HLW cell full scale demonstration test in Bure URL: method of realization and behaviour characterization

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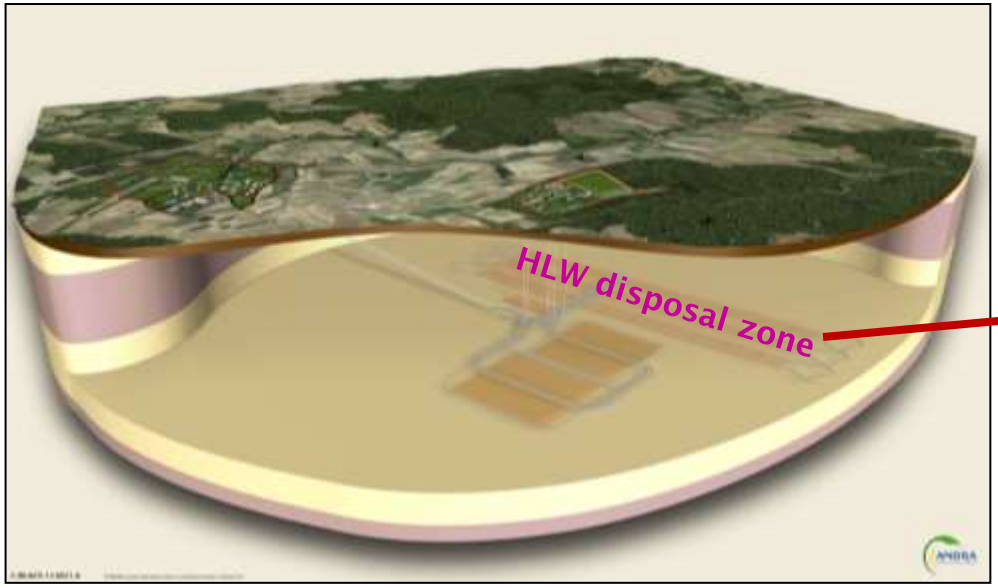
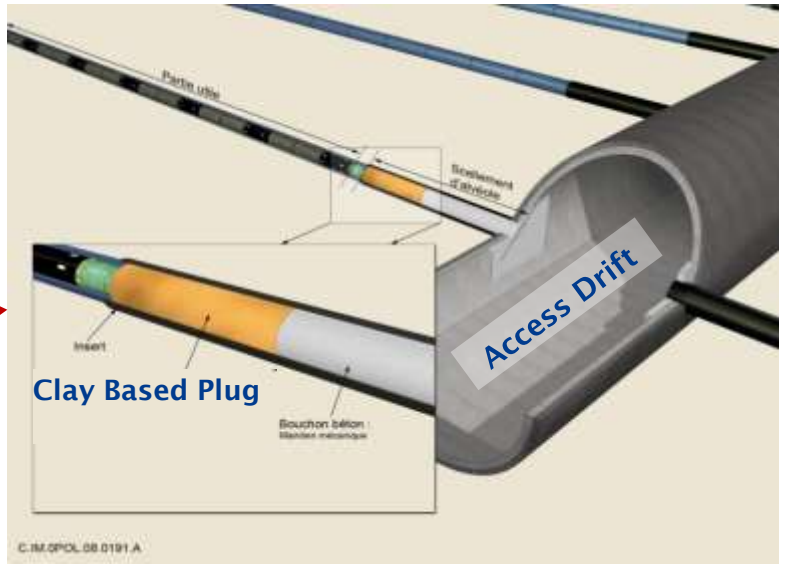
2009 Concept of disposal cells for long life and High Level activity Wastes (HLW)





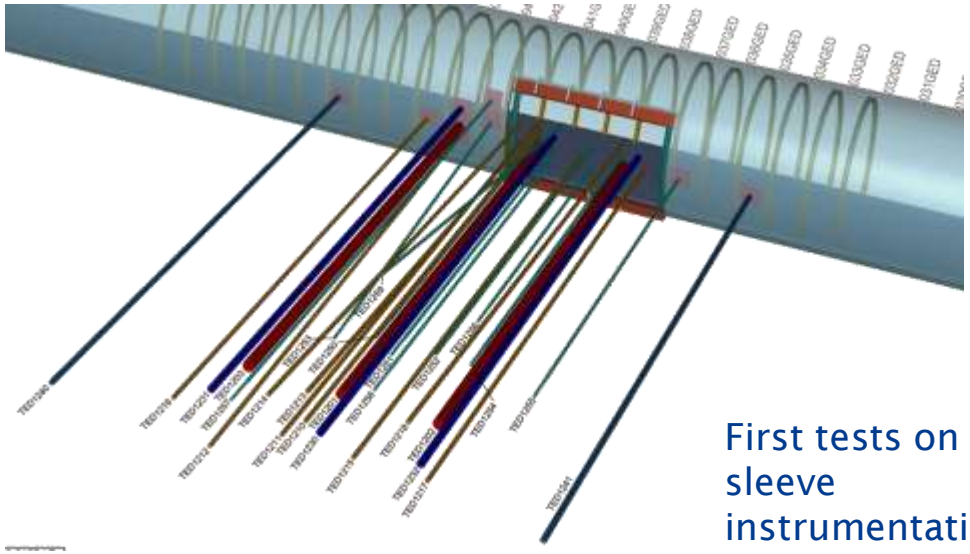
- Horizontal micro-tunnels (∅ ≈ 0,7 m ; length ≥ 80 m) cased with a steel sleeve
  - 10 m long head part used for cell closure
  - Useful part containing the waste packages
- Steel grade of the sleeve: non-alloy steel
  - API5LX65MS : Petroleum steel (« sour service », σy ≥ 450 MPa)

Waste package

Former experiments

Small scale THM experiments

TED: small scale reproduction of 3 cells

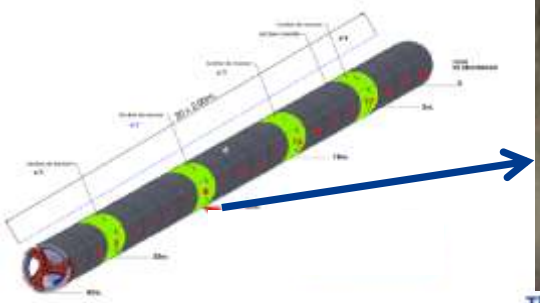


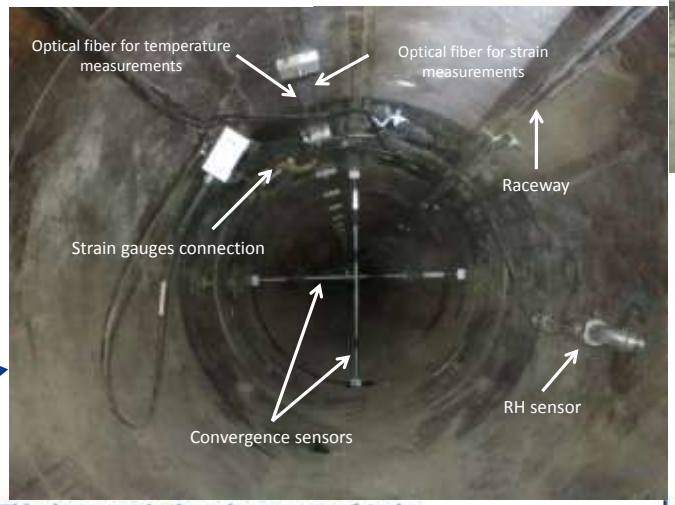
First tests on sleeve instrumentation

Thermal anisotropy

Coupling effects (pore pressure)

