



PRACLAY 2025

CLOSING THE HEATING CHAPTER,
OPENING THE COOLING PHASE

sck cen



EURIDICE

NIRAS
ONDRAF

27th Exchange Meeting
TABLOO Dessel, 7th of November 2025

Welcome

Mieke De Craen

EURIDICE

07-11-2025
27th Exchange Meeting

Major Milestone for the Large-Scale *In Situ* PRACLAY Heater Test:

**Concluding the Heating Phase
Introducing the Cooling Phase**

13h30-13h40	Welcome	Mieke De Craen, Team manager of EURIDICE
13h40-14h20	The PRACLAY in situ Experiment: demonstrating geological disposal feasibility of heat-emitting waste in poorly indurated clays	Séverine Levasseur, Scientific Project Manager NIRAS/ONDRAF
14h20-15h00	Ten years of continuous monitoring of the heater test	Jan Verstricht, Project Engineer EURIDICE
15h00-15h30	<i>Coffee break</i>	
15h30-16h10	Observations during 10 years of heating	Temenuga Georgieva, Research Engineer EURIDICE
16h10-16h50	THM characterization of the Boom Clay: Feedback from the PRACLAY Heater test and preparation of the cooling phase	Arnaud Dizier, Research Project Leader EURIDICE
16h50-17h	Closing remarks and prospects	Maarten Van Geet, director of EURIDICE
17h-18h	<i>Drink</i>	



PRACLAY 2025

CLOSING THE HEATING CHAPTER,
OPENING THE COOLING PHASE

sck cen



EURIDICE

NIRAS
ONDRAF

27th Exchange Meeting
TABLOO Dessel, 7th of November 2025

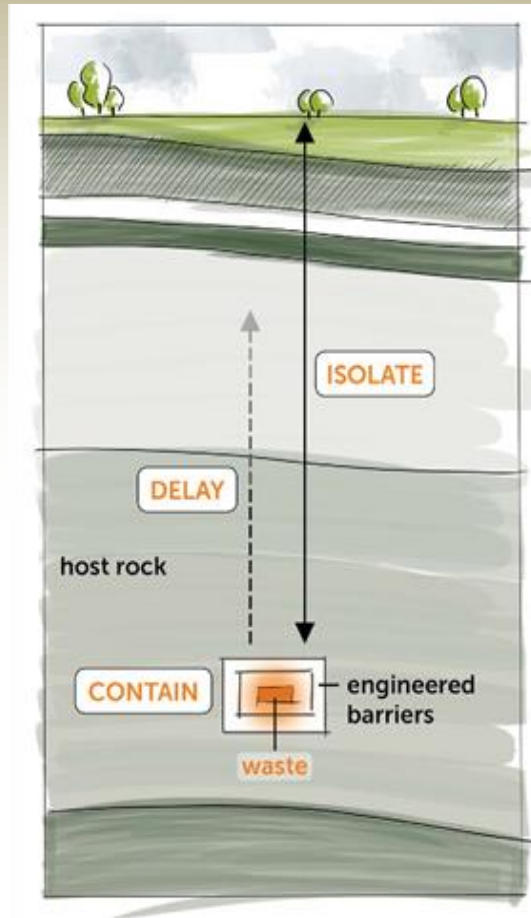
The PRACLAY in situ Experiment

*Demonstrating geological disposal feasibility of heat-emitting waste in
poorly indurated clays*

S. Levasseur, X. Sillen, M. Van Geet
A. Dizier, T. Georgieva, J. Verstricht, M. De Craen

NIRAS/ONDRAF & EURIDICE

Geological disposal as an option for the long-term management of LL-ILW and HLW (B&C) waste

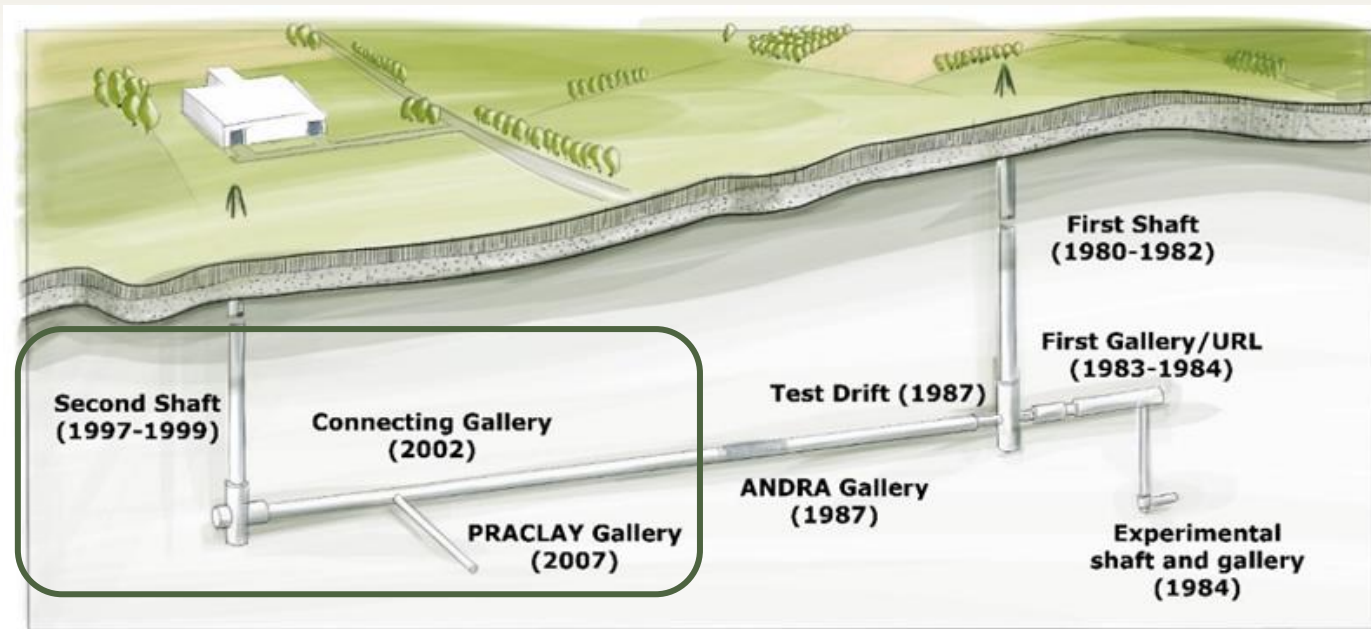


- **Current concept (generic)**
 - in poorly indurated clays (about 50 years of research on Boom Clay)
 - reference depth between 200 and 600 m
- **Multi-barrier system**
- Heat-emitting waste: C waste (vitrified HLW or SF)
 - Full containment during the thermal phase (a few hundred to a few thousand years)
- **Geological disposal facility (GDF) must not undermine the confining properties of the host formation**
 - **Need to evaluate the consequences of thermal perturbations on the hydromechanical / safety relevant properties of the host formation (THM behaviour)**

HADES URL – 225 m deep in Boom Clay

High Activity Disposal Experimental Site

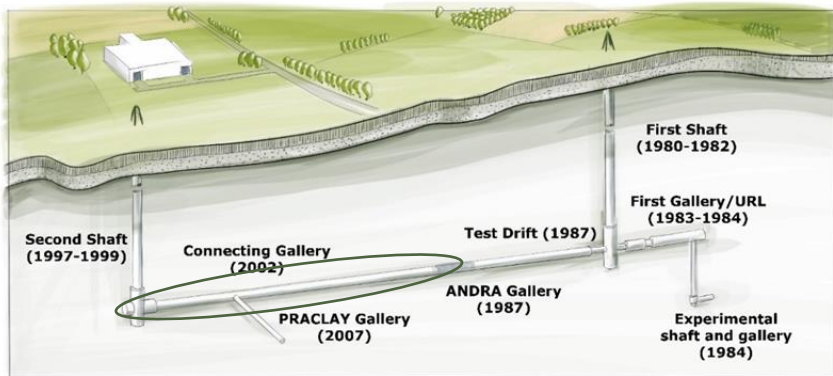
Managed by EURIDICE – *European Underground Research Infrastructure for Disposal of nuclear waste in Clay Environment*
(ONDRAF/NIRAS & SCK CEN partnership since 1995)



Demonstrate feasibility with industrial techniques

1. Construction of the Connecting Gallery (2002)

- **Excavation of 90m in 2 months (from Jan – Mar 2002) with Tunnelling machine (road header under the shield protection)**
 - Lining placed rapidly to limit over-excavation
→ 2m/day on avg.
 - Smooth and circular excavation profile supported by Wedge block system (Unreinforced concrete segments)



©EURIDICE



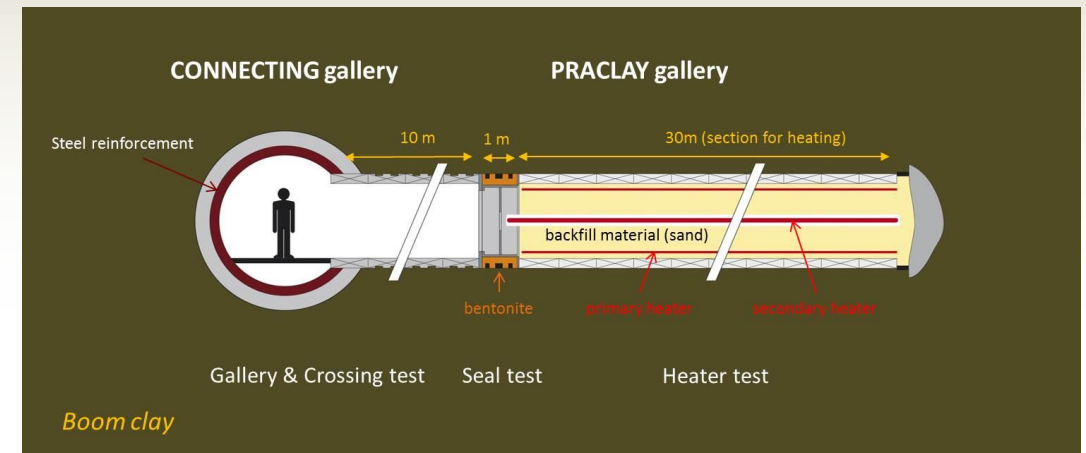
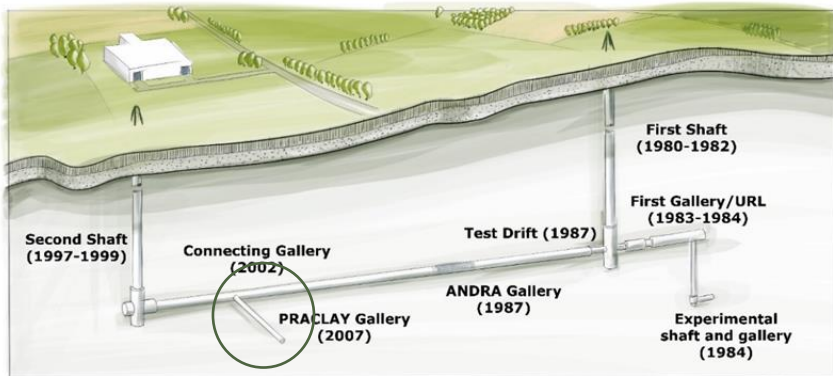
External diameter: 4.8m
Internal diameter: 4.0m
Concrete C75/90

Demonstrate feasibility with industrial techniques

2. PRACLAY in situ Experiment

PRACLAY = Preliminary demonstration tests for clay disposal

- Demonstration at representative scale that the Boom Clay can withstand perturbations induced by a GDF with minimal damage
 - The excavation of galleries
 - The thermal load (from vitrified HLW or spent fuel)



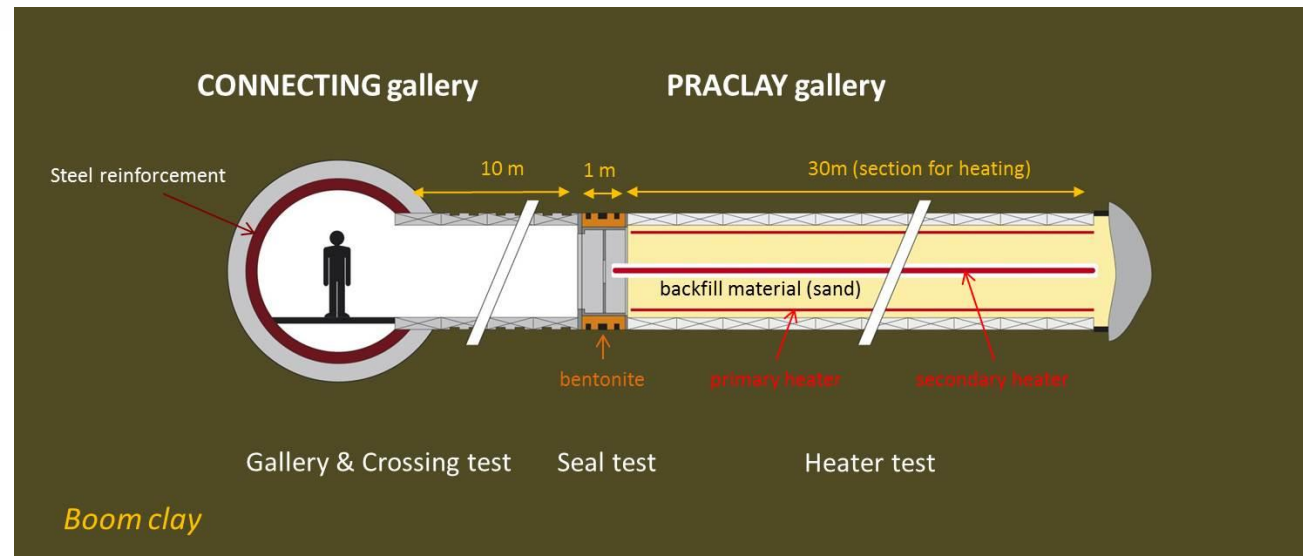
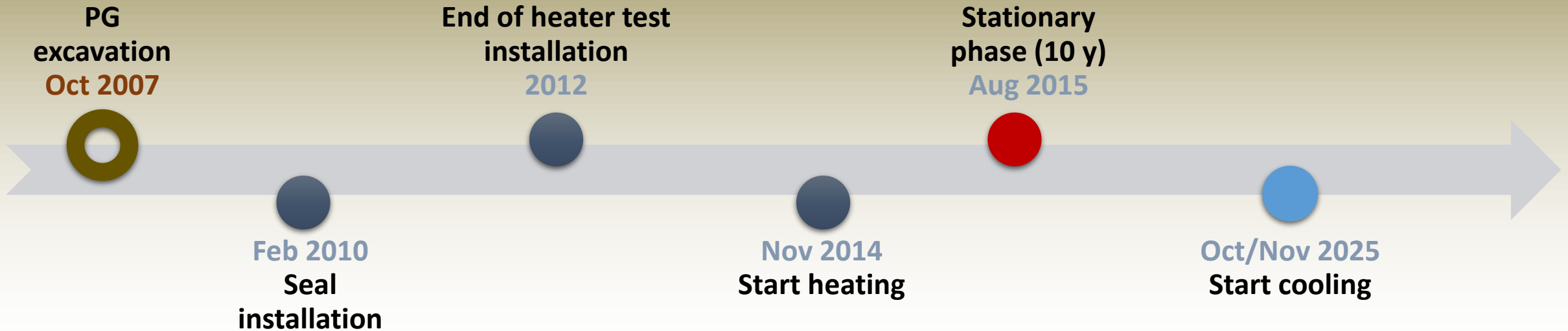
Series of demonstration tests

- the Gallery & Crossing Test
- the Heater Test
- the Seal Test



Important milestones in the stepwise confirmation of a GDF feasibility

PRACLAY in situ experiment – Timeline



Gallery & Crossing Test (2007)

- **Excavation of the gallery perpendicular to the Connecting Gallery**
 - Installation of a reinforcement ring
 - Tunnelling machine (road header under the shield protection)
 - Excavation rate: 2m/day on avg.

External diameter: 2.5m
Internal diameter: 1.9m
Concrete C80/95



Gallery & Crossing Test (2007)

Scientific Lessons

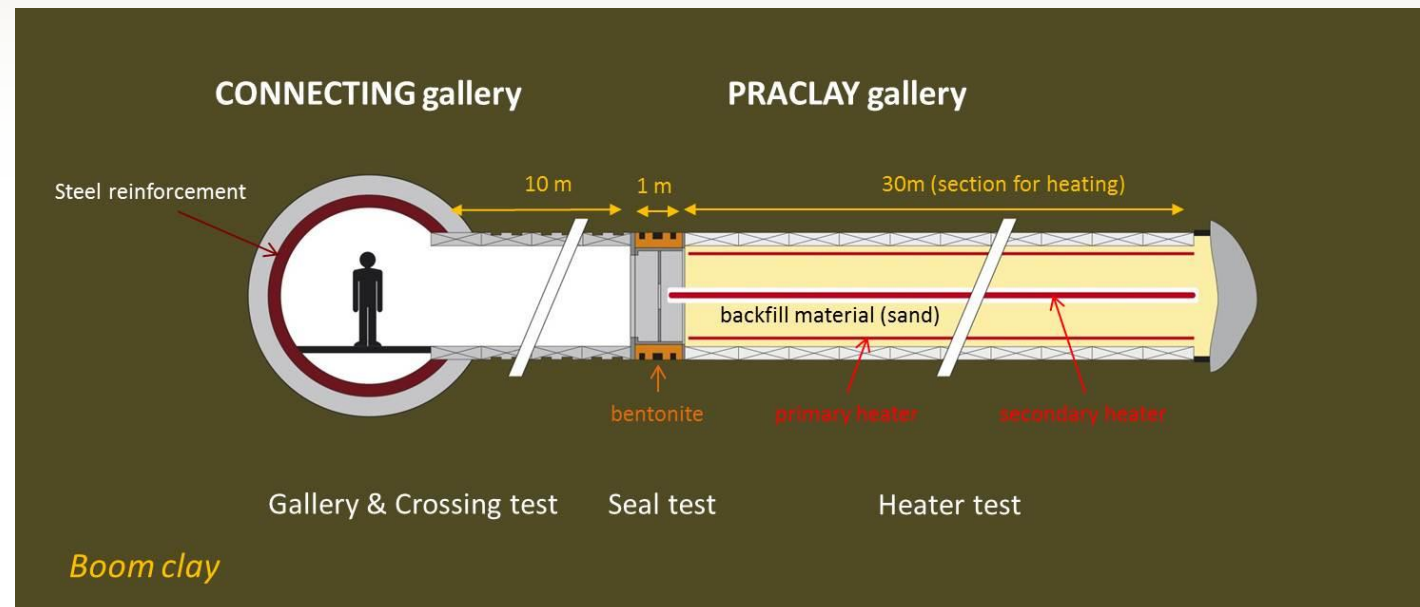
- **Demonstrated the feasibility to**
 - **construct a crossing**
 - without using a mounting chamber
 - for a ratio of access gallery internal diameter /disposal gallery external diameter ≥ 1.6
 - restart the tunnelling machine in case of stopping
- **Enhanced knowledge of the hydromechanical behaviour of the EDZ in Boom Clay (during and after excavation)**
 - Confirmation of observations made during excavation of Connecting Gallery
 - Observation of EDZ fractures reactivation in the crossing zone



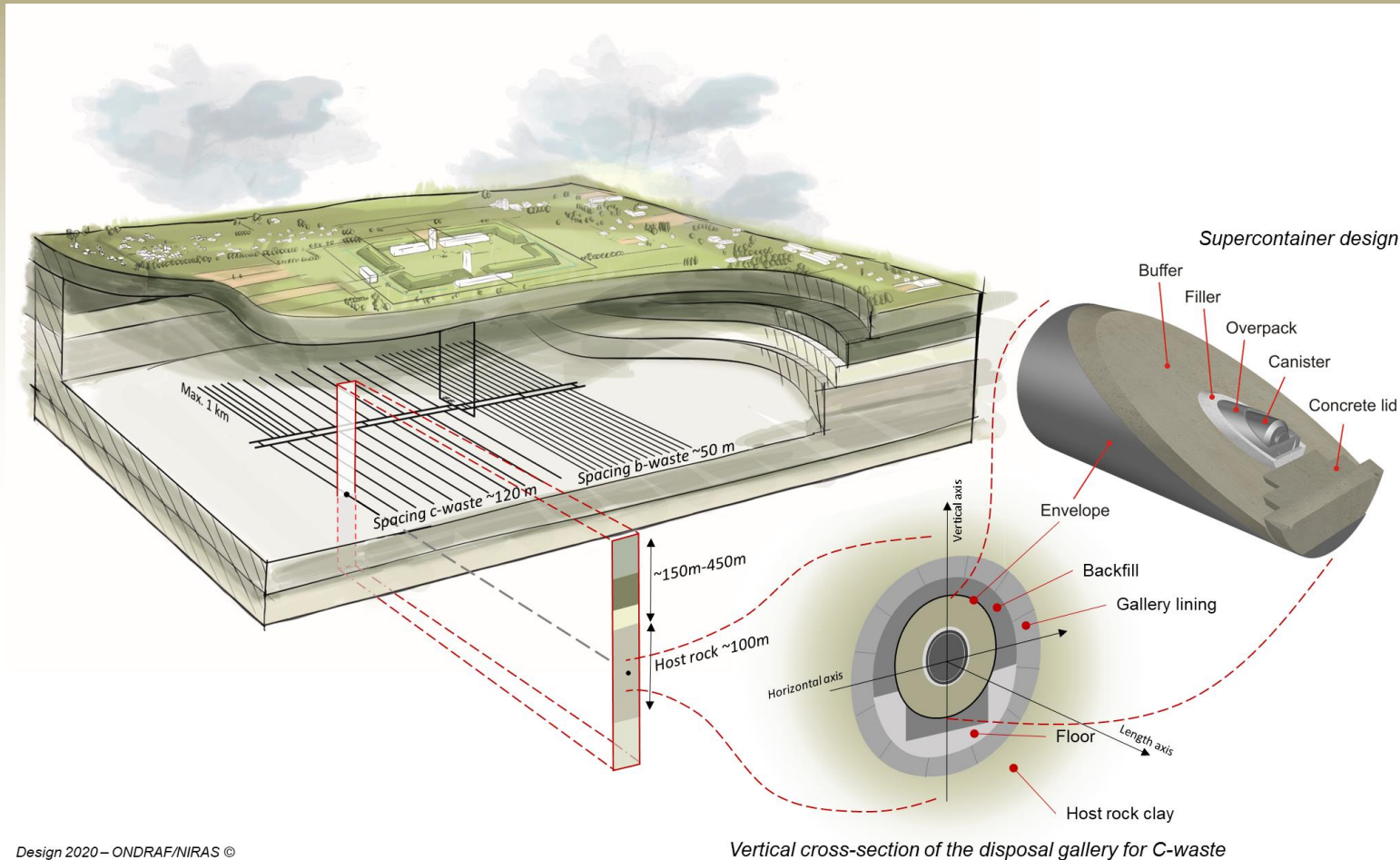
PRACLAY Heater Test (since 2014)

Objectives

- Obtain a good comprehension of the THM perturbations involved in the evolution of the poorly indurated clays around a repository
- Assess to which extent induced temporary or permanent modifications could affect the safety function of the Boom Clay



Disposal of heat-emitting waste: current design



Design 2020 – ONDRAF/NIRAS ©

Thermal pre-design requirements

- Limit T at the overpack (corrosion)
- Limit ΔT beyond the host formation

Design parameters to accommodate the heat output

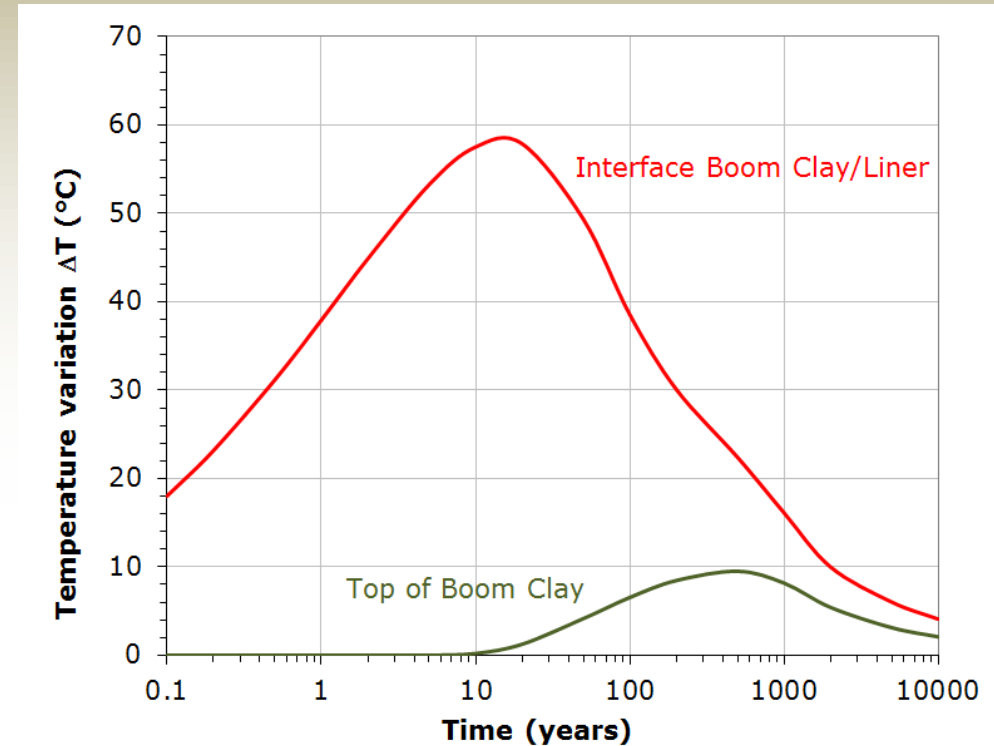
- Cooling time before disposal
- The number of VHLW canisters / SF assemblies in a supercontainer
- The distance between supercontainers within a disposal gallery
- The distance between disposal galleries

Disposal of heat-emitting waste: current design

- **Thermal perturbations**

- Thermal load in gallery at time of disposal about 250 W/m
- Temperature variations at the interface between repository lining and Boom Clay estimated higher for spent fuel than for vitrified high level waste

→ Max. 60°C



*Example of Spent Fuel – UOX50
for a disposal at HADES URL depth
where initial temperature is about 16°C*

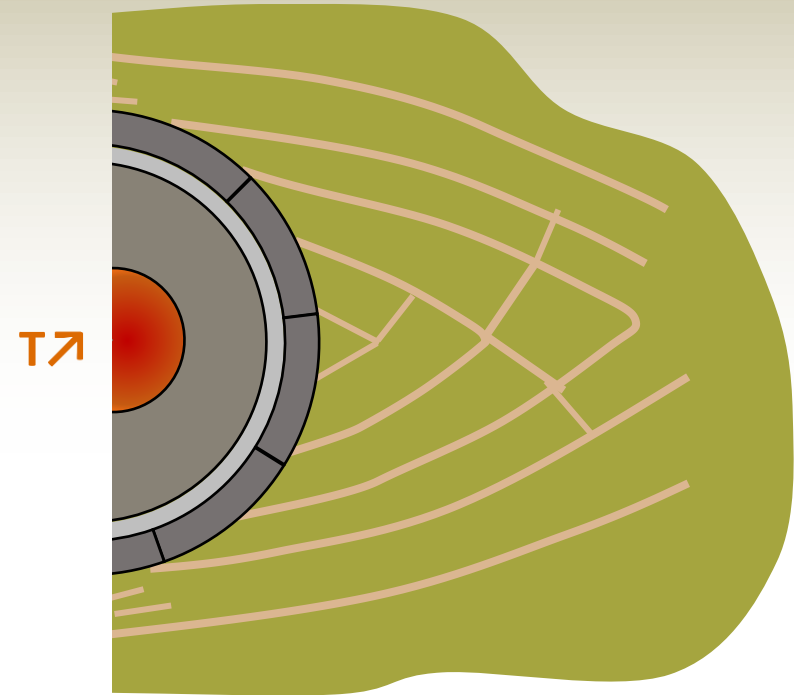


Disposal of heat-emitting waste: current design

- **Thermal perturbations**

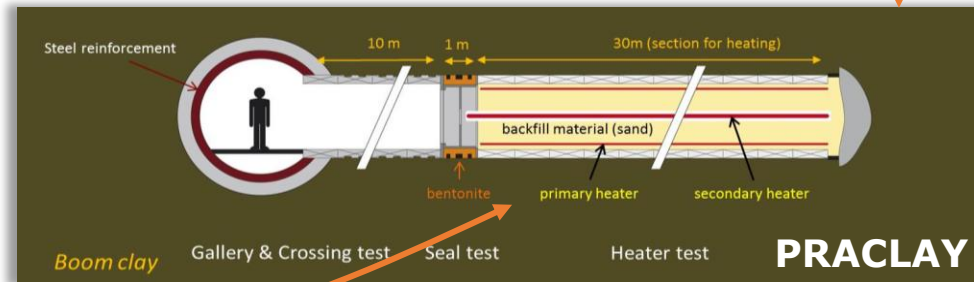
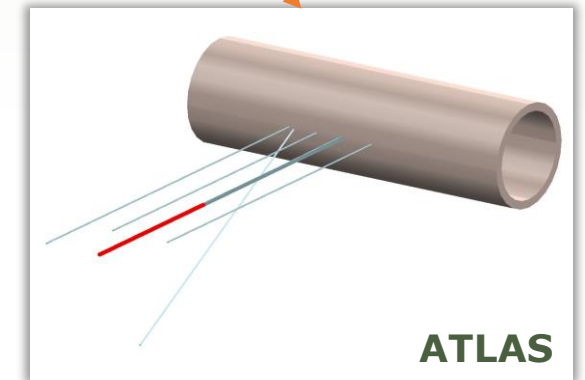
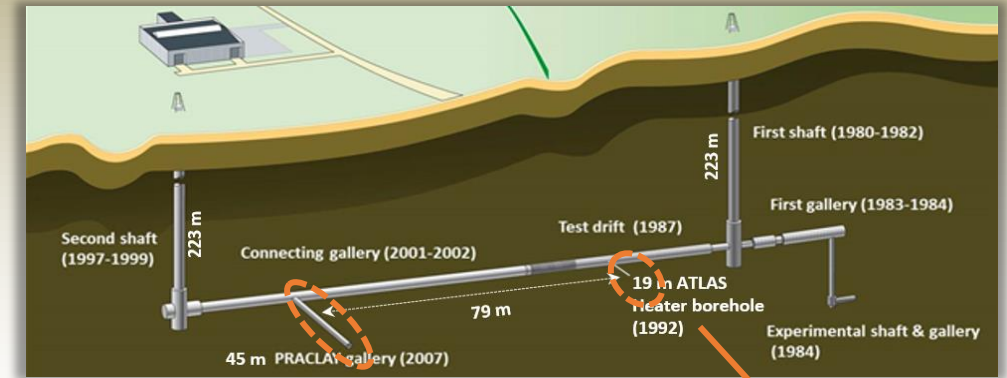
→ need to evaluate the consequences of

- thermal transient on the evolution of the Excavation Damaged Zone (EDZ)
- the possible additional damage created by thermal load
- the thermal load impact on:
 - the safety relevant properties of Boom Clay
 - far field stress state, deformations & uplift



Disposal of heat-emitting waste: current design

- **Characterization programme of Boom Clay THM behaviour**
 - Numerous lab tests over a wide range of mechanical conditions
 - In-situ small-scale heater tests e.g., ATLAS (1993 – ...)
- **Demonstration of the Boom Clay capacity to withstand the thermal load imposed by heat emitting wastes**
 - In-situ large-scale heater test PRACLAY (2014 – ...)



PRACLAY Heater Test – Objectives

Validate and/or improve knowledge on BC THM behaviour by studying in situ thermal properties and anisotropy at large scale

Confirm the $T \rightarrow HM$ coupling in Boom Clay at a scale representative of a disposal gallery + estimate possible upscaling effect

- “Simple” THM experiment
 - Main focus is on Boom Clay
 - Independent of a particular design

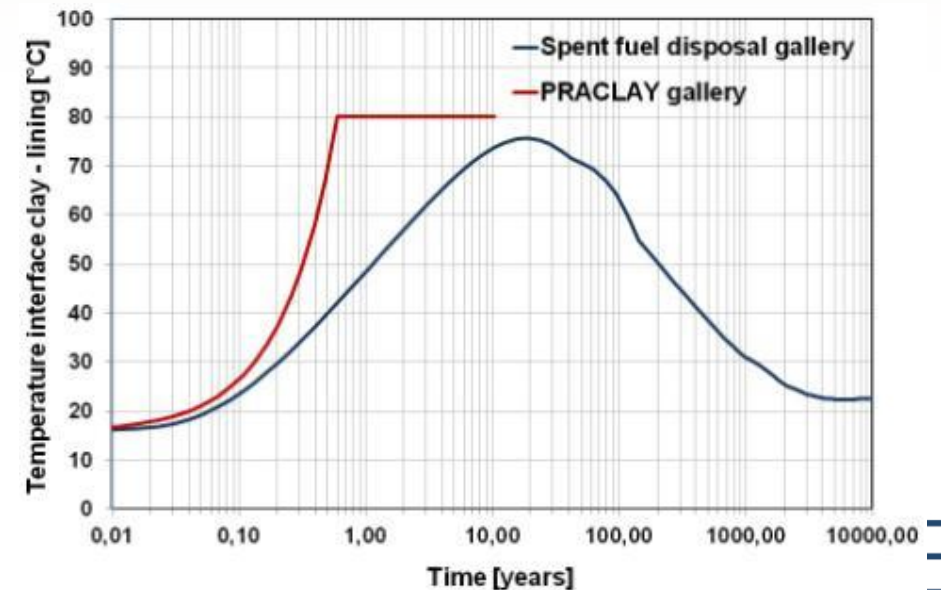
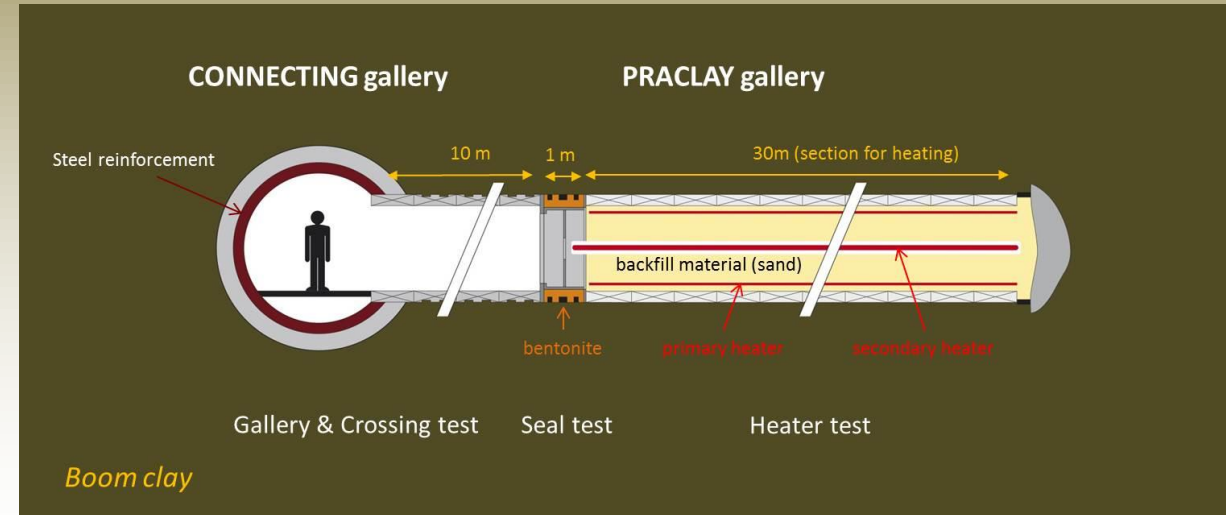
Verifying that the Boom Clay can withstand the thermal transient up to the time of maximum near field temperature

- Conducted under a reasonably conservative combination of thermal and hydraulic boundary conditions

PRACLAY Heater Test – Design

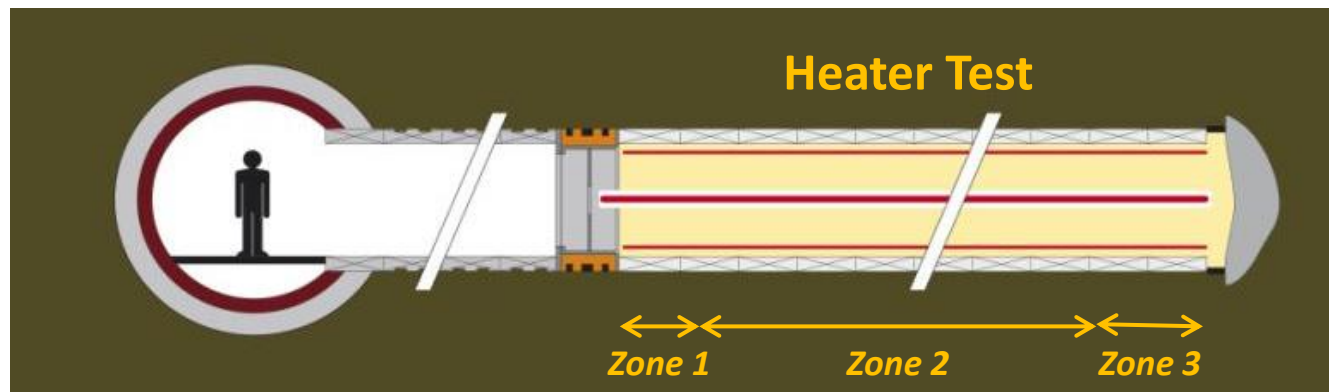
- **Thermal conditions**

- Temperature at gallery extrados = 80°C
 - > real repository
- Faster temperature increase
 - More penalising
- Heating during 10 years
- Heated gallery section = 30 m
 - No gain in test representativity by a longer section
 - Sufficiently far from the Connecting Gallery
 - The mid plane simulates a section around a disposal gallery



PRACLAY Heater Test – Design

- Primary heater
 - Electrical heater cables close to the gallery lining split in 3 heating zones
 - Inaccessible during the Heater Test and therefore twice as much heater cables than necessary (100% redundancy)
- Secondary or backup heater
 - Electrical heater inside a central tube
 - Accessible and replaceable at all times during the test

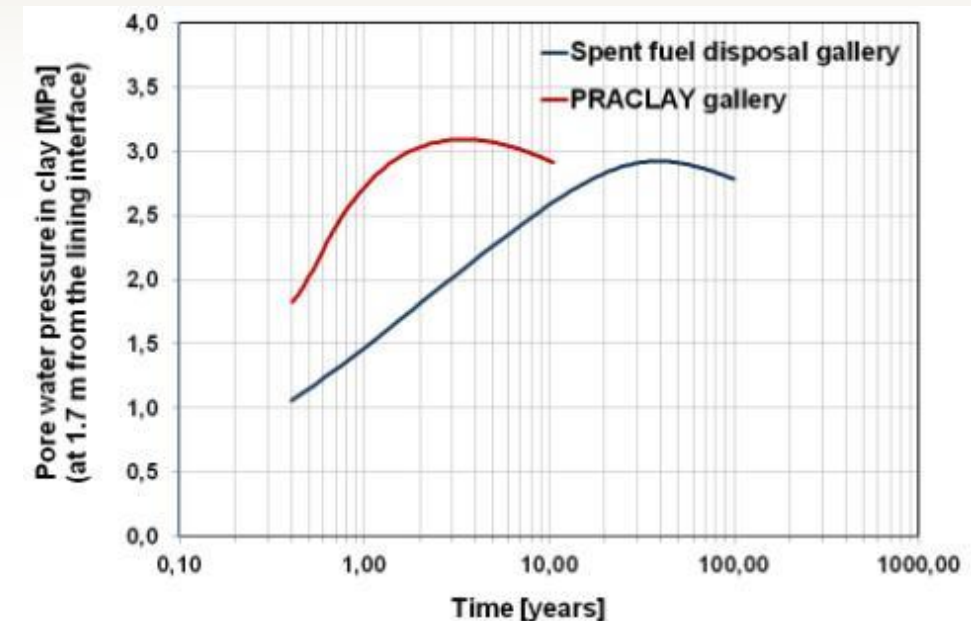
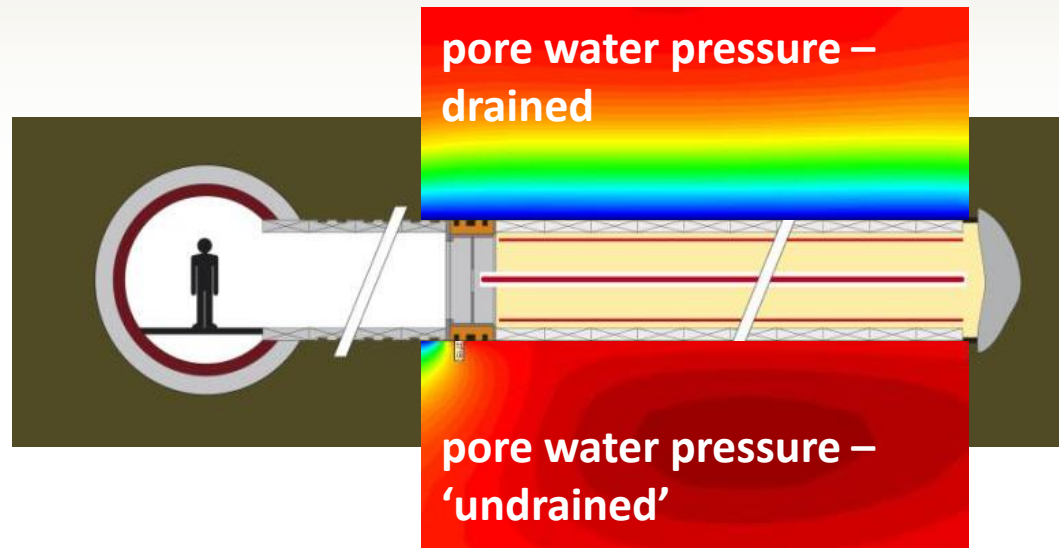


