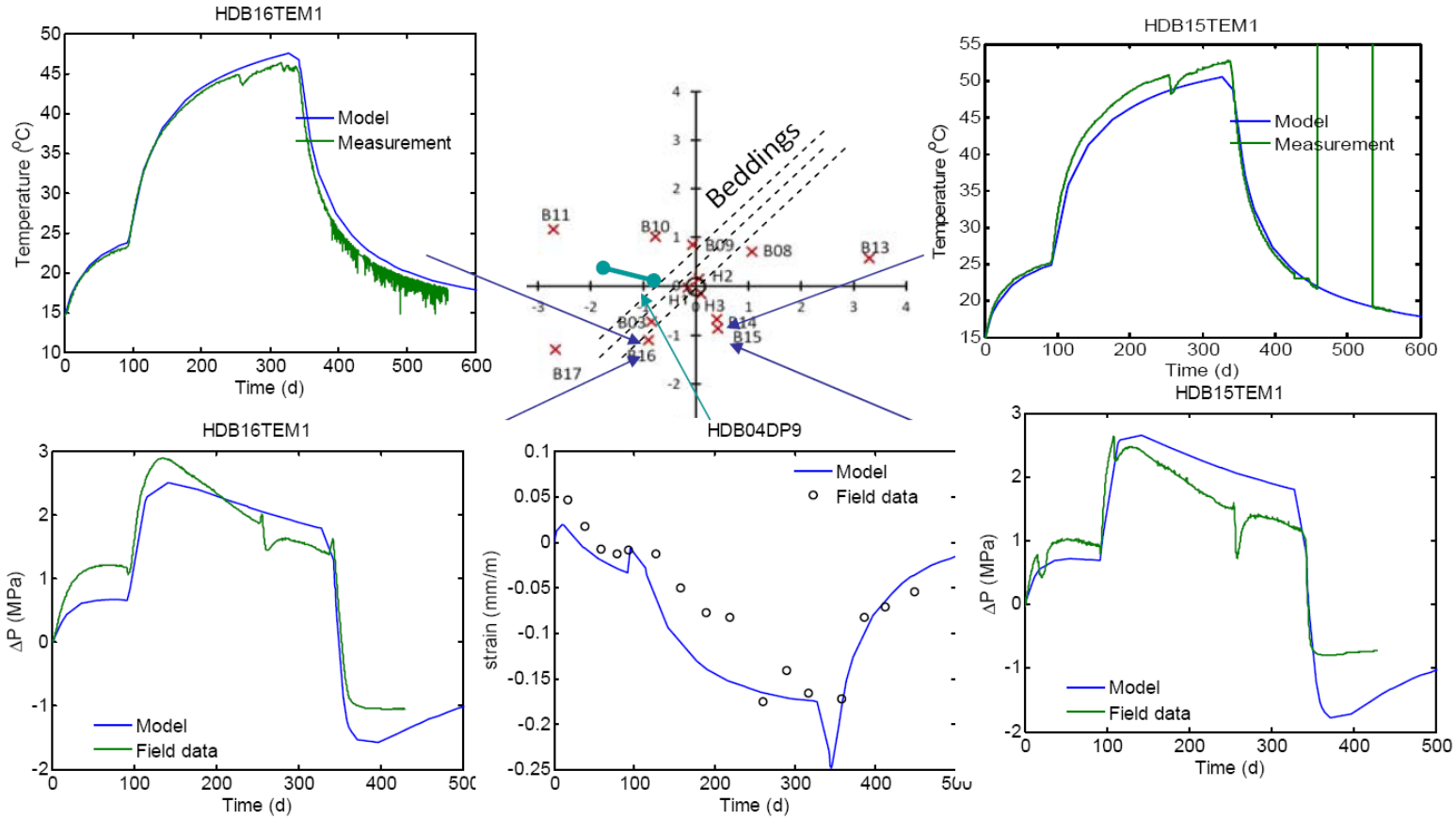
- *Temperature*
- *Pressure*
- *Mechanical strain*