Numerical simulations





Full scale HLW cell demonstrators

Definition and perfecting of excavation tool and method.
First data on micro-tunnel and surrounding rock HM behavior

Anisotropic mechanical behavior in relation with damaged zone around the cell

Main objectives of the test

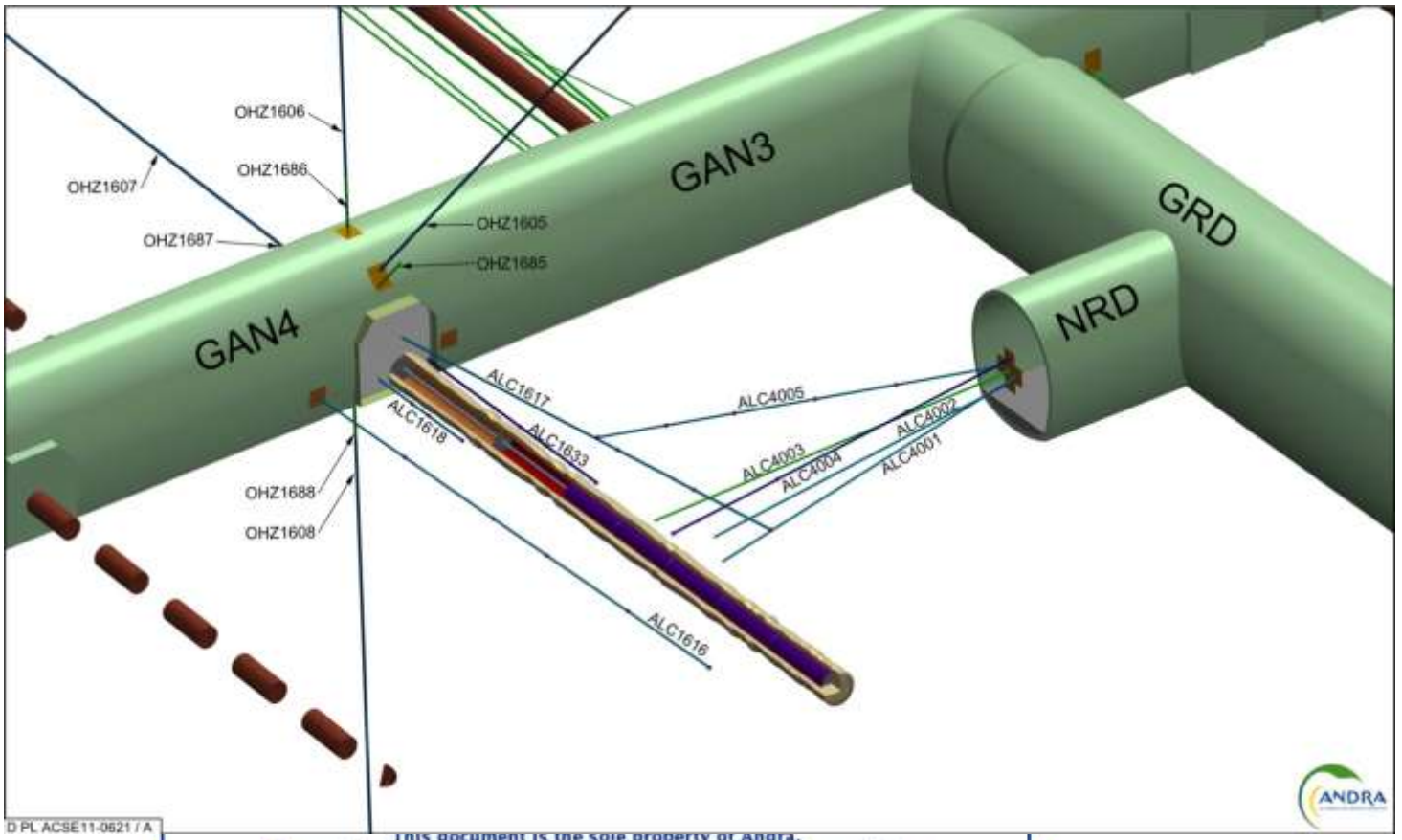
- Test the construction feasibility of a HLW cell representative of the 2009 benchmark concept (head & useful part),
- Study the behaviour of the cell under thermal loading by simulating the heat produced by waste packages
- Verify the ability of the head insert to absorb the thermal dilation of the sleeve in the useful part (to limit axial loading on the drift wall)
- Provide data on the sleeve behaviour under thermal loading,
- Study the THM behaviour of the interface between rock and sleeve, and of the surrounding rock (not included in LUCOEX).

Demonstration cell characteristics

25 m long micro tunnel parallel to σ_H

- Head part excavated 791 mm Ø, steel insert 767 mm $Ø_{out}$, length 6 m
- Body part excavated 750 mm Ø, steel sleeve 700 mm $Ø_{out}$, length 19 m
- Base plate, shield plug and insert cover plate

Heating carried out between 10 and 25 m depth, up to 90°



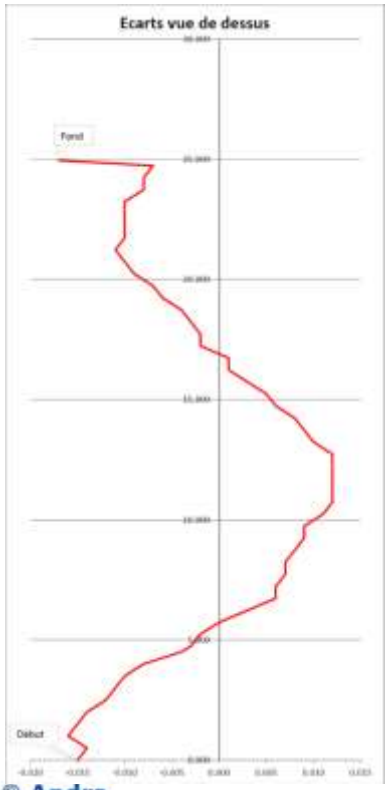
Cell excavation (CSM Bessac)

Excavation from 23rd to 31st October 2012.