PRACLAY Heater Test – Design

- Hydraulic boundary conditions

- heating of Boom Clay in undrained conditions

more penalizing: the higher the pore pressure build-up during heating, the higher the risk of damage/failure for host rock



PRACLAY Heater Test – Design

- **Hydraulic boundary conditions**

- **heating of Boom Clay in undrained conditions**

more penalizing: the higher the pore pressure build-up during heating, the higher the risk of damage/failure for host rock

- Backfilling the gallery with sand (saturated and pressurized)
- Hydraulic seal as hydraulic cut-off for the heated part of the gallery
 - Impermeable boundary condition for the Heater Test
 - 1m long bentonite ring & steel structure

→ **Seal test**



PRACLAY Seal Test (2010)

- Not representative of the design considered in a repository
 - Not demonstrating seal feasibility and efficiency in real repository
- But opportunity to test
 - the feasibility of installing a horizontal seal
 - the seal – host formation interface (as a complement of the RESEAL exp)

→ ***important lessons learned for the design of the seal of a real disposal gallery***

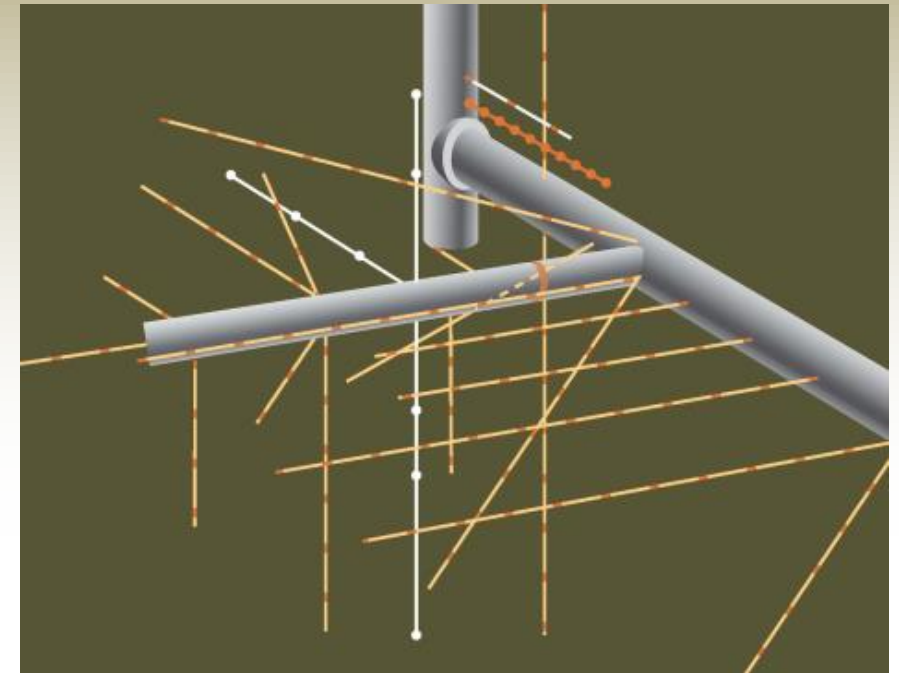
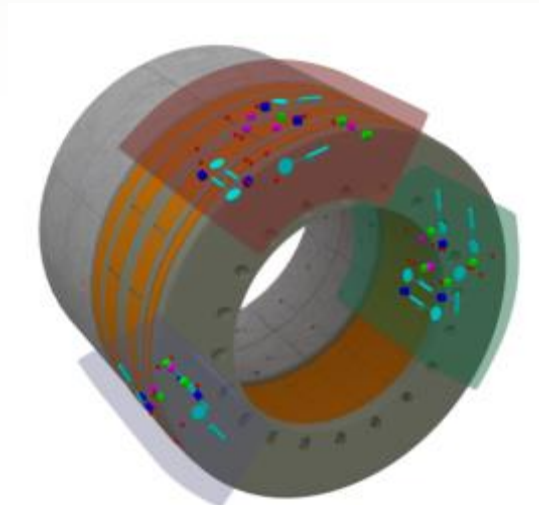


PRACLAY Heater Test – Design

- **Monitoring strategy**

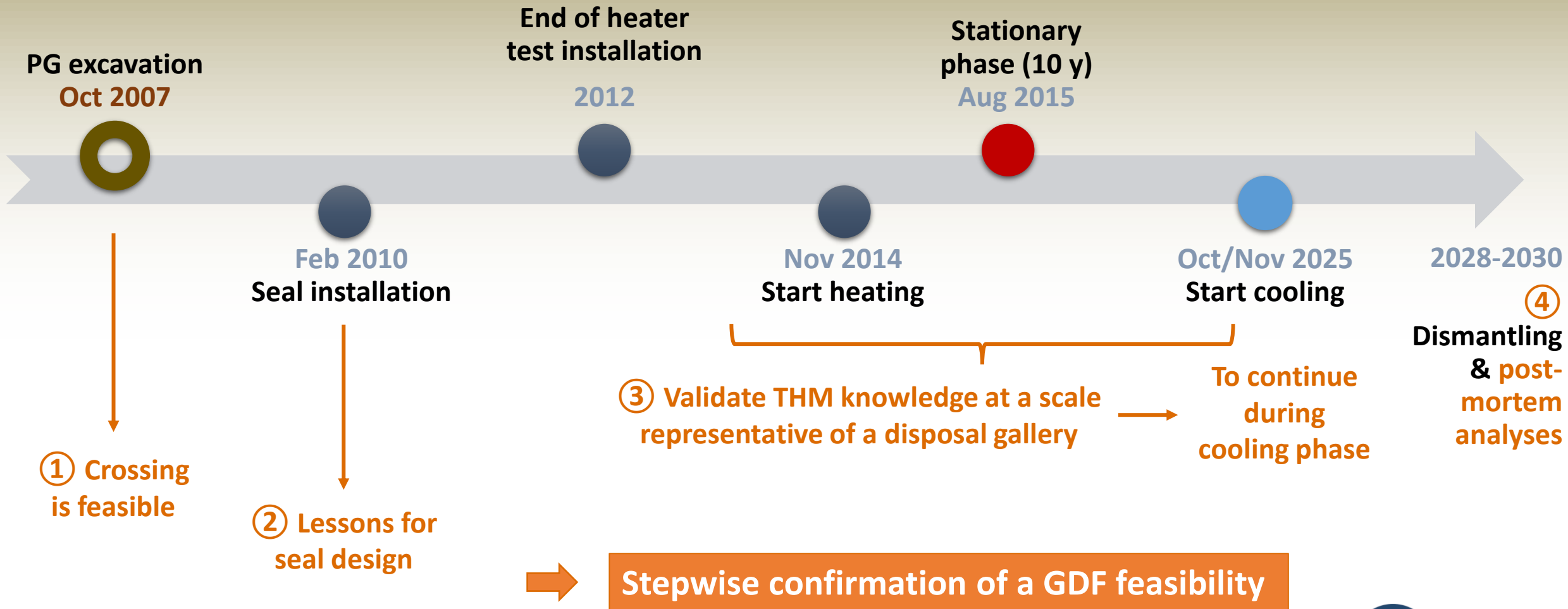
➔ 1100 sensors in total, with redundancy

- mainly thermocouples, multifilter piezometers + some total pressure sensors and inclinometer



PRACLAY in situ Experiment

Preliminary demonstration tests for clay disposal



Large-Scale In Situ PRACLAY Heater Test *Concluding the Heating Phase & Introduction to the Cooling Phase*

- 10 years of continuous monitoring of the heater test
by Jan Verstricht
- Observations during 10 years of heating
by Temenuga Georgieva
- THM characterization of the Boom Clay: Feedback from the PRACLAY Heater test
and preparation of the cooling phase
by Arnaud Dizier



PRACLAY 2025

CLOSING THE HEATING CHAPTER,
OPENING THE COOLING PHASE

sck cen



EURIDICE

NIRAS
ONDRAF

27th Exchange Meeting
TABLOO Dessel, 7th of November 2025

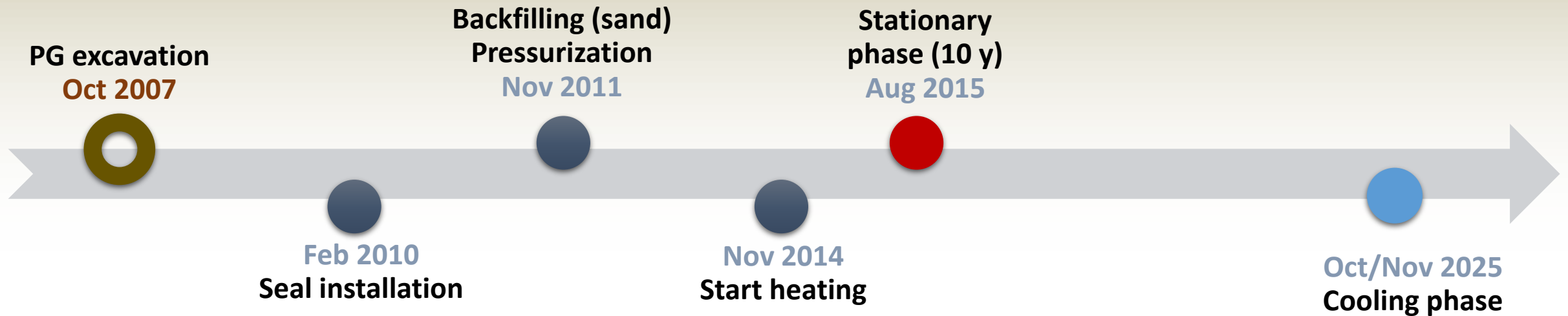
Ten years of continuous monitoring of the heater test

J. Verstricht, D. Nackaerts

EURIDICE

07-11-2025
27th Exchange Meeting

But the monitoring story started 20 Years Ago



Monitoring – essential part of PRACLAY Tests

- Scientific
 - Do the observations match our predictions? Do we understand the system?
 - Upscaling from smaller heating tests (e.g. ATLAS)
 - Continuation of previous steps (gallery excavation,...)
- Technical
 - Daily follow-up / maintaining test parameters
- Operational Safety
 - Unforeseen risks due to elevated temperatures and pressures?
- Strategic added value
 - What and how to monitor in repository-like conditions



Which components are monitored ?

- Focus on the Boom Clay host rock
 - Perturbations (near field)
 - Overall temperature and water pressure distribution (incl. far field)
- PRACLAY Gallery → source term
 - Also defines the boundary conditions of the test
 - Operation of the heater test
 - Safety related : large volume of heated and pressurized water
- Seal as the most critical component
 - Large pressure (and temperature) gradients

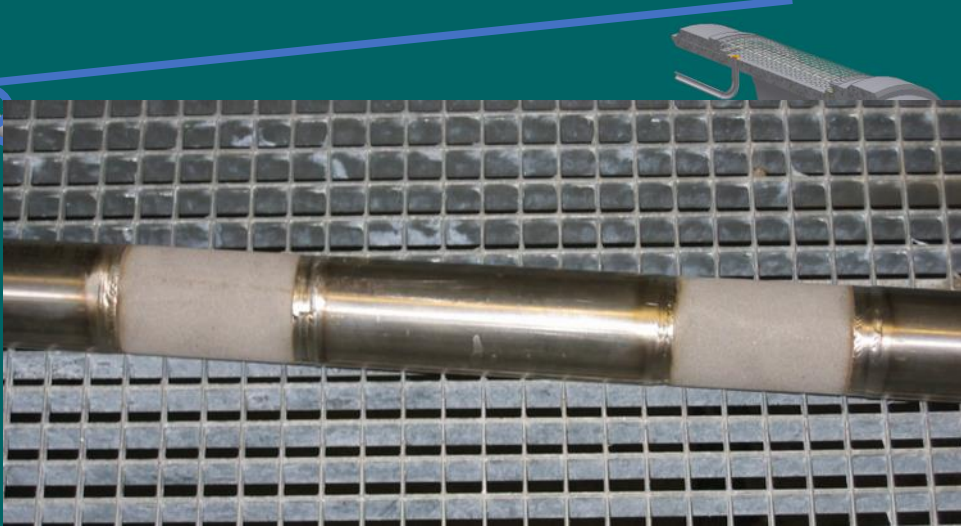




Multifilter piezometer boreholes

→ back-bone of monitoring network

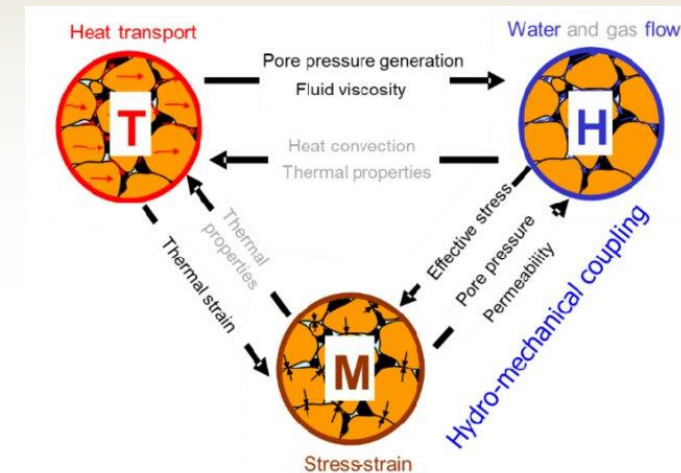
- What? Piezometer measures pressure of the porewater
- How?
 - Filters integrated in borehole casing to collect porewater
 - Porewater led to pressure sensors by capillary tubes



Multifilter piezometer boreholes

→ back-bone of monitoring network

- Why?
 - porewater pressures are an excellent indicator for variety of phenomena (coupled behaviour)
 - versatile instrument: in addition to pressure monitoring
 - permeability measurement, sampling, on-line monitoring
 - long-term reliability
 - proven performance of in HADES conditions
 - several set-ups > 30 y operating
 - pressure sensor remains accessible (calibration, replacement)

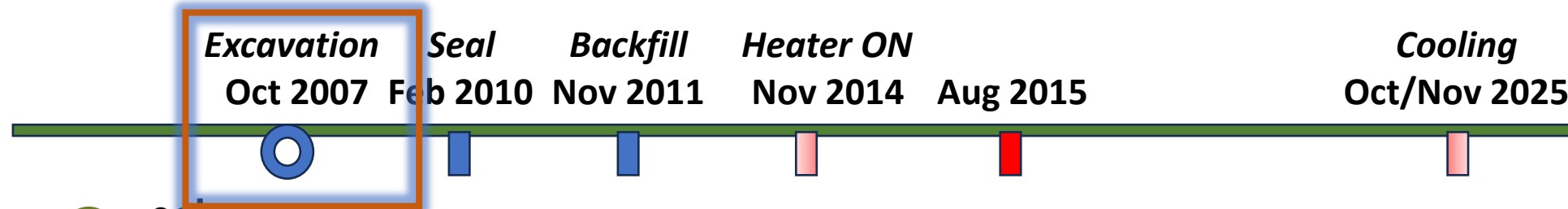


Installation in boreholes up to 45 m deep

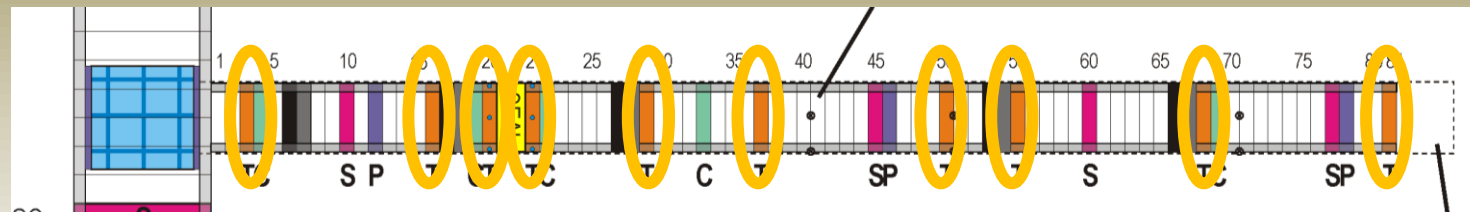


Instrumented segments for the PG lining (2007)

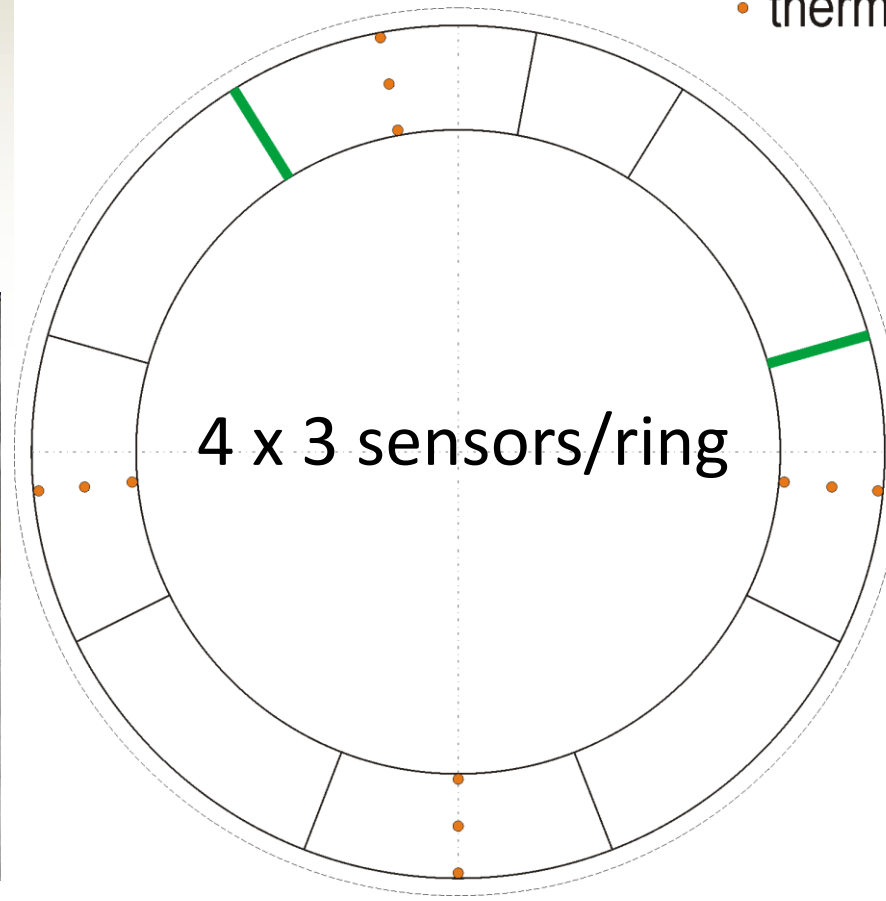
- Thermal conditions
 - Temperature (gradient) across lining
- Mechanical load on the lining
 - Embedded strain gauges
 - Pressure and load cells
 - Convergence measurements (invar wire extensometer)
- (Steel specimen for corrosion analysis)



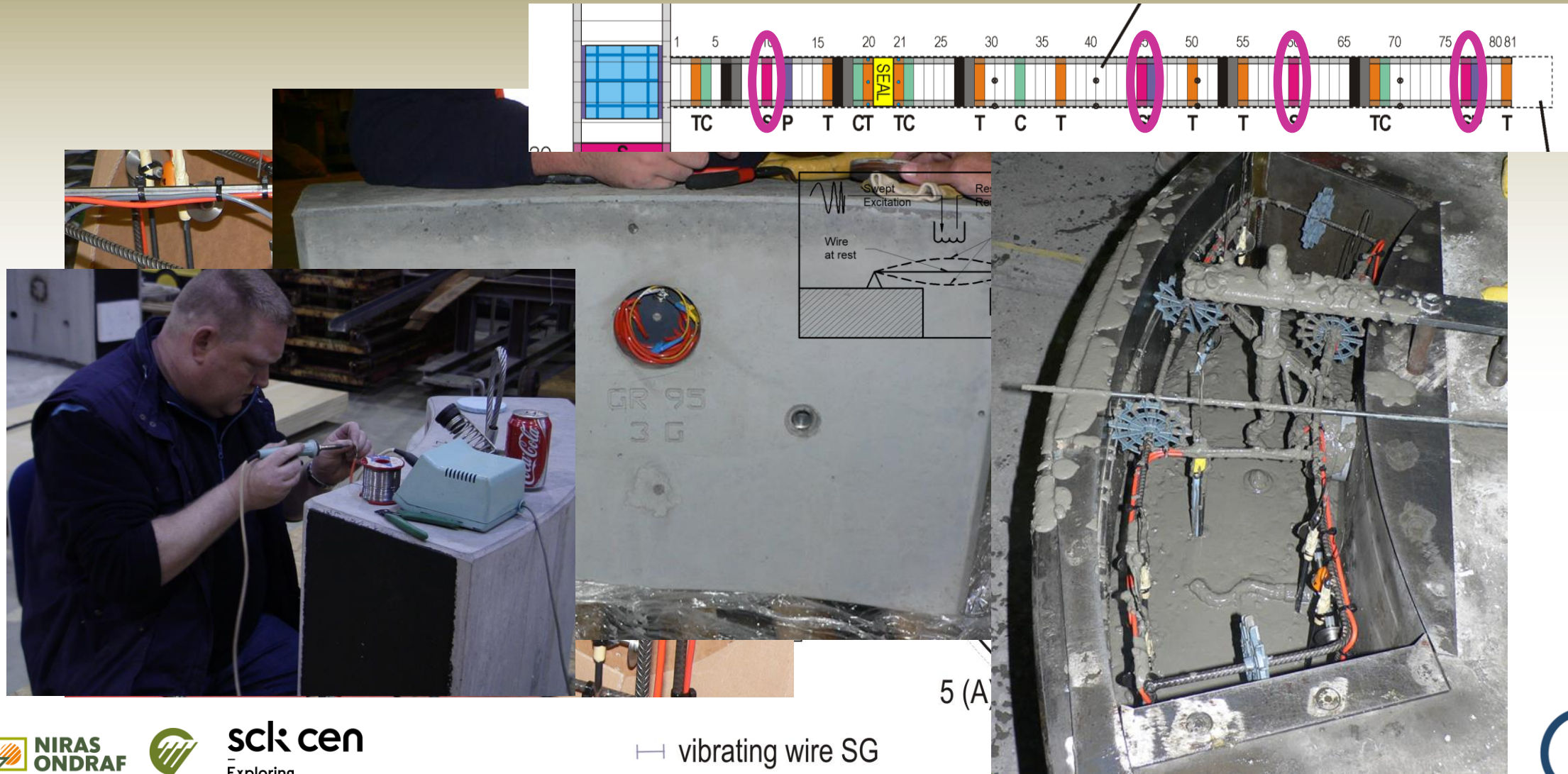
Ten rings instrumented with thermocouples



• thermocouple

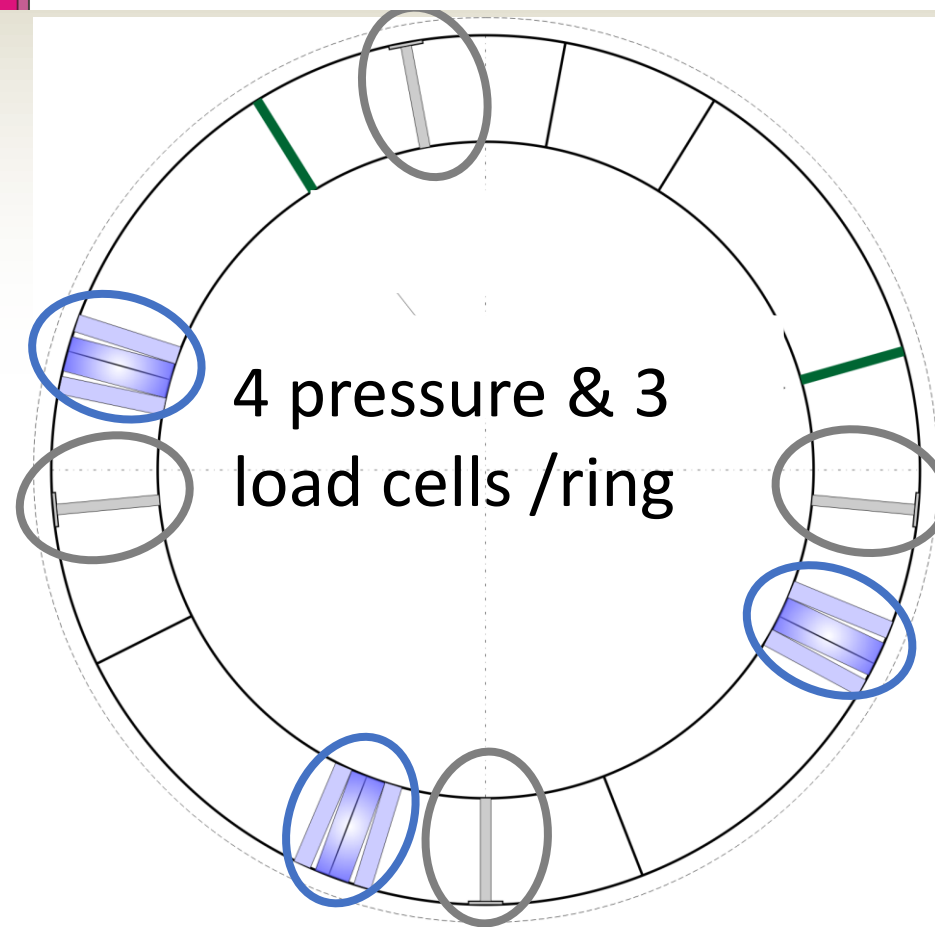
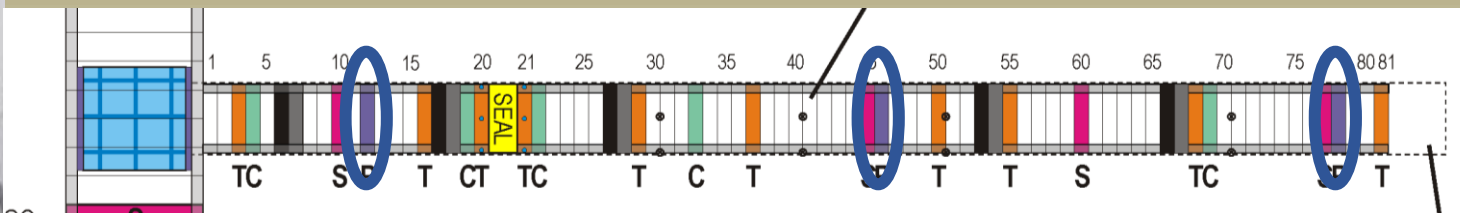


Four rings instrumented with strain gauges

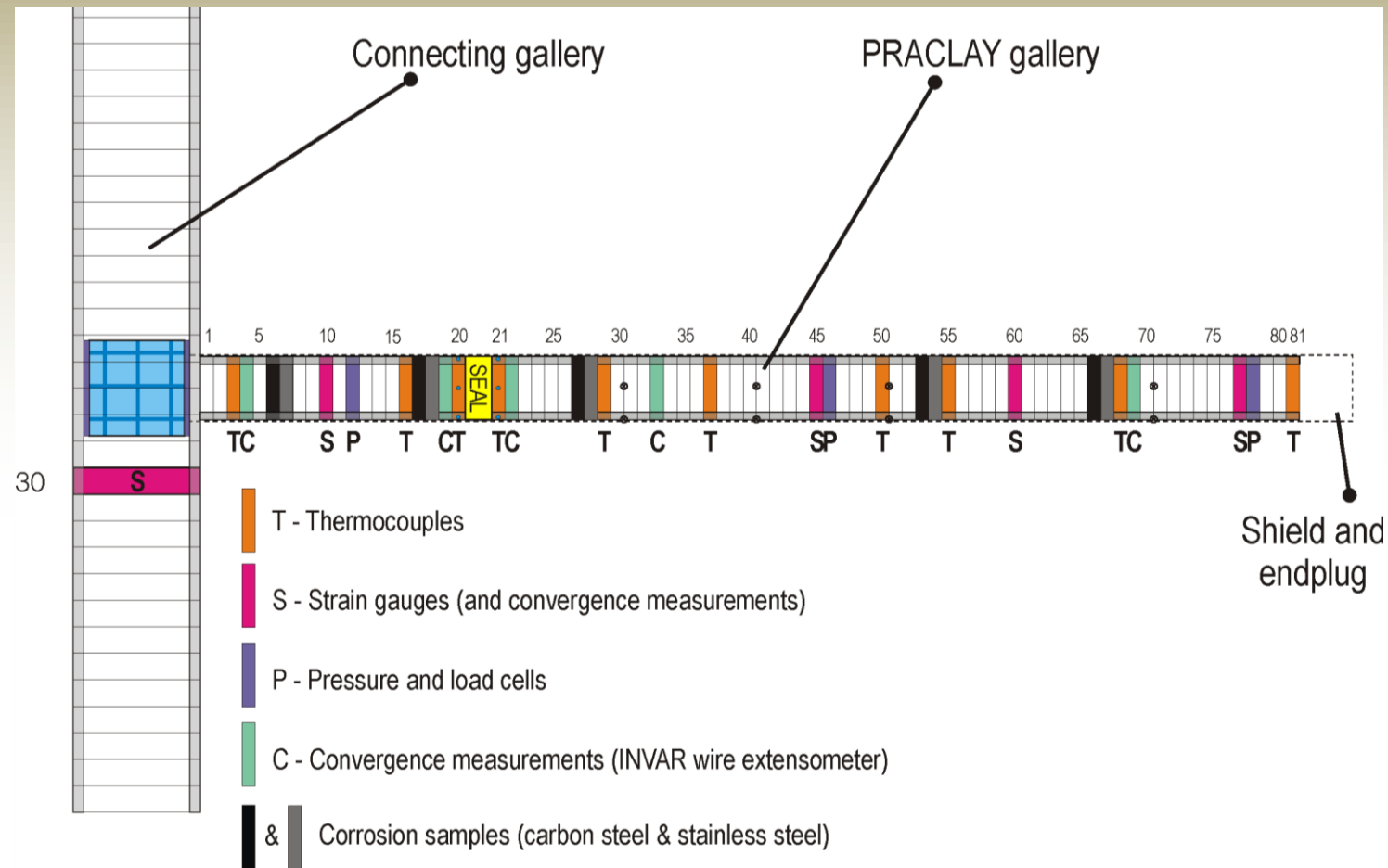


— vibrating wire SG

Pressure and load cells in three rings

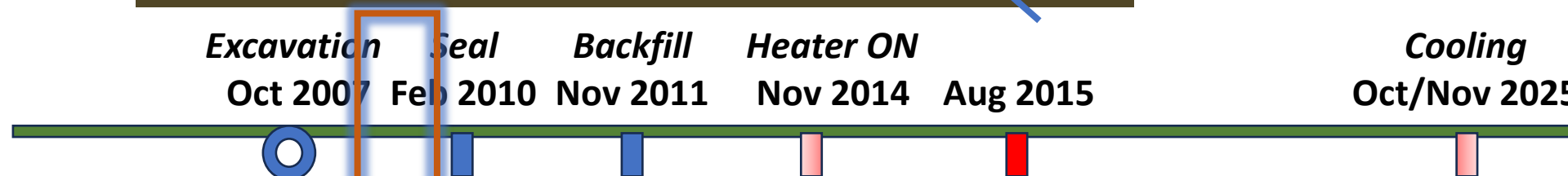
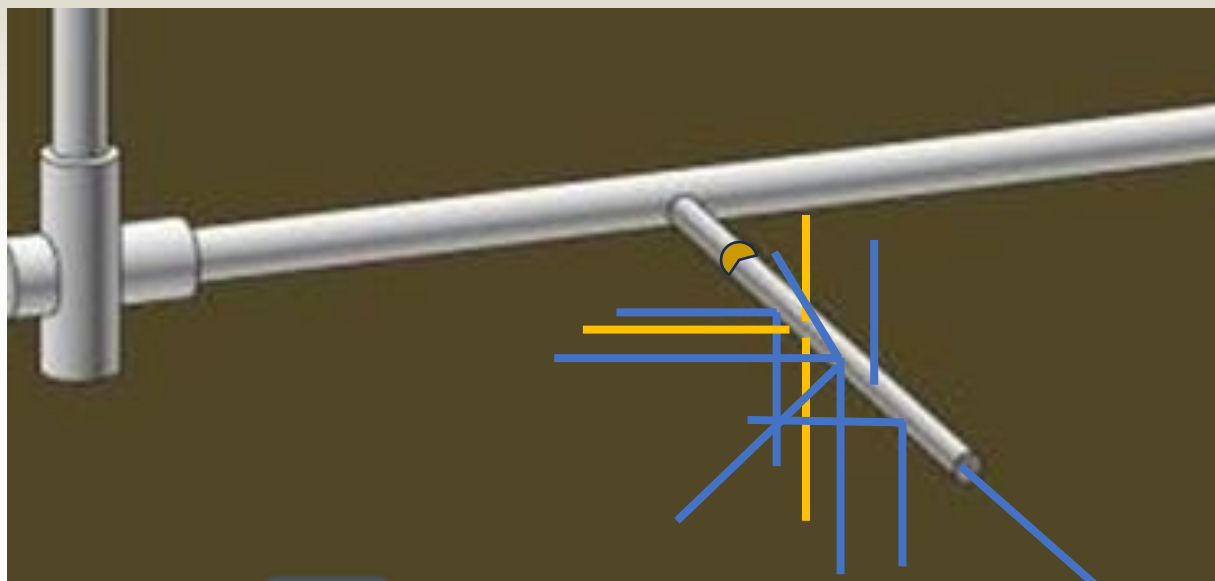


Resulting in > 300 sensors in the PG lining



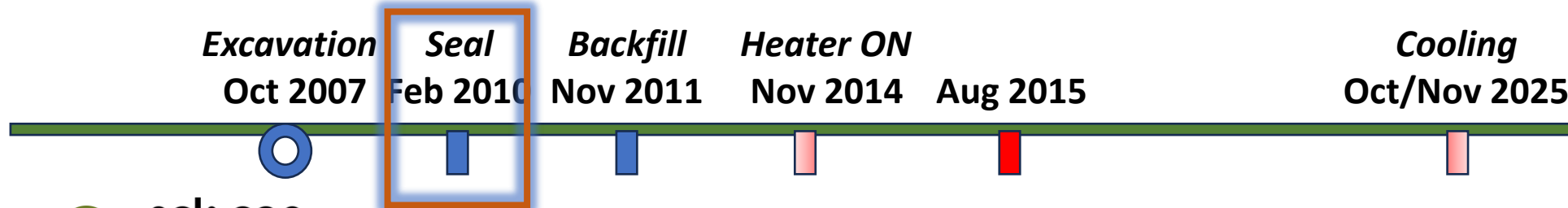
Observation boreholes from the PG (2009)

- Additional borehole piezometers (10) to add radial sensing points
- Three extensometer boreholes to monitor displacements

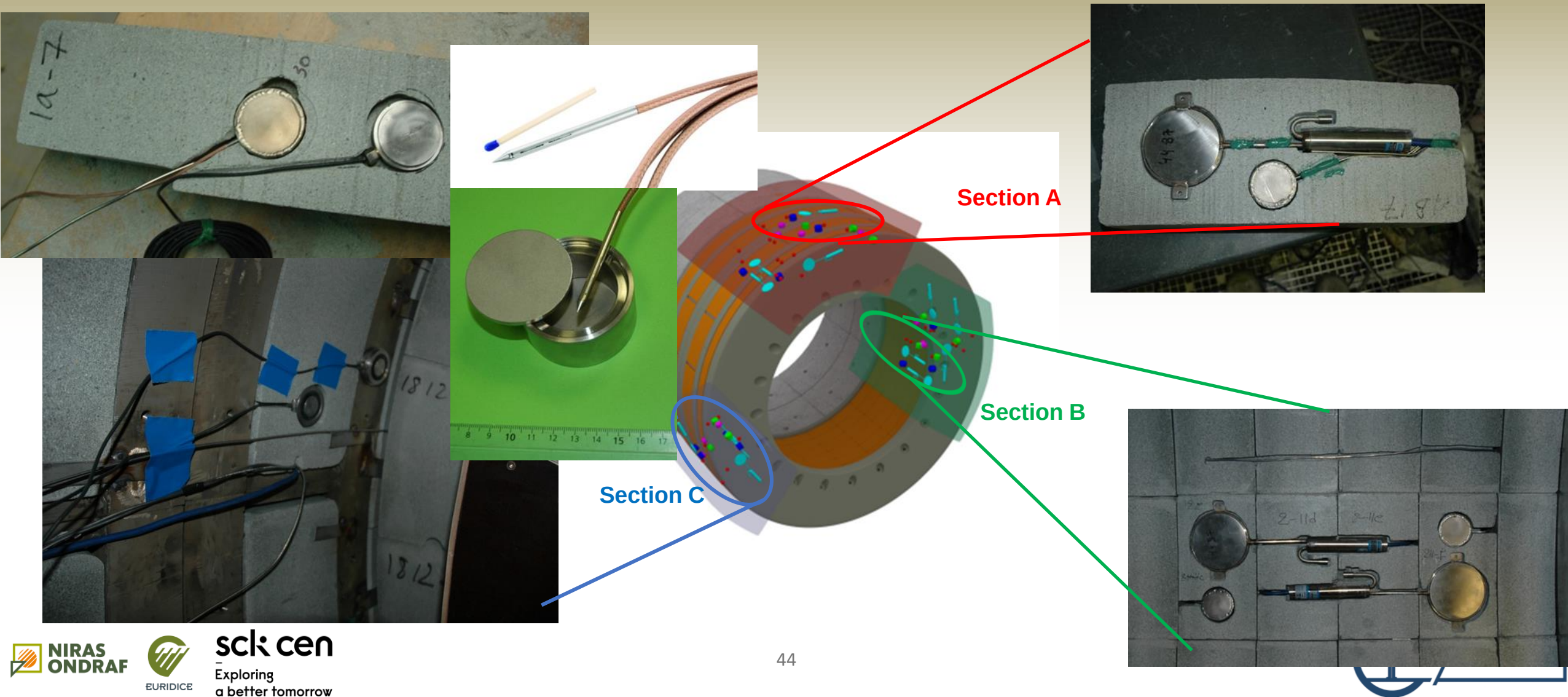


How is Seal performance monitored ? (2010)

- Critical component in the P
• Undrained conditions for the
• High porewater pressure and
- Hydro-mechanical monitoring
• Check swelling of bentonite
• Through moisture content –
- Temperature and pore pressure