HE-D also used for in situ characterization of anisotropic THM properties of Opalinus Clay

Mont Terri HE-D Experiment With In-Situ Heating of Opalinus Clay

Comparison of model results with in situ measurements

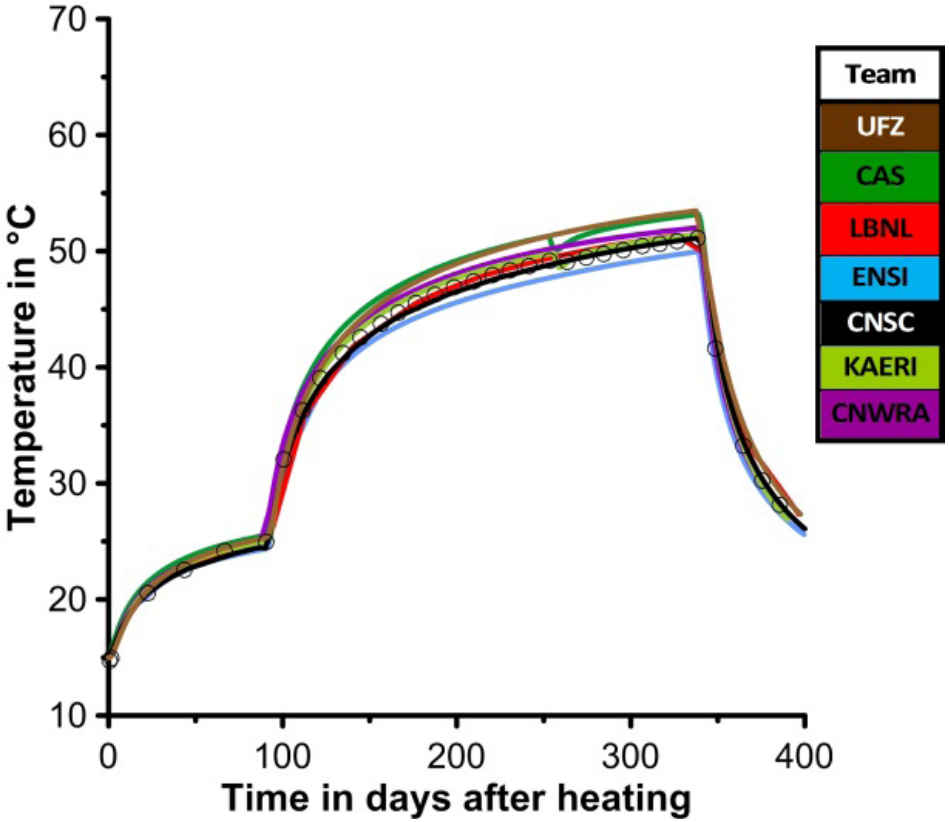


Back-calculated thermal conductivities of $K_{\parallel}$= 2.15 W/m-K and $K_{\perp}$ = 1.19 W/m-K ($K_{\parallel}/K_{\perp}$=1.8)
Permeability k = 5×10^{-20} m^2 and a pore-compressibility of 1×10^{-9} Pa^{-1} resulted in a good match between simulated and observed pressure evolution ⇒ in situ properties of Opalinus Clay

Mont Terri HE-D Experiment With In-Situ Heating of Opalinus Clay

Comparison of model results between international research teams in DECOVALEX:

Team	Principal Investigator	F.O.	Country	Code
UFZ	W. Wang	BGR	Germany	OpenGeoSys
CAS	P. Pan	CAS	China	EPCA3D
LBNL	J. Rutqvist	DOE	USA	TOUGH-FLAC
ENSI	B. Graupner	ENSI	Switzer-land	OpenGeoSys
	S.T. Nguyen	IRSN	Canada/ France	COMSOL
JAEA	S. Nakama	JAEA	Japan	THAMES
KAERI	C. Lee	KAERI	South Korea	FLAC3D
CNWRA	C. Manepally	NRC	USA	FLAC-xFlo