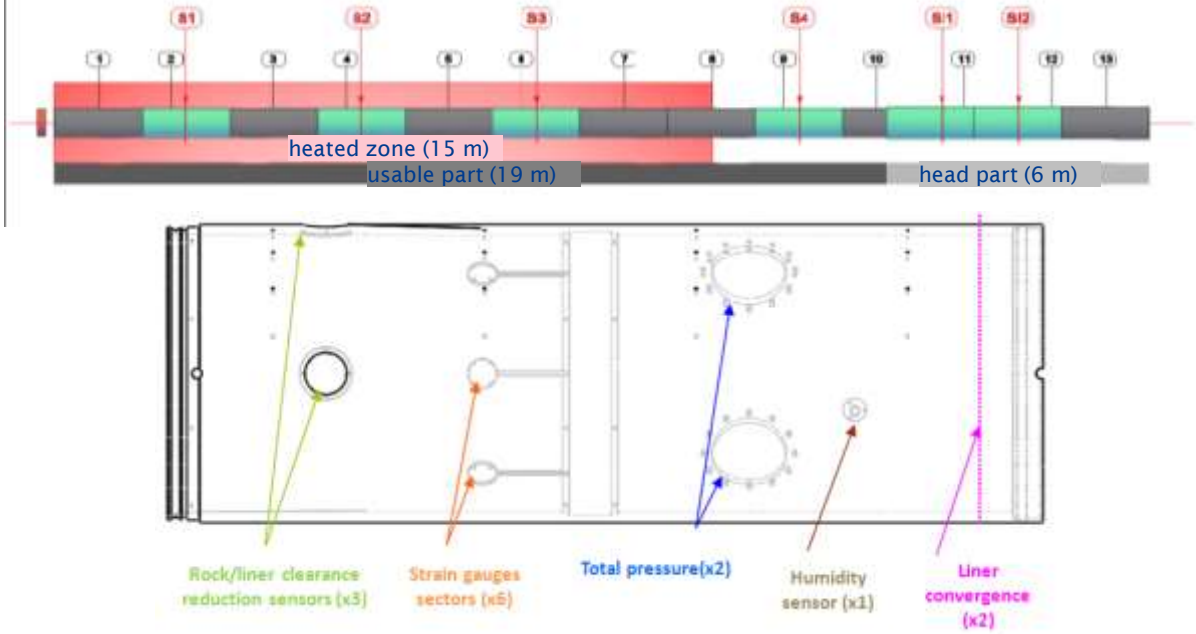
Small deviation to theoretical trajectory:

- 3 cm in horizontal plane
- 8 cm in vertical plane

Base steel plate



Cell instrumentation and equipment



sleeve and insert instrumentation (Egis Géotechnique)

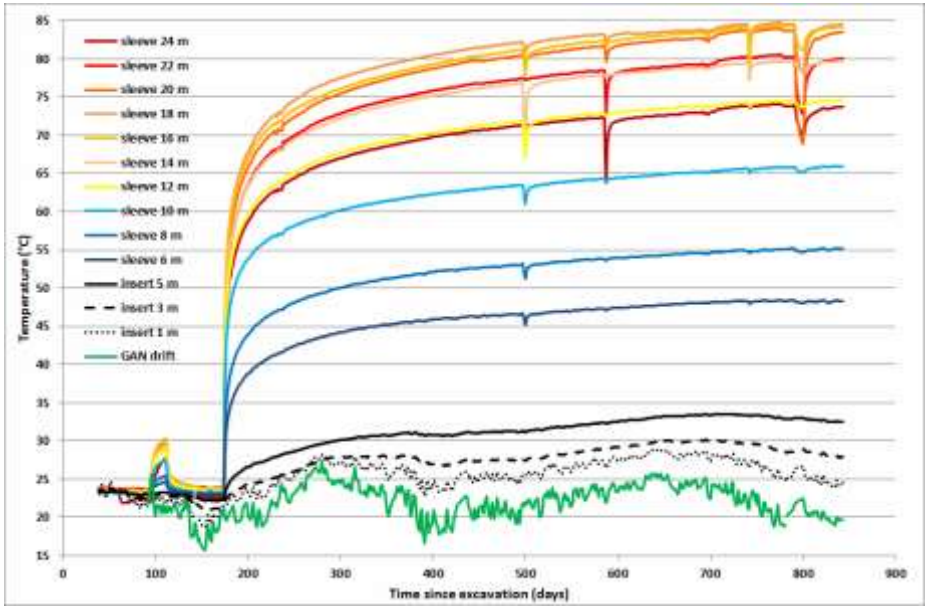
Heaters: 5 elements
3 m long – 50 cm ø
(Aitemin)

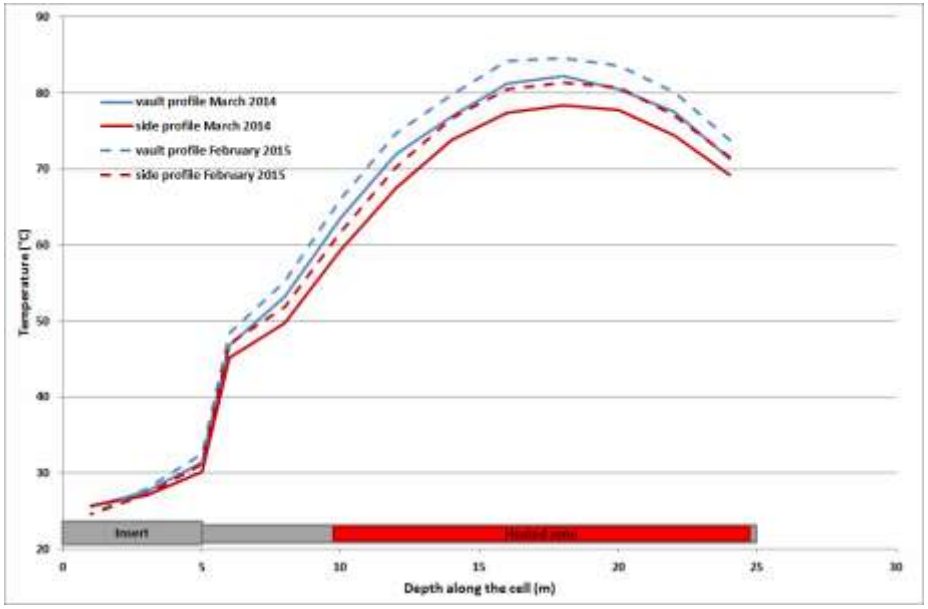
Heating phase

Heating test at very low power (33 W/m) from 31st January to 15th February 2013

Main heating phase at 220 W/m started on18th April 2013

- 90°C in 2 years on the sleeve





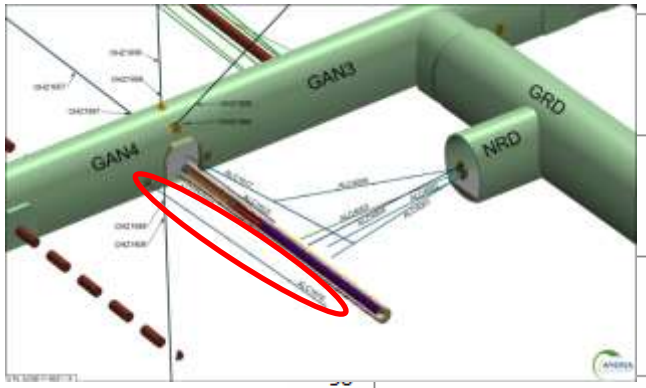
T° profile at the vault about 4°C > T° profile on the side

