Belgian programme
on radioactive waste management

THM characterization of the Boom Clay

Understanding the PRACLAY Heater test and preparing the cooling phase

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27th Exchange Meeting

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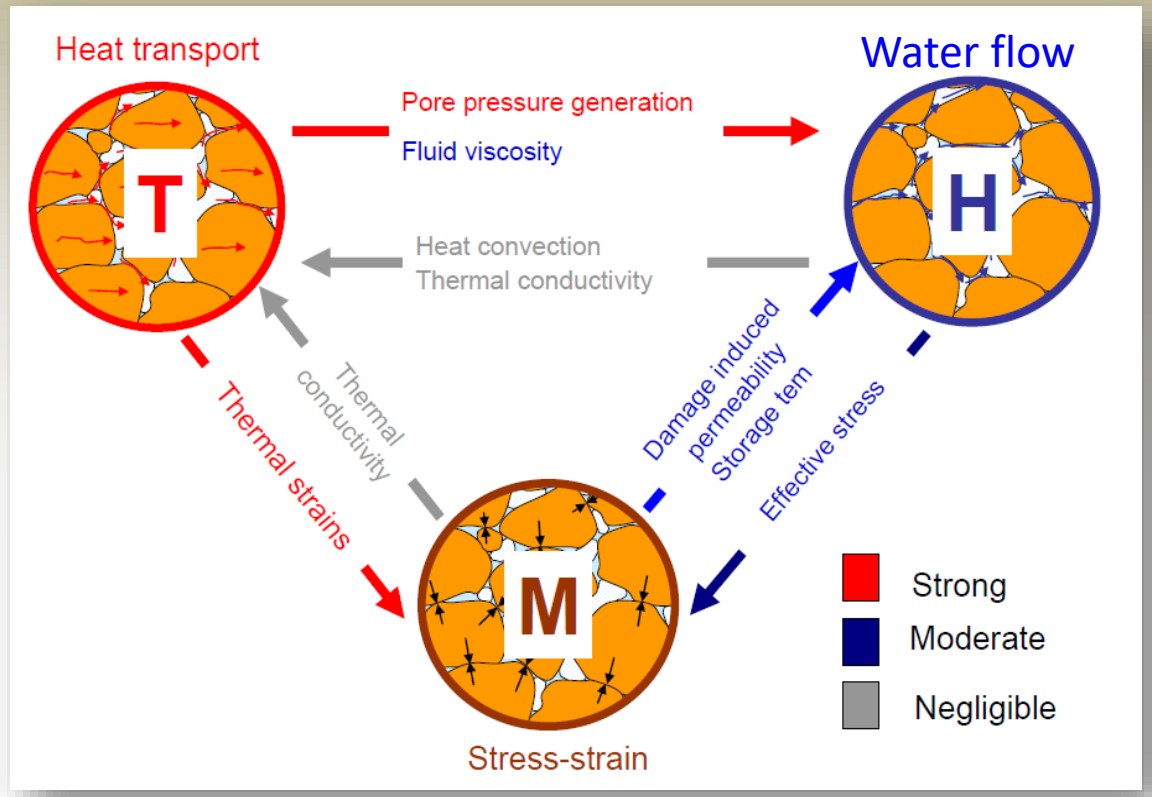
Thermo-hydro-mechanical processes

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



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

- Stress – strain relationship (σ-ε)
- Elasto-plastic properties (E, ν, c, φ...)

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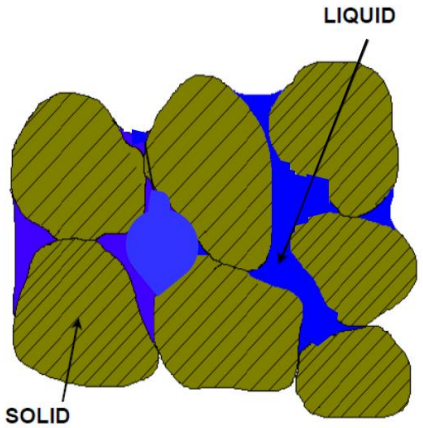
Boom Clay - THM characterisation