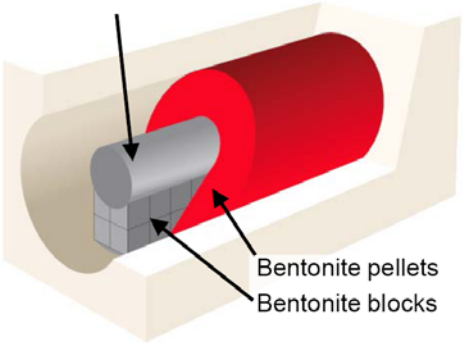
The results of DECOVALEX modeling of Mont Terri HE-D Experiment will be summarized in a joint international journal article by the end of 2014

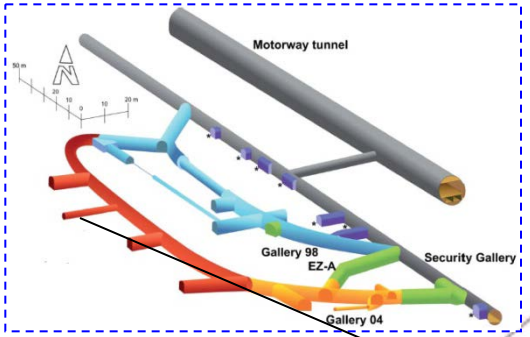
Model Predictions of the Mont Terri FE Experiment

Mont Terri Full-scale Emplacement (FE) Experiment is undertaken by NAGRA and other partners as an ultimate test for the performance of geologic disposal in Opalinus Clay, with focus on both the **EBS components and the host-rock behavior**; it will be one of the largest and longest running heater tests worldwide.