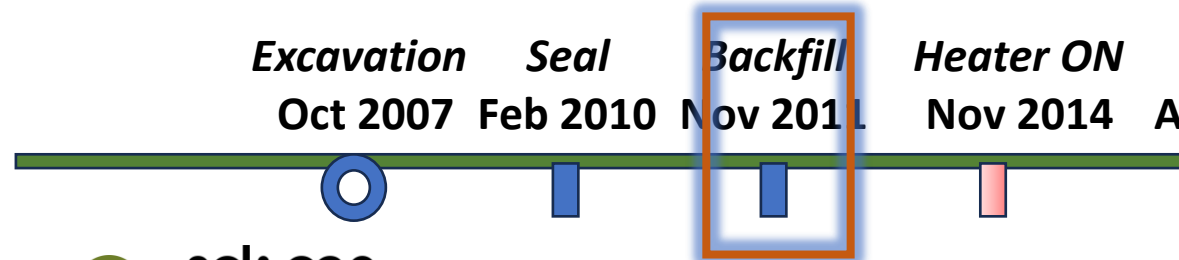


Seal sensors clustered in three sections



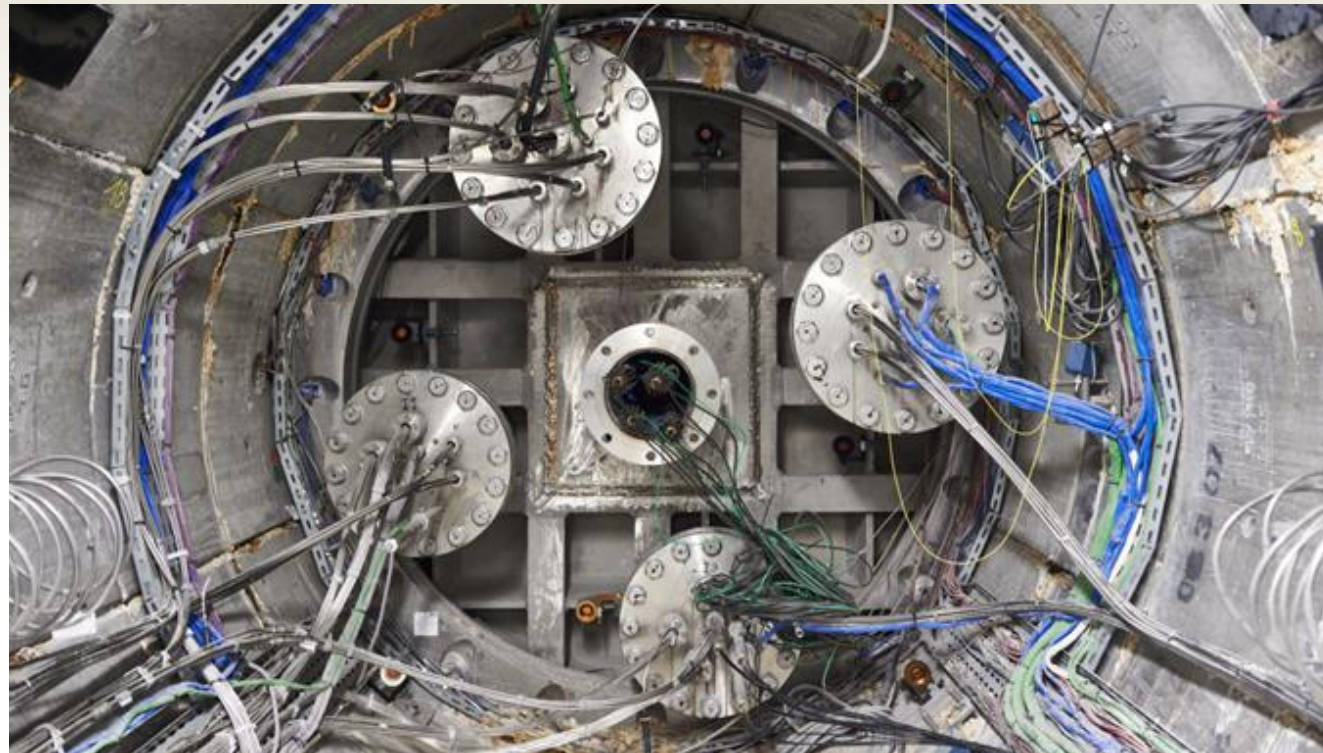
PG interior & backfill sensing

- Temperature
 - Check heater cables
- Water pressure
 - Uniform pressure along the gallery backfill



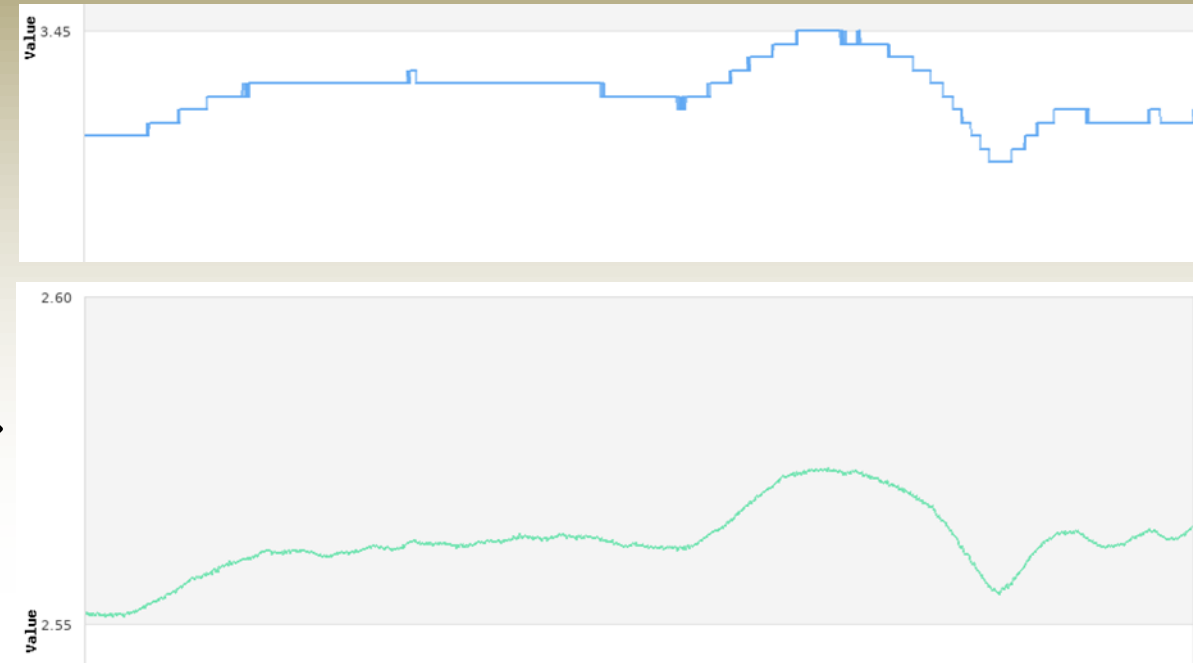
Cabling & Seal feed-through for many sensors

- Challenging operational conditions
 - cabling and junctions subject to elevated water pressure and temperature
 - watertightness



Upgrading of the monitoring set-up to prepare for the cooling

- Data acquisition replacement
 - e.g. higher measurement resolution
- Inclinator replacement
 - Improved measurement technology →
- Longer time spans
 - equipment becoming obsolete

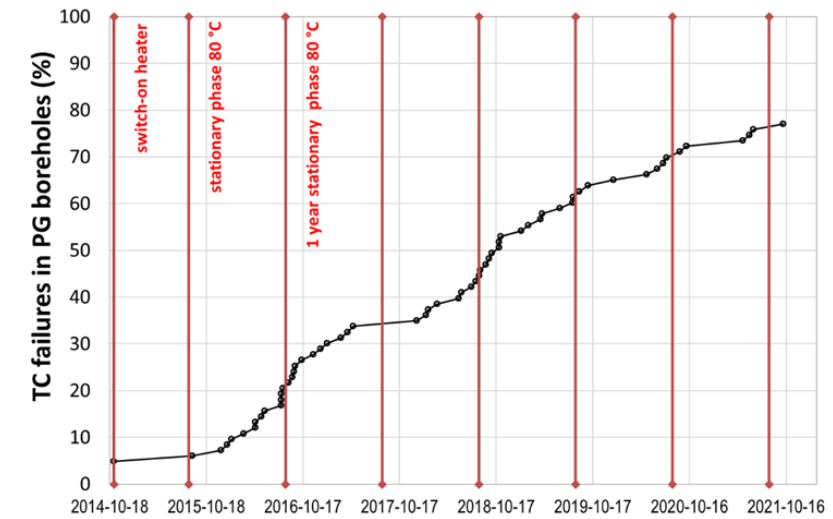
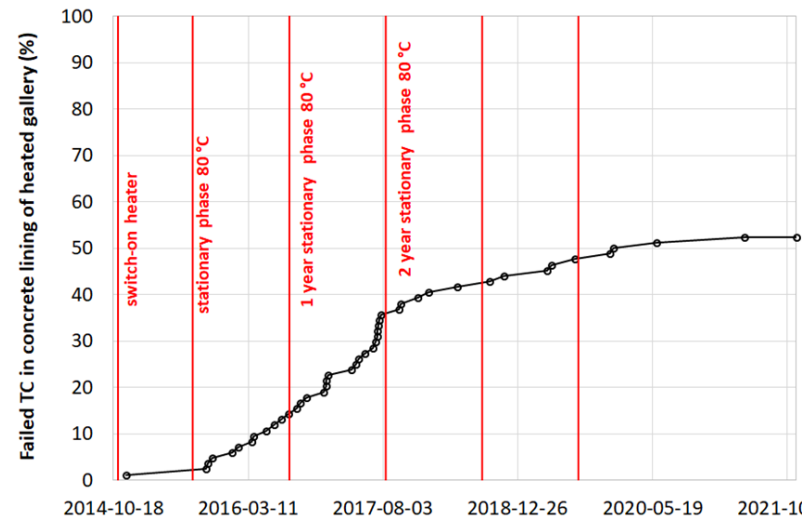
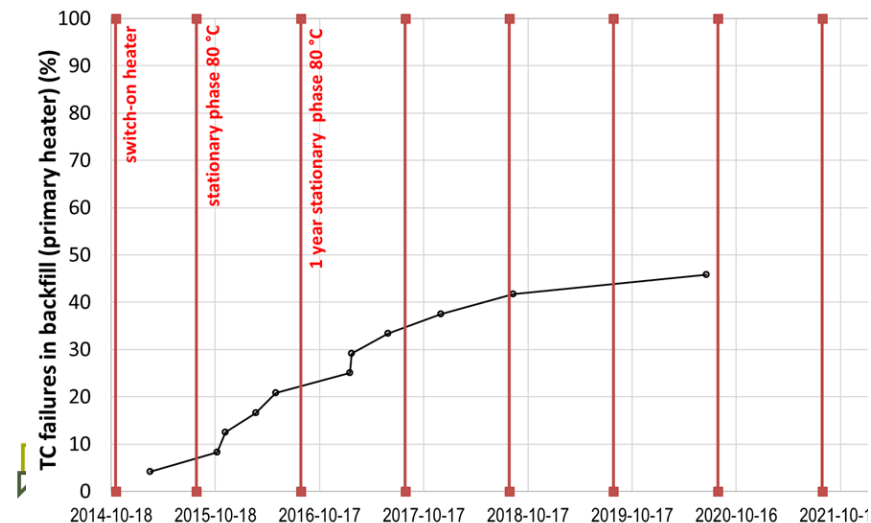
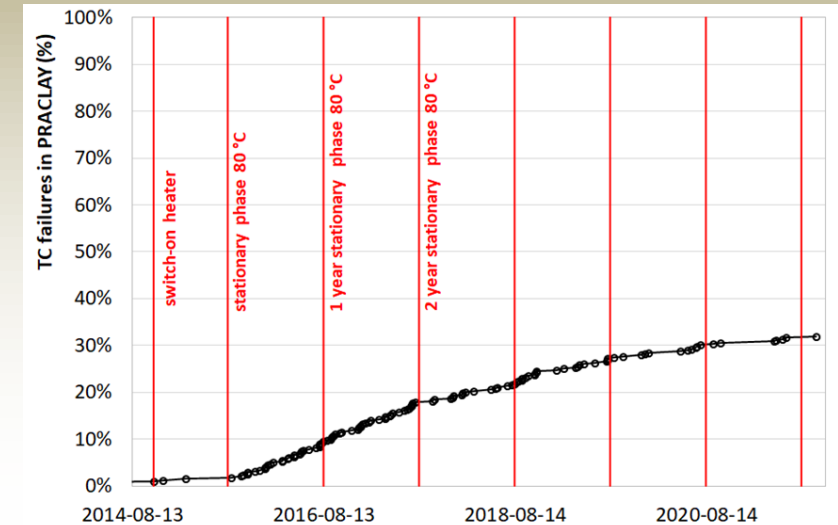


Important REX on sensor performance

- Long-term sensing → experience for long-term operation
- Conditions in/around PG beyond standard geotechnical specifications
 - Elevated temperatures ($> 80\text{ }^{\circ}\text{C}$) and water pressures ($> 2.5\text{ MPa}$)
- Extensive assessment has been performed on the different sensor types and installations

Thermocouple performance depends on location

	# TC sensors	# Failed	% Failed
CG PIEZO	109	0	0
PG PIEZO	83	64	77%
LINING	120	44	37%
HEATER	24	11	46%
SEAL	43	2	5%
<i>*when considering only heated part of the lining</i>			
TOTAL	379	121	32%



Main sensor performance assessment results

- Temperature and water pressure conditions
 - Avoid cable connections where possible
 - Extensive sensor testing
 - endurance (long-term) testing at relevant conditions
 - Less but more robust sensing points?

Conclusions

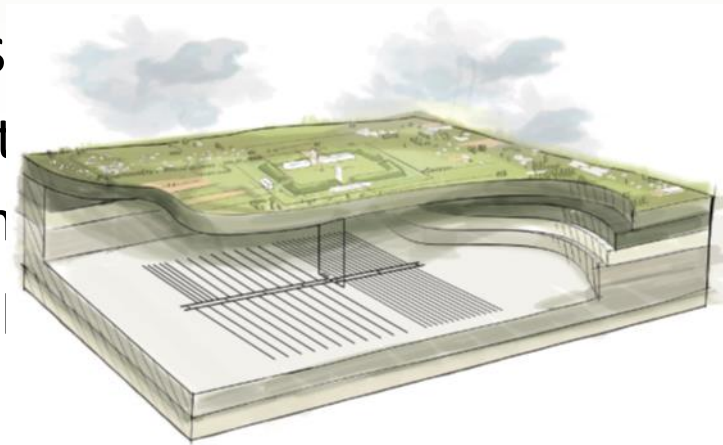
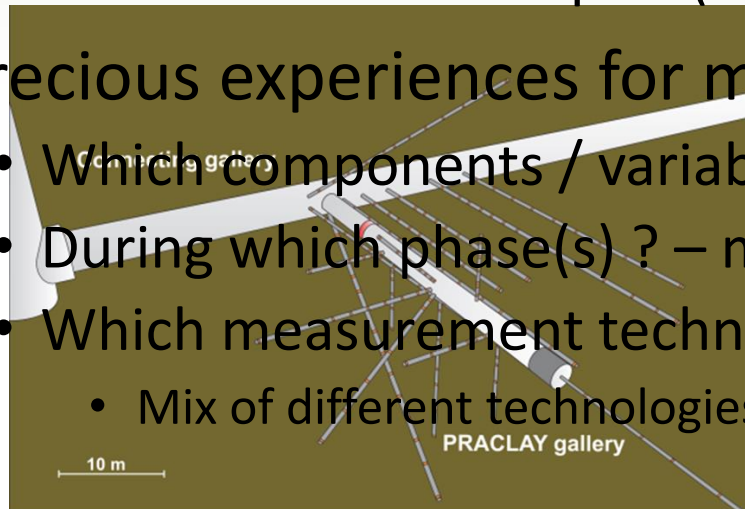
- An extensive and unique dataset has been generated
 - Data management including validation
- Input for design of repository monitoring

Monitoring perspectives

- Long-term monitoring technically feasible
- PRACLAY monitoring not a blueprint for repository monitoring
 - Different monitoring objectives
 - Non-invasive techniques ($\leftrightarrow$ monitoring boreholes)

- Precious experiences for monitoring s

- Which components / variable
- During which phase(s) ? – mc
- Which measurement technique
 - Mix of different technologies



The heating stopped – monitoring continues

- Monitoring effects during cooling
- Dismantling
→ sensor analysis

... for 10 more years ?!





PRACLAY 2025

CLOSING THE HEATING CHAPTER,
OPENING THE COOLING PHASE

sck cen



EURIDICE

NIRAS
ONDRAF

27th Exchange Meeting
TABLOO Dessel, 7th of November 2025

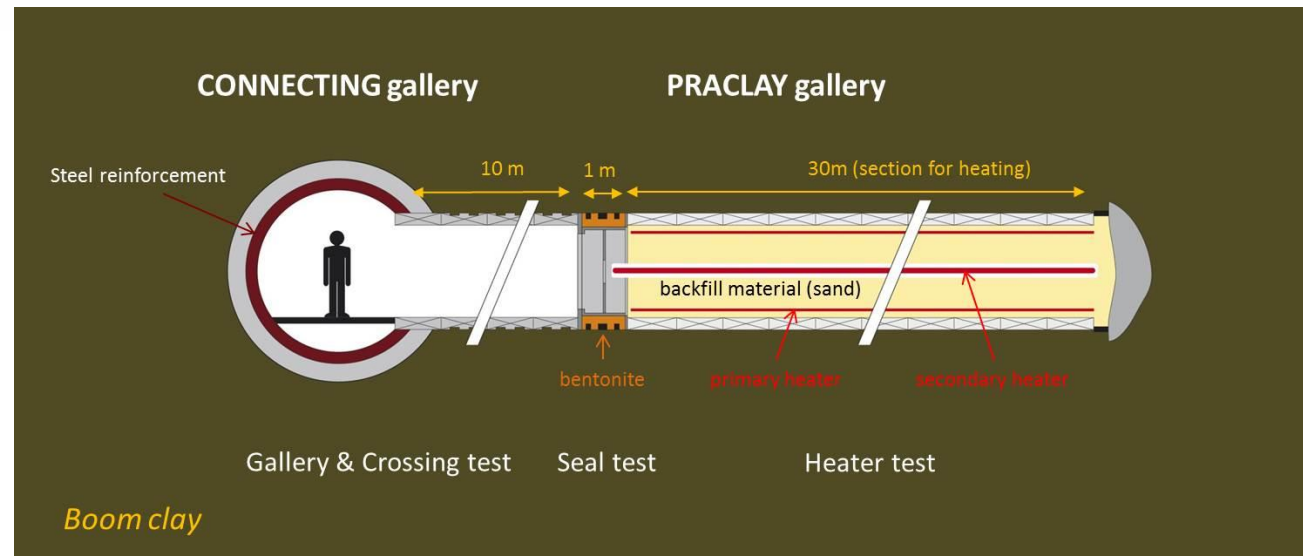
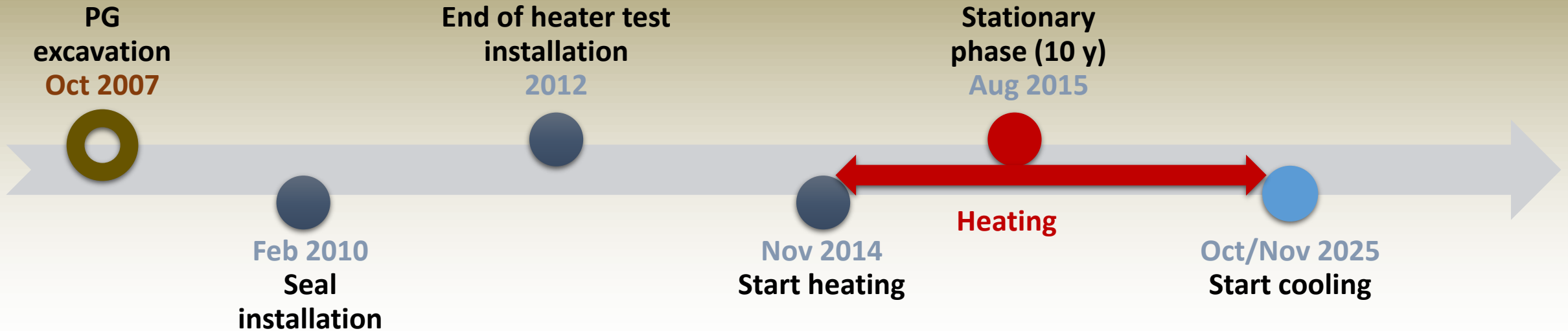
OBSERVATIONS during 10 years of heating

Can the clay withstand the thermal load from heat-emitting waste?

T. Georgieva, A. Dizier, J. Verstricht, D. Nackaerts, S. Levasseur

EURIDICE & NIRAS/ONDRAF

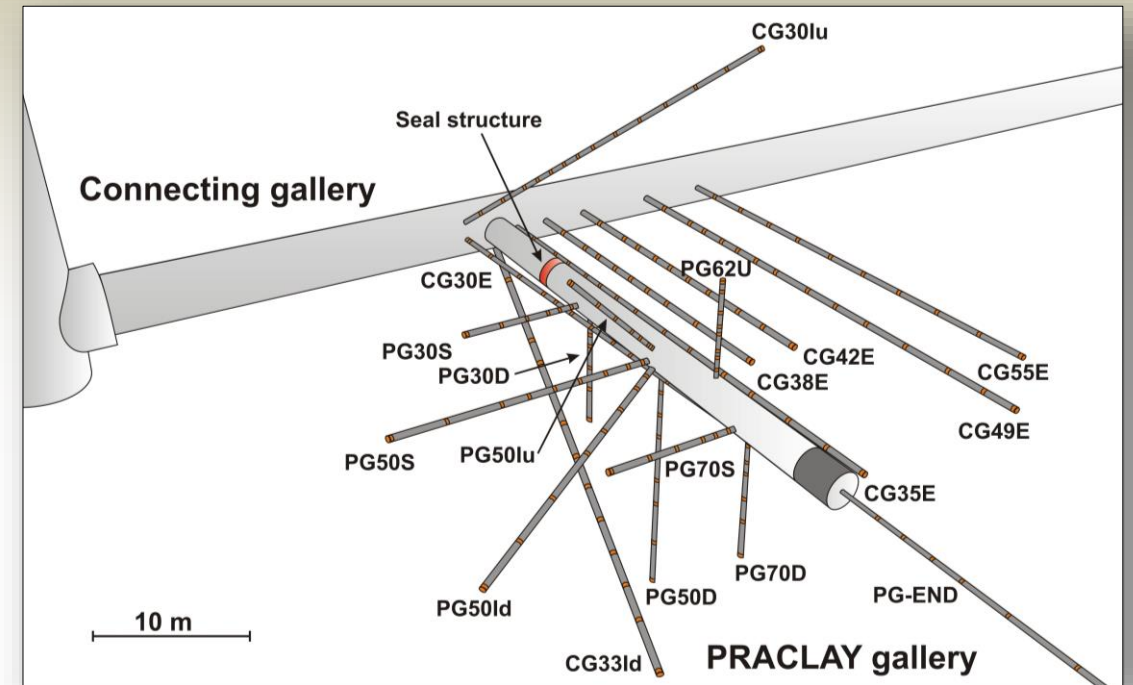
PRACLAY in situ experiment – Timeline



OUTLINE

- Heater Test – Steering parameters
- Observations
 - Boom Clay
 - Test set-up (Seal/ Concrete lining)
- Conclusion

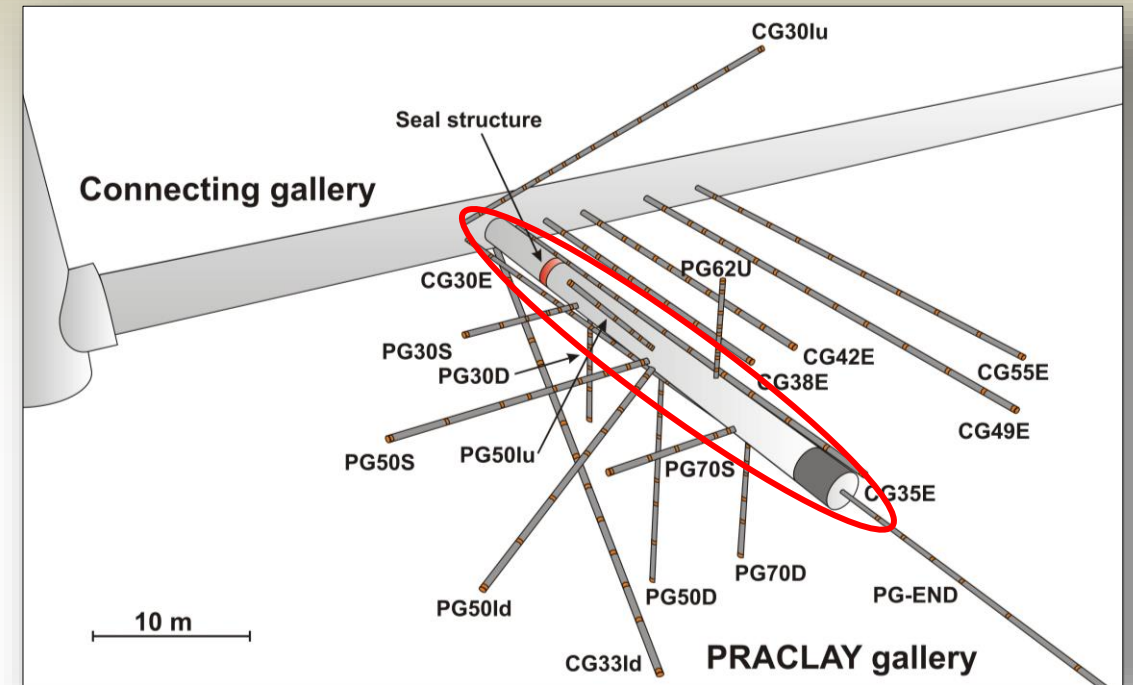
Monitoring set-up



OUTLINE

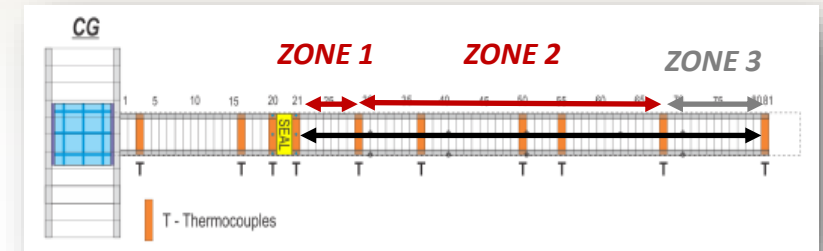
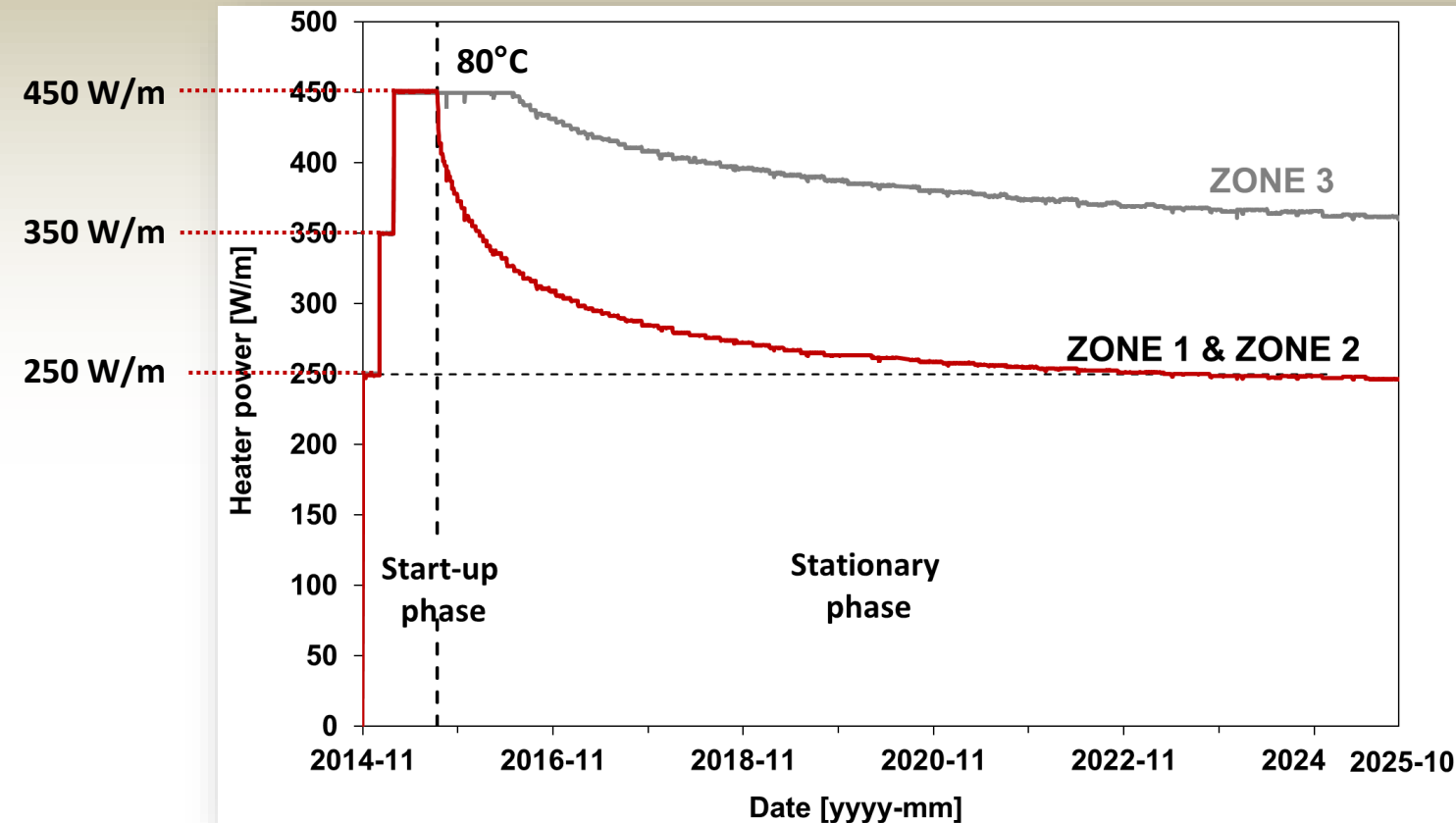
- Heater Test – Steering parameters
- Observations
 - Boom Clay
 - Test set-up (Seal/ Concrete lining)
- Conclusion

Monitoring set-up



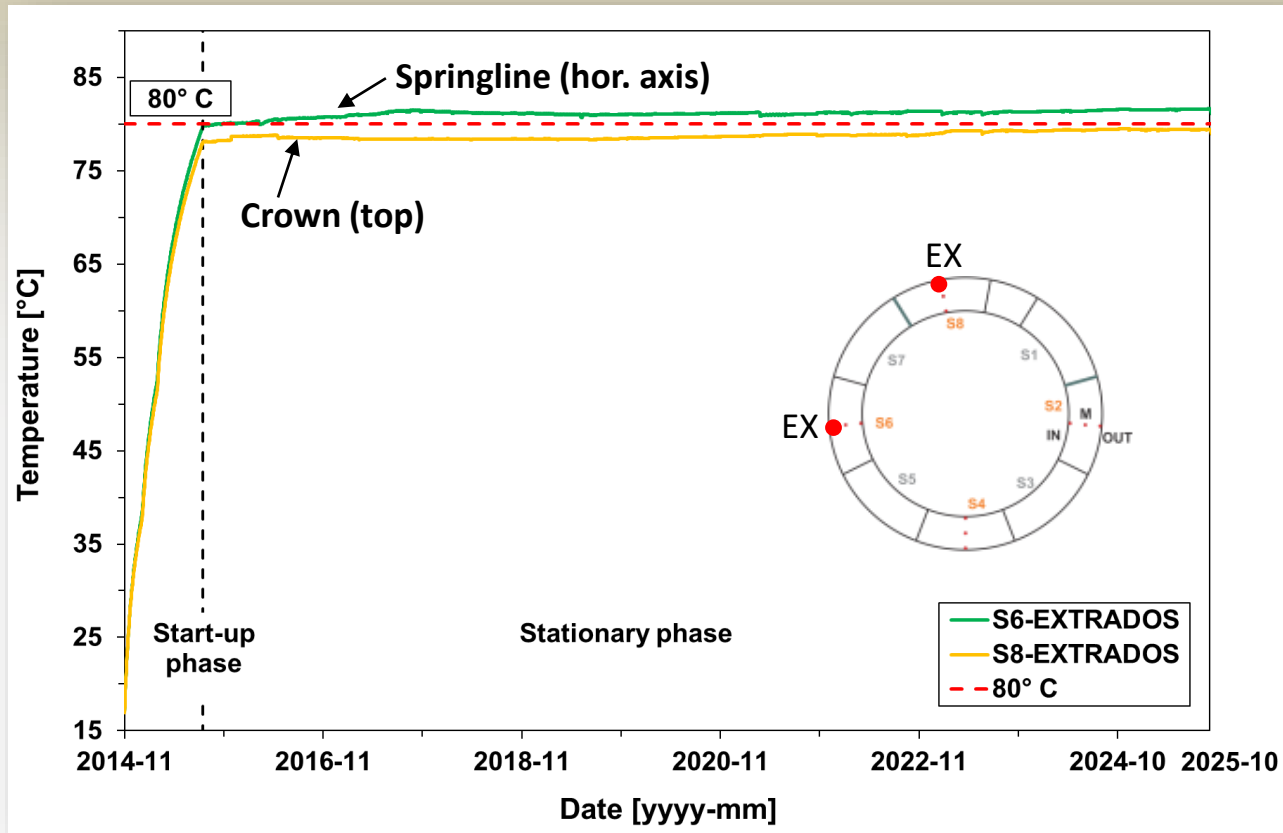
Heating the clay to 80°C

3 Heating steps

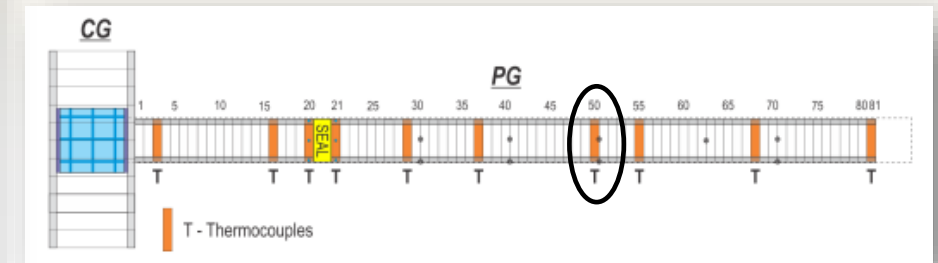


Stable heating at 80°C during 10 years

Temperature at the concrete/clay interface

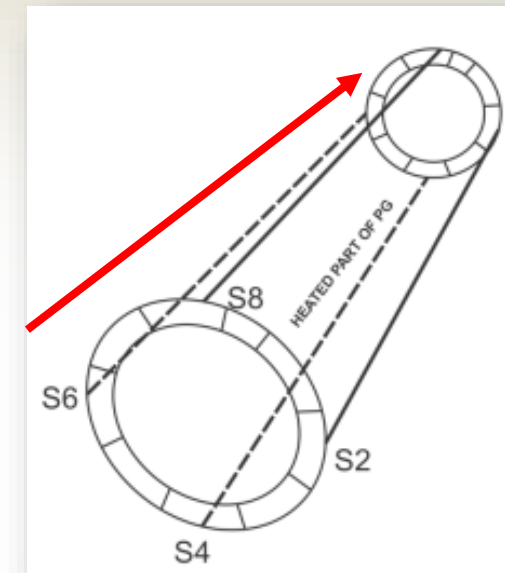
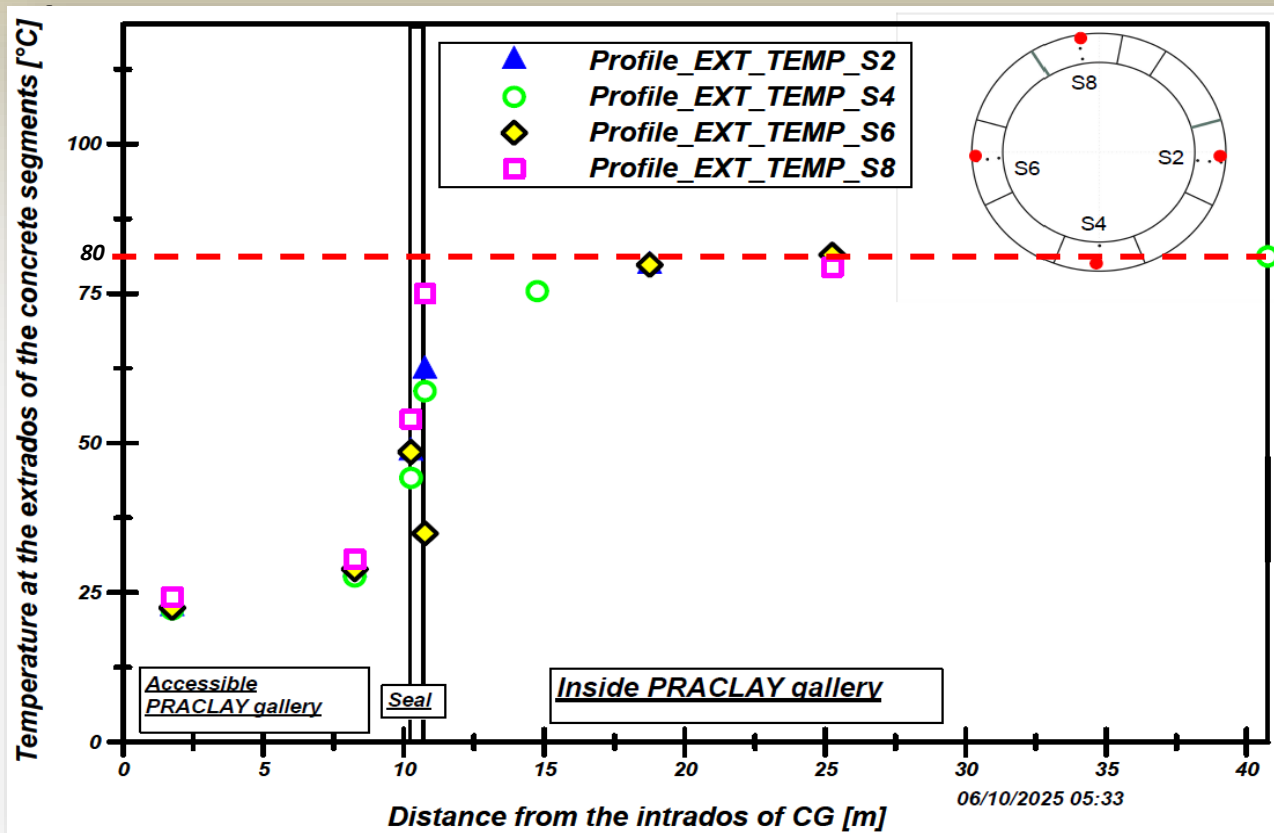


Ring 50



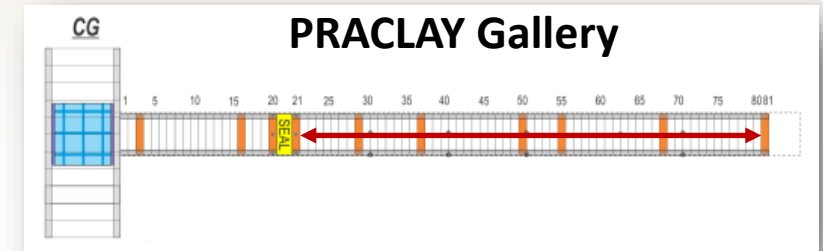
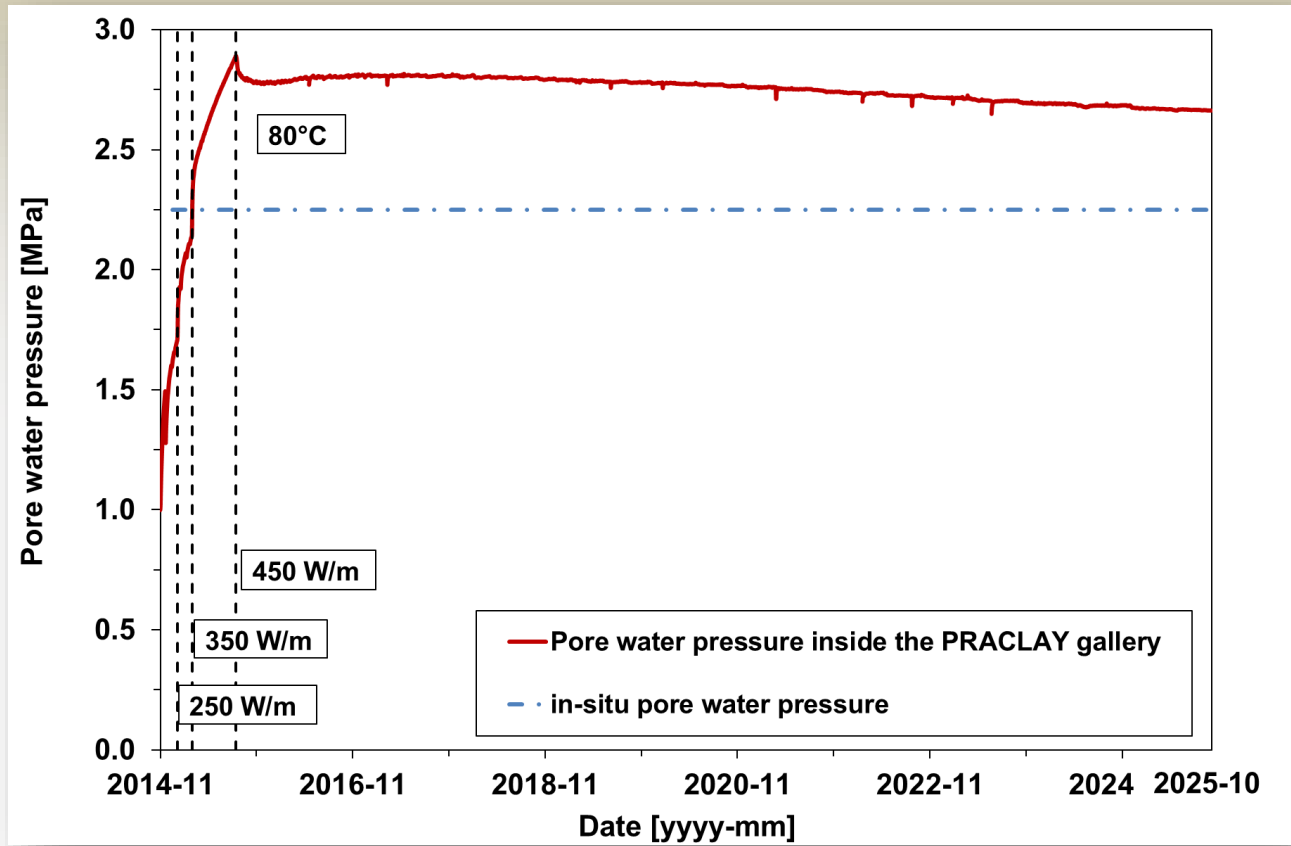
Temperature is uniform along the PG lining