- convection and influence of boundary conditions

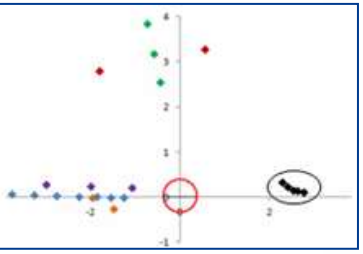
T° profile centered on 18 m depth (center of the heated zone)

THM impact on the surrounding rock – Pore pressure evolution

Measuring points between 1.9 and 2.3 m from cell wall and 10 to 22 m depth from access drift

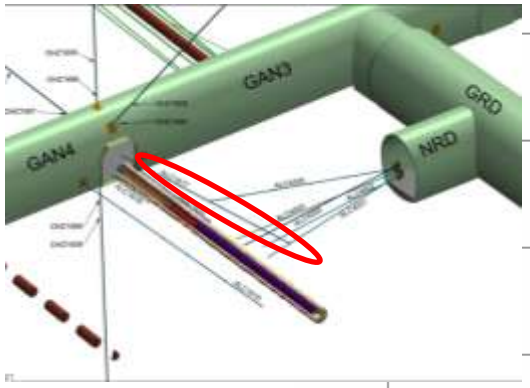


Horizontal plane

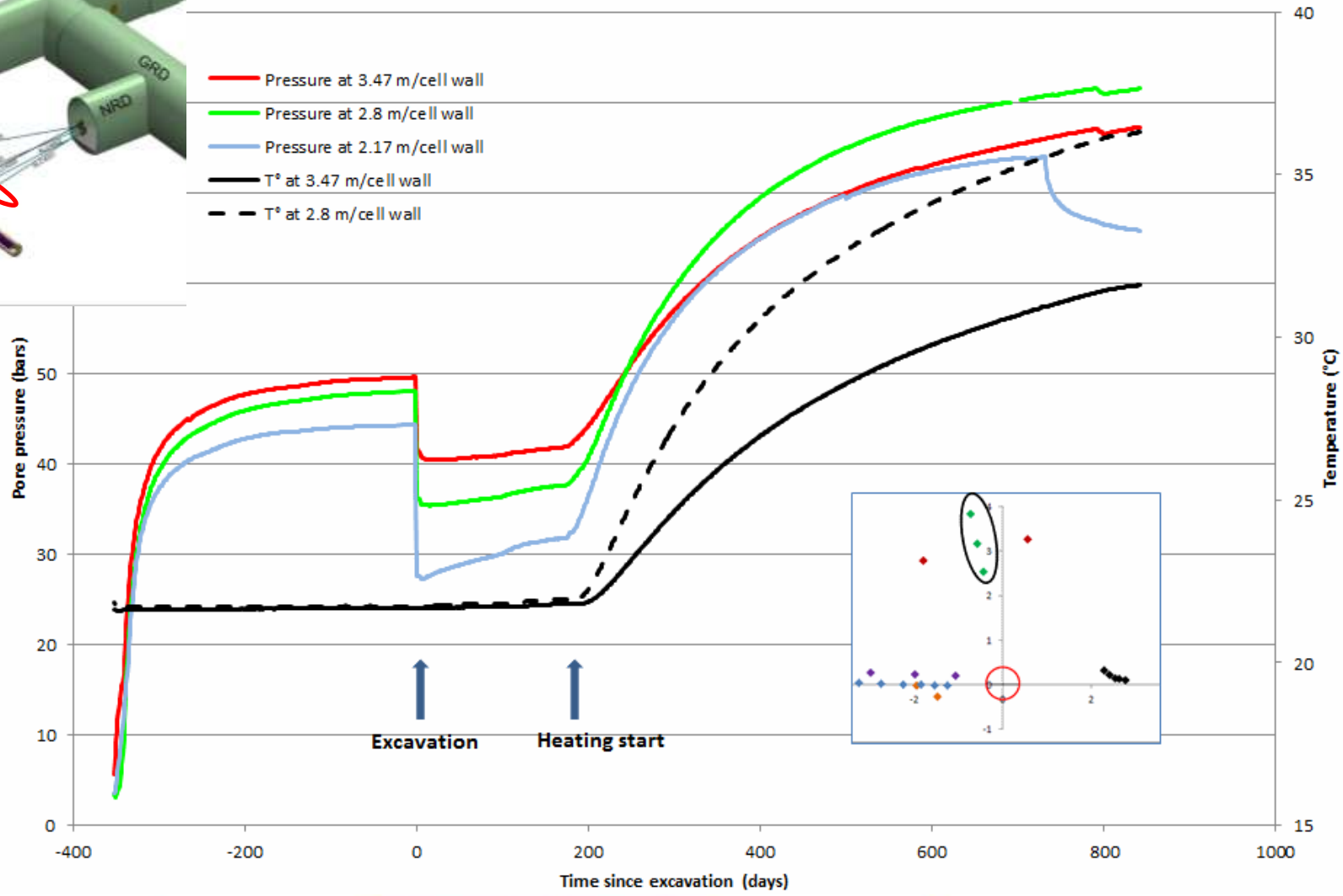


THM impact on the surrounding rock – Pore pressure evolution

Measuring points between 2.2 and 3.5 m from cell wall and 13 to 22 m depth from access drift