NAGRA's HLW emplacement concept

in 'reality': Canister
for FE: Heater

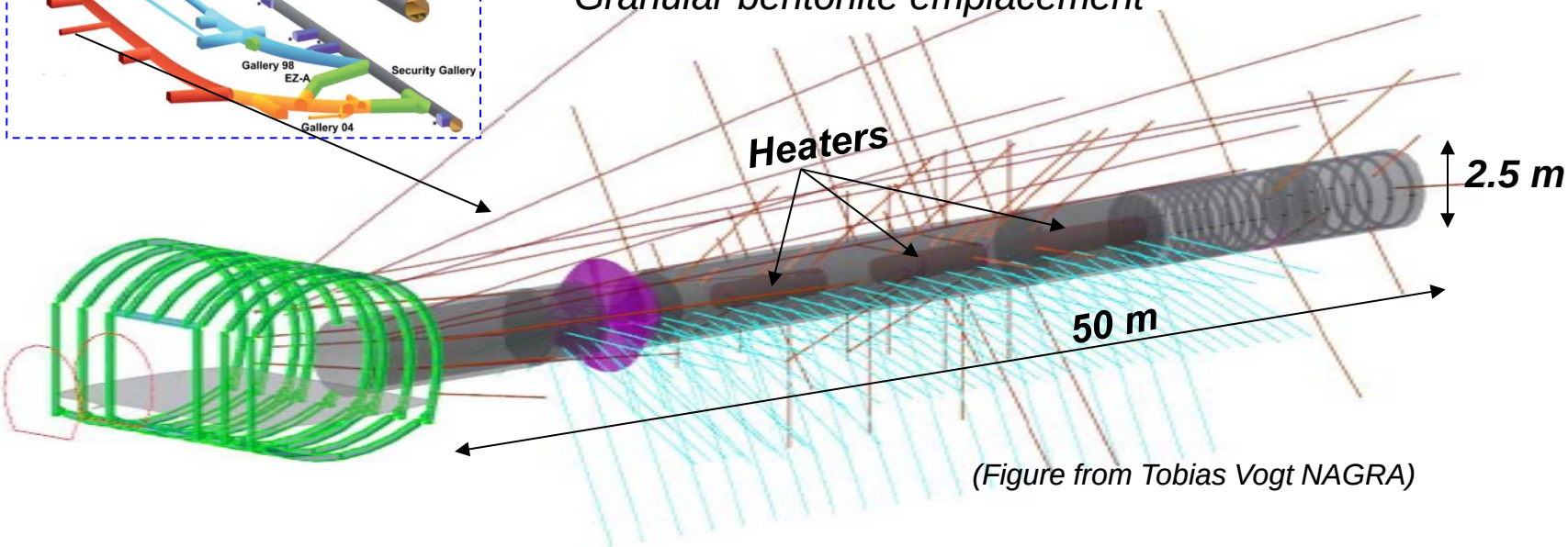




Full-scale

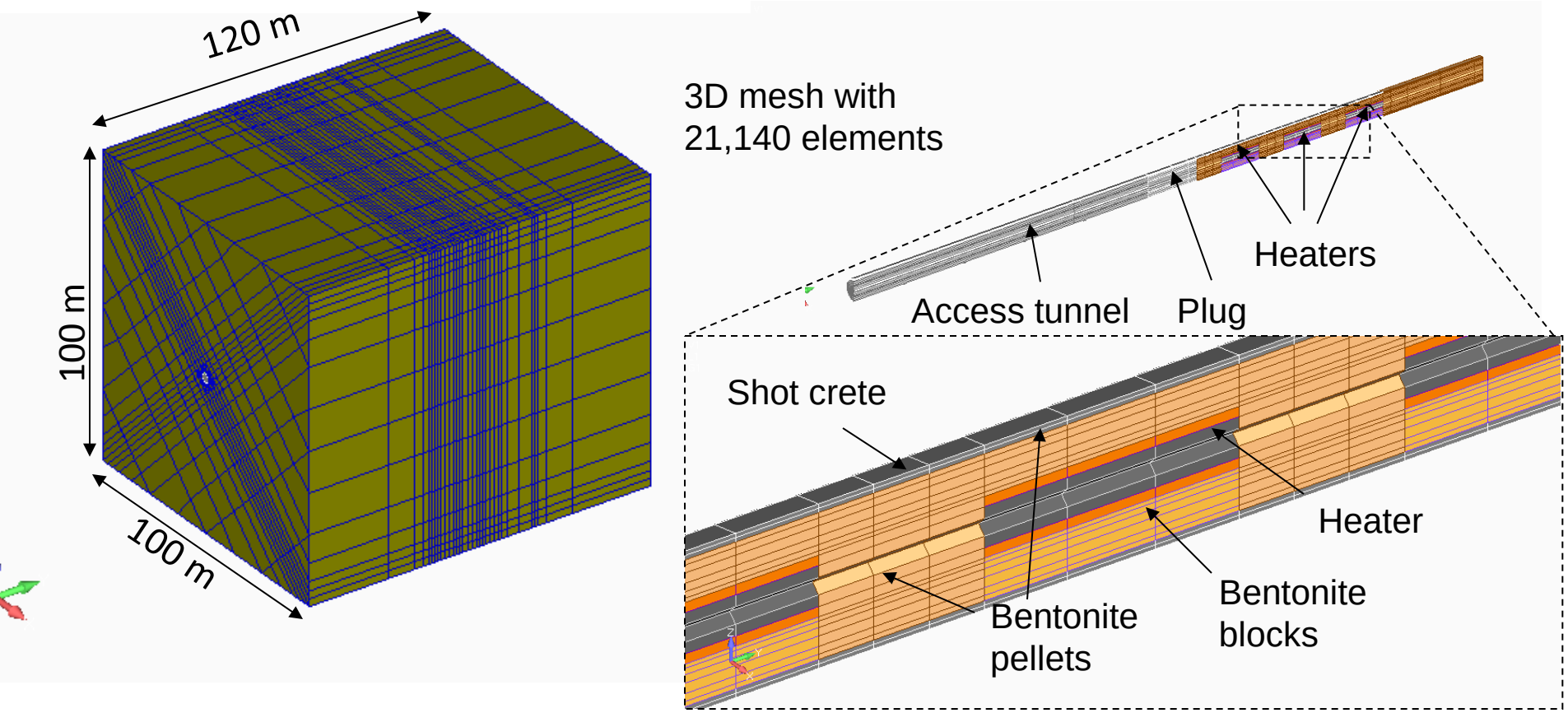