Temperature profiles in concrete lining along the PG at the end of stationary heating



Excess pwp induced by the thermal loading

Pore water pressure (pwp) inside the PG

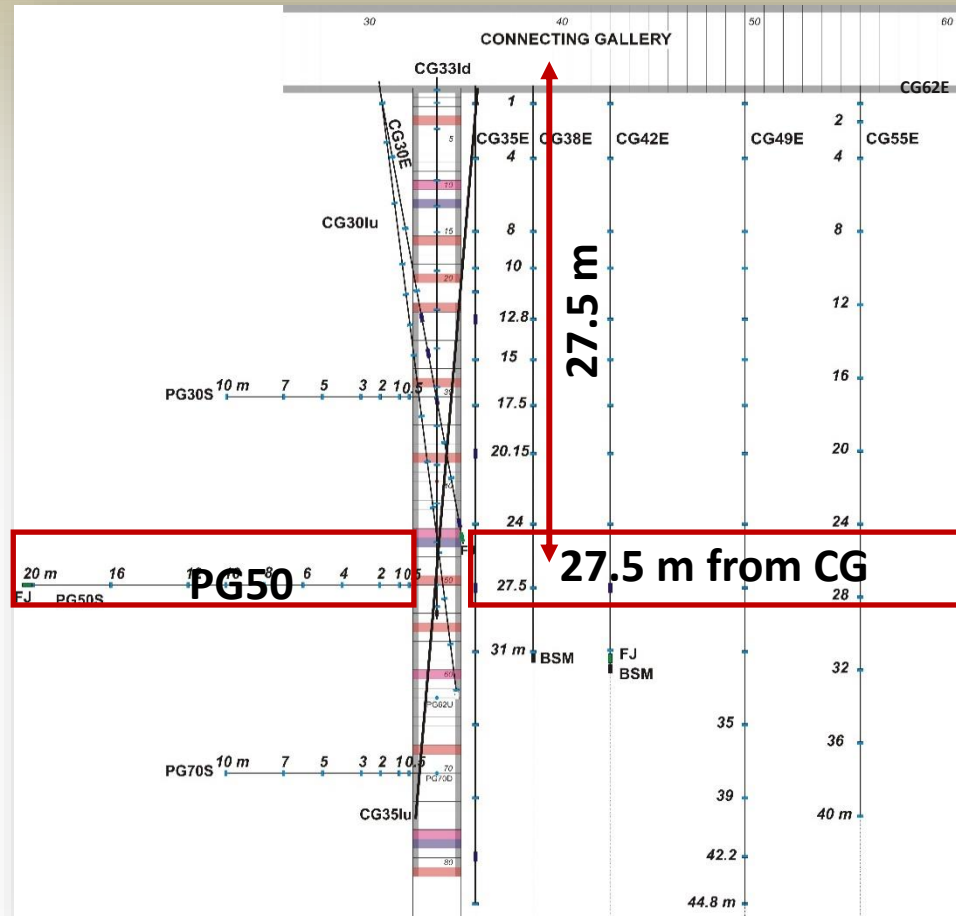


OUTLINE

- Heater Test – Steering parameters
- Observations
 - Boom Clay
 - Test set-up (Seal/ Concrete lining)
- Conclusion

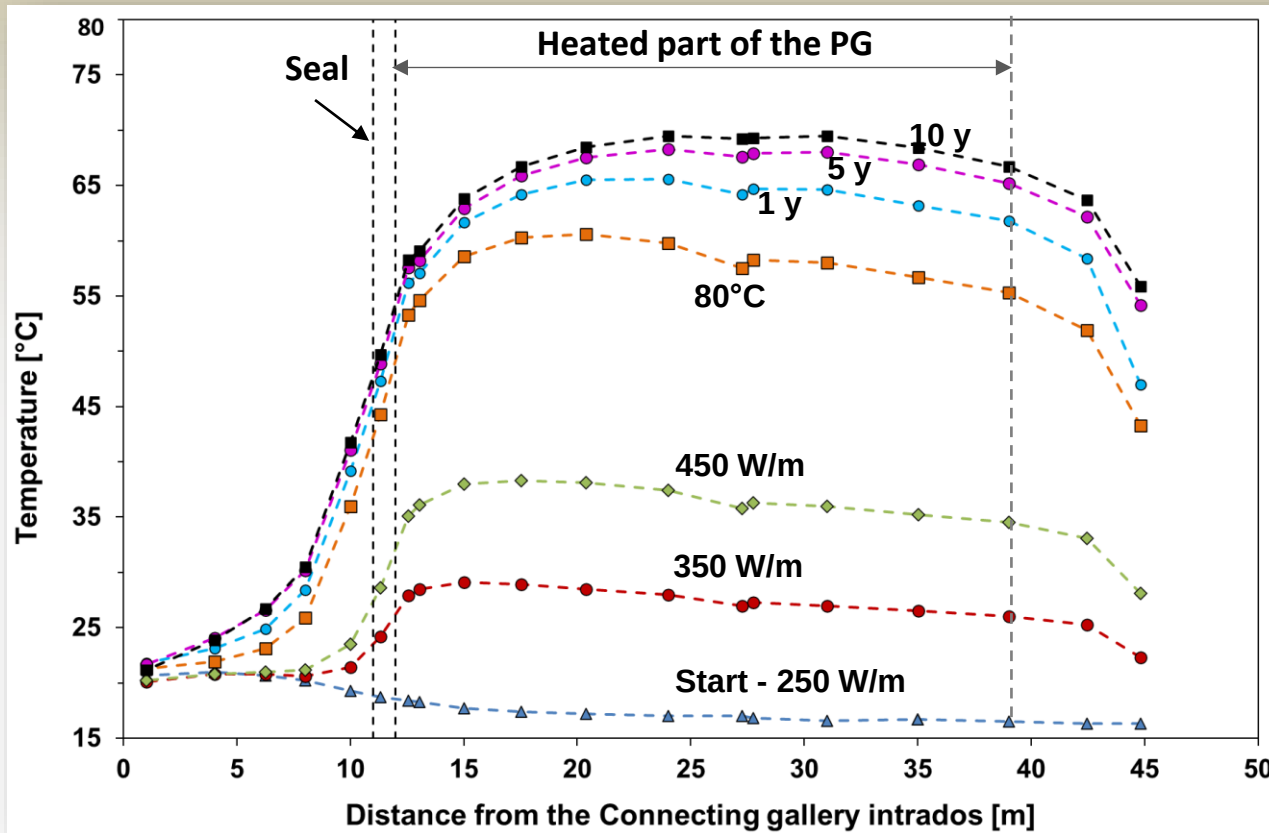


What do we observe in the clay?

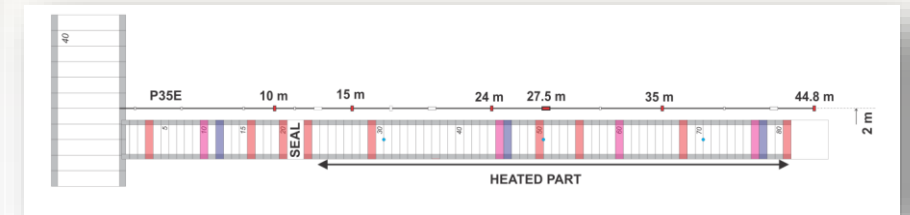


Temperature in the Boom Clay along the PG

Temperature profiles in borehole CG35E at various times

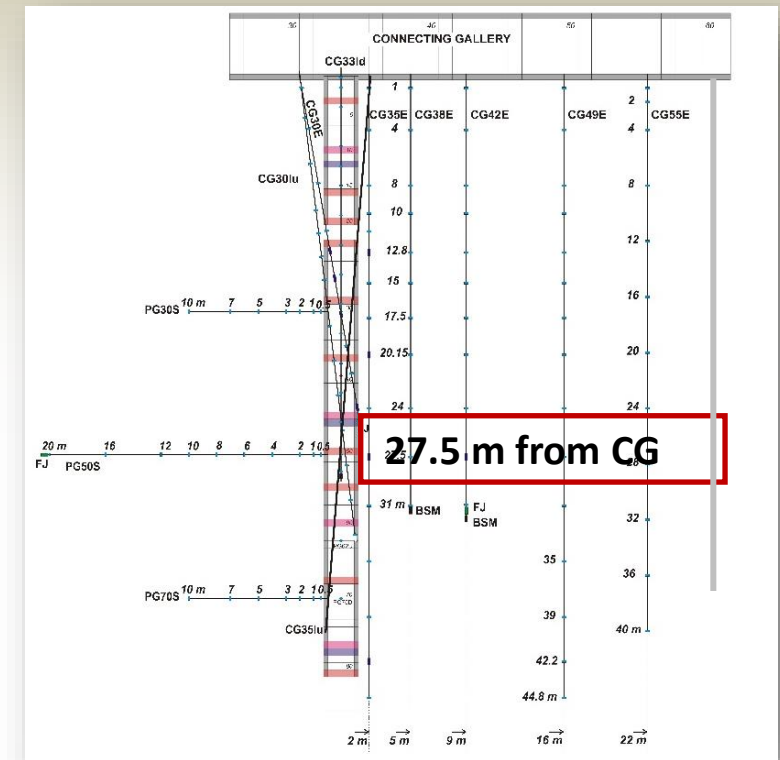
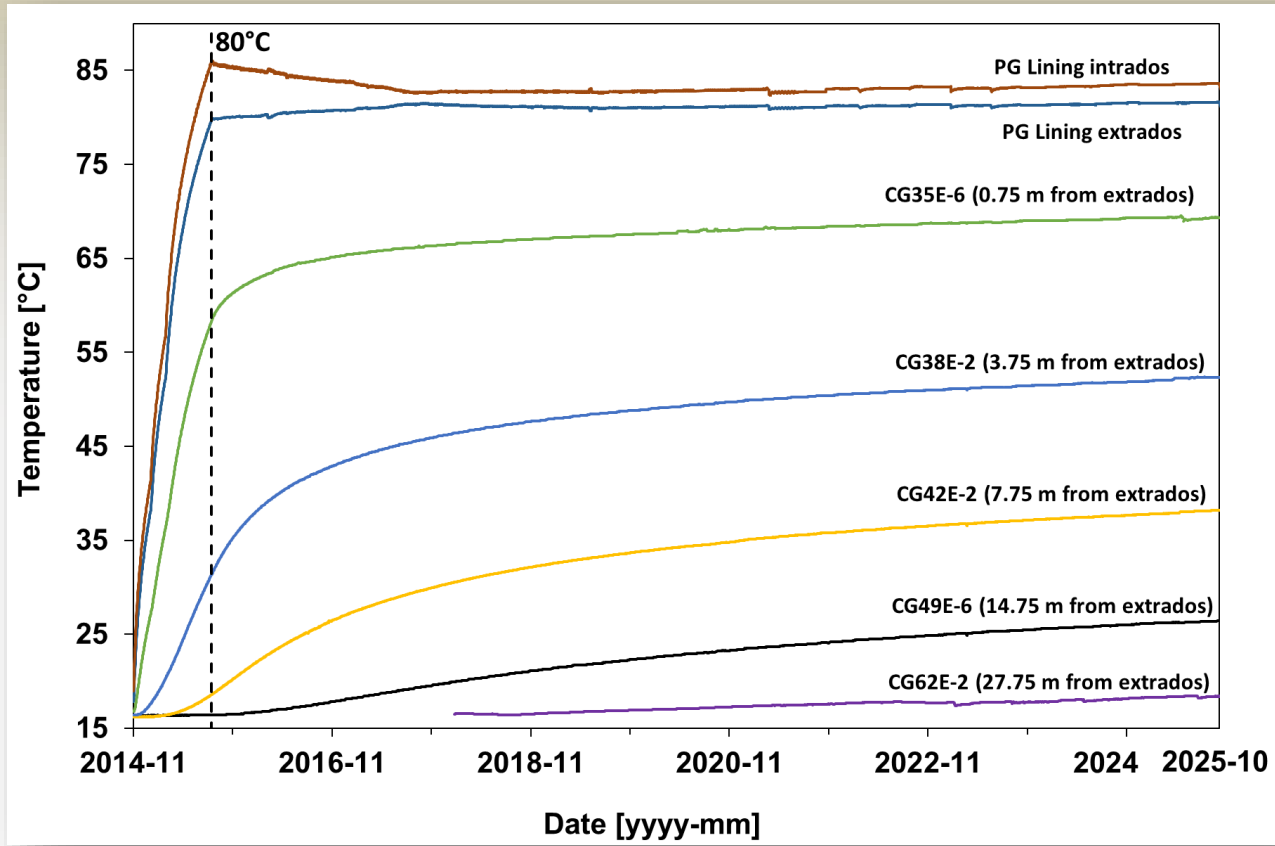


CG35E: ~2 m from PG → perturbed zone



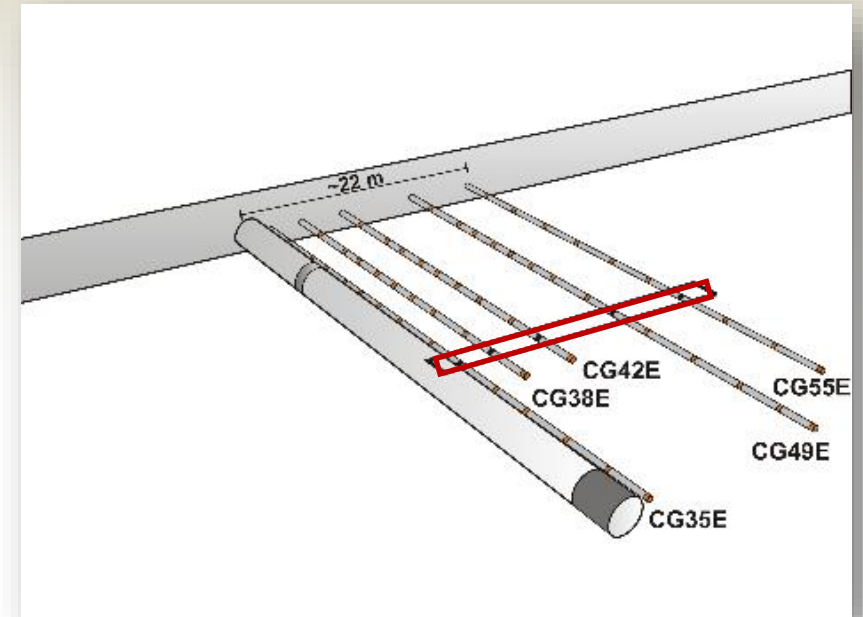
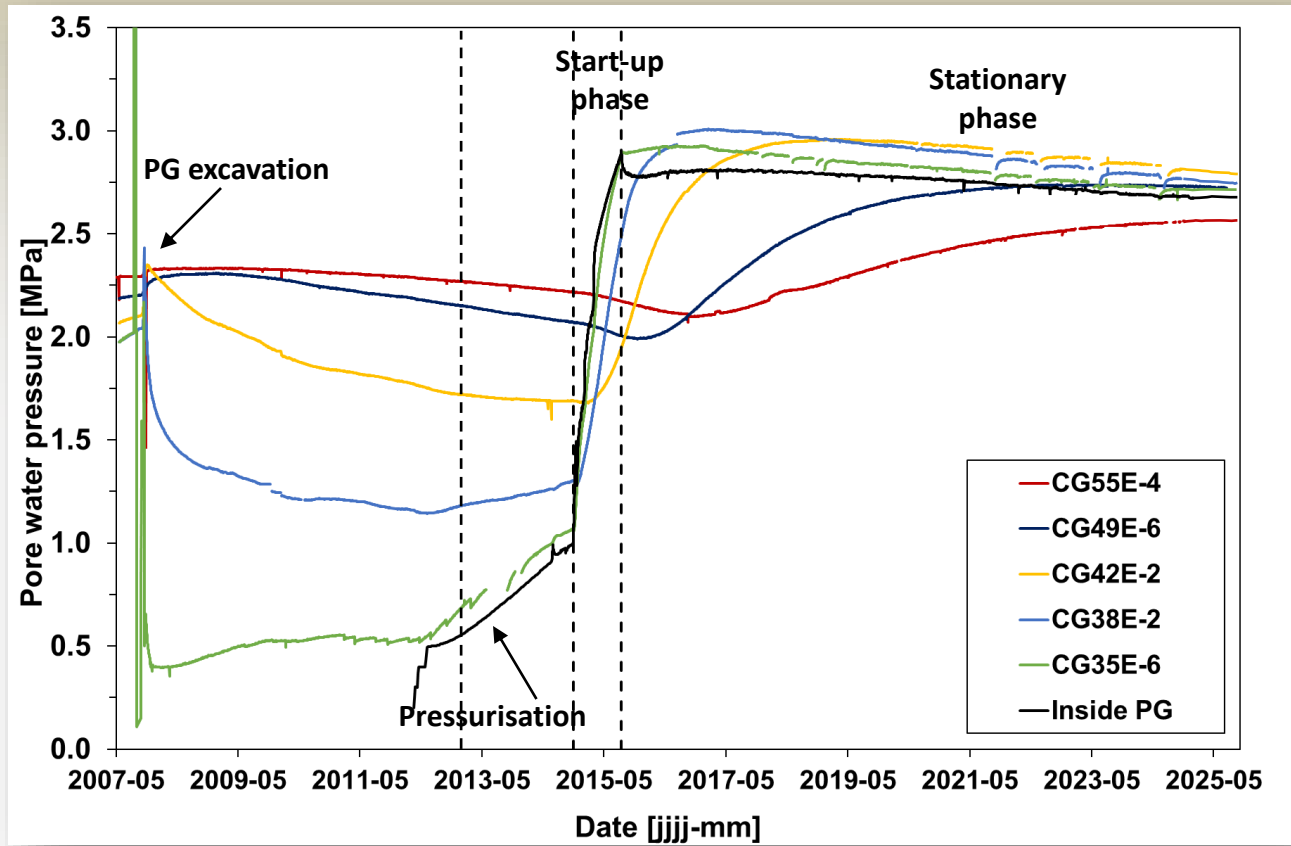
Temperature evolution in time

Various horizontal distances from the PG



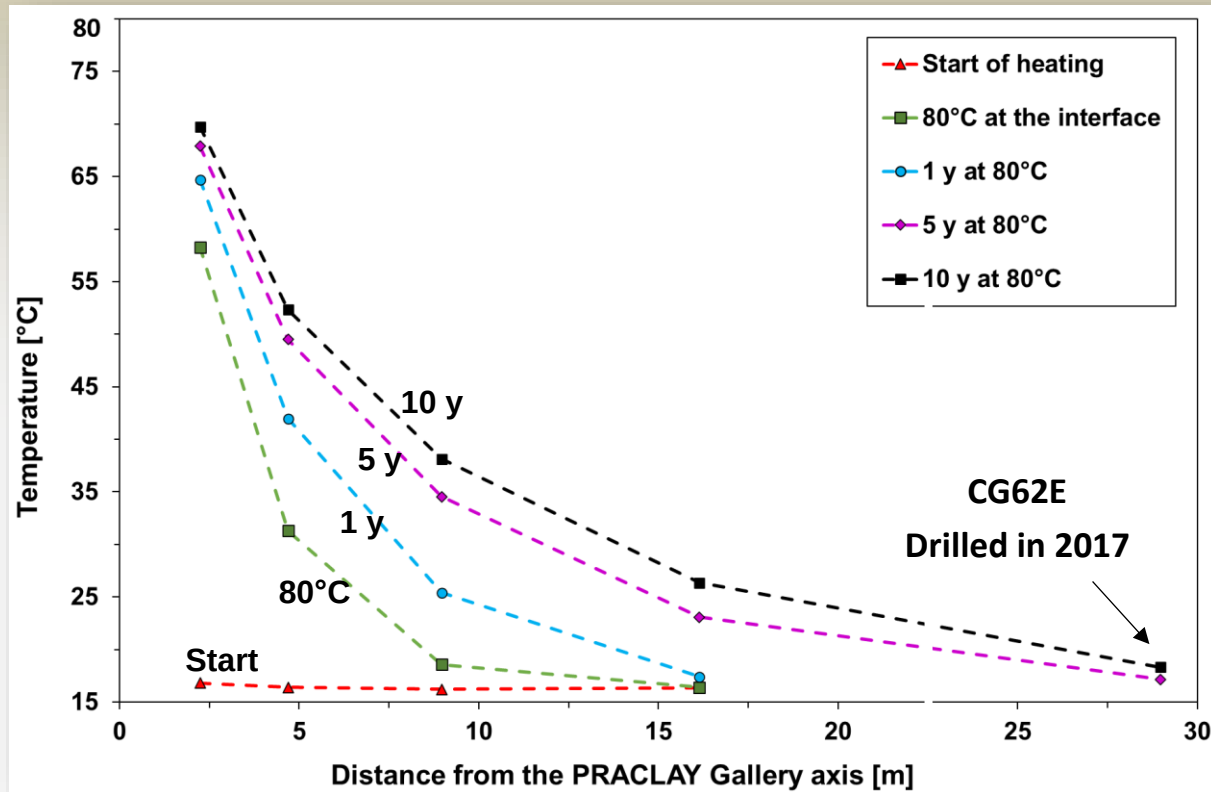
Pore water pressure evolution

Pore water pressure in function of time

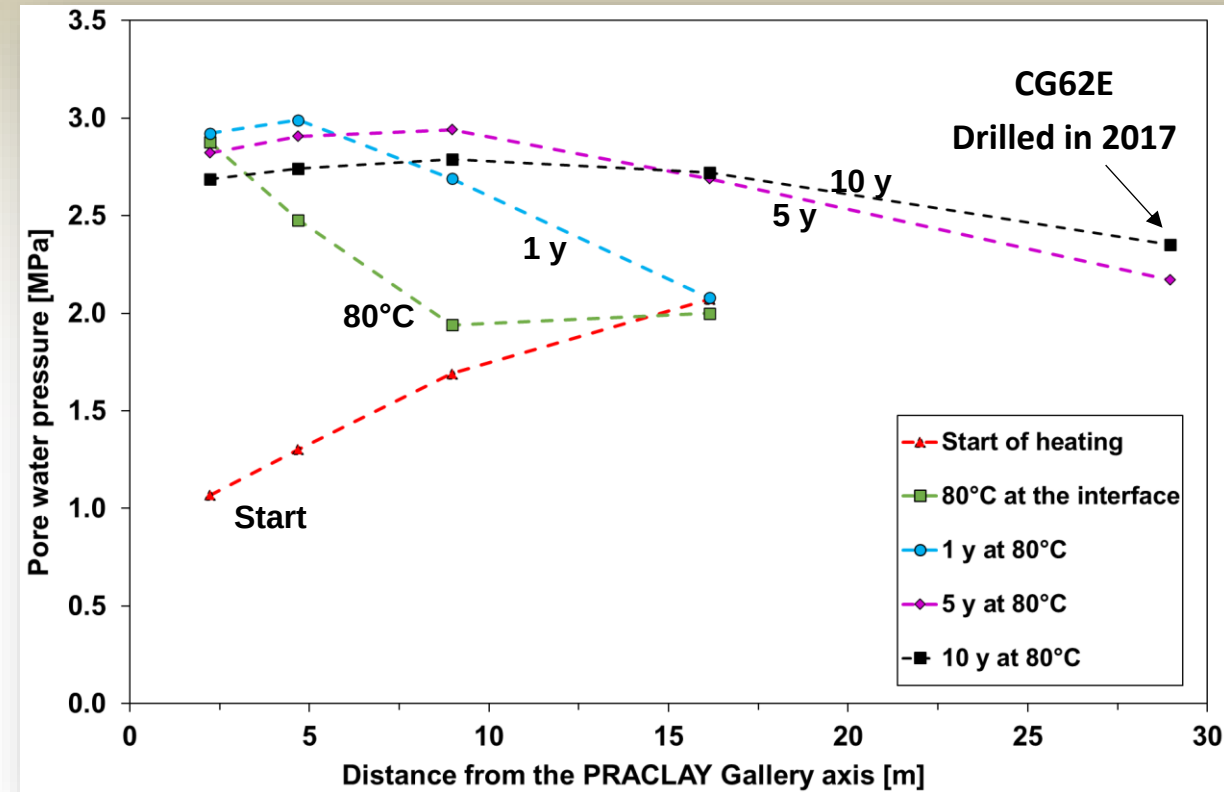


Effects in function of horizontal distance to PG

Temperature profiles

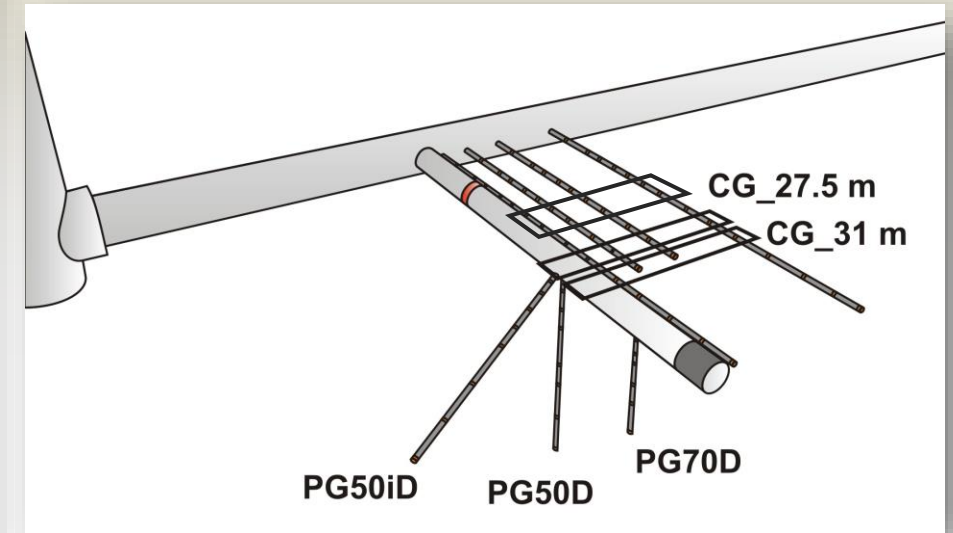
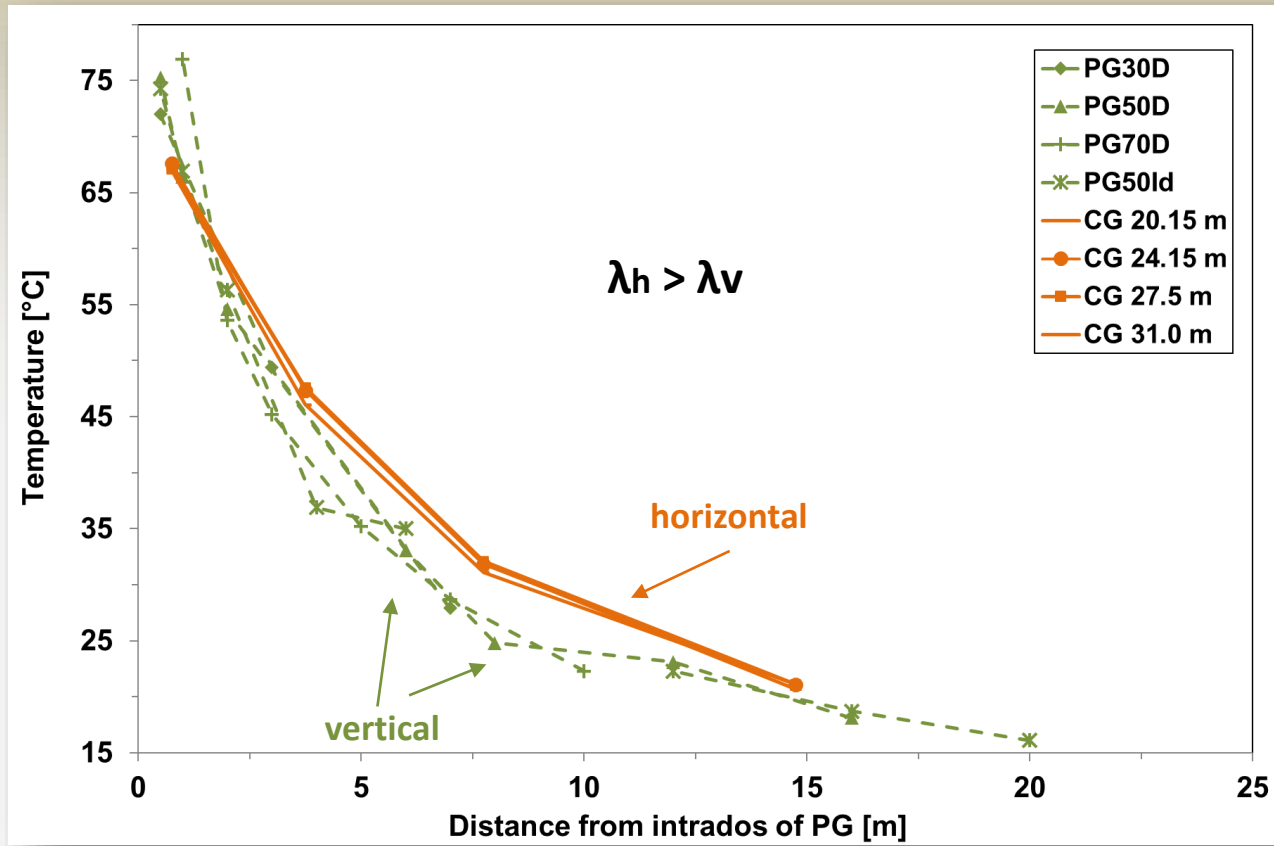


Pore water pressure profiles



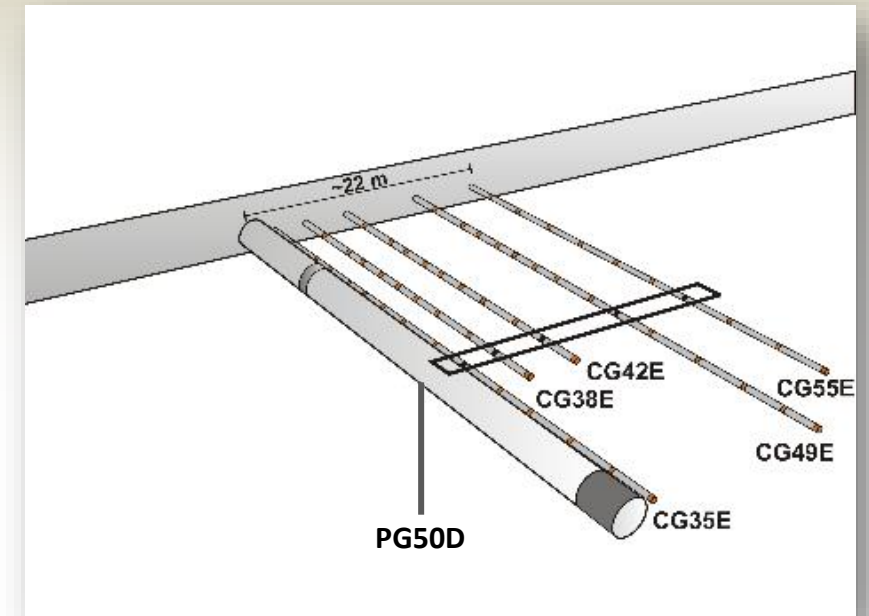
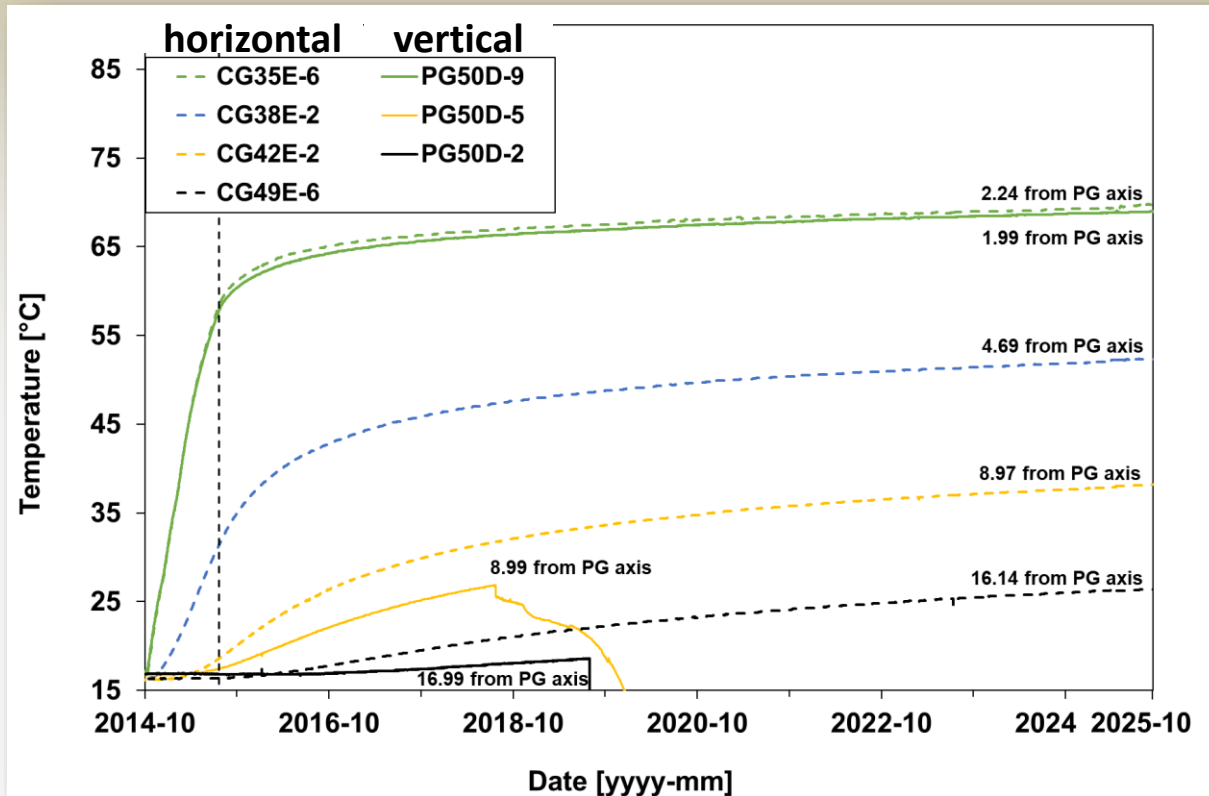
Temperature profiles during steady state

Horizontal versus vertical



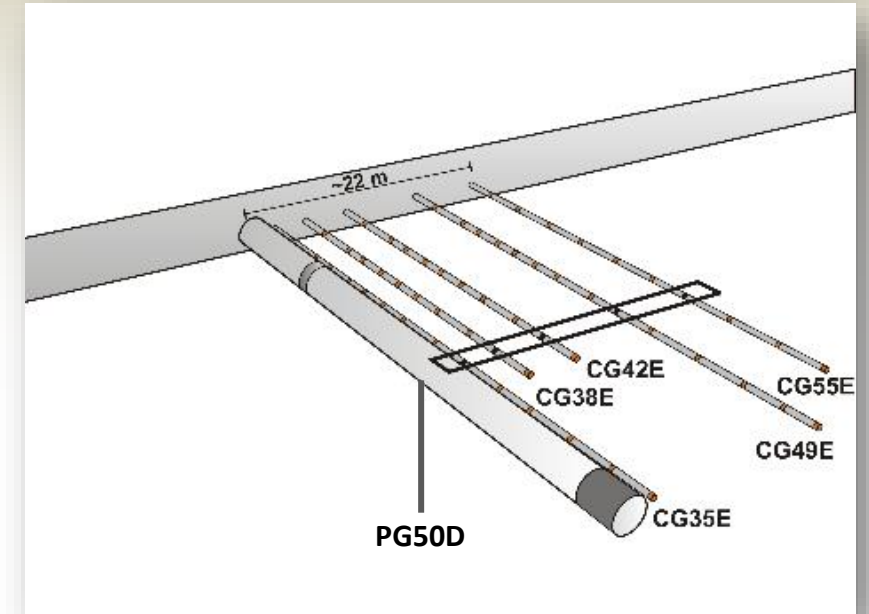
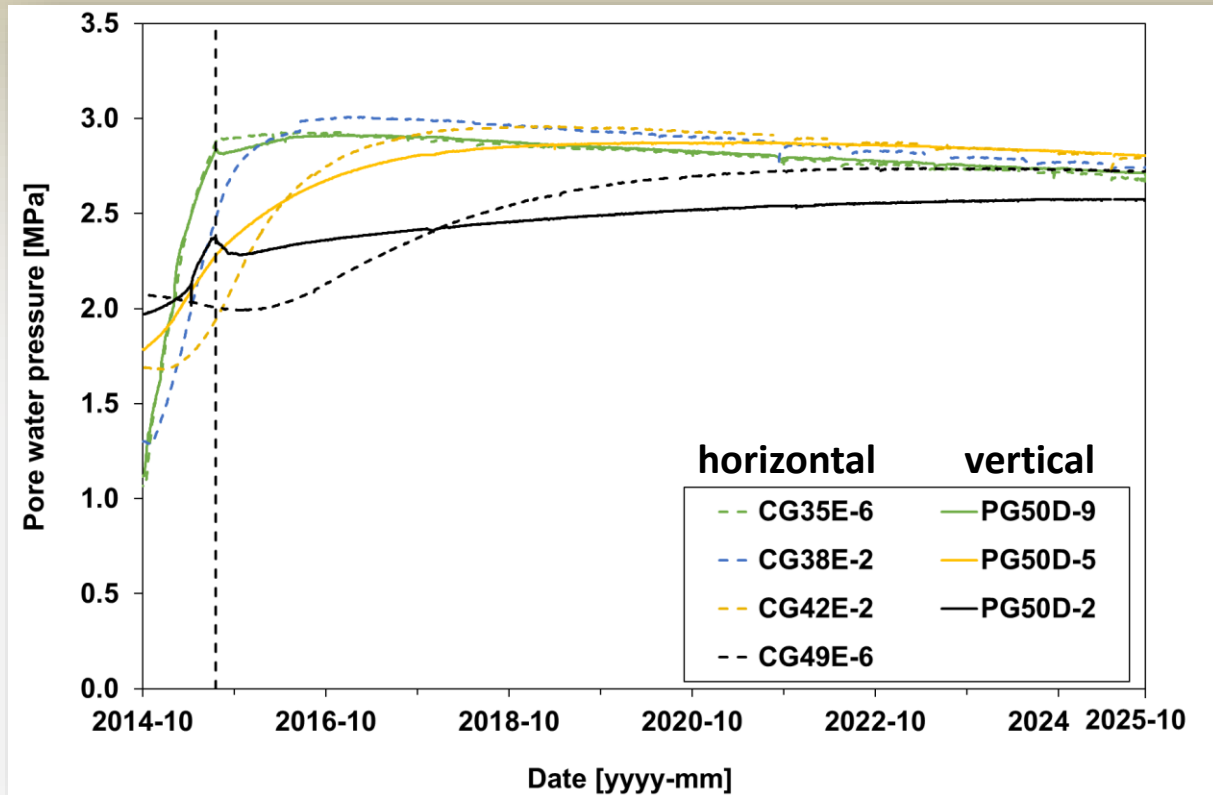
Vertical vs horizontal boreholes