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



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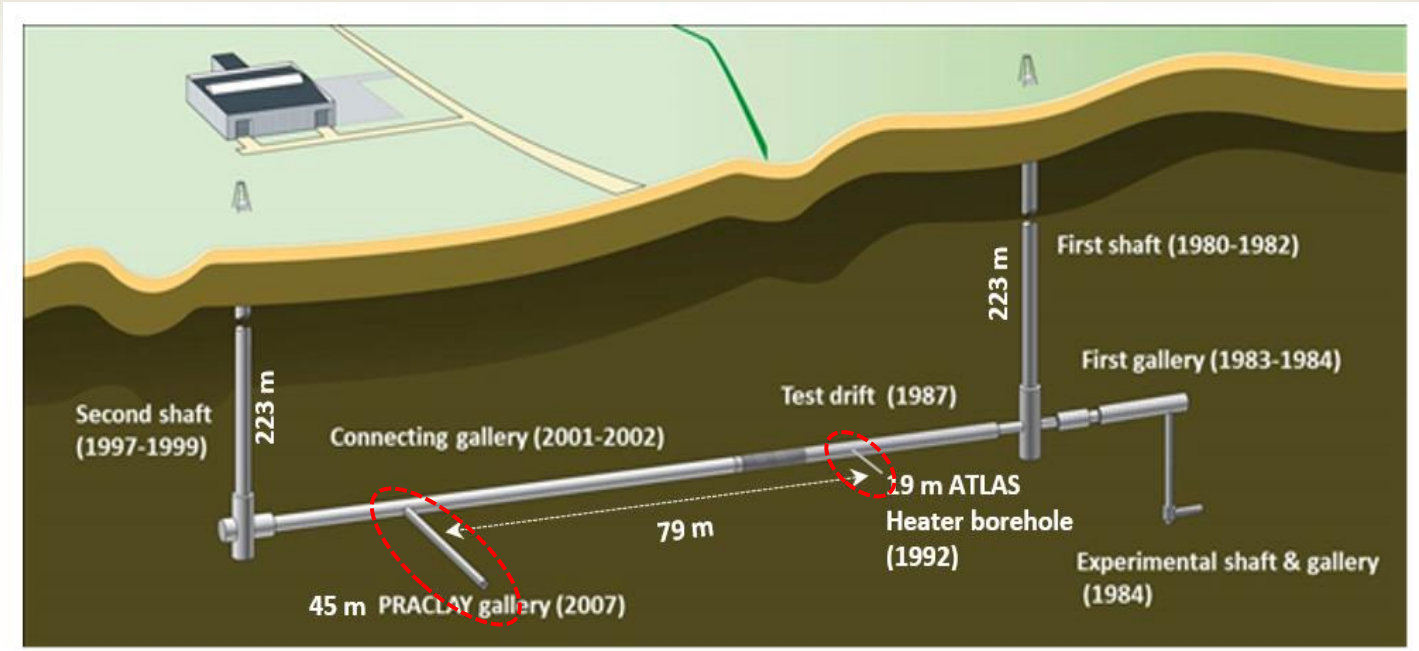
THM characterisation at HADES URL