15-20 years of heating

Granular bentonite emplacement



(Figure from Tobias Vogt NAGRA)

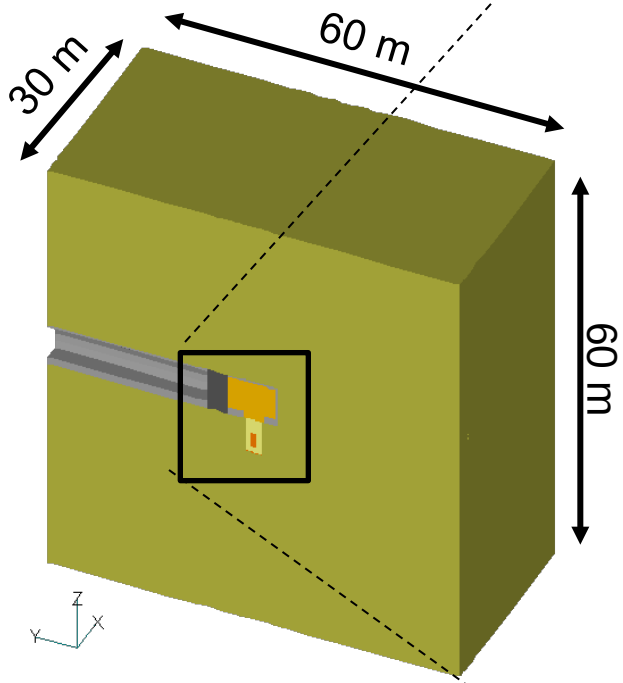
Model Predictions of the Mont Terri FE Experiment