Temperature evolution



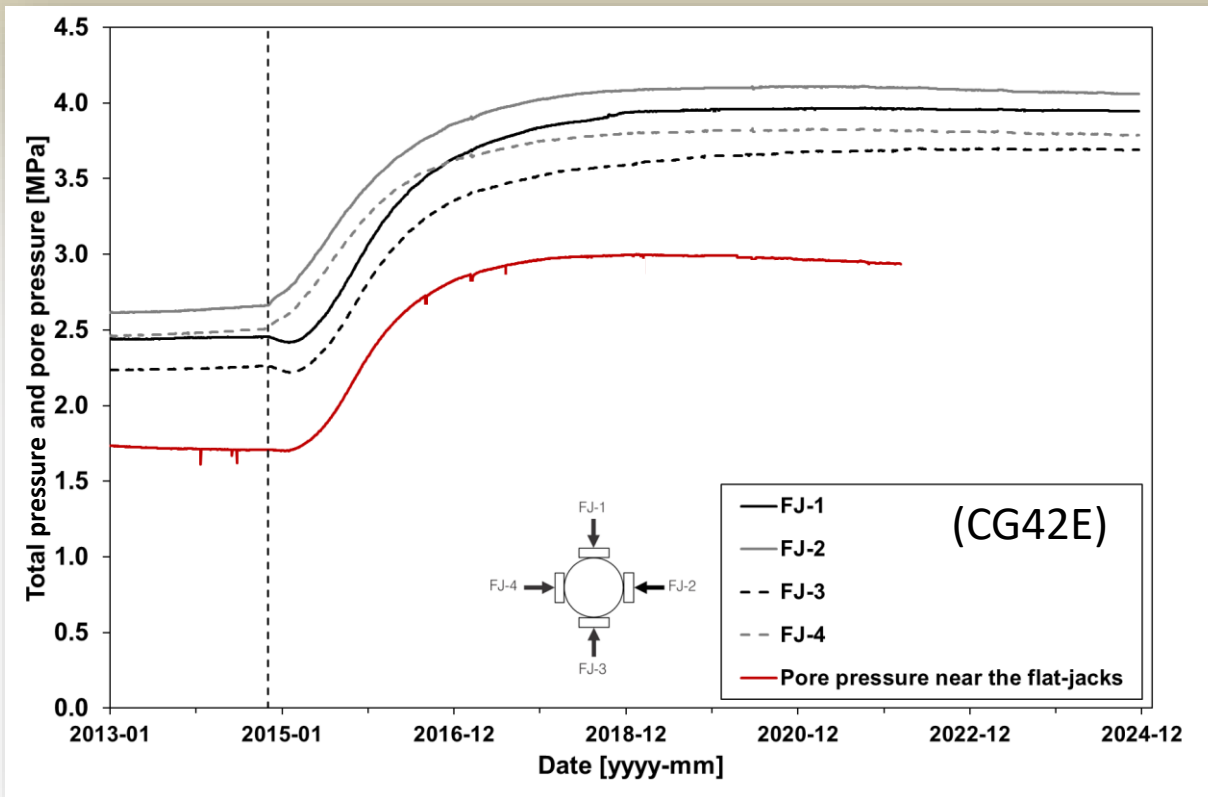
Vertical vs horizontal boreholes

Pore water pressure evolution

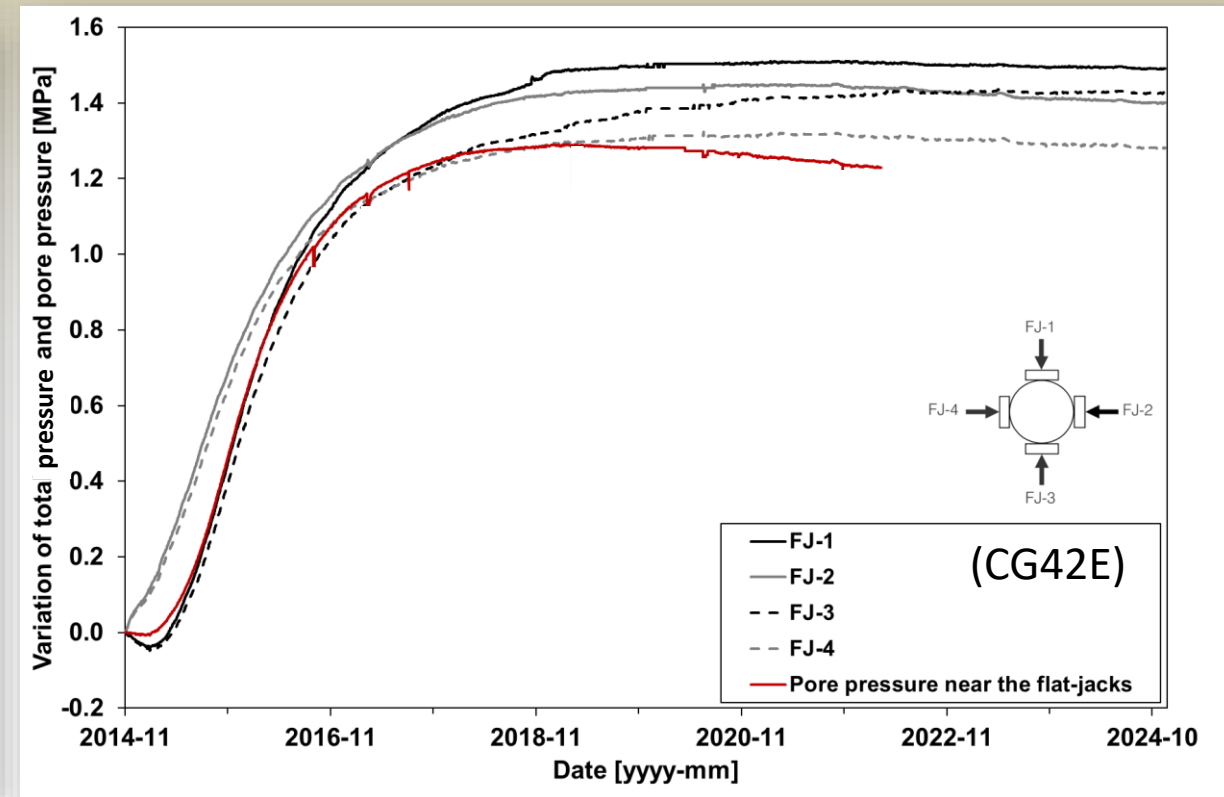


Total pressure in the clay: 9 m from the PG

Total pressure



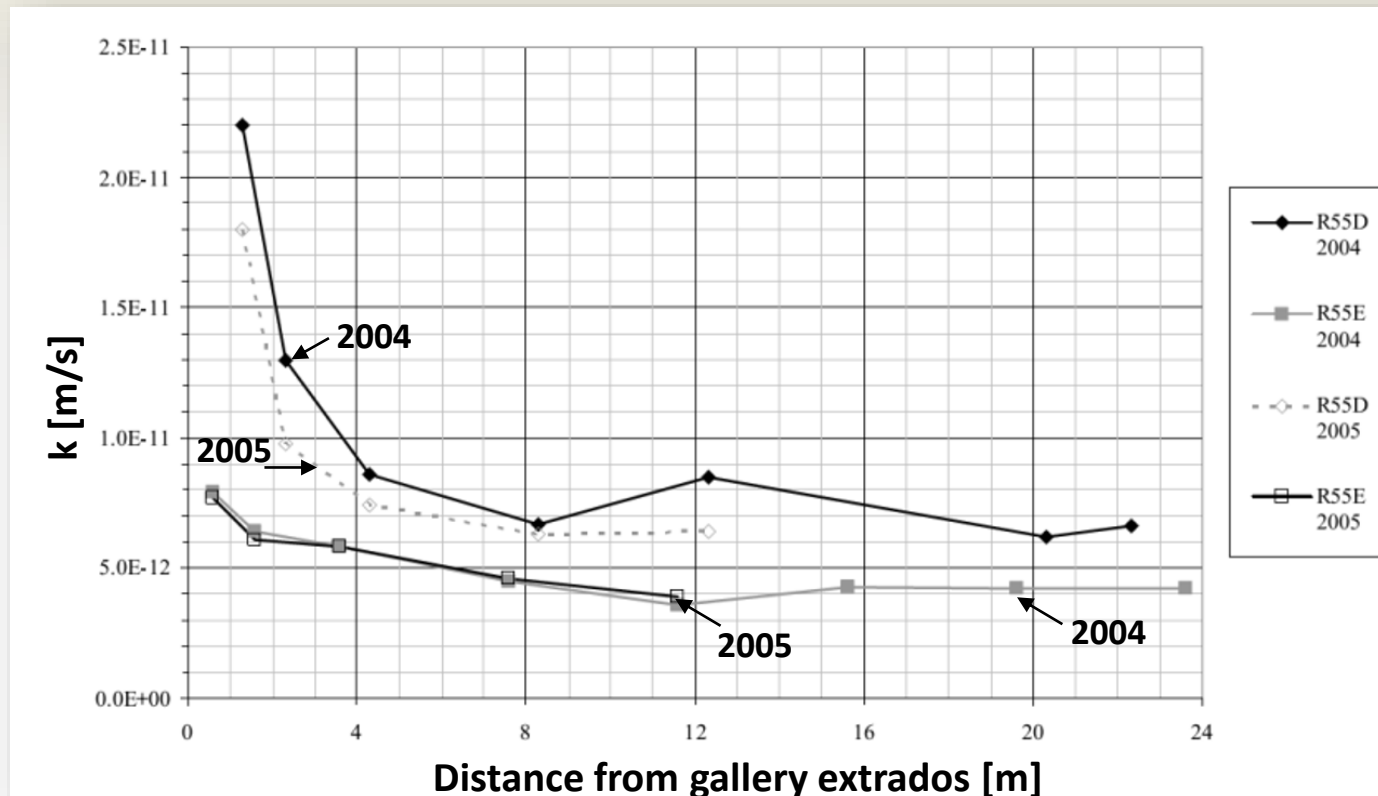
Variation of total pressure



Does the clay withstand the thermal load?

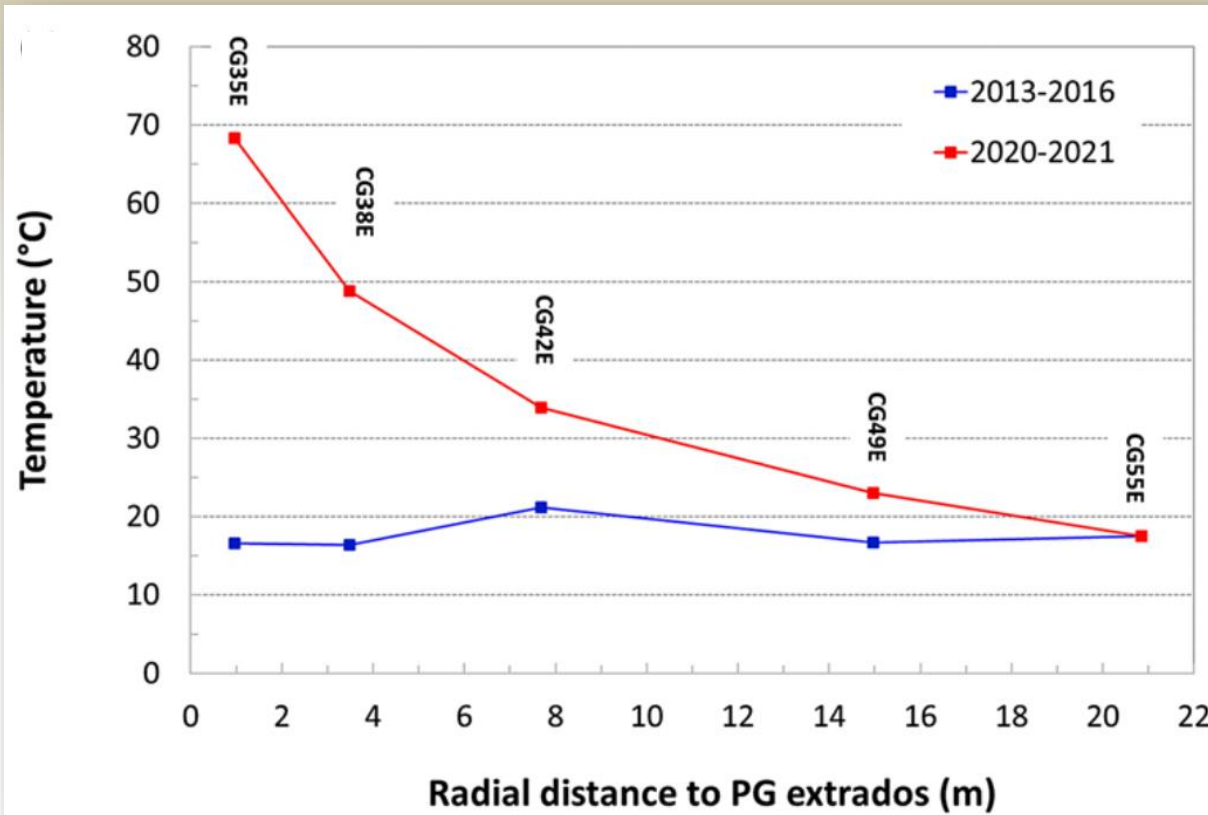
- Pore water pressure observation → no sudden changes
- Damages → modification of permeability

Permeability tests shortly after the excavation of the Connecting Gallery

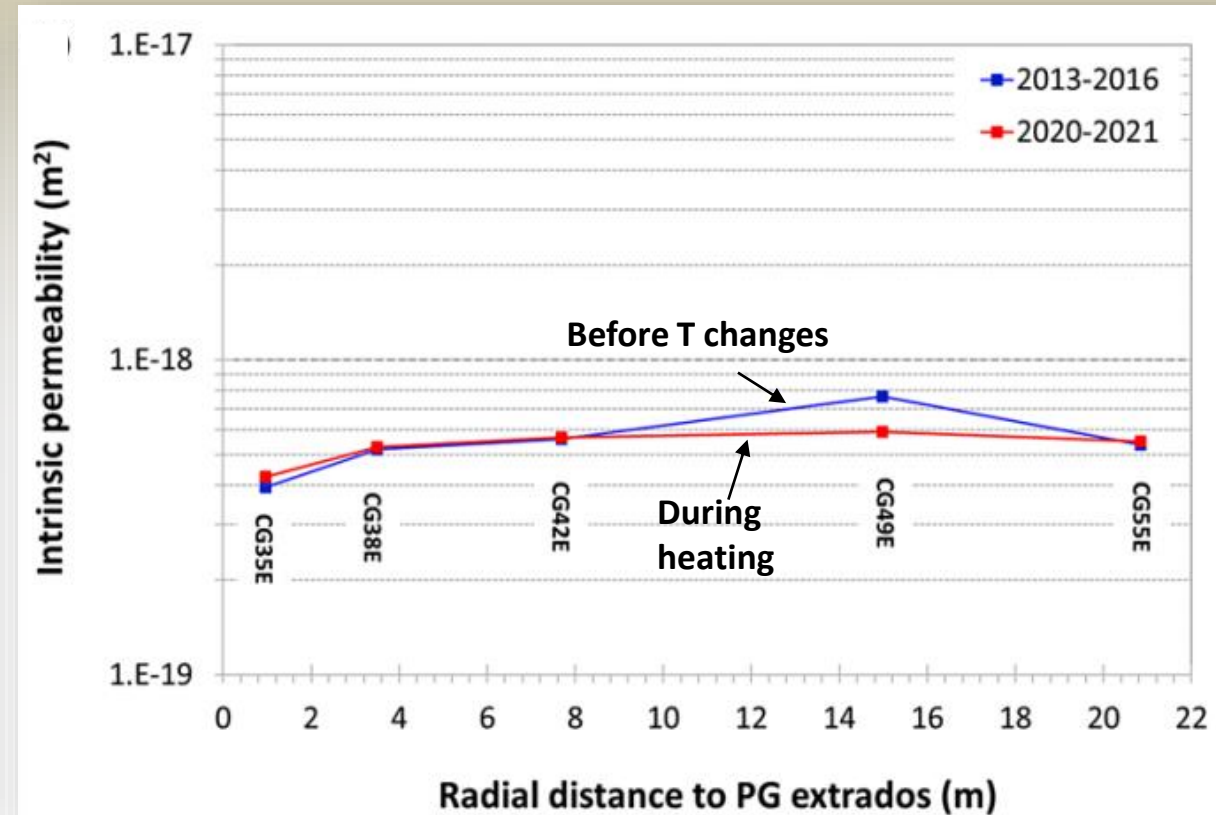


Does the clay withstand the thermal load?

Temperature profiles



Intrinsic permeability profiles



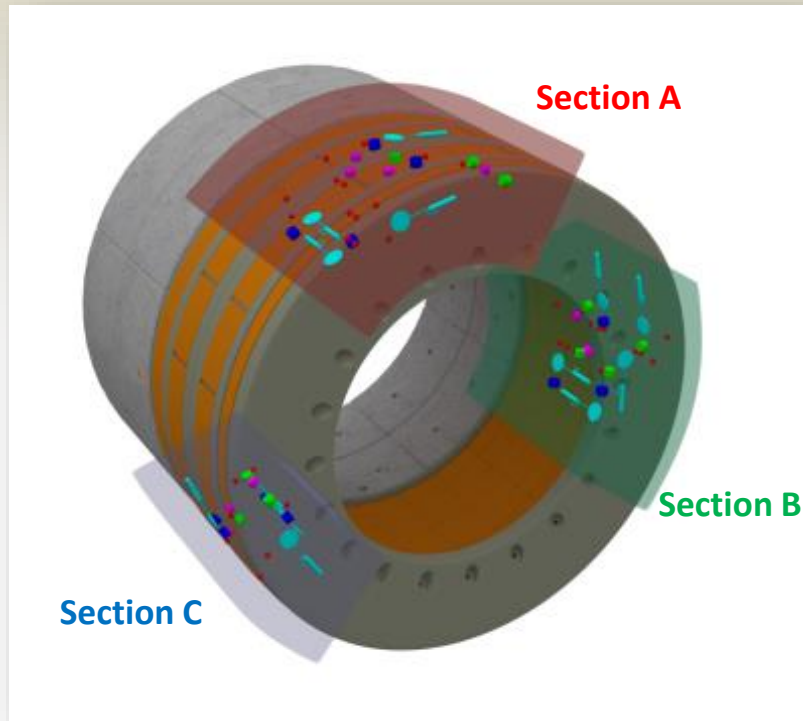
OUTLINE

- Heater Test – Steering parameters
- Observations
 - Boom Clay
 - Test set-up (Seal/ Concrete lining)
- Conclusion

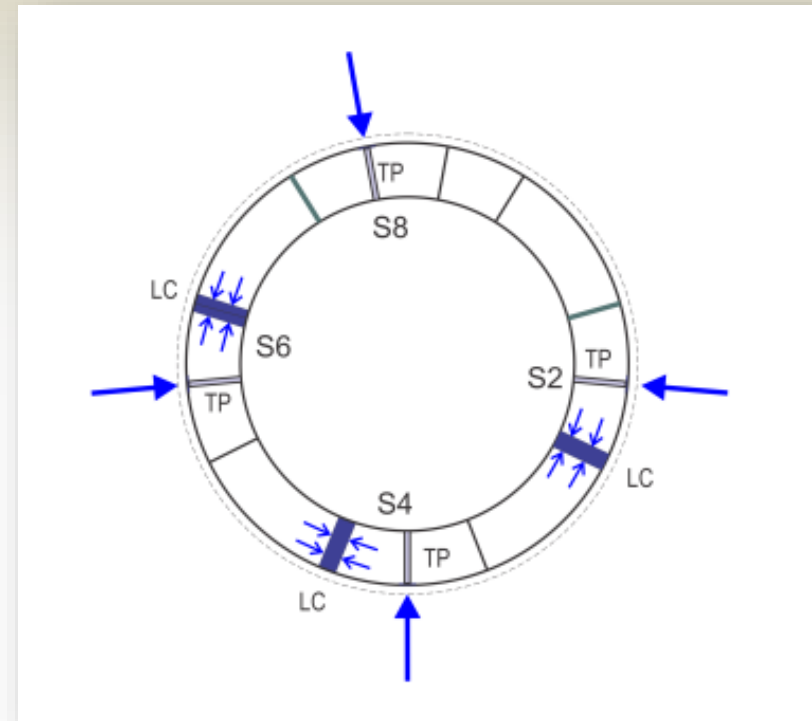


What do we observe in the seal and the concrete lining?

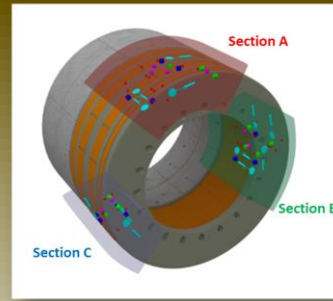
Seal



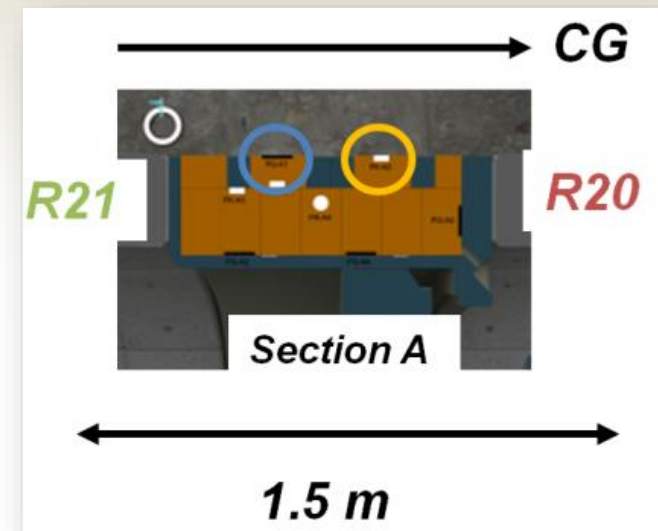
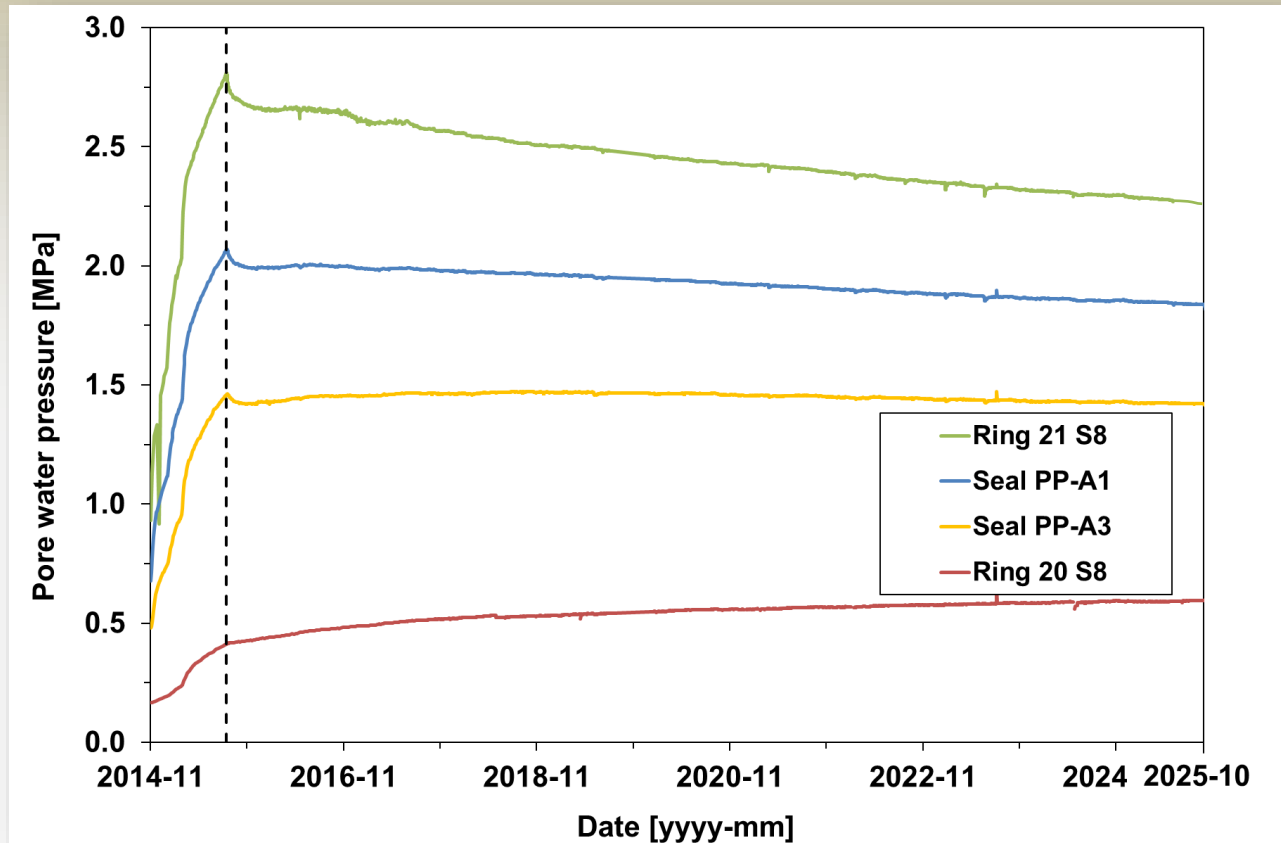
Concrete lining



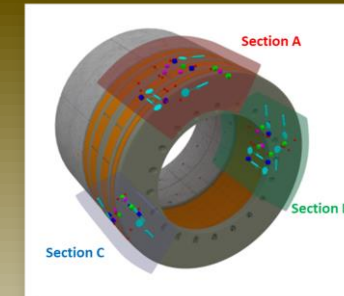
Pore water pressure evolution in the seal



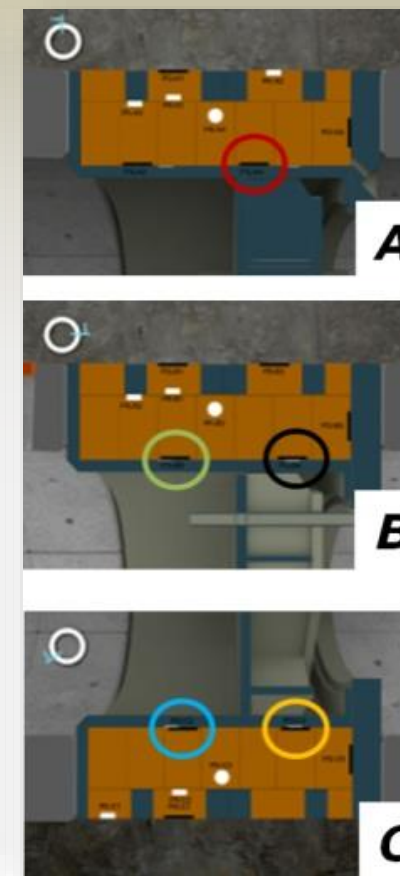
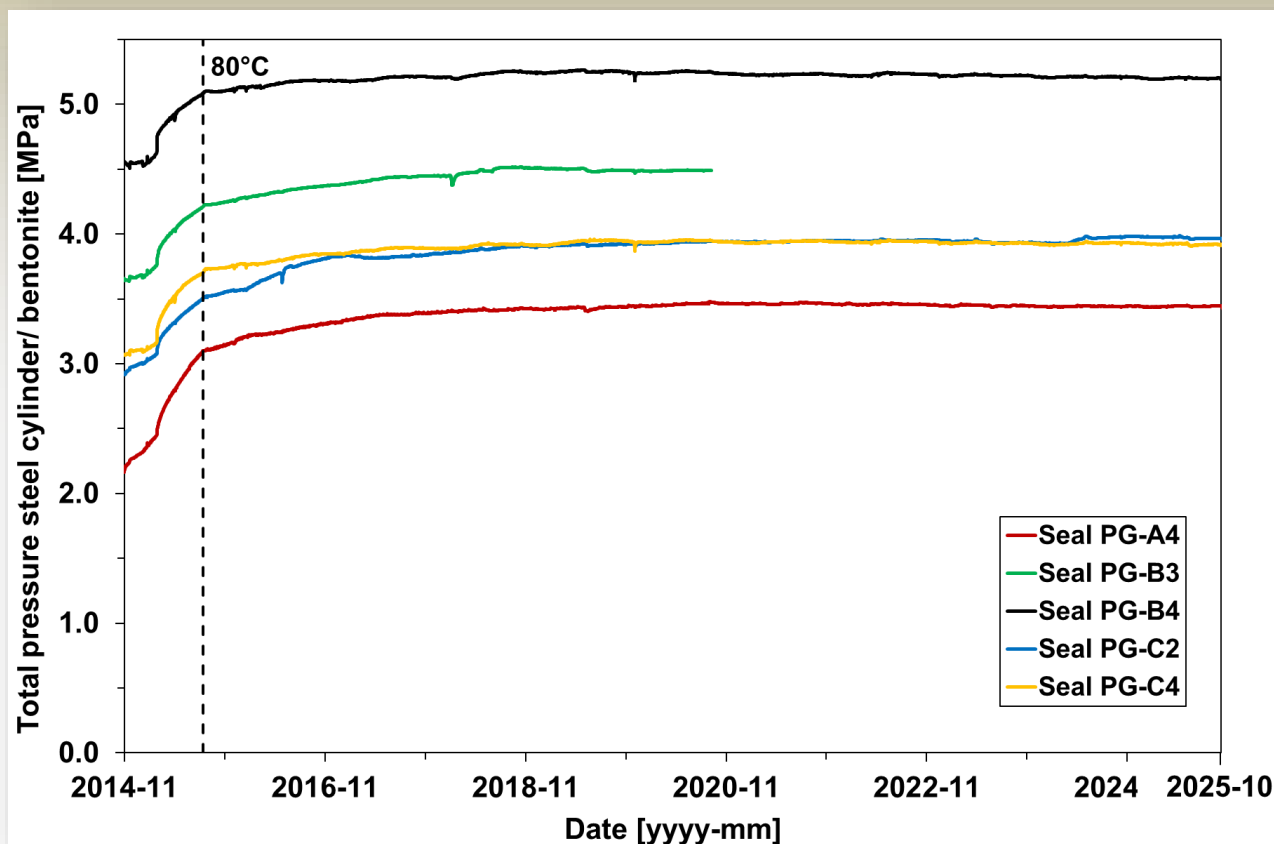
At Boom Clay/ bentonite interface



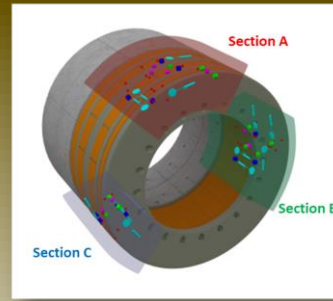
Total pressure evolution at in the seal



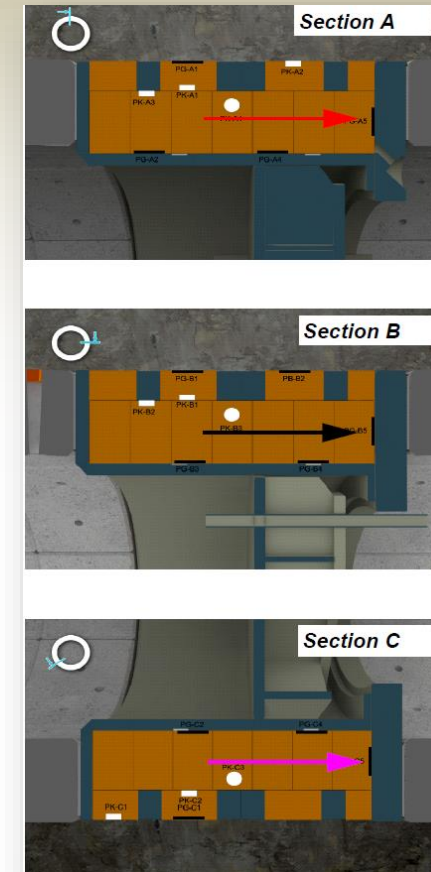
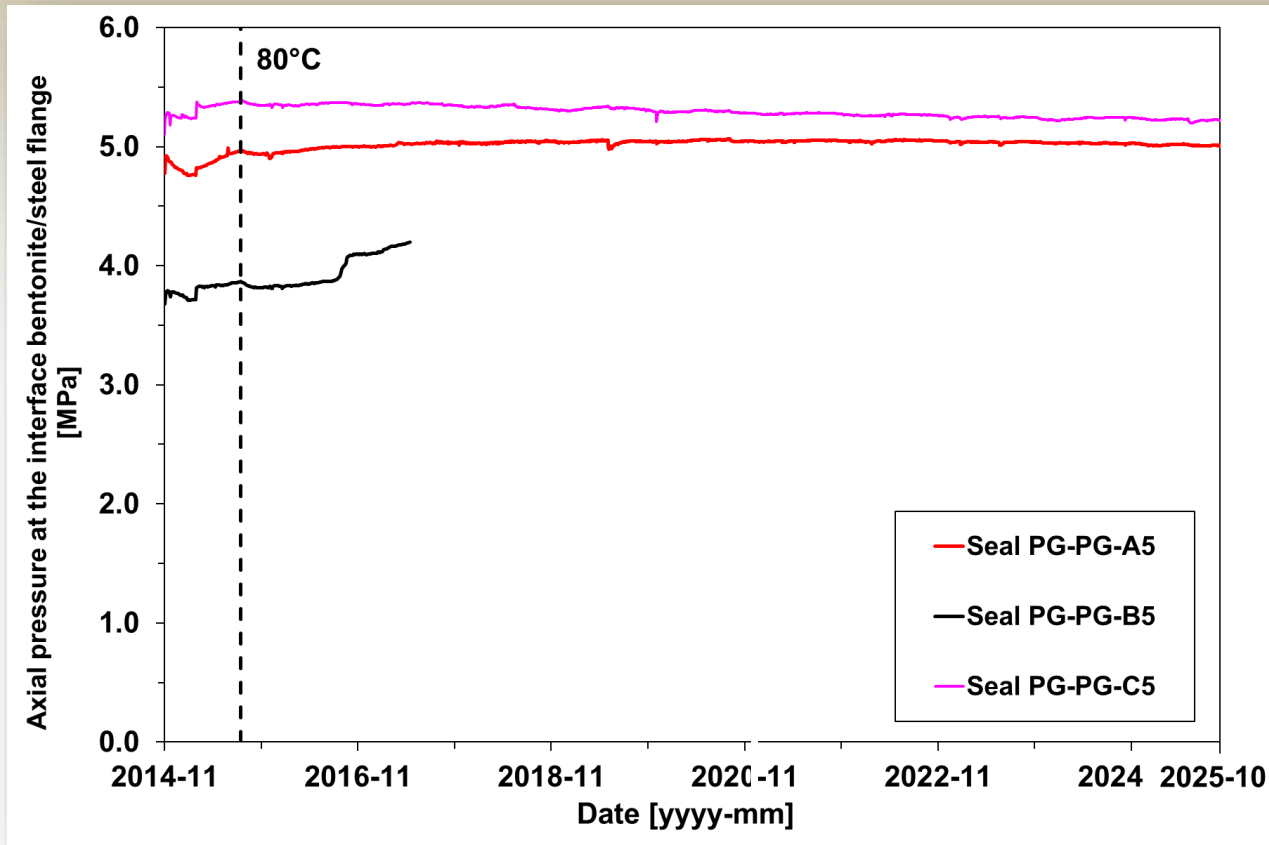
At Boom Clay/ bentonite interface



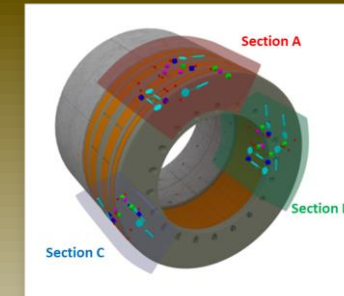
Axial pressure evolution in the seal



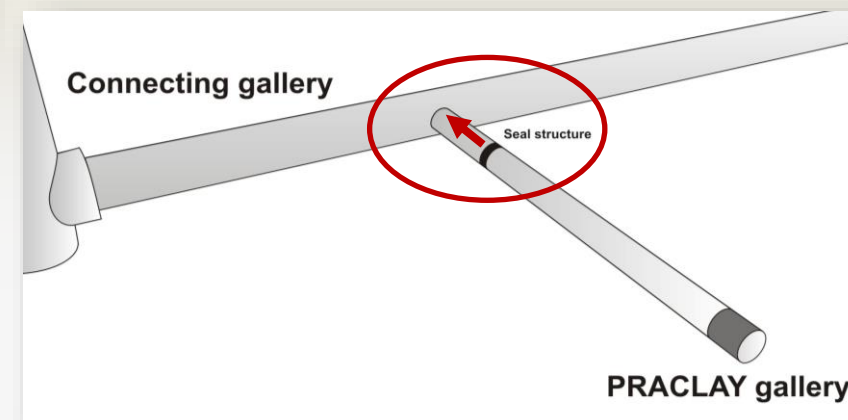
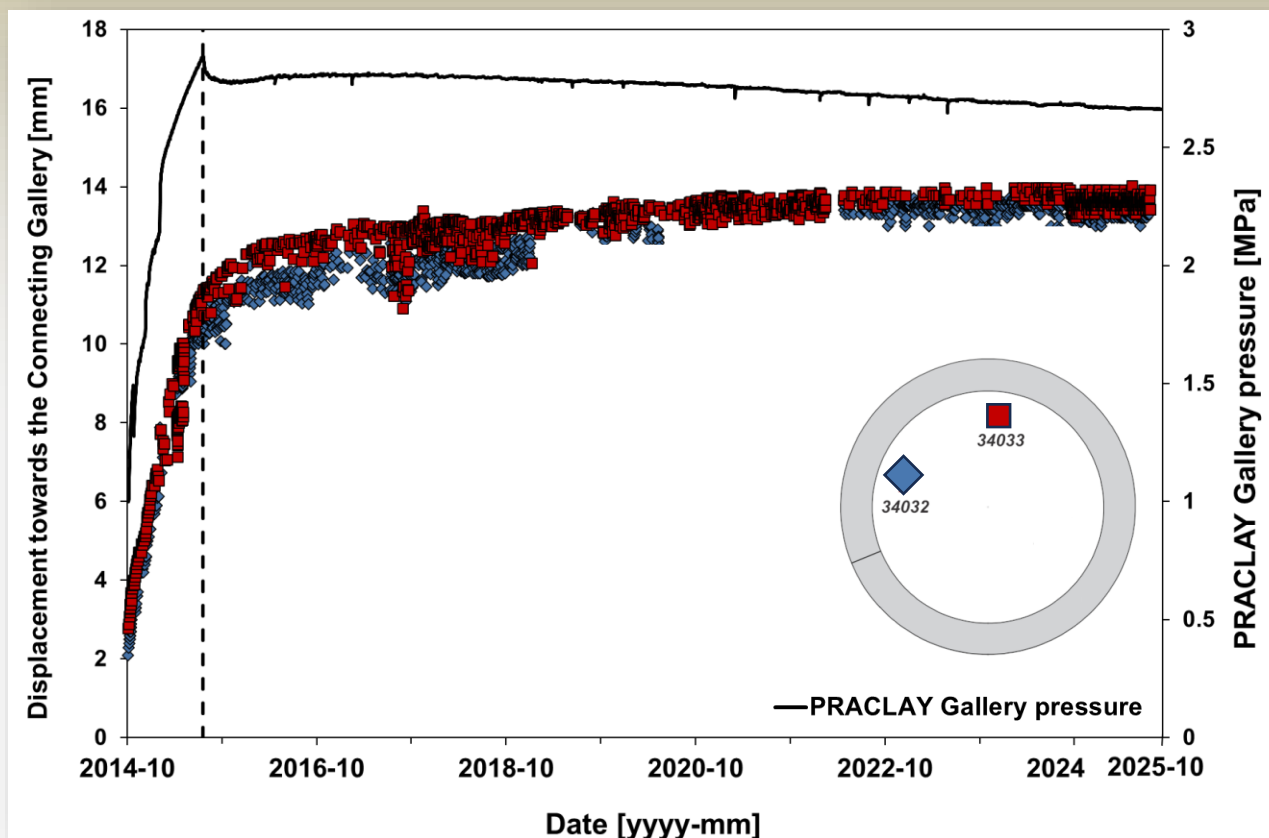
At bentonite/steel cylinder interface