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



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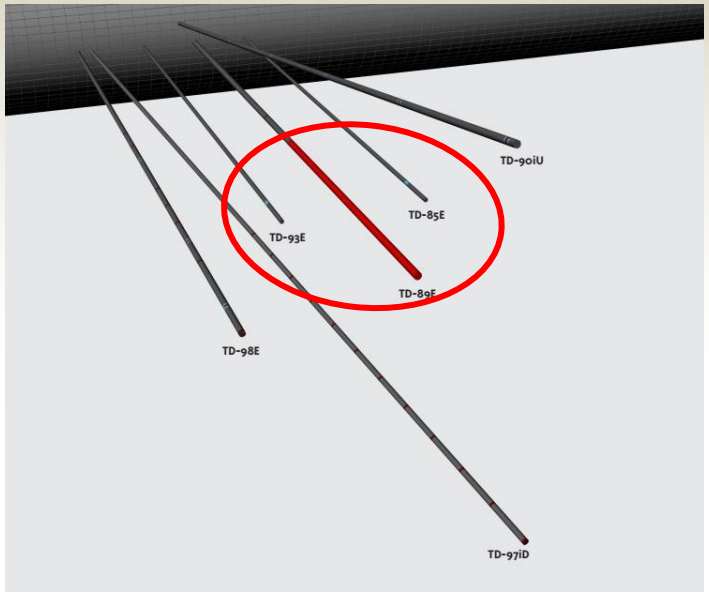
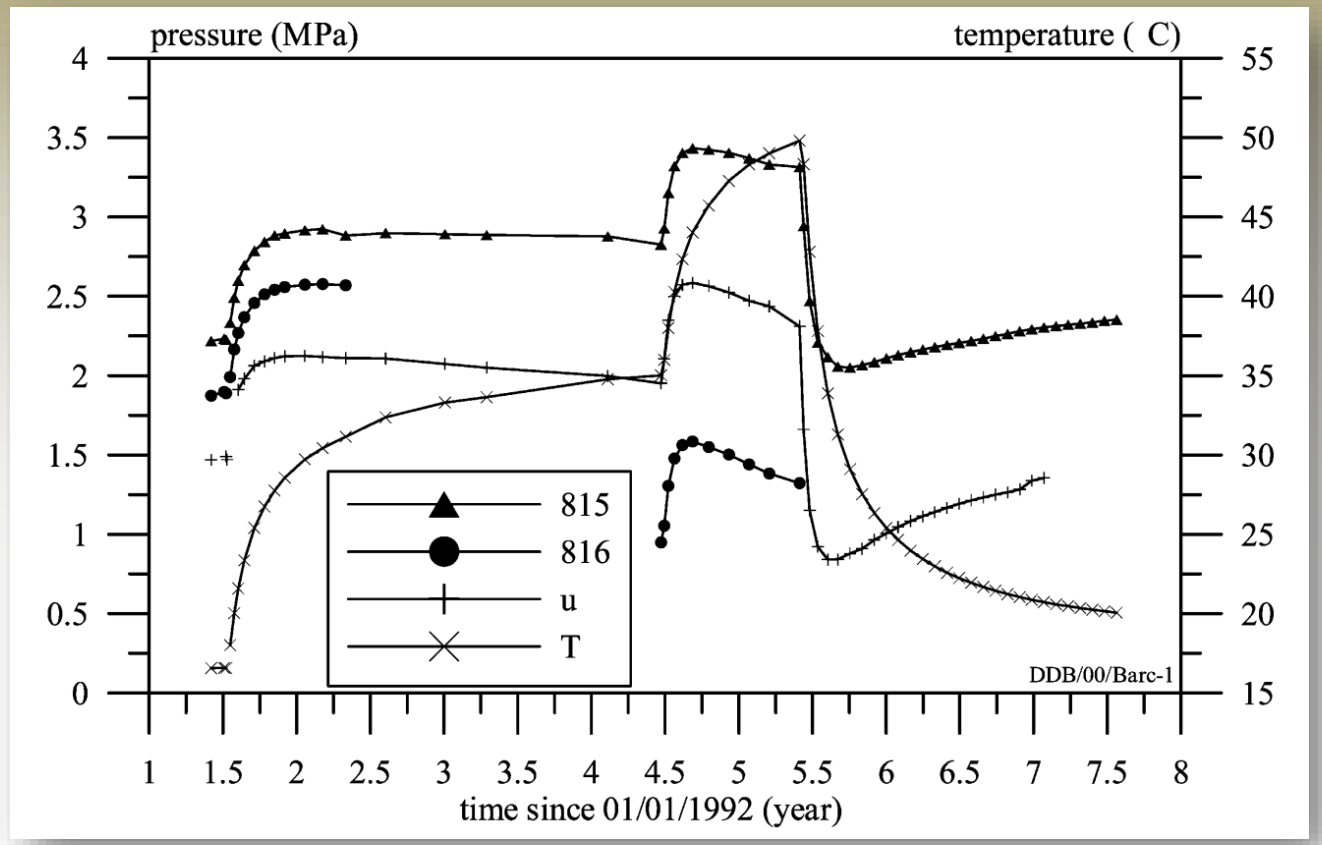
First insight on the Boom Clay THM Behaviour