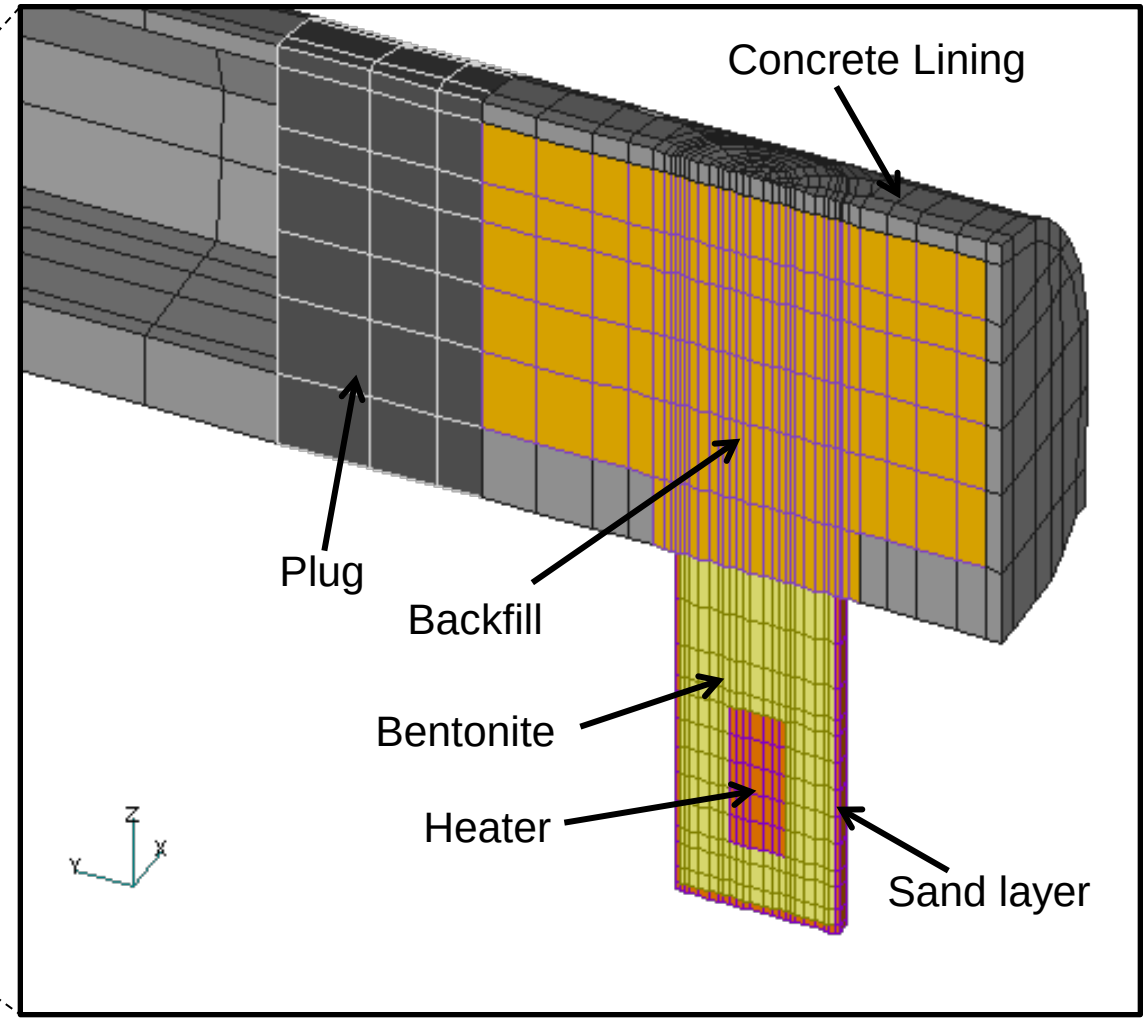


- Current temperature predictions for 1500 W up to 160°C peak temperature
- Heating to start end of this year
- Will ramp up heat power in one heater 500, 1000, 1500 W and use modeling to calibrate and predict peak temperature (should be below 150 °C)