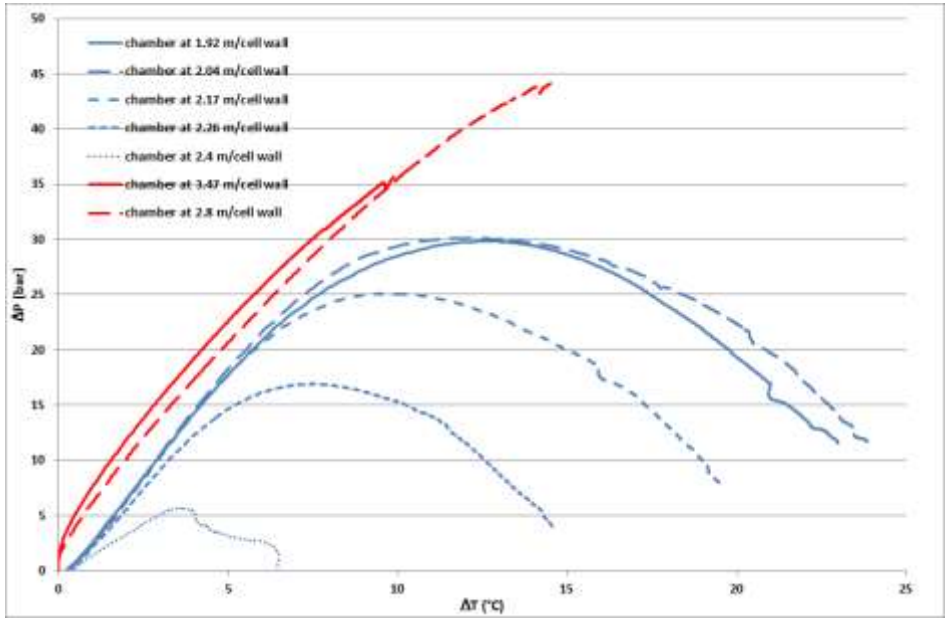


Vertical plane

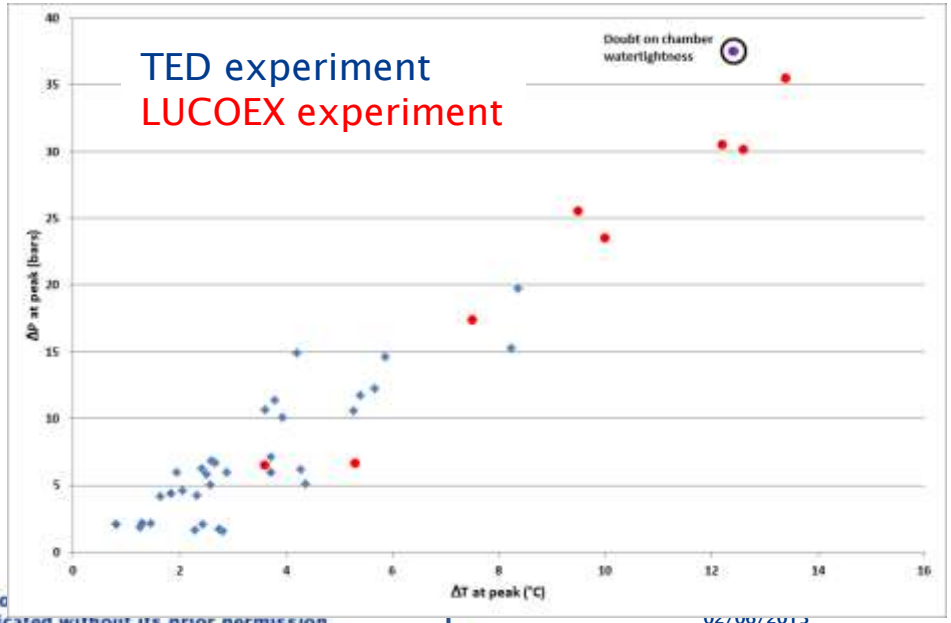


THM impact on the surrounding rock – Pore pressure evolution

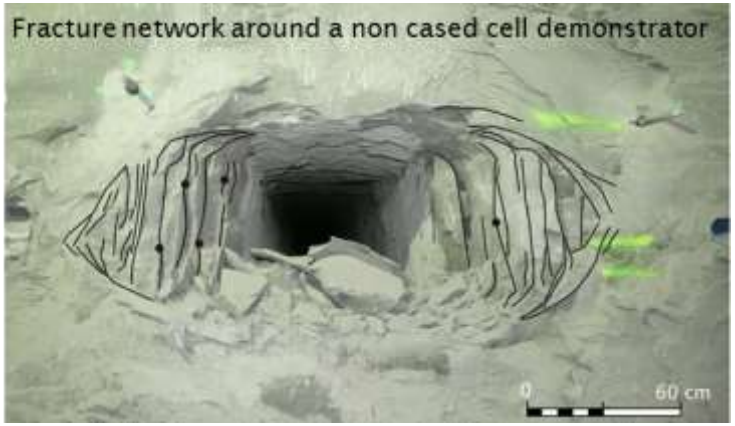
- ✓ At a given distance from the cell wall, thermal induced overpressure peak is reached later in the vertical plane (relative to horizontal plane)
- ✓ Pressurization coefficient between 3 and 5 bar/°C

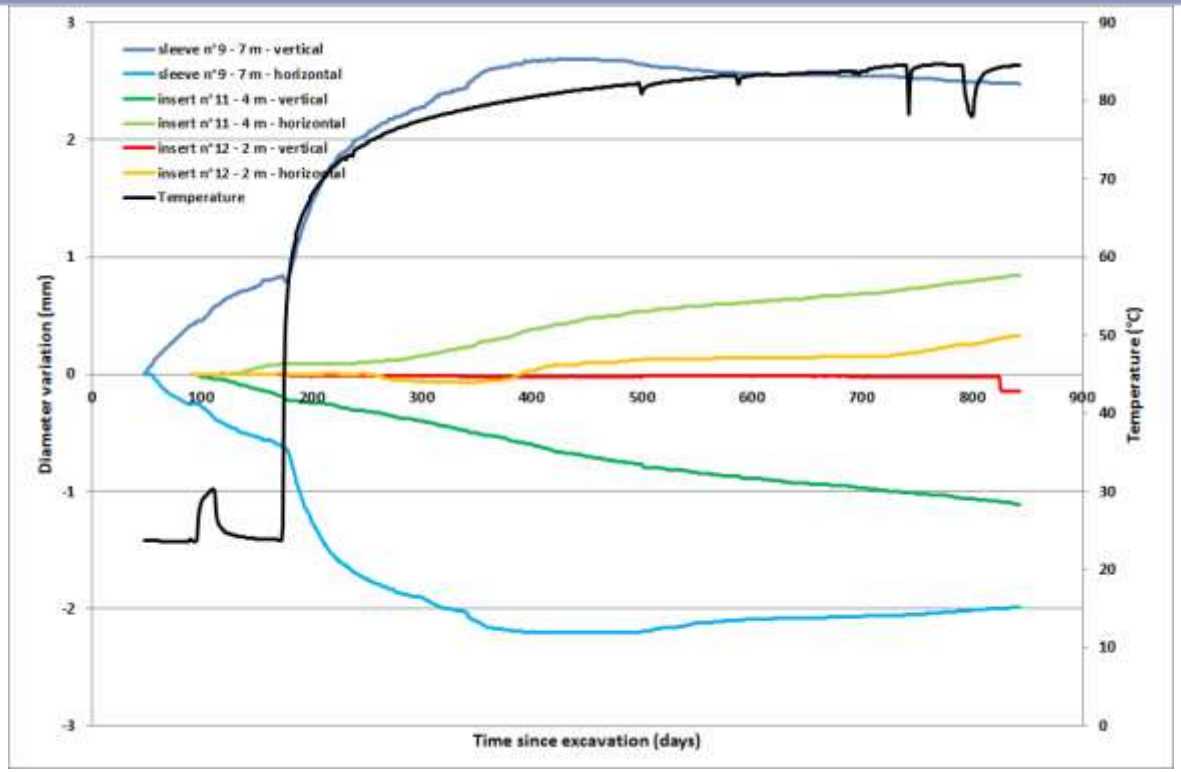


$\Delta P_{peak}/\Delta T_{peak}$ correlation consistent with small scale THM experiment