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





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

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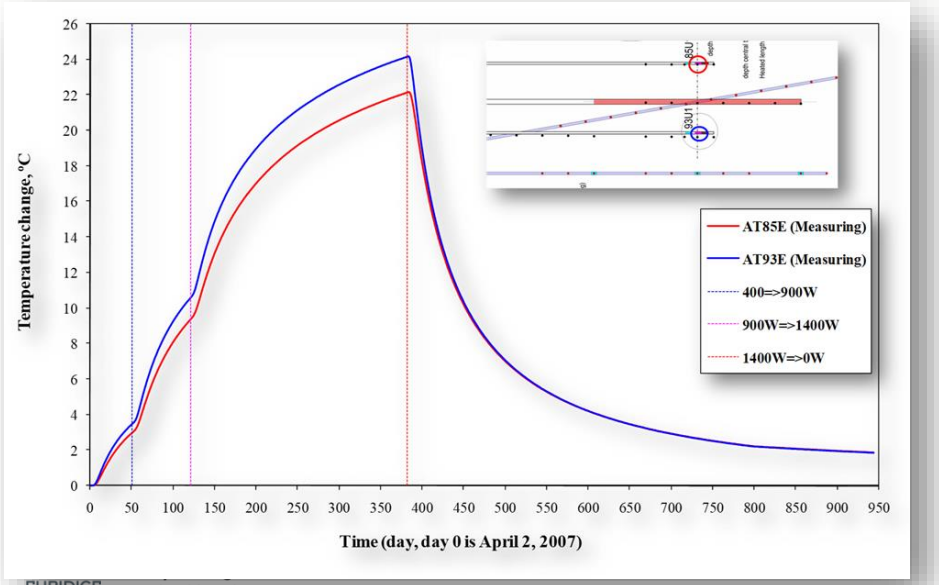
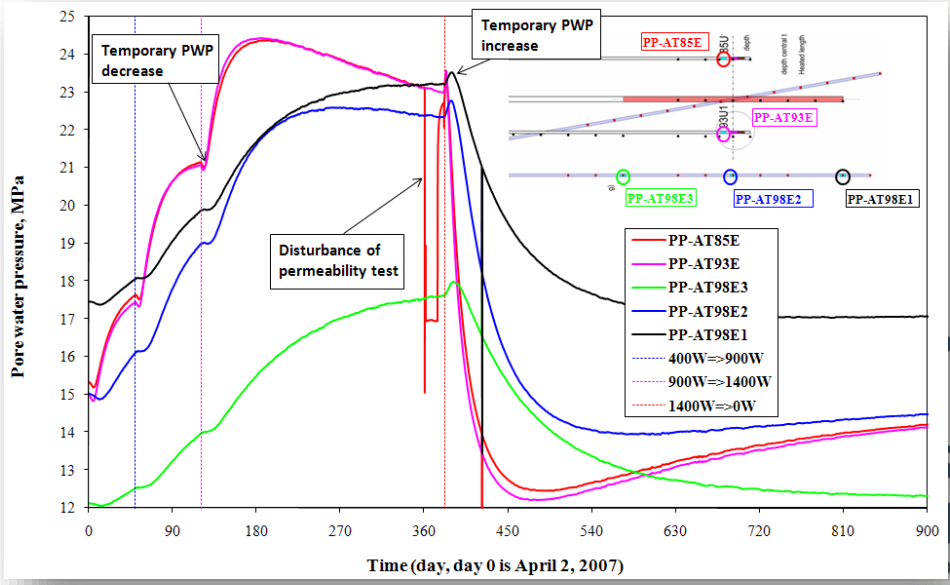
THM refinement from ATLAS III & IV