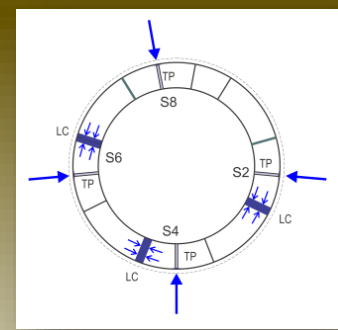
Displacement of the seal



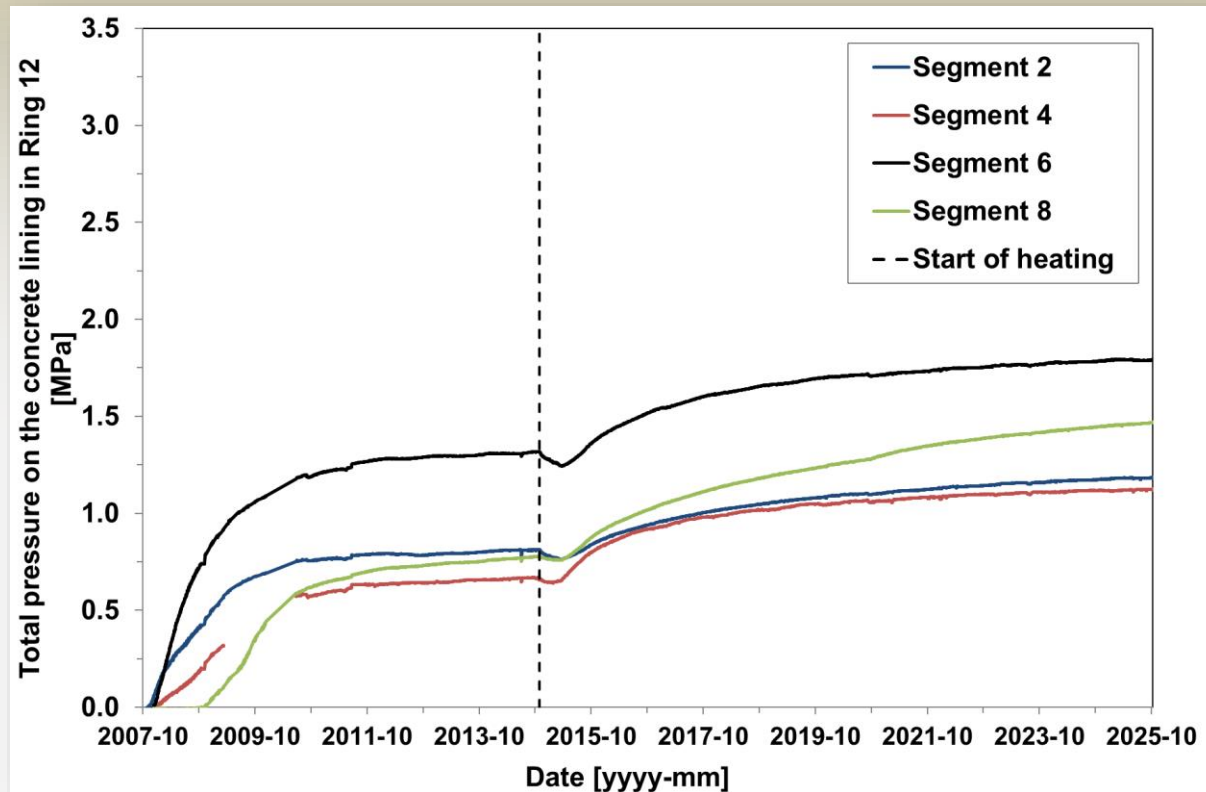
Towards the Connecting Gallery



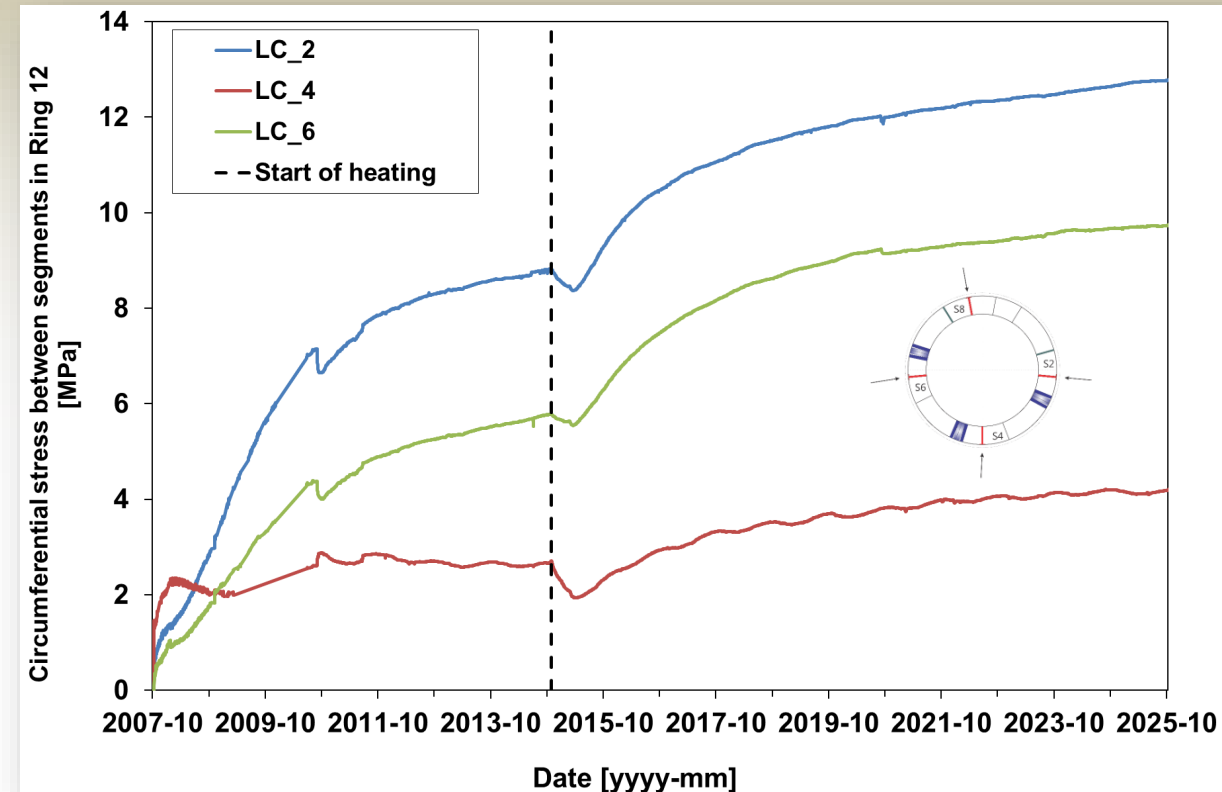
Observations in the lining: non-heated part



Total pressure in the non-heated part (Ring 12)

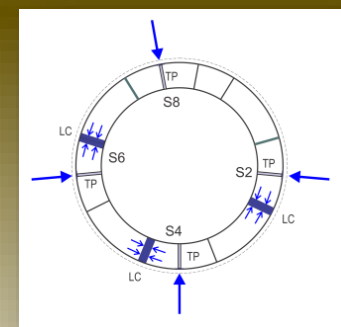


Circumferential stress in the non-heated part (Ring 12)

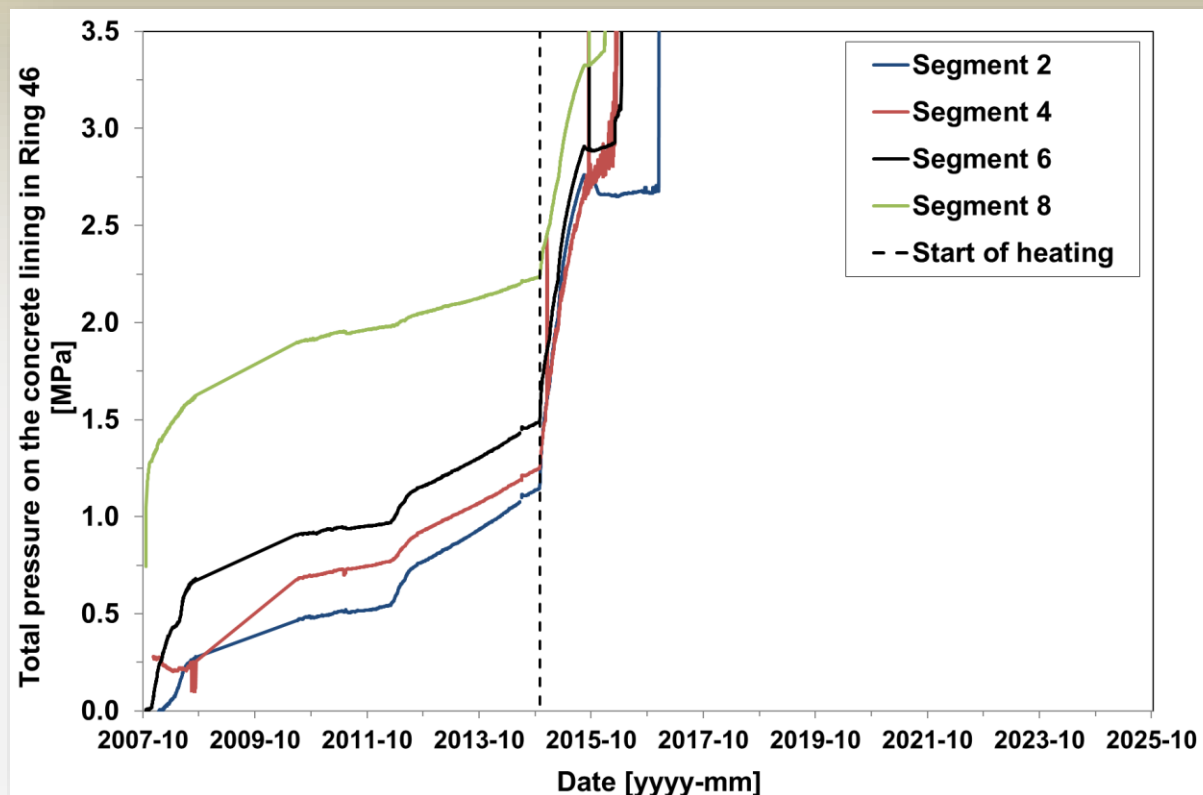


Concrete lining: C80/95

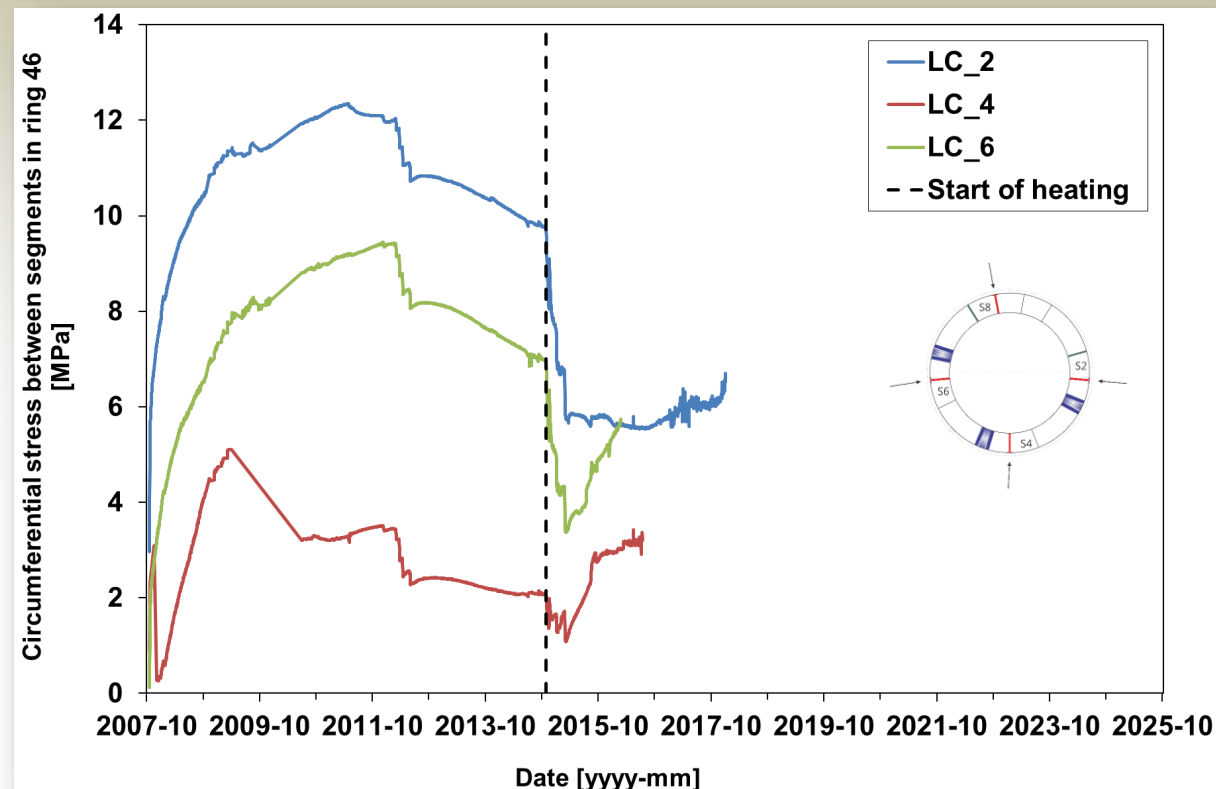
Observations in the lining: heated part



Total pressure in the heated part (Ring 46)



Circumferential stress in the heated part (Ring 46)



Concrete lining: C80/95



OUTLINE

- Heater Test – Steering parameters
- Observations
 - Boom Clay
 - Test set-up (Seal/ Concrete lining)
- Conclusion



CONCLUSIONS

- No interruption of the heater system
→ good performance of the test set-up
- Boom Clay is able to withstand the thermal loading
 - ✓ No indication of abrupt changes in pore water pressure nor large displacement
 - ✓ No changes in the intrinsic permeability
 - ✓ Anisotropic responses, as expected (vertical vs horizontal profiles)
- Seal fulfils its role as a hydraulic cut-off
- Stresses in the lining remain well below the ultimate strength
→ **Important input for THM** knowledge and repository design





**THANK YOU
TO THE WHOLE
PRACLAY TEAM**



PRACLAY 2025

CLOSING THE HEATING CHAPTER,
OPENING THE COOLING PHASE

sck cen



EURIDICE



NIRAS
ONDRAP

27th Exchange Meeting
TABLOO Dessel, 7th of November 2025

THM characterization of the Boom Clay

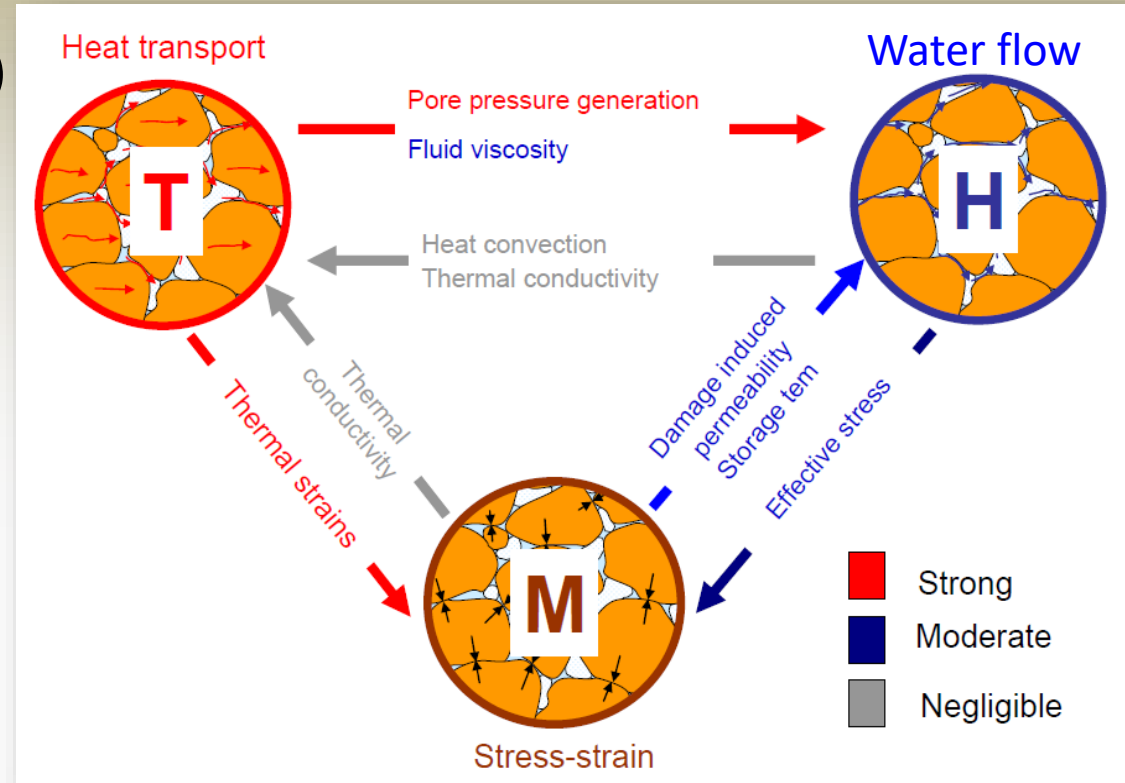
Understanding the PRACLAY Heater test and preparing the cooling phase

A. Dizier, G. Flood-Page, G. Chen, S. Levasseur

EURIDICE & NIRAS/ONDRAF

Thermo-hydro-mechanical (THM) processes

- Thermal conductivity (λ_H, λ_V)
- Heat capacity (C_p)

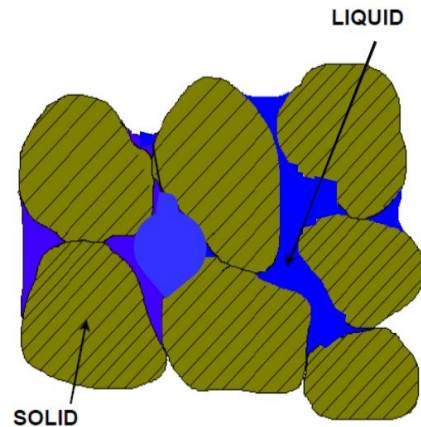


- Permeability (K_H, K_V)
- Porosity (n)

- Stress – strain relationship (σ - ϵ)
- Elasto-plastic properties ($E, \nu, c, \phi...$)

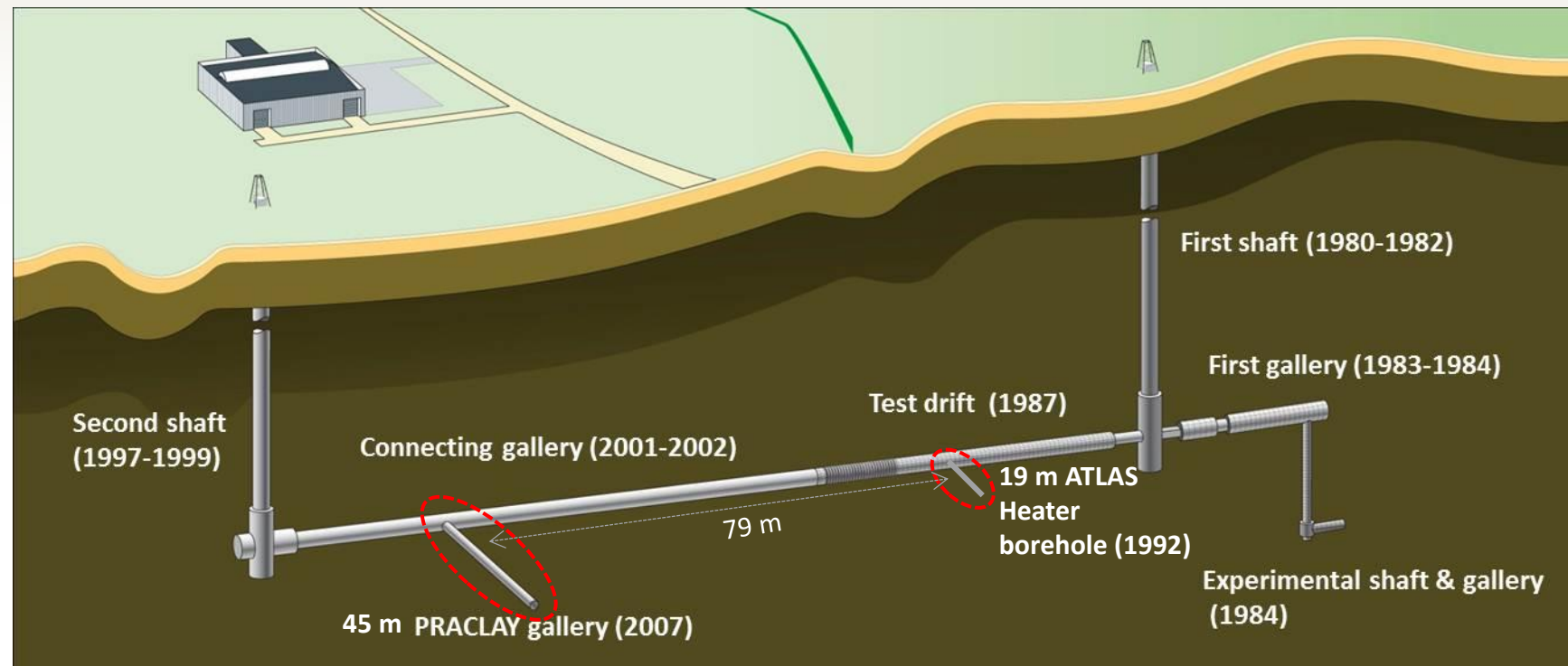
Boom Clay - THM characterisation

- Sedimentary clay – anisotropic properties
- Saturated porous medium
- Low permeability
- Thermo-hydro-mechanical processes



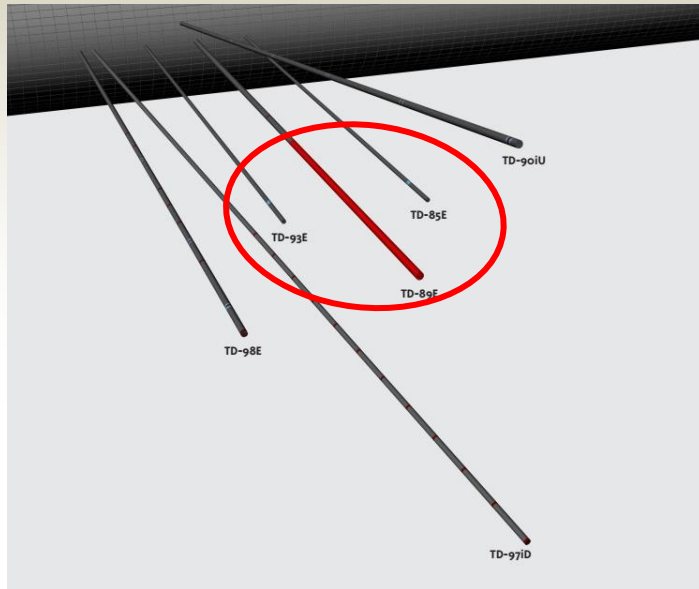
THM characterisation at HADES URL

- Existing Boom Clay THM knowledge – Laboratory scale
- In-situ characterisation
 - ATLAS I, II, III, IV (1992 -...)
 - PRACLAY (2014-...)

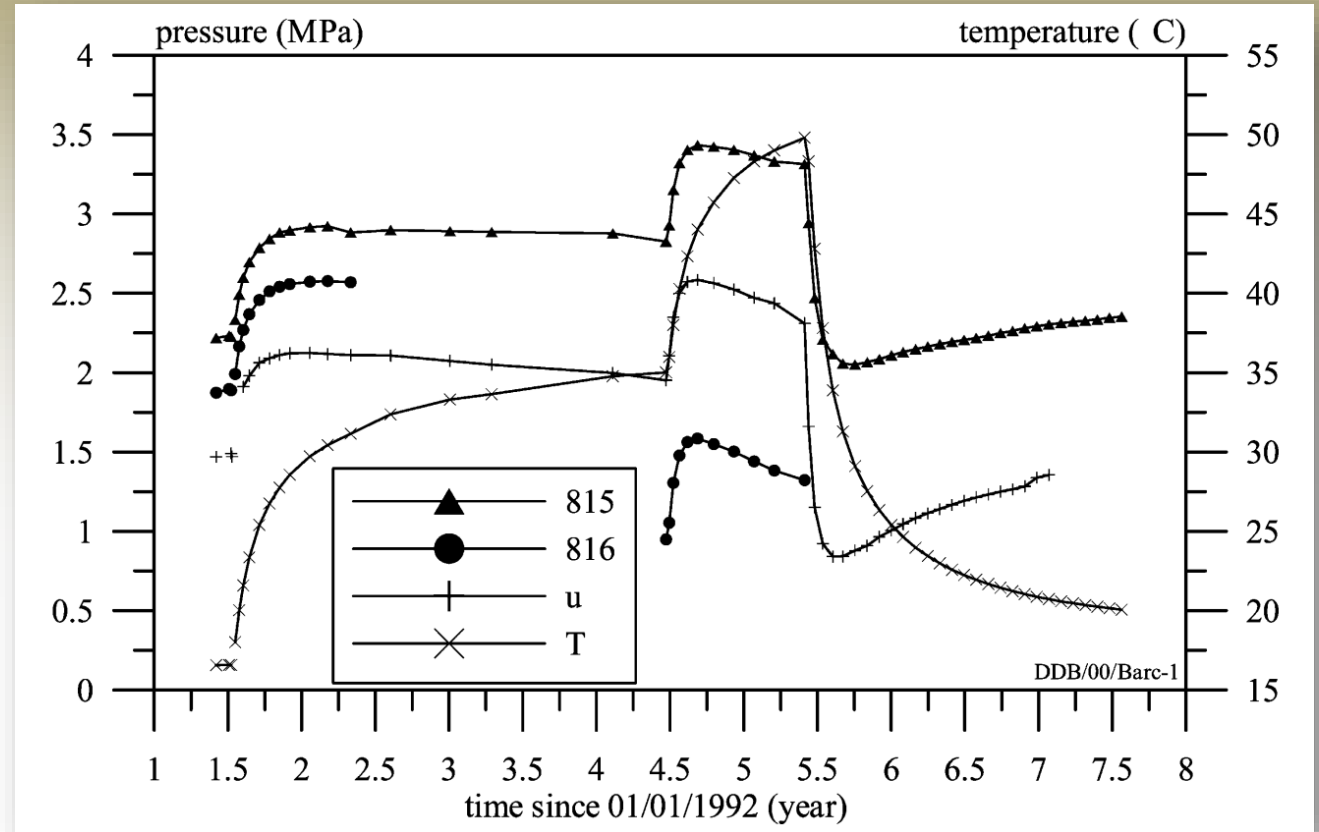


First insight on the Boom Clay THM Behaviour

- **ATLAS I-II (1993 -1998)**



- Limitations:
 - Relatively little instrumentation and low data acquisition rate (manual)
 - Sharp heating transients

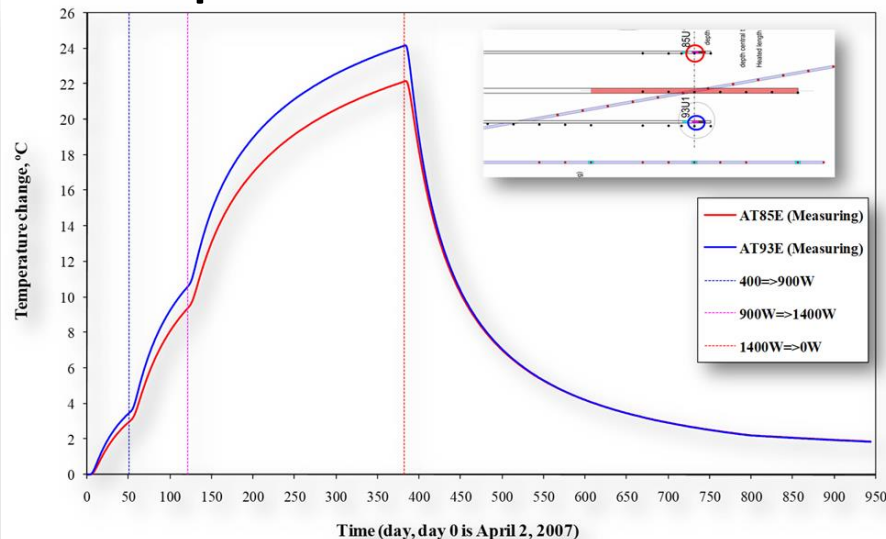


THM refinement from ATLAS III & IV

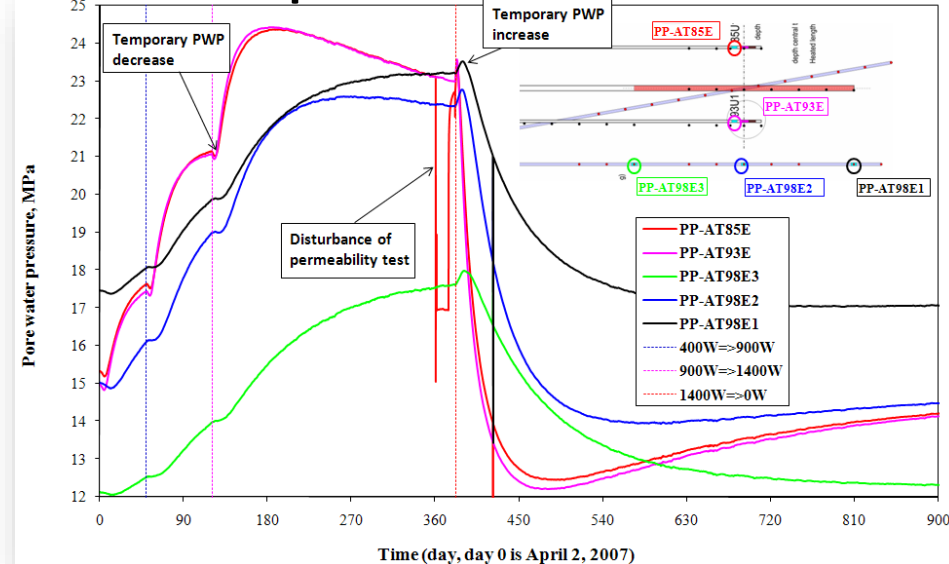
- **ATLAS III & IV (2007-2012)**

- Additional boreholes (horizontal and inclined) + Additional T & p_w sensors
- Same heating strategy for ATLAS III (2007 – 2008) and ATLAS IV (2011 – 2012)
- Improvements:
 - High data acquisition rate
 - Investigation of thermal anisotropy

Temperature in function of time

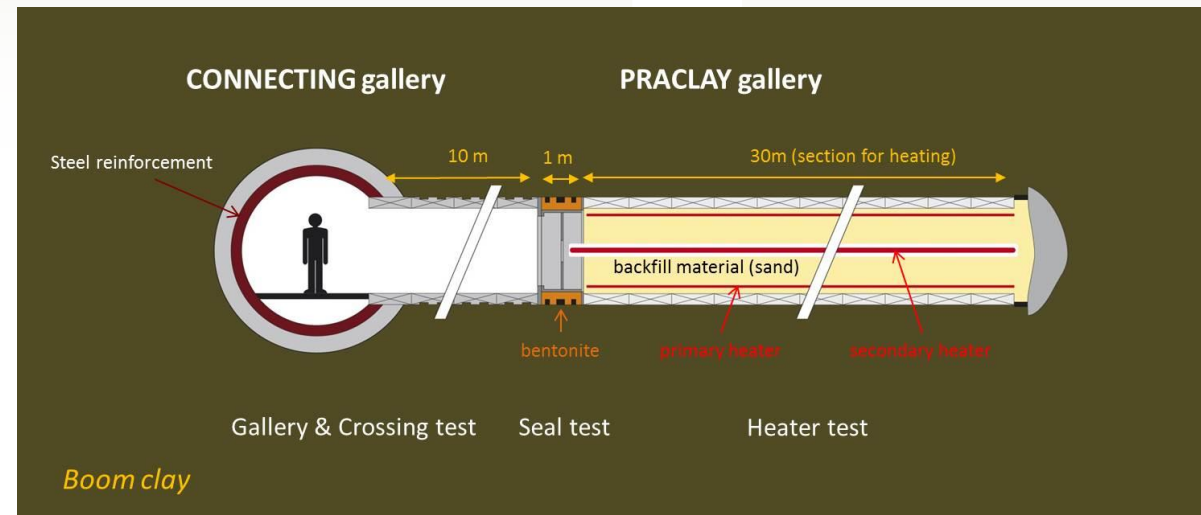


Pore water pressure in function of time



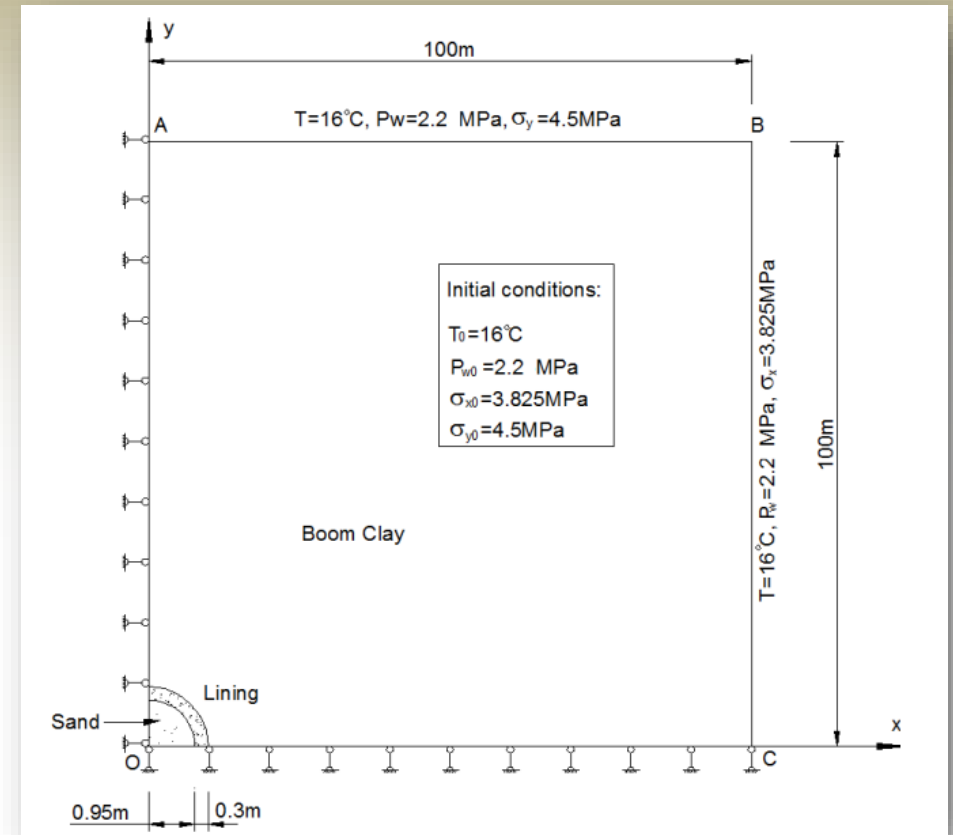
Enhanced THM knowledge from the PRACLAY Heater test

- Large amount of modelling
- 2D Plane Strain THM, 2D Axisymmetric THM, 3D T models
 - Isotropic/Anisotropic THM model
 - Heater power/Temperature boundary condition



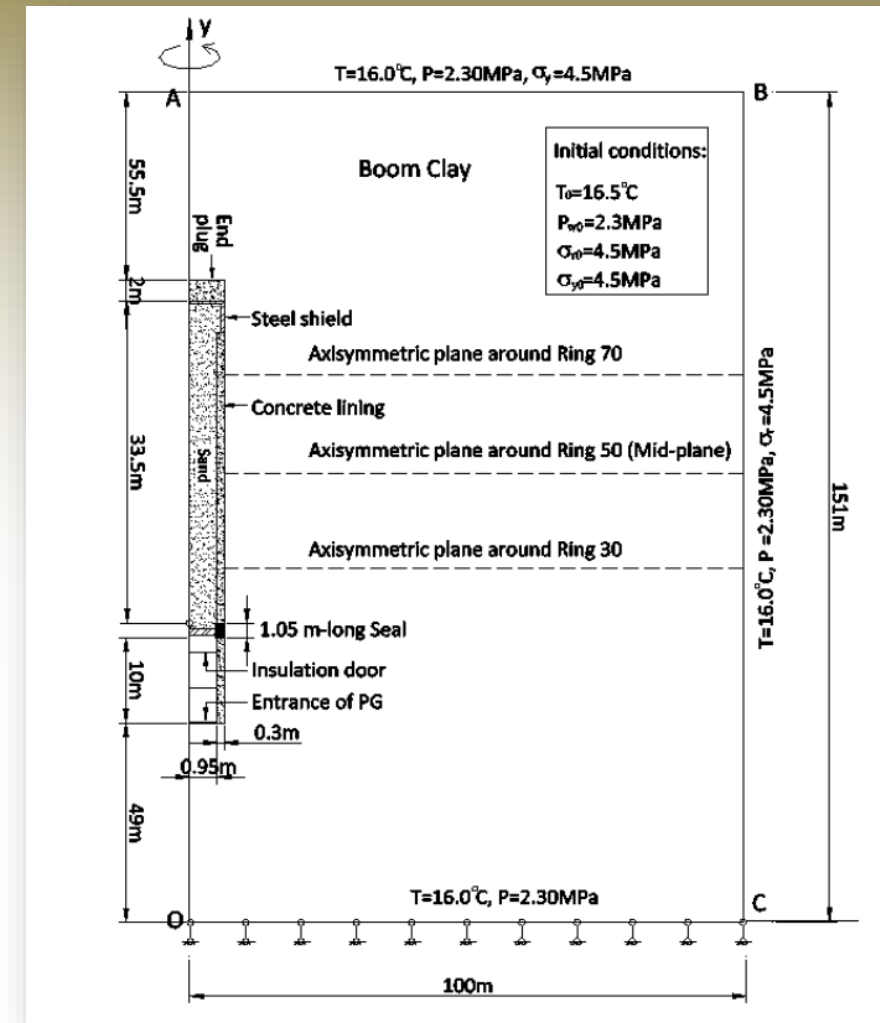
2D Plane Strain Model

- Cross section perpendicular to the PRACLAY gallery
 - ➔ No heat or water flux perpendicular to the section
 - ➔ Sand/ concrete lining/ Boom Clay
- Anisotropic permeability
- Anisotropic stress state
- Mechanical behaviour:
 - Cross-anisotropic elasticity parameters
 - Drucker-Prager yield criterion



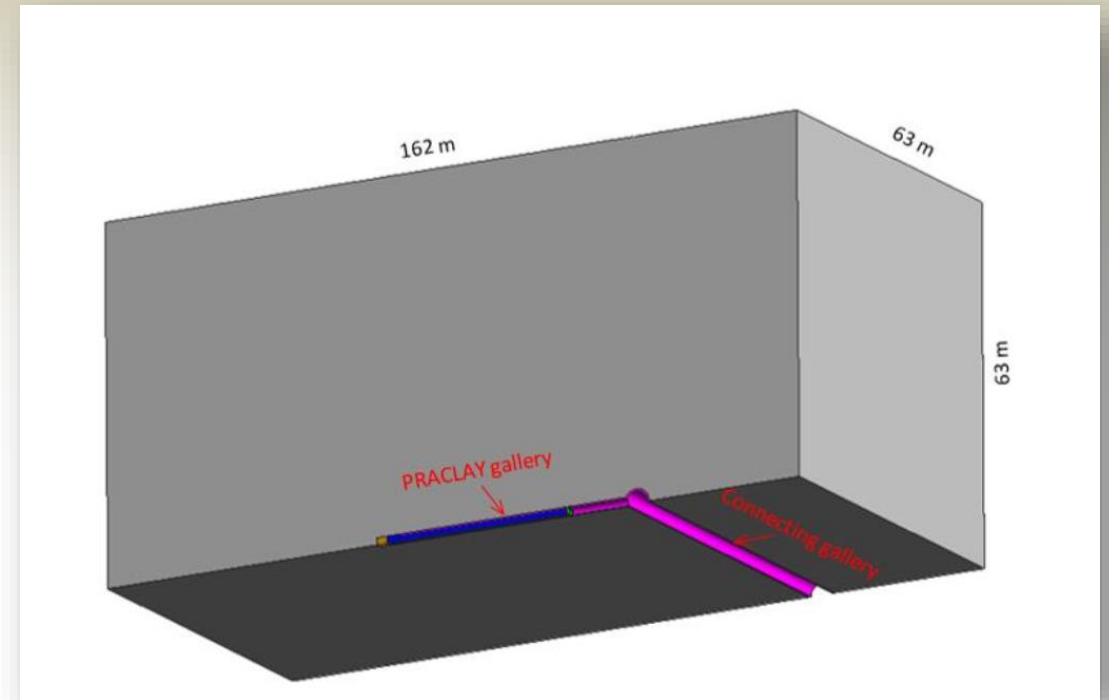
2D Axisymmetric model

- Along the axis of the PRACLAY gallery
 - ➔ Dissipation of heat/ water flux in all directions
 - ➔ Cannot consider the anisotropic properties
 - ➔ All components of the experiment
- Isotropic permeability
- Isotropic stress state
- Mechanical behaviour:
 - Isotropic elasticity parameters
 - Drucker-Prager yield criterion