Sleeve thermomechanical loading - convergence





Before heating

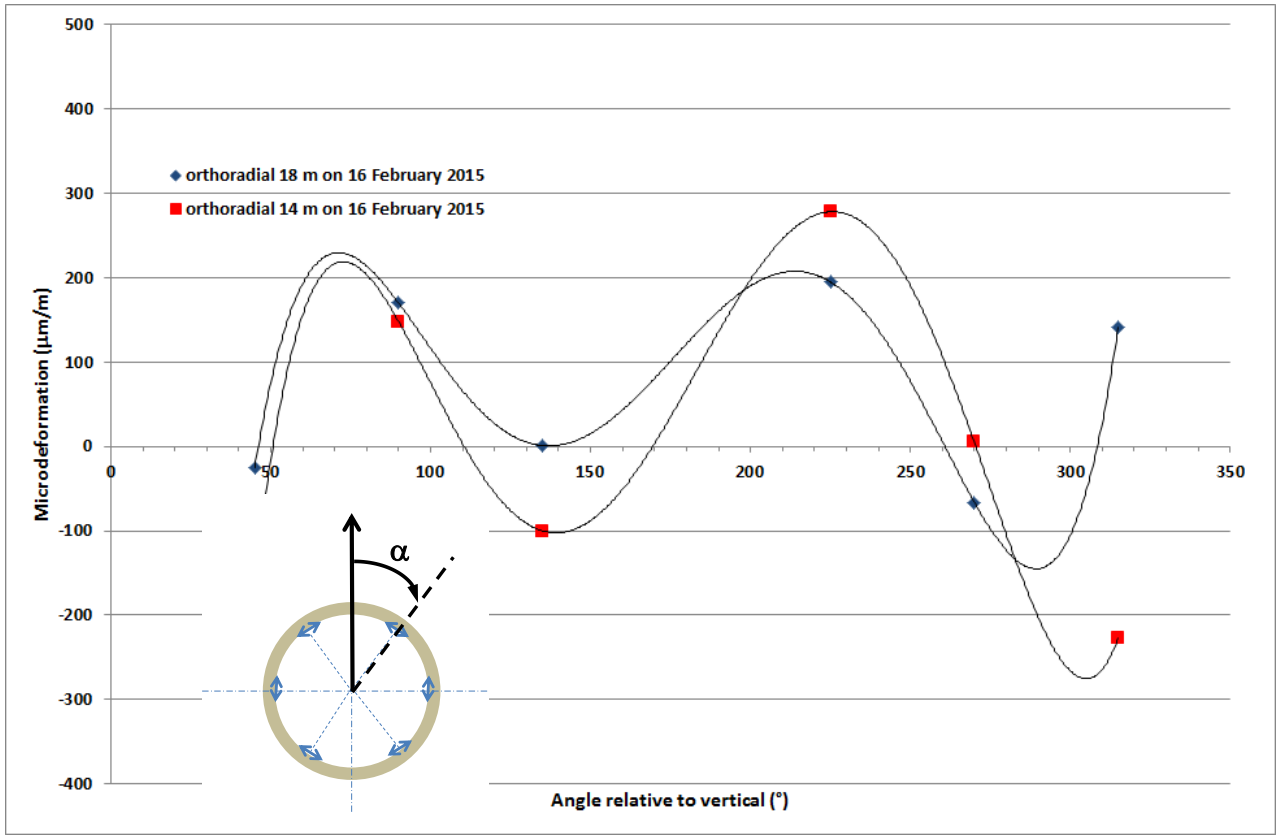
- Convergence of the sleeve in the horizontal direction (corresponding to the maximum extension of the damaged zone)
- Sleeve deformation is observed as soon as the sensors are connected (contact between rock and sleeve through excavation rubble)

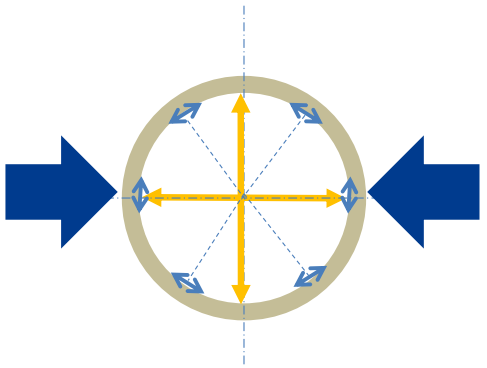
Impact of a thermal load

- Increase of deformation rate until contact with the vault
- Decrease of sleeve ovalization after 400 days due to a decrease of loading anisotropy

Opposite behaviour of the insert (lower initial annular space, circumferential variation of rock strength)