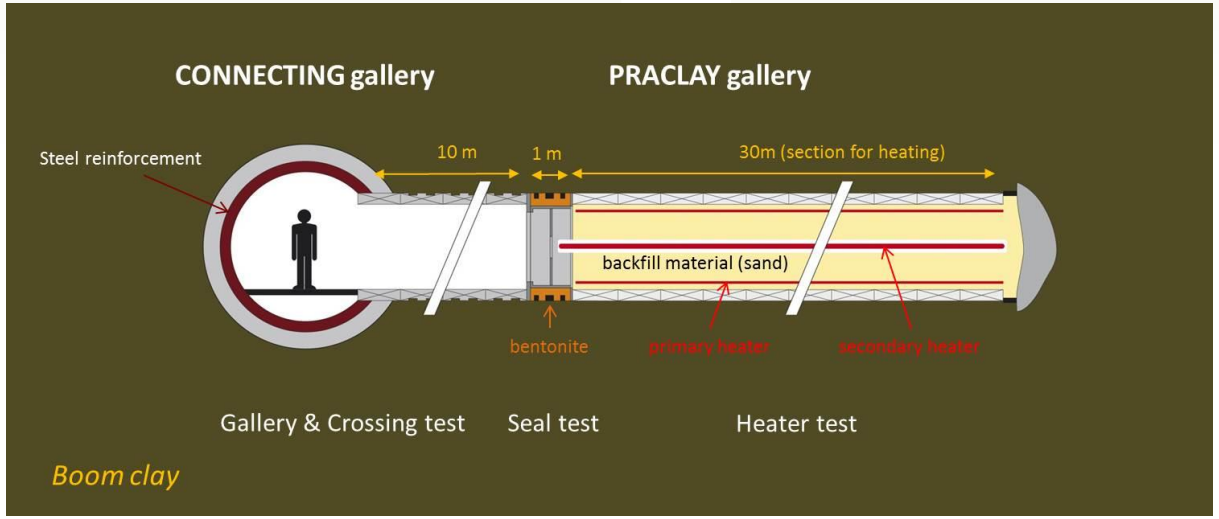
- **ATLAS III & IV (2007-2012)**
  - Additional boreholes (horizontal and inclined) + Additional T & p_w sensors
  - Same heating strategy for ATLAS III (2007 – 2008) and ATLAS IV (2011 – 2012)
  - Improvements:
    - High data acquisition rate
    - Investigation of thermal anisotropy





Enhanced THM knowledge from the PRACLAY Heater test

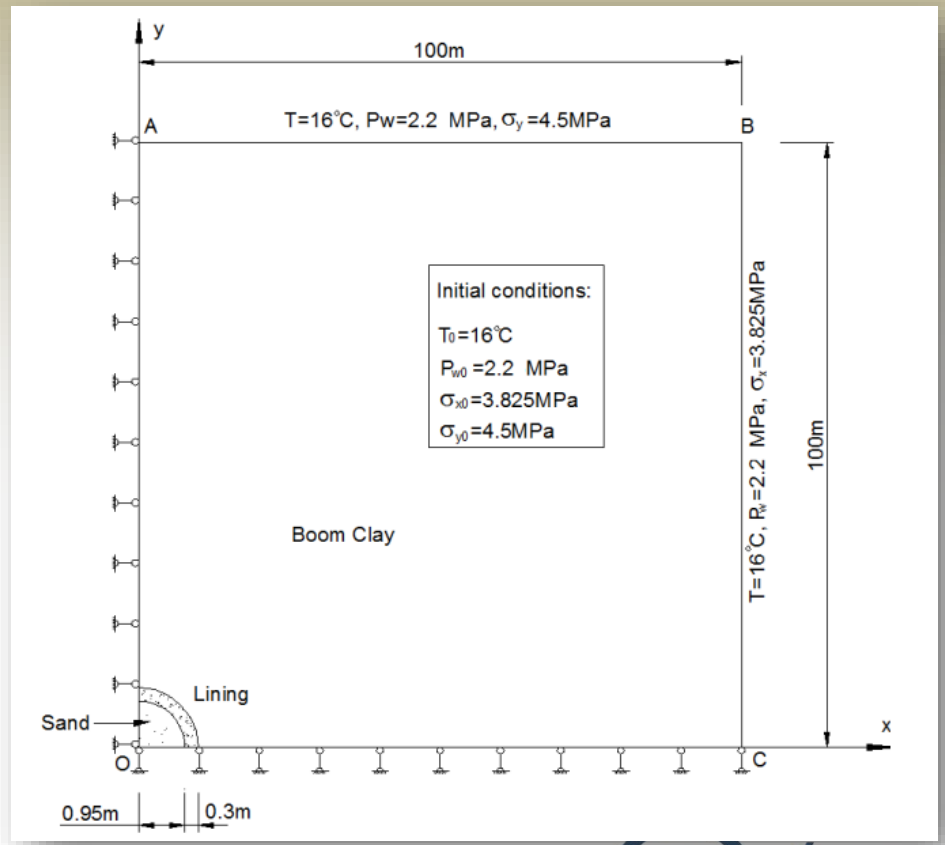
- Large amount of modelling
- 2D Plane Strain THM, 2D Axisymmetric THM, 3D T models
  - Isotropic/Anisotropic THM model
  - Heater power/Temperature boundary condition