Horonobe EBS experiment predictive analysis

3D TOUGH-FLAC model grid

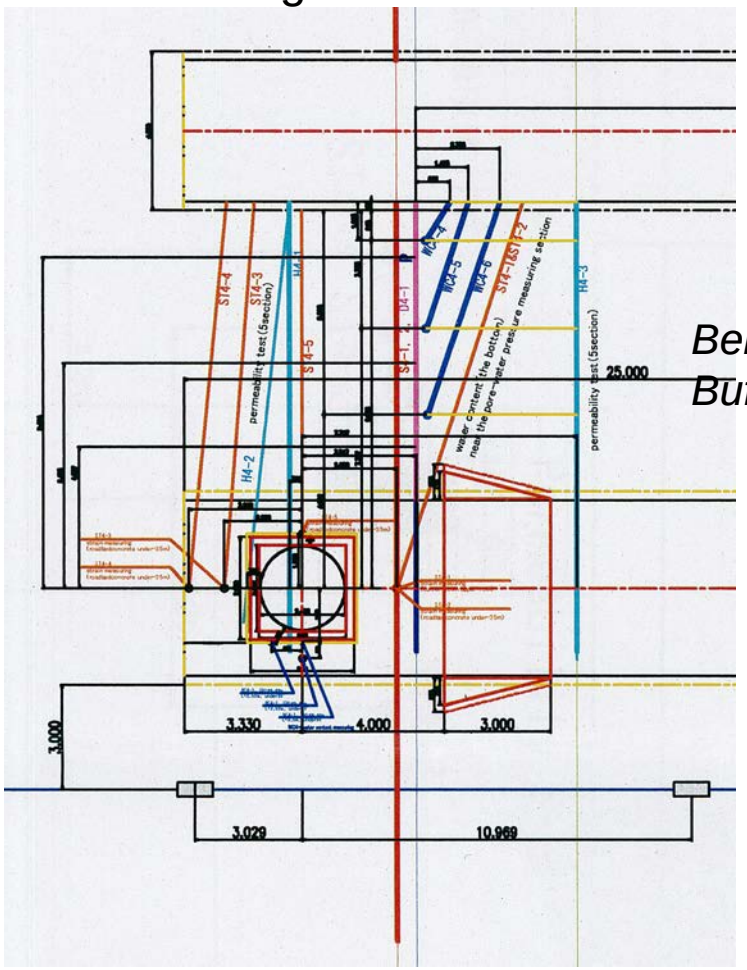




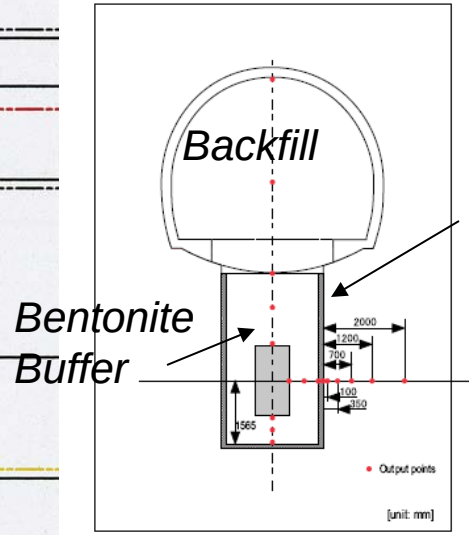
Step 2: Horonobe EBS predictive analysis (Jan 2014 – Oct 2014).

Horonobe EBS experiment predictive analysis

Plane view of tunnels and monitoring boreholes

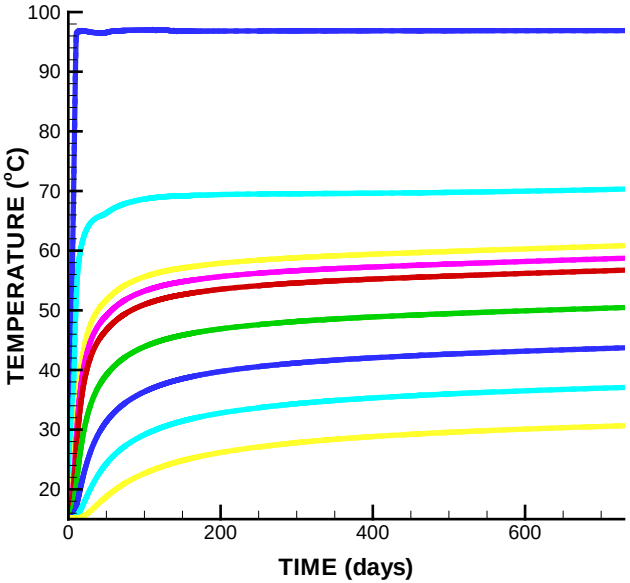


Monitoring points in backfill and near field



Cross section
(test pit)

Calculated temperature in 3D TOUGH-FLAC model



- *Important backfill and buffer interaction*
- *Backfill (In tunnel) higher permeability and lower water retention*
- *Buffer can be saturated from the backfill if not from the rock*

Next Steps

- Complete model prediction for Horonobe EBS Experiment (ongoing)
- 3D mesh and “model prediction” for HE-E Experiment (the field experiment is already ongoing)
- Participate in FE heater test design of heat load and make (final) model prediction for FE Heater Experiment (Already have 3D model and made preliminary predictions)

- Review of properties used for various types of bentonite-buffer materials in these experiments
- Apply the Barcelona Basic Model for bentonite in modeling all these experiments
- Apply the dual-structure model (Barcelona Expansive Model); will greatly benefit from collaboration with other research teams within DECOVALEX and Mont Terri FE modeling group