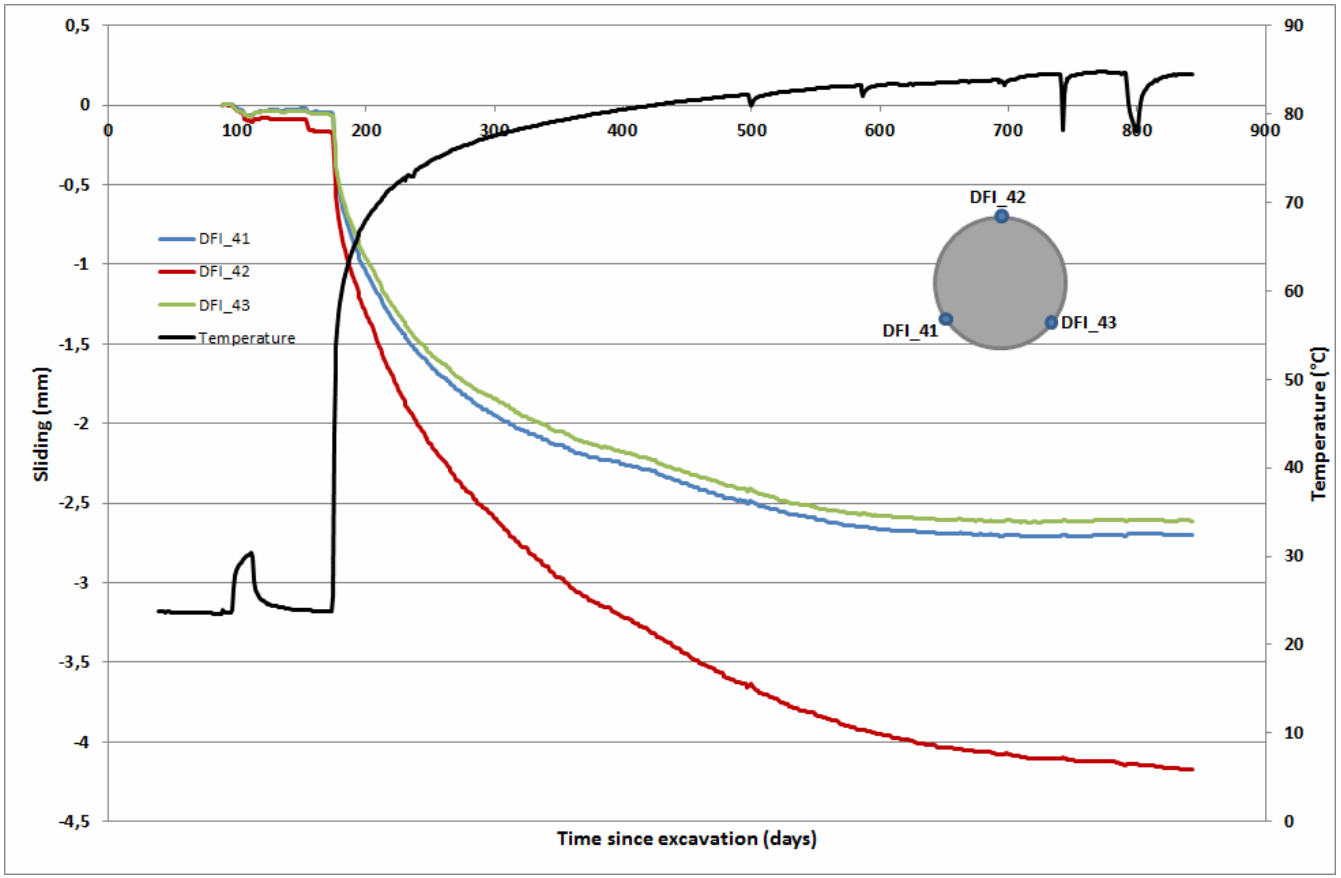
Sleeve thermomechanical loading – mechanical signature





- Representative of a mainly horizontal loading (consistent with convergence measurements)
- Axial local strains remain less than 150 µm/m: no significant compressive effect due to the heating

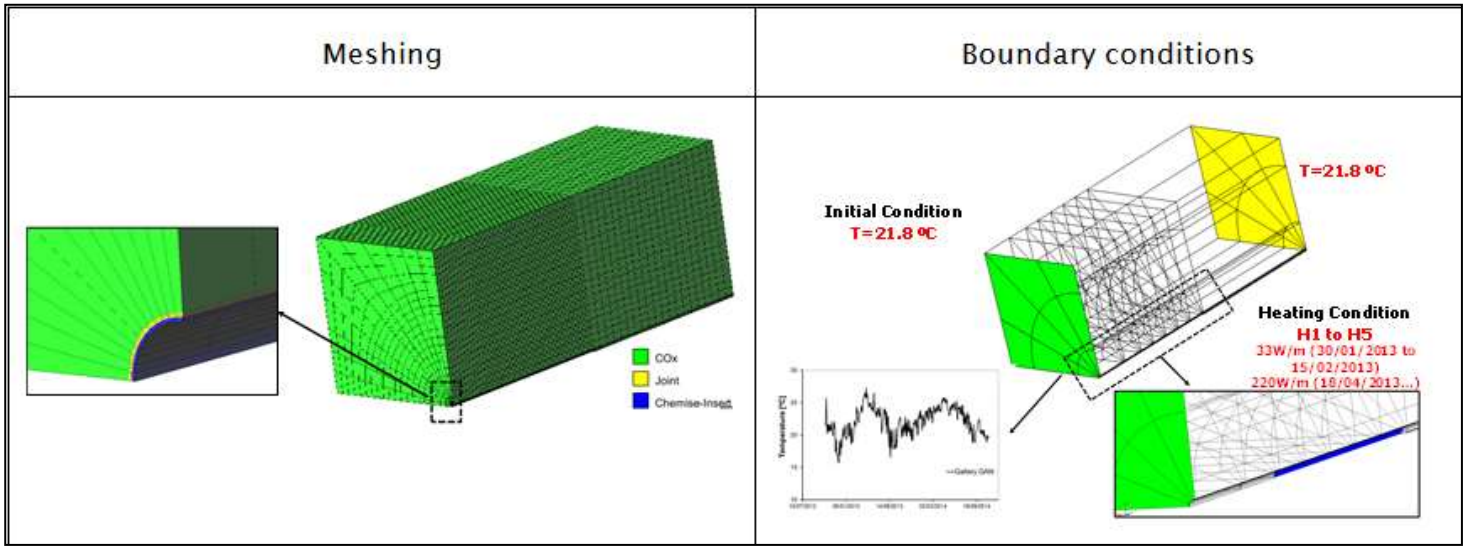
Sleeve sliding inside the insert



- Maximum sliding = 4 mm, for a theoretical free thermal dilation of about 10 mm (homogeneous temperature over the heated zone)
  - dilation also towards cell's end and influence of cell wall convergence