3D model

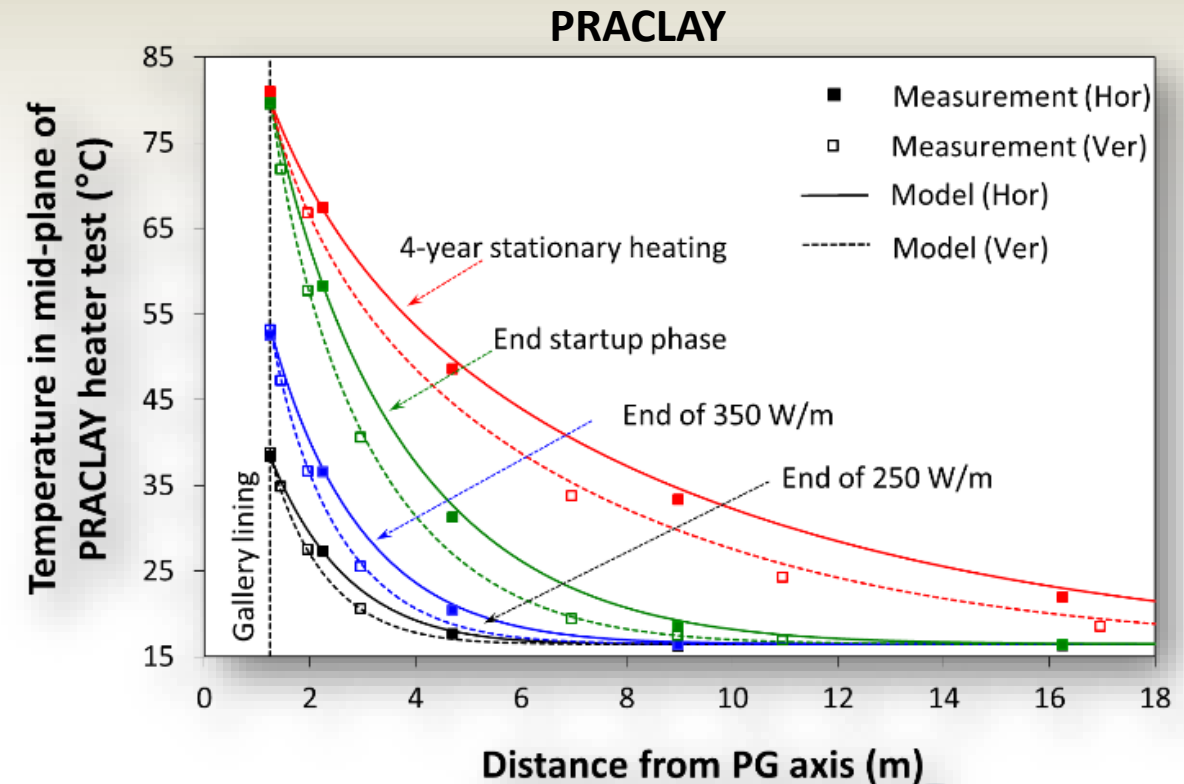
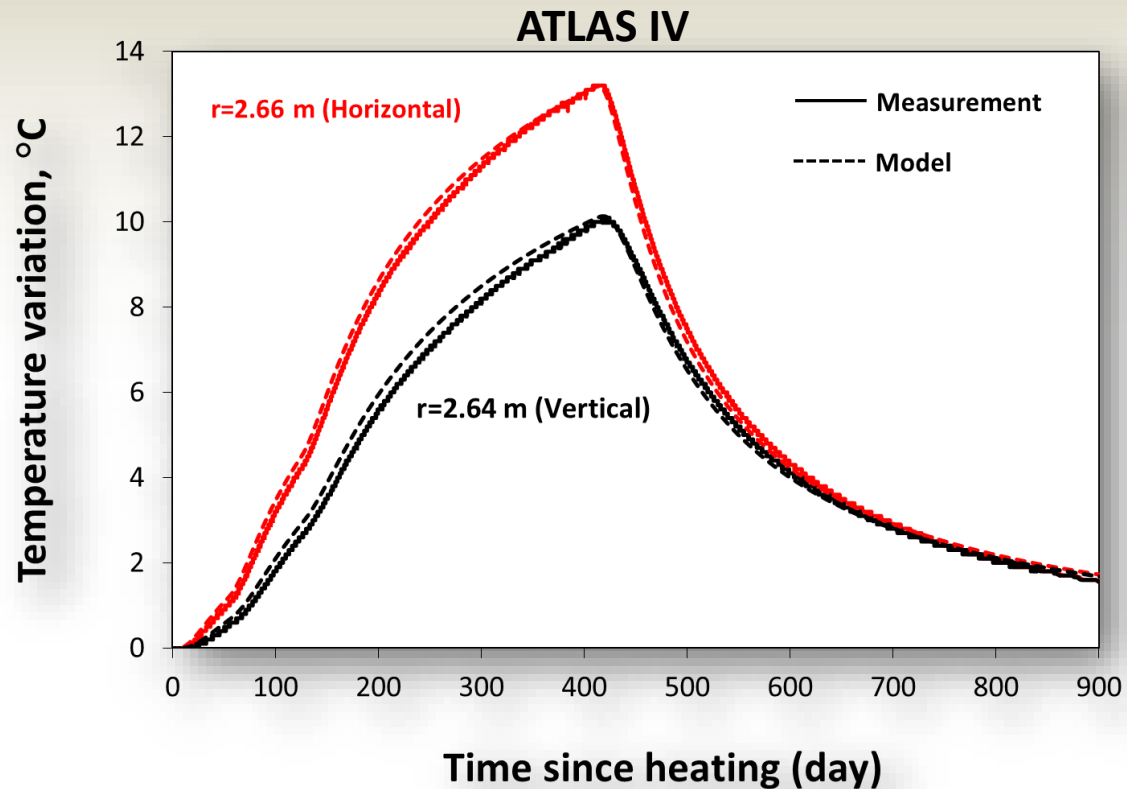
- Including effects of the Connecting Gallery
 - ➔ Dissipation of heat/ water flux in all directions
 - ➔ Anisotropic properties OK
 - ➔ All components of the PRACLAY experiment
 - ➔ Very heavy to realise for a fully coupled THM analysis



PRACLAY Heater test – 3D thermal modelling

3D model – Thermal analysis

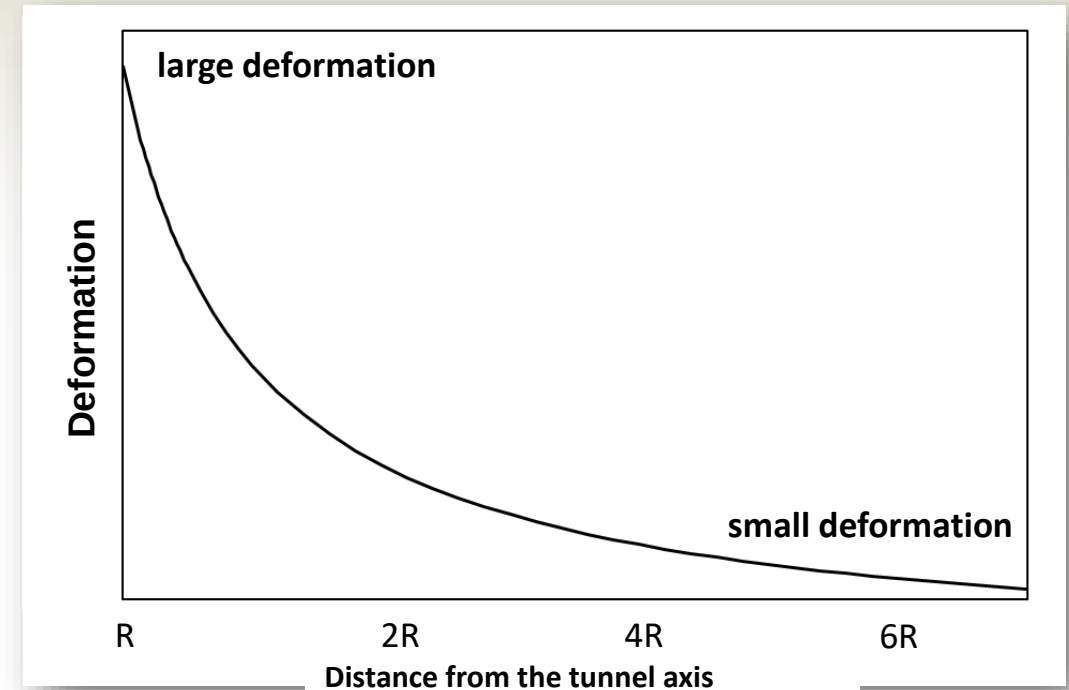
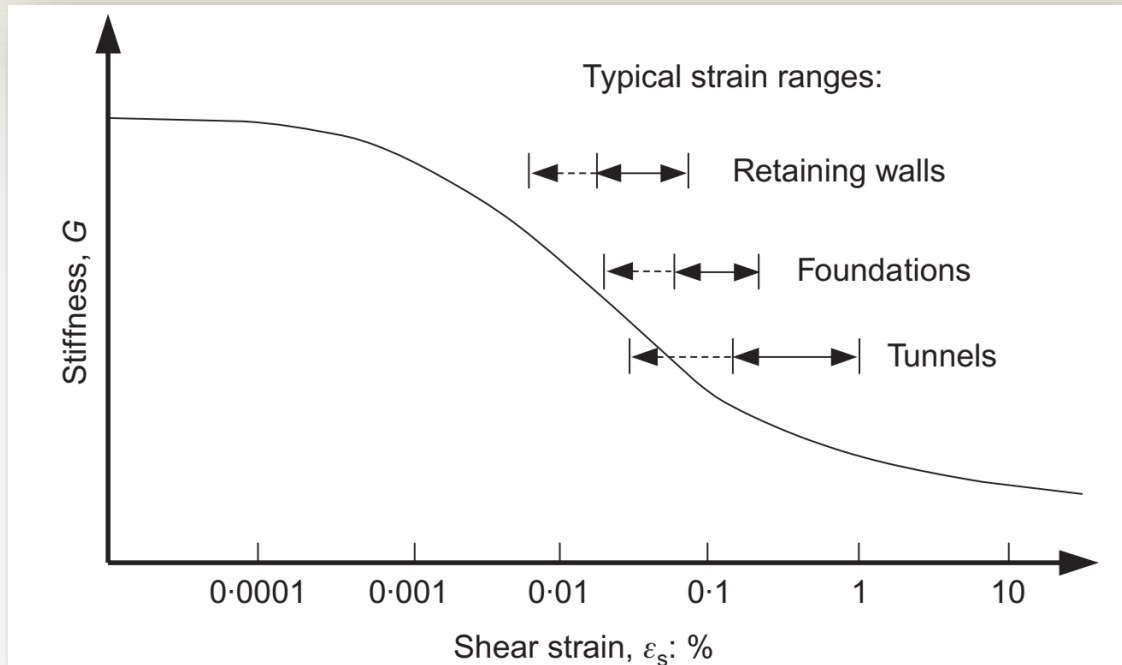
Thermal conductivity assessment: $\lambda_h = 1.9 \text{ W/(mK)}$ / $\lambda_v = 1.20 \text{ W/(mK)}$



PRACLAY Heater test – 2D Plane strain

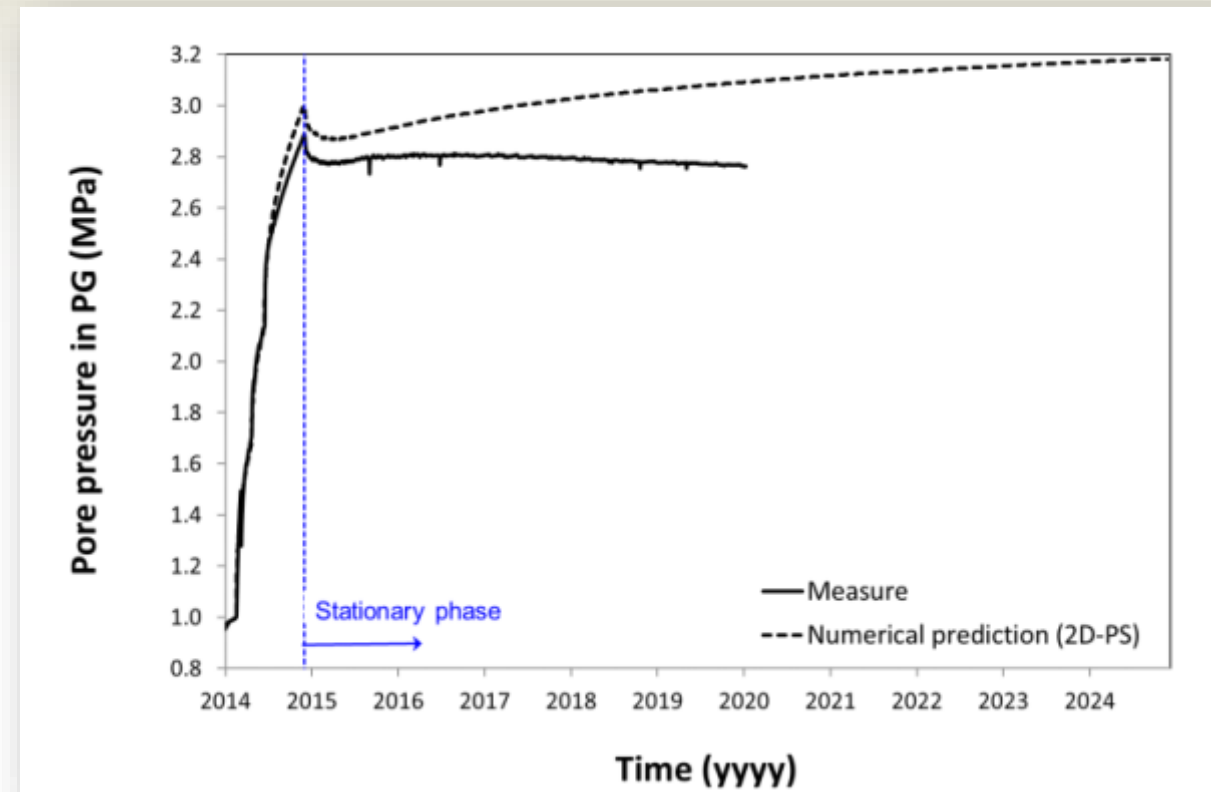
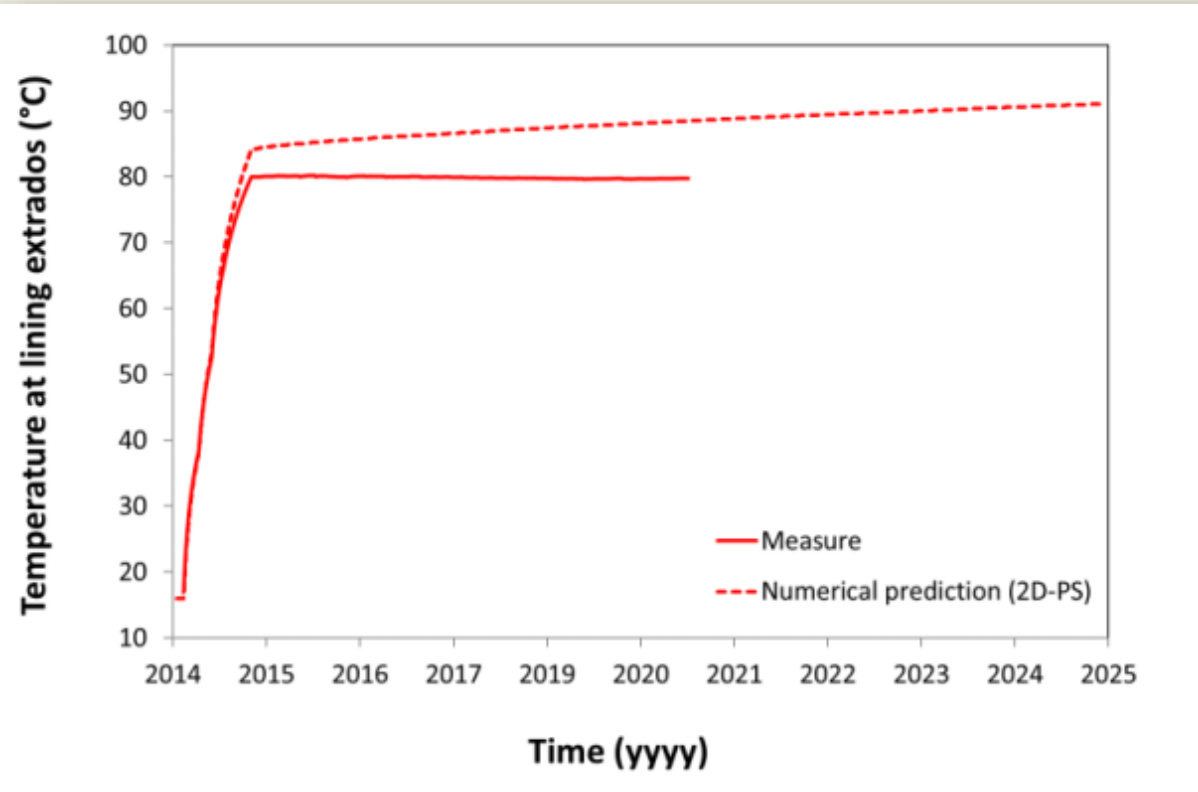
2D Plane Strain – THM analysis

- Additional mechanisms to consider the degradation of the shear modulus with strain
→ transition near-field / far-field

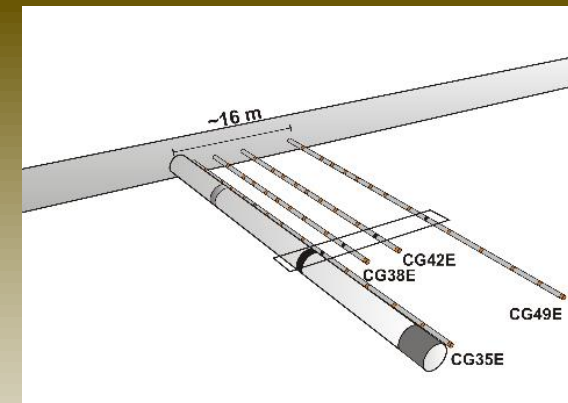


2D Plane Strain – THM analysis

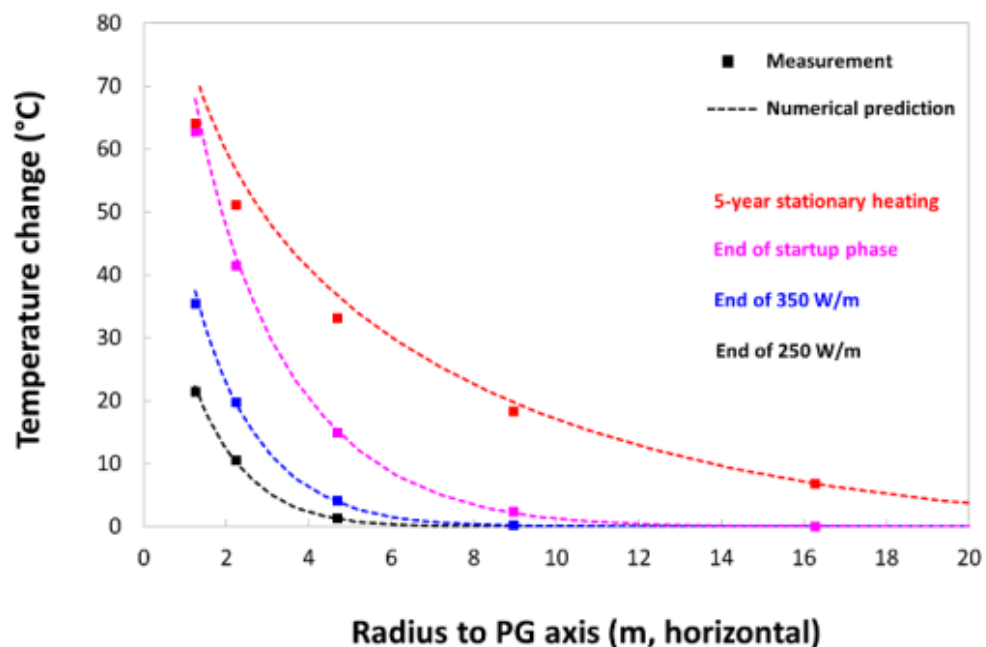
- Steering parameters:
 - Temperature evolution at lining / Boom Clay interface
 - Pore water pressure evolution in PRACLAY gallery



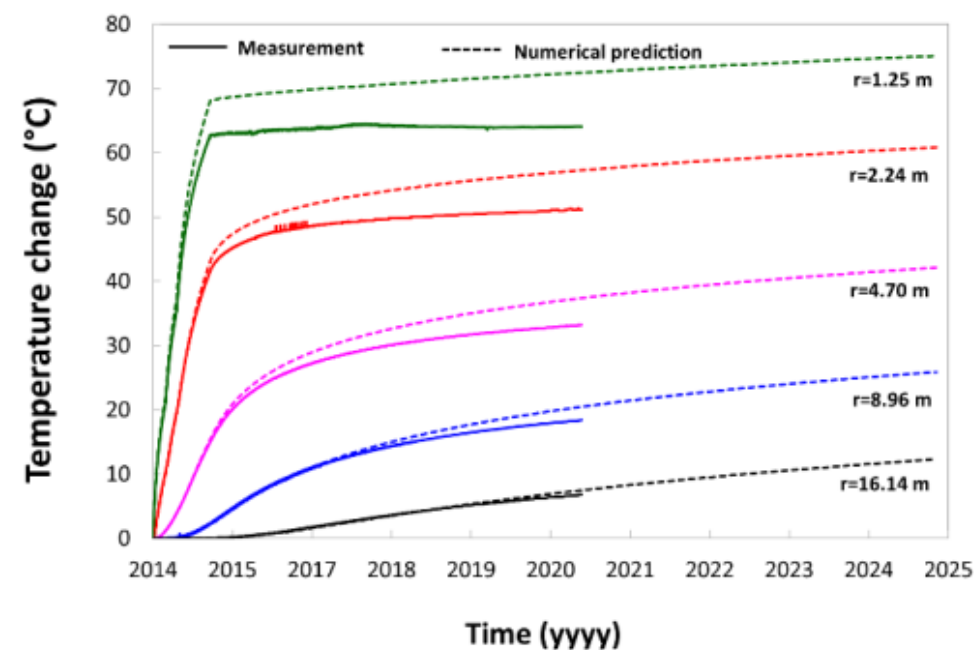
Temperature in the Boom Clay



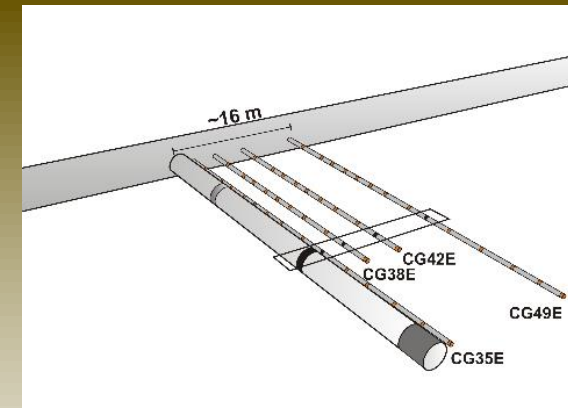
Profiles



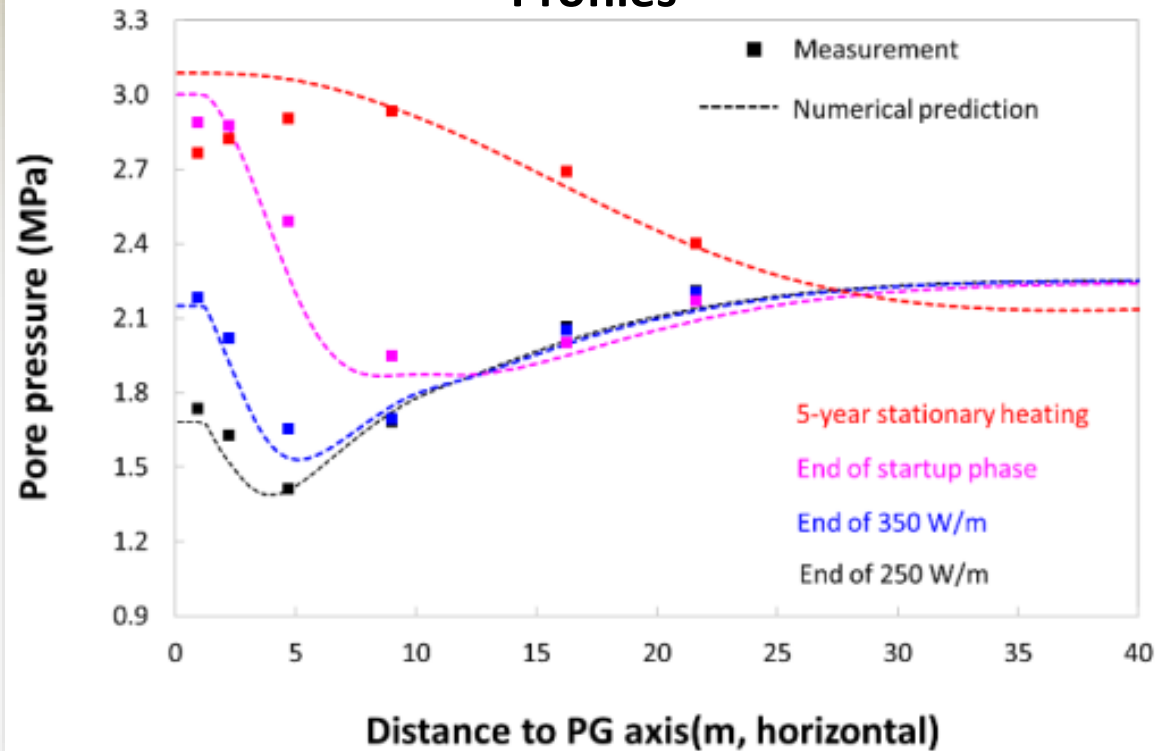
Evolution in time



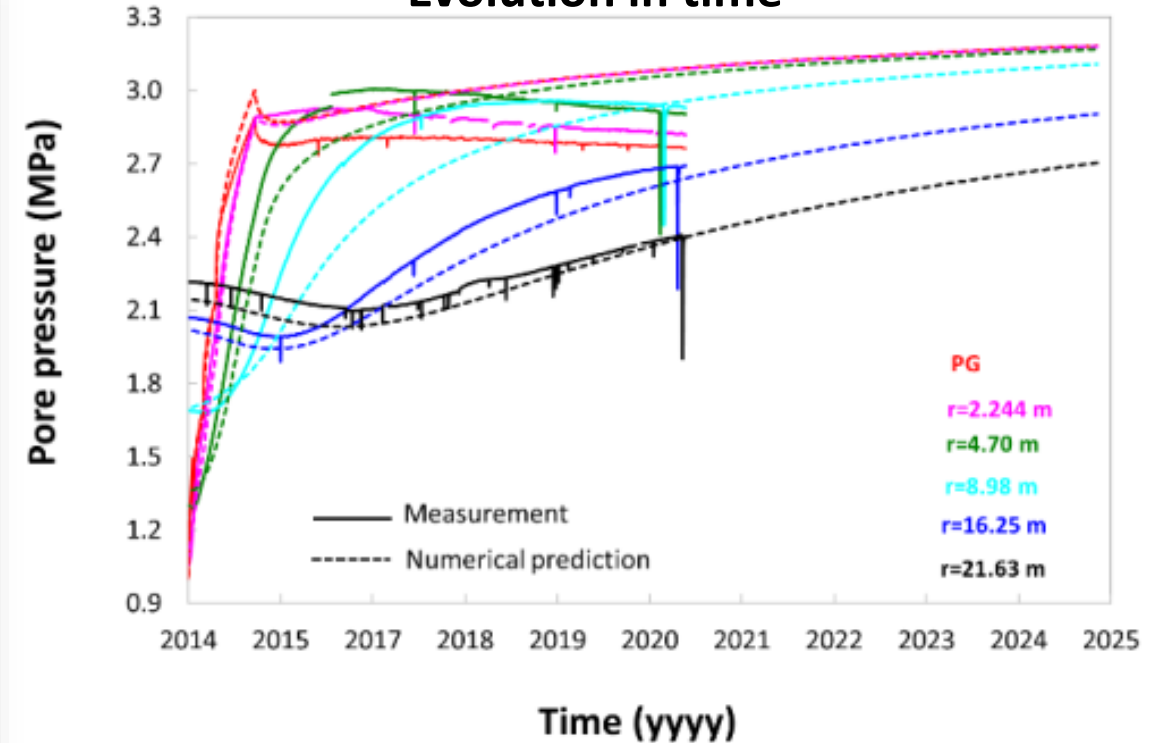
Pore water pressure in the Boom Clay



Profiles



Evolution in time

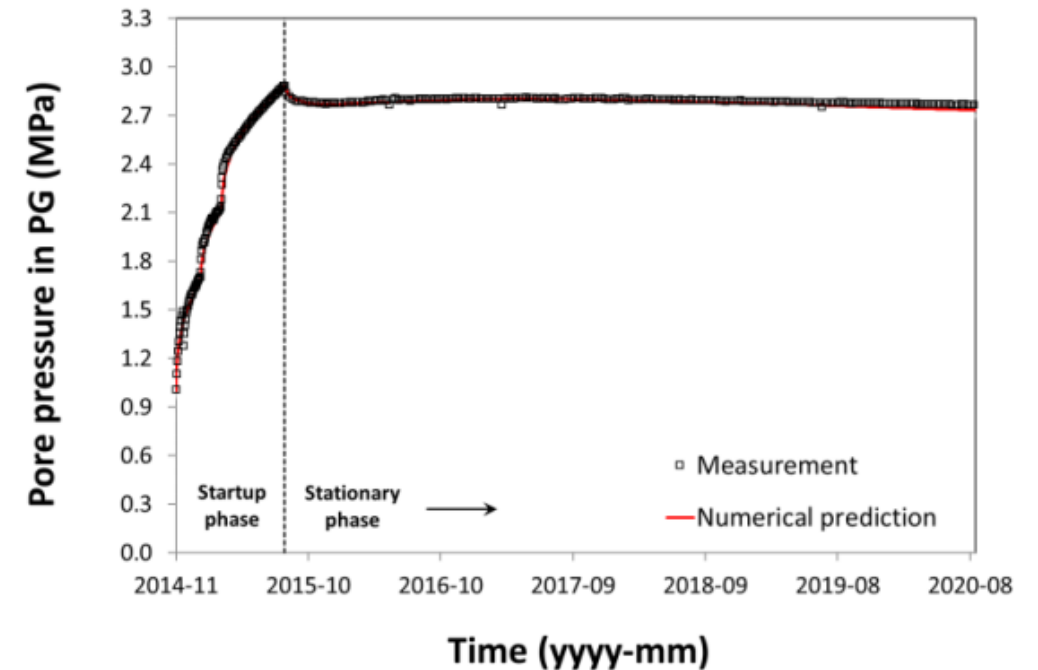
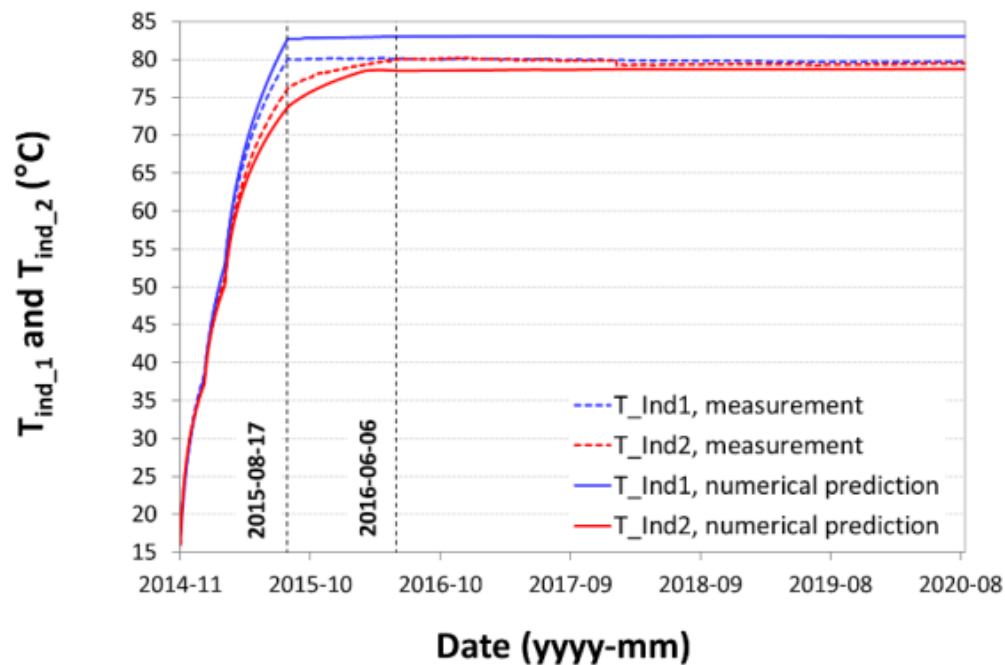


PRACLAY Heater test – 2D Axisymmetric model

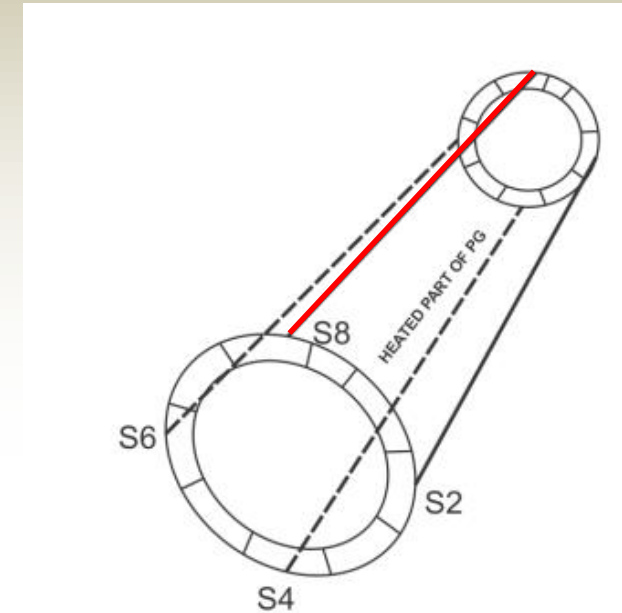
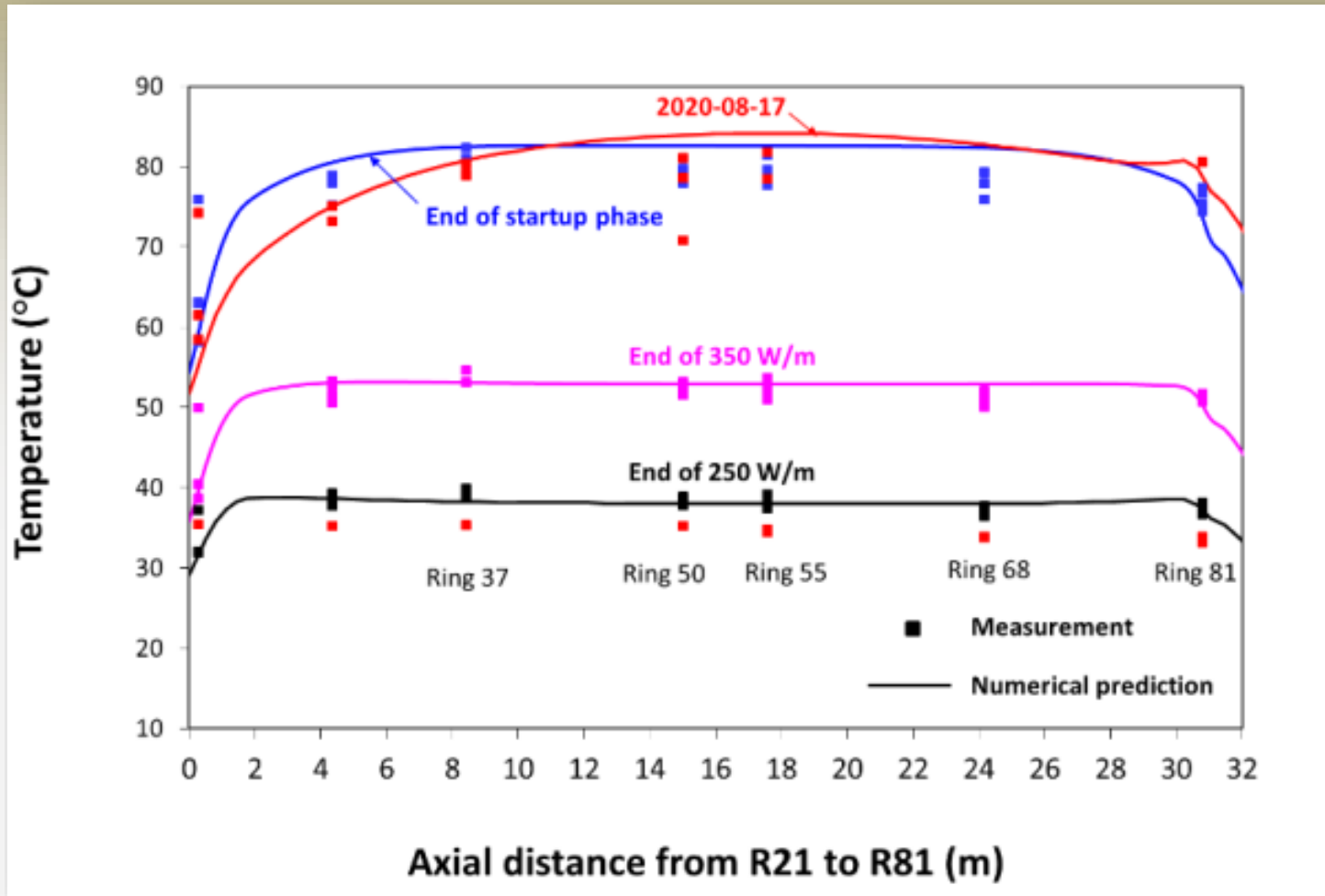
2D Axisymmetric – THM analysis

Steering parameters:

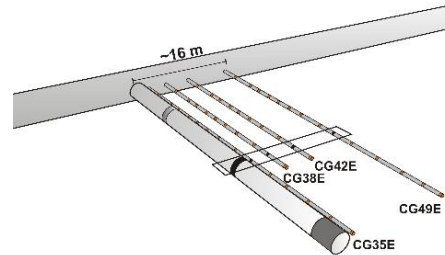
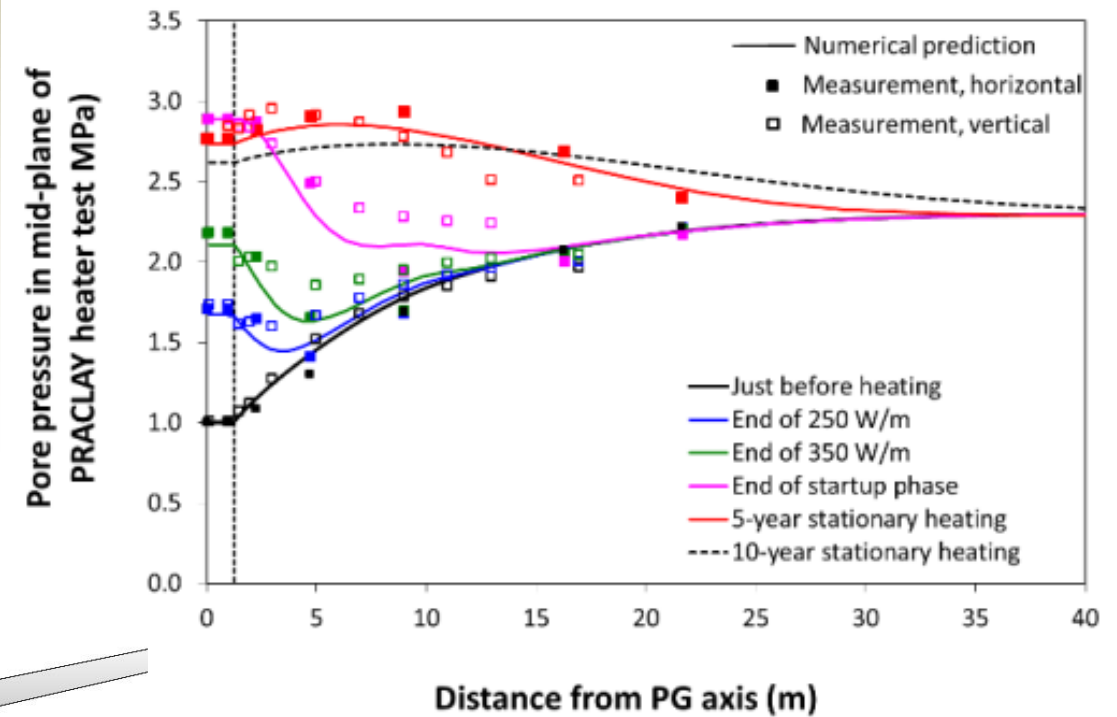
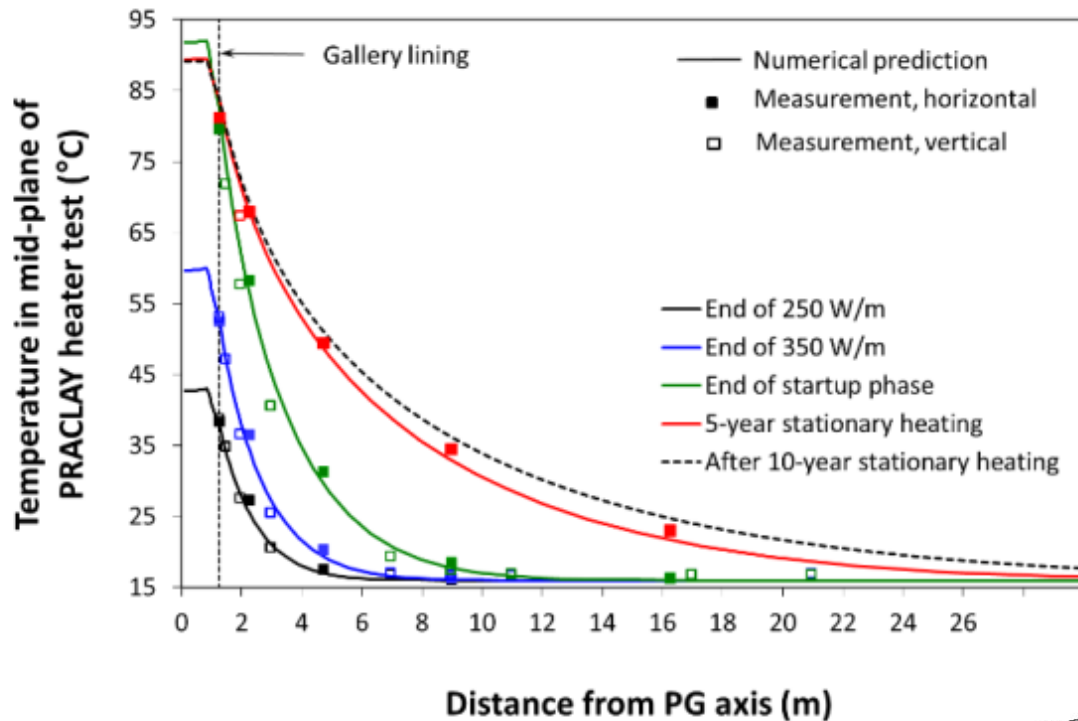
- Temperature evolution - lining / Boom Clay interface
- Pore water pressure evolution in PRACLAY gallery