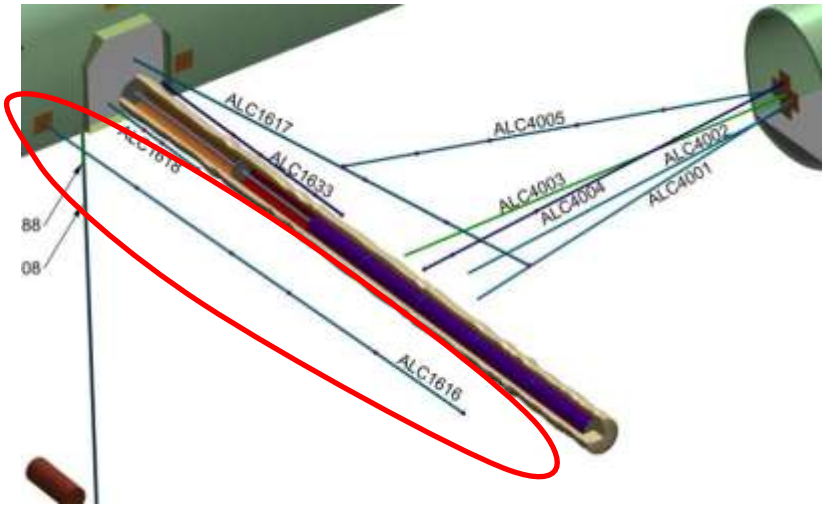
Numerical simulations

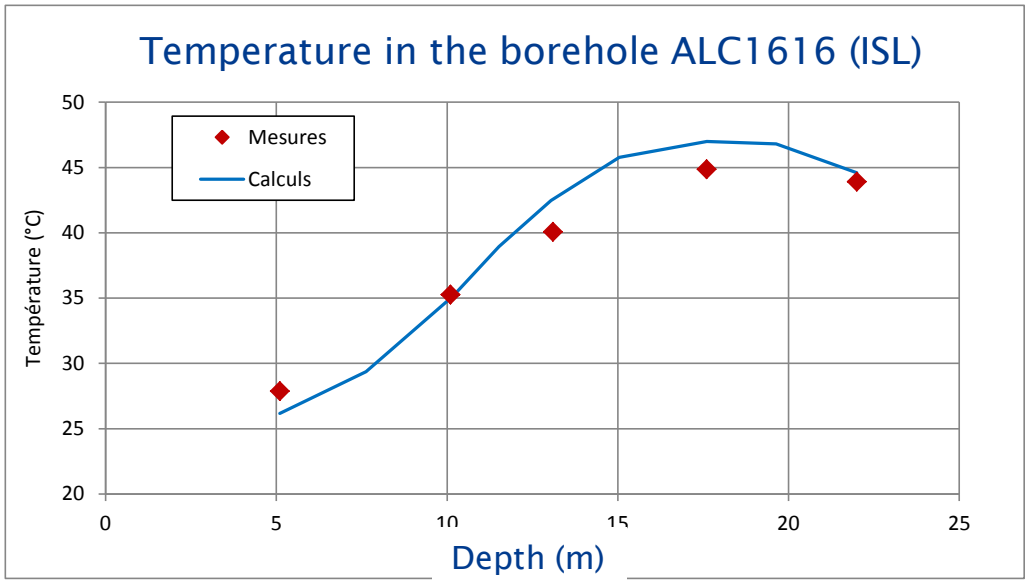
- Objective: help to identify the main mechanisms involved in the evolution of the THM behaviour of the cell
  - ISL Ingénierie (french engineering company)
  - UPC (Polytechnic University of Catalonia)
- Conceptual models
  - Multiple-phase approach, hydromechanical coupling (Biot model)
  - Thermal parameters are identical as those used in TED experiment



3D thermal model (UPC)

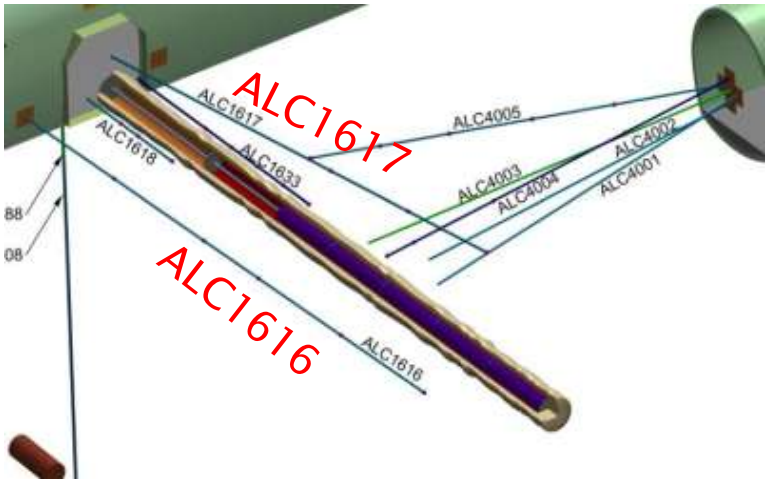
Numerical simulations – Thermal calculations (ISL & UPC)



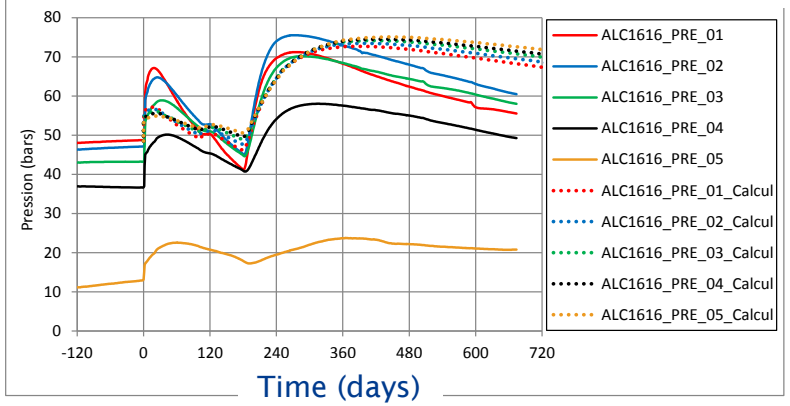


- Overestimation of the near-field rock temperature in the heated zone and underestimation in the cell head (ISL & UPC)
  - No impact on the overall interpretation of the experimental results
  - Improve the description of the numerical models (boundary conditions in the access drift, rock rubble in the annular space, thermal conductivity degradation in the damaged zone, …)

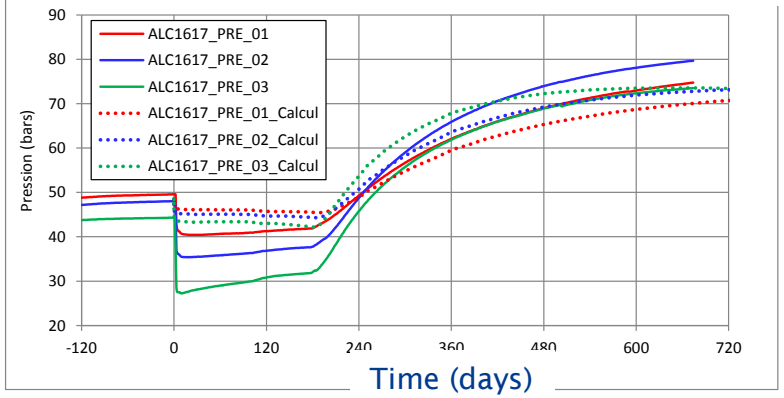
Numerical simulations – THM calculations (ISL)



Pore pressure in borehole ALC1616 (horizontal plane)



Pore pressure in borehole ALC1617 (vertical plane)



- Good qualitative reproduction of the phenomena (ISL)
  - Pore pressure variation due to cell excavation is considerably underestimated (not an objective of this work)
  - Time to reach the peak in the horizontal plane is overestimated
  - Work in progress : calibration of main HM coupling parameters (α_m, M)

Conclusions

A HLW cell representative of 2009 concept has been successfully excavated and instrumented

THM impact of the heating on surrounding rock is consistent with small scale THM experiment

TM loading applied on the sleeve is mainly horizontal

- Convergence rate increases with heating
- Contact at the vault after 400 days followed by a decrease of loading anisotropy

Sleeve sliding inside the insert is limited

- Sliding also towards the cell's end and influence of cell wall convergence

First numerical simulations of near-field THM behaviour of the rock are encouraging