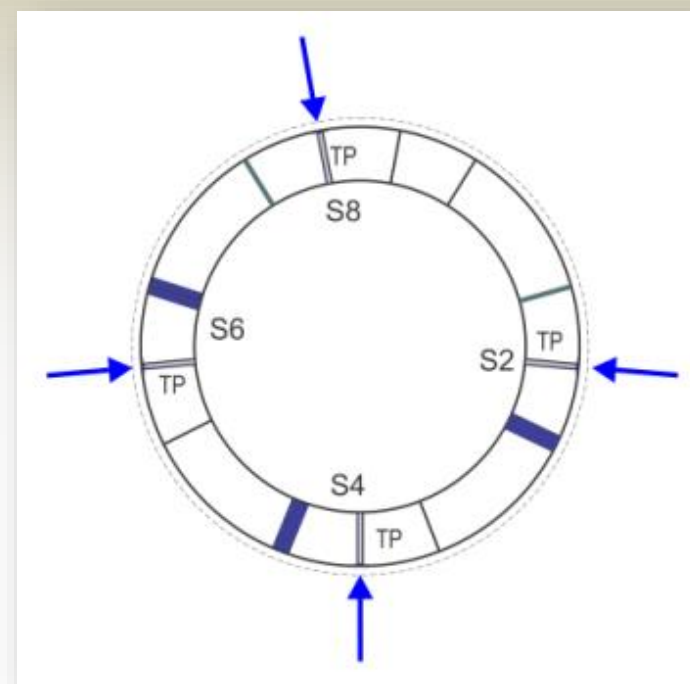
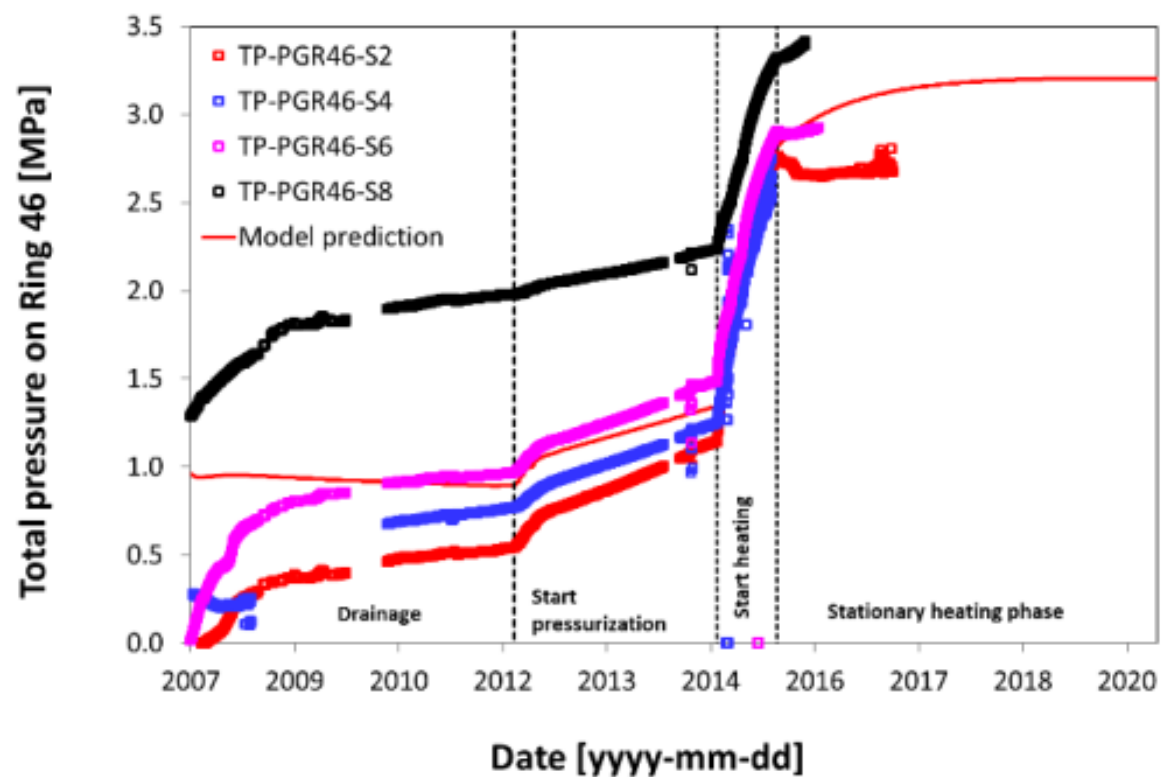
Temperature profiles - lining / Boom Clay interface



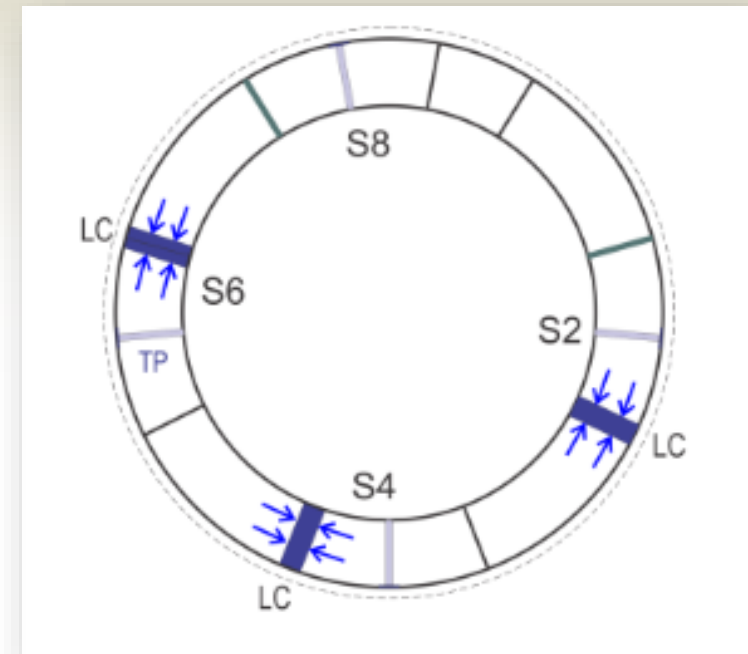
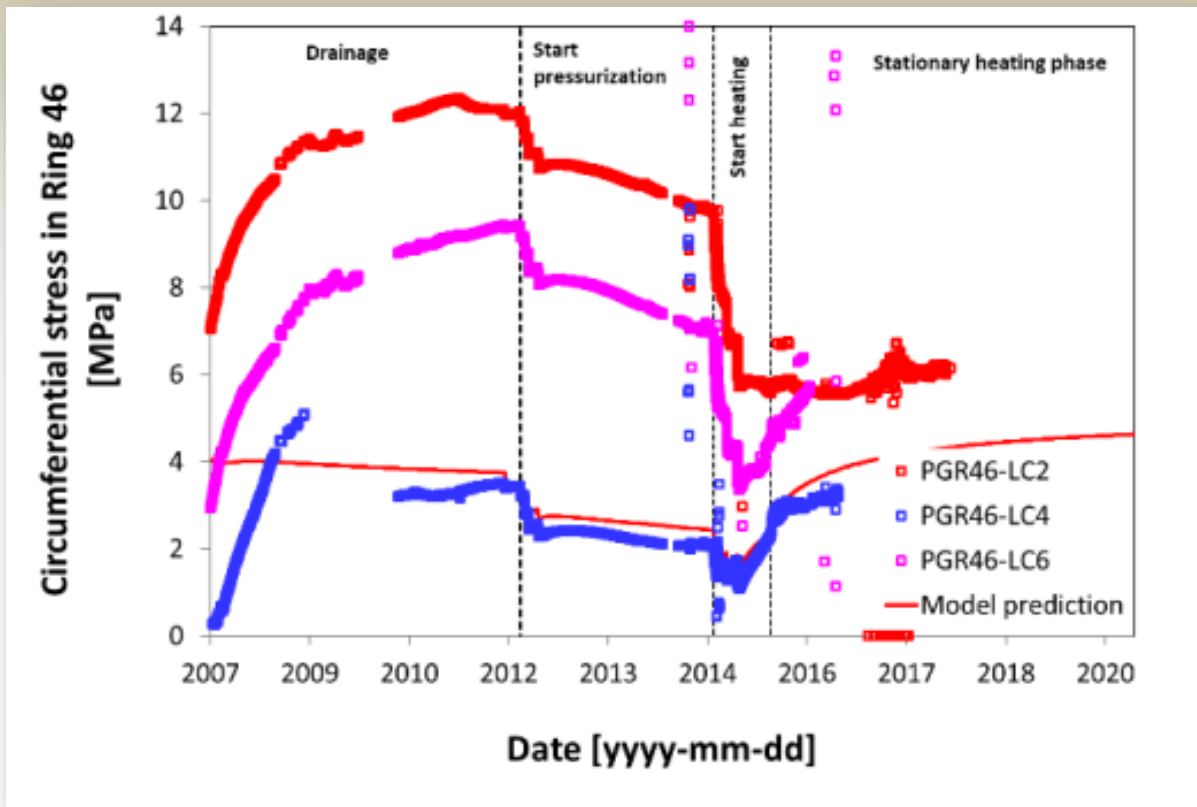
Temperature and pore water pressure profiles



Total pressure acting on the lining



Stresses inside the segmental lining

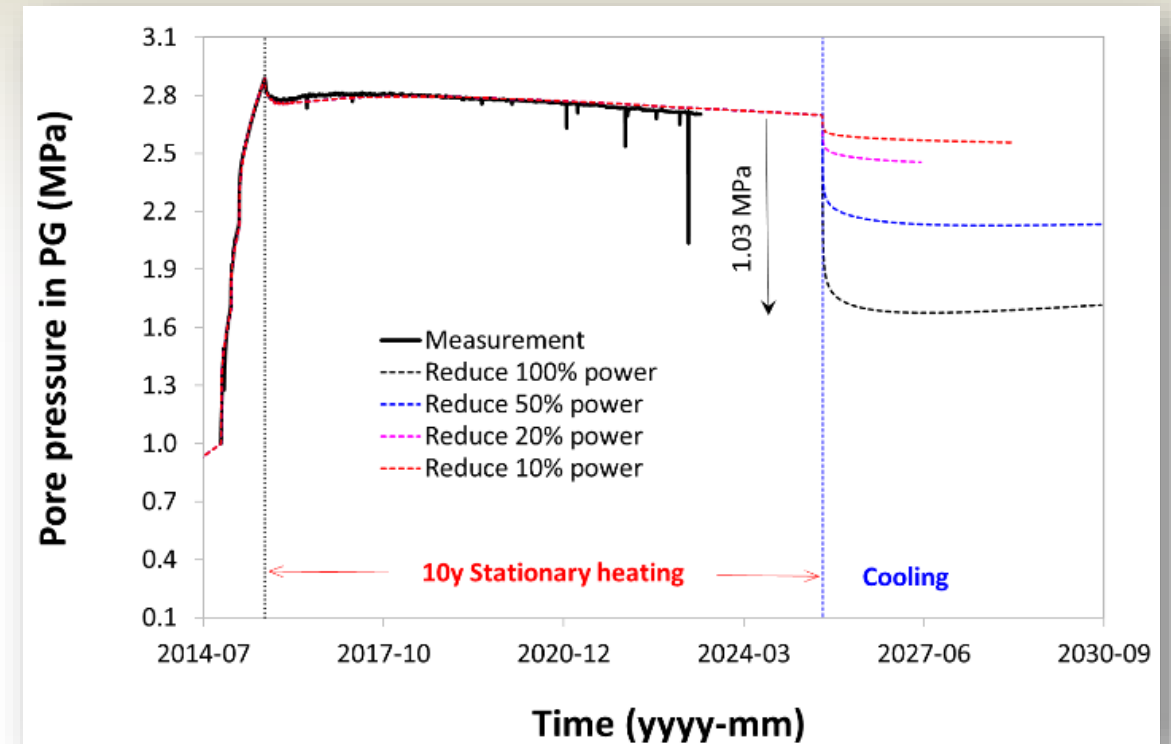
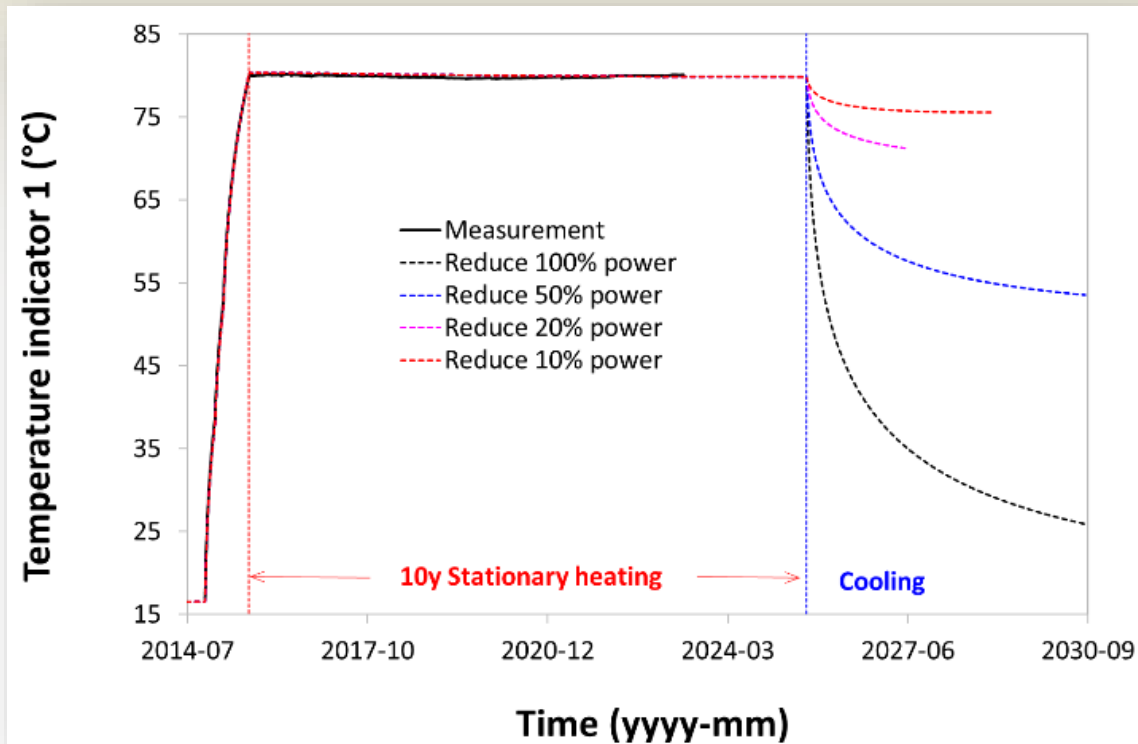


PRACLAY Heater test – Cooling phase

What can we expect during the Cooling phase ?

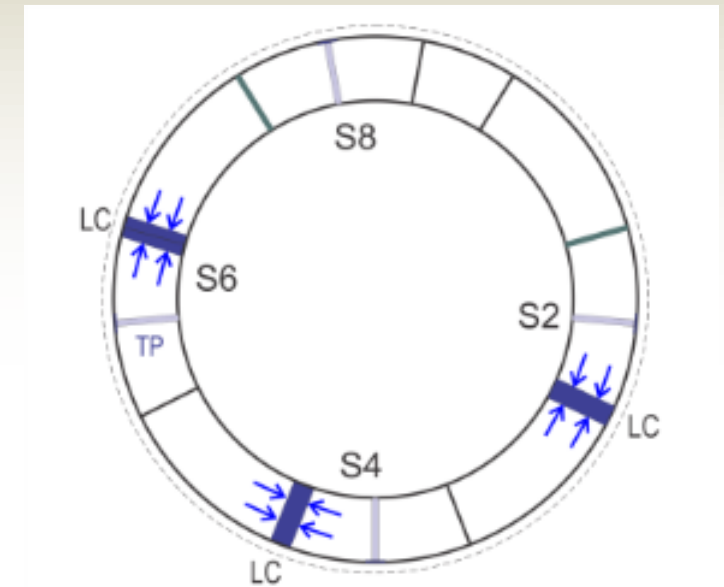
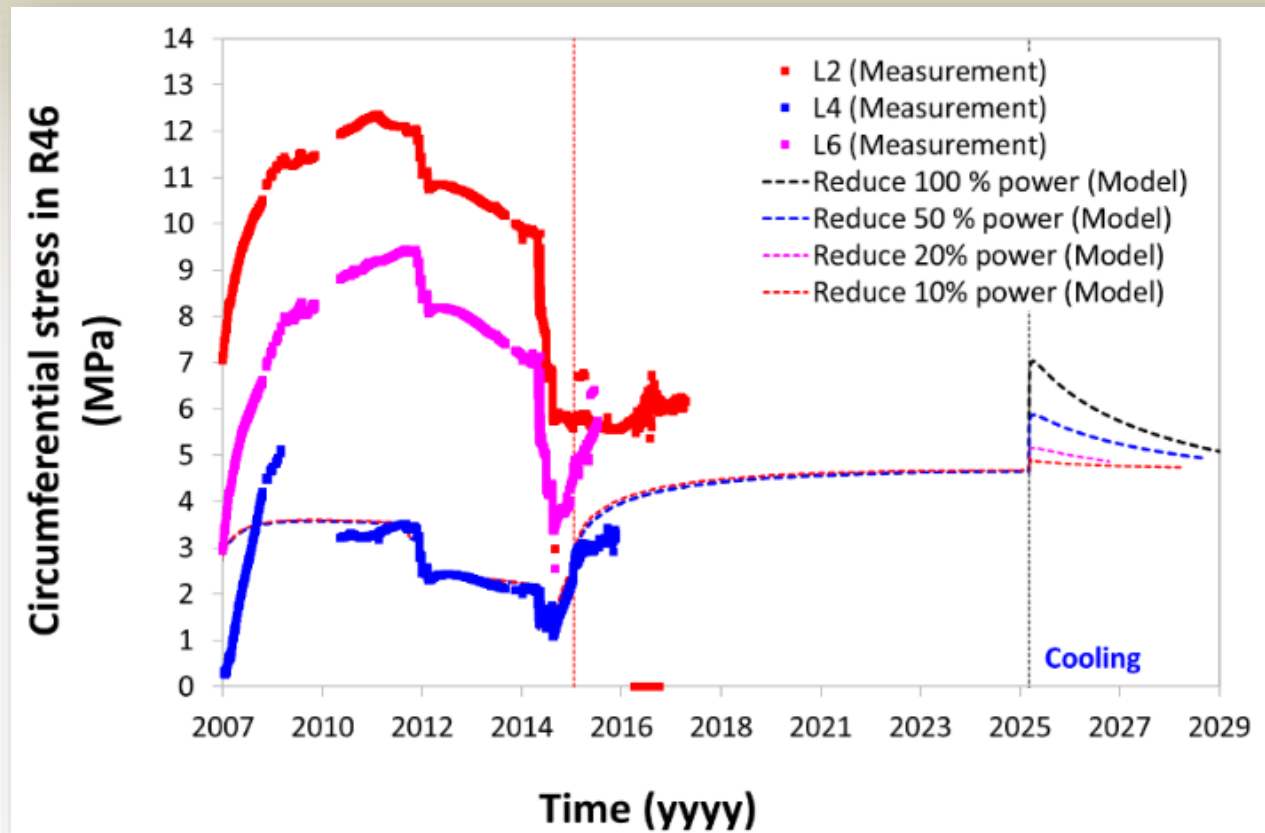
Four scenarios of power decrease were defined: 100% - 50% - 20% - 10%

➔ Temperature and pore water pressure variation in clay and in the gallery modelled



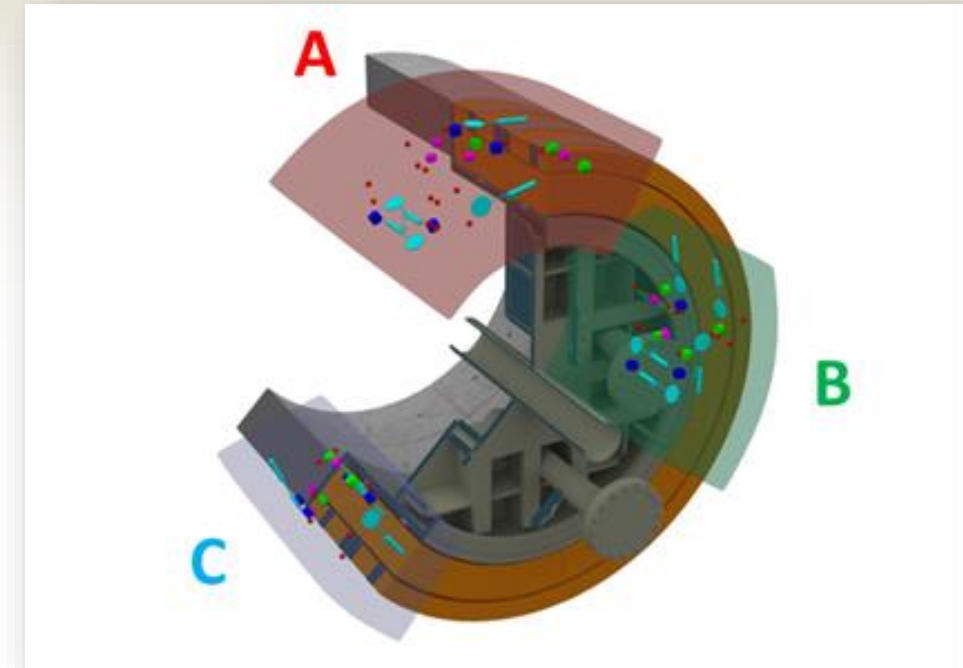
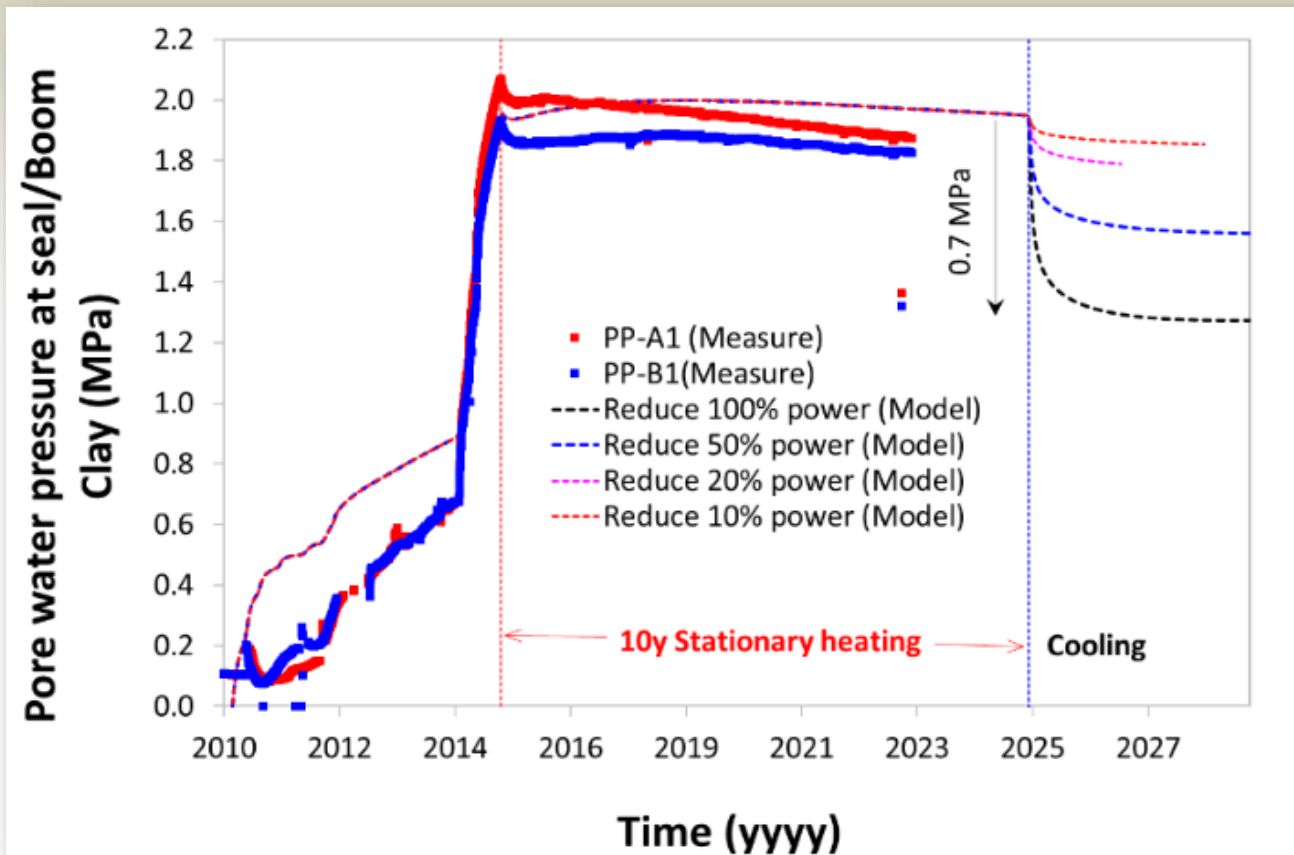
What can we expect during the Cooling phase ?

Effect on the lining?



What can we expect during the Cooling phase ?

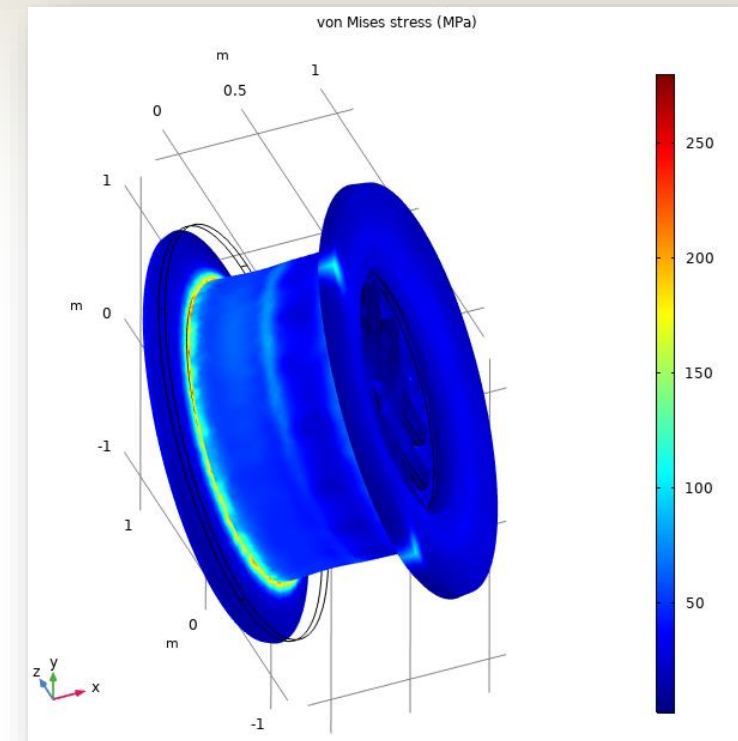
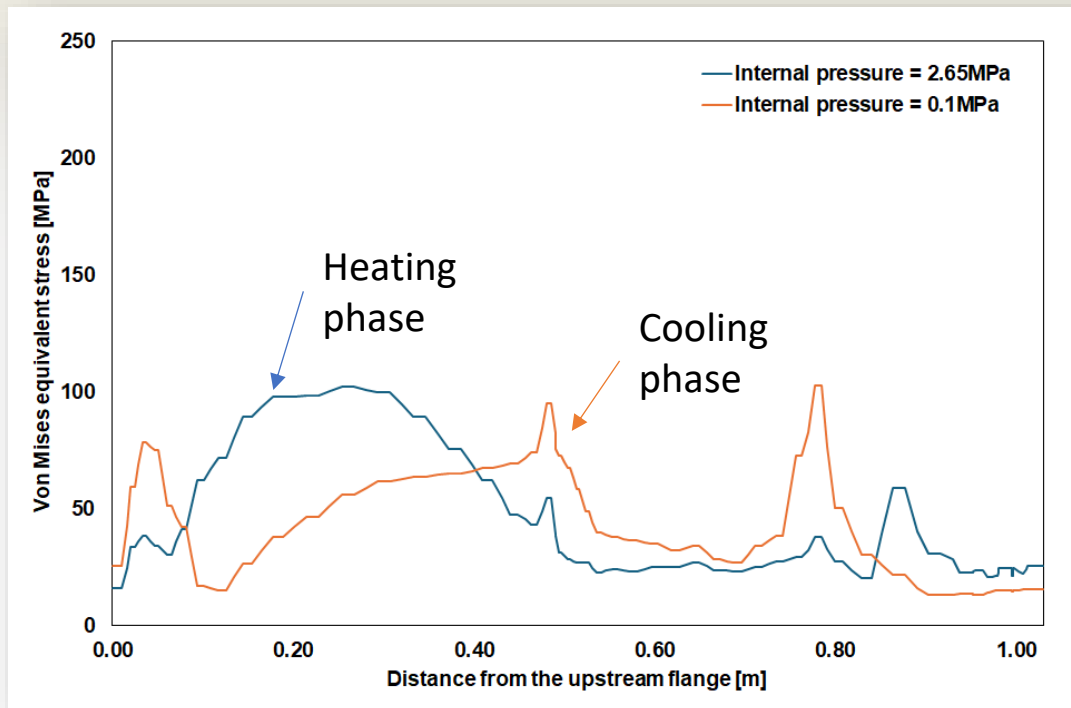
Effect on the seal?



What can we expect during the Cooling phase ?

Effect on the seal? Is the cooling phase unfavourable for the seal?

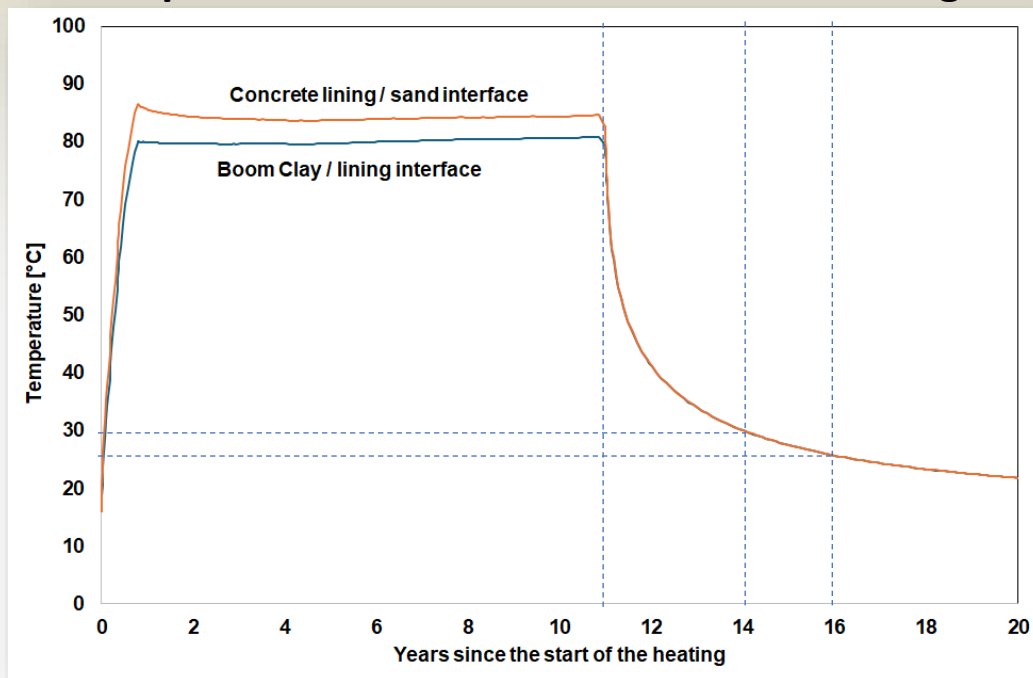
- Finite element analysis of the seal structure
 - ➔ State of stress is not modified significantly during the cooling



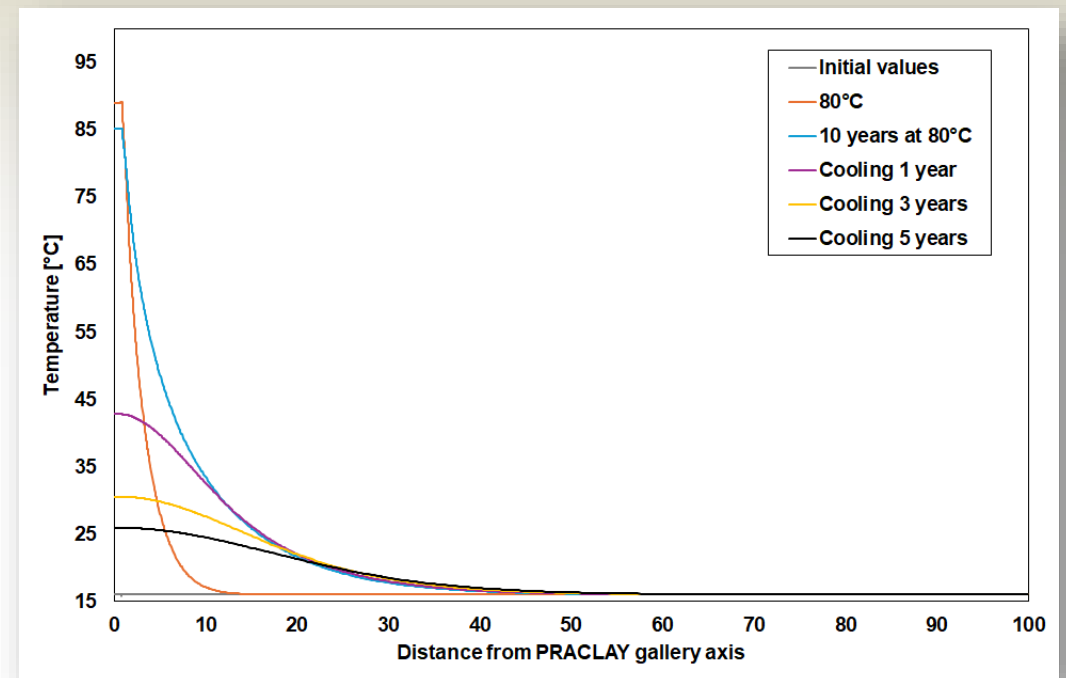
What can we expect during the Cooling phase?

Selected scenario: 10% of reduction during 1 month before complete shutdown

Temperature evolution in the concrete lining



Temperature profiles in Boom Clay



→ Temperature around 30°C after 3 years of cooling, around 25°C after 5 years



Conclusions

- Validation / confirmation of our understanding of THM behaviour of the Boom Clay at large scale
- Good capabilities to reproduce the THM processes in the Boom Clay
 - Anisotropic behaviour of the Boom Clay cannot be neglected
 - Shear strain stiffness degradation is an important aspect
- Verification that the Boom Clay can withstand the thermal transient up to the time of maximum near field temperature
- After 11 years, cooling phase initiated in 2 steps : 10% before complete shutdown
 - Minimum time before dismantling: 3 years



To be continued...



Closing remarks and conclusions

Maarten Van Geet

EURIDICE & NIRAS/ONDRAF

07-11-2025
27th Exchange Meeting

So far, the PRACLAY Heater Experiment has met its pre-defined success criteria with highly positive results

Succes Criteria

1. Thermal Impact on the Clay

Assess heat dissipation from heat-emitting waste

Evaluate THM effects on damaged/disturbed host rock

Confirm absence of Boom Clay liquefaction

2. Structural Stability Concrete

Assess concrete lining stability under thermal stress

3. Migration of radionuclides

Strengthen evidence of limited thermal impact on radionuclide transport

4. Monitoring & Strategy

Advance monitoring under realistic conditions

Develop a robust monitoring strategy

5. Communication & Integration

Embed PRACLAY experiment in overall communication strategy

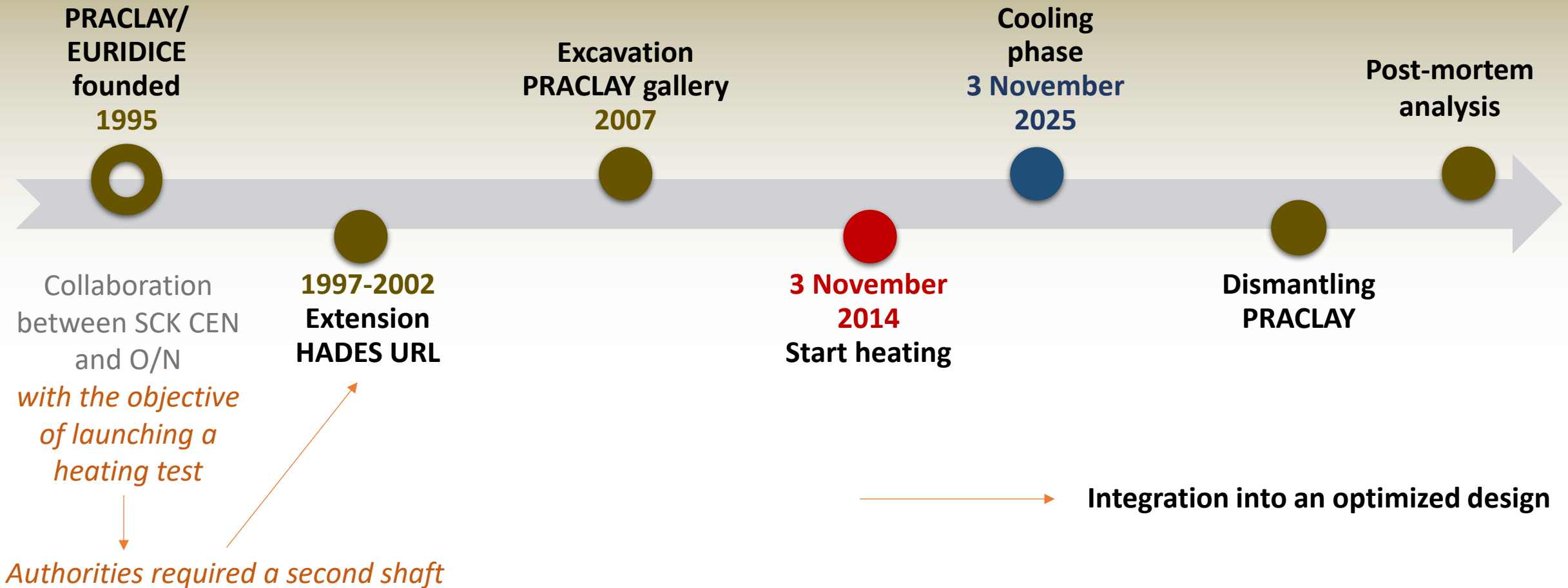
Positive Evaluation

The success criteria set before launching the PRACLAY Heater Experiment are met

But it takes time

- **Commitment to Quality:** Not a lack of effort, but a deliberate, evidence-based approach
- **Stepwise Demonstration:** From laboratory to large-scale, ensuring feasibility and safety
- **Rigorous Validation:** Long-duration experiments are essential in this context

Timeline of PRACLAY



A warm Thank You to everyone who contributed!