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



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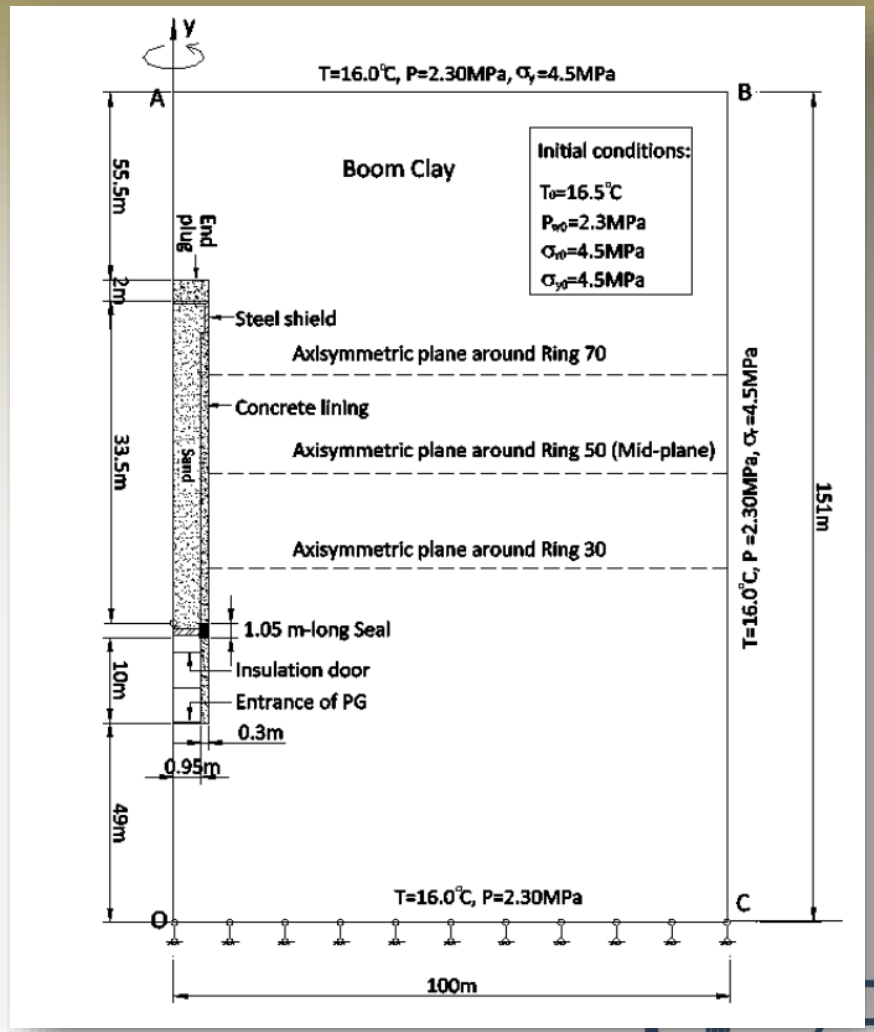
2D Axisymmetric model

- 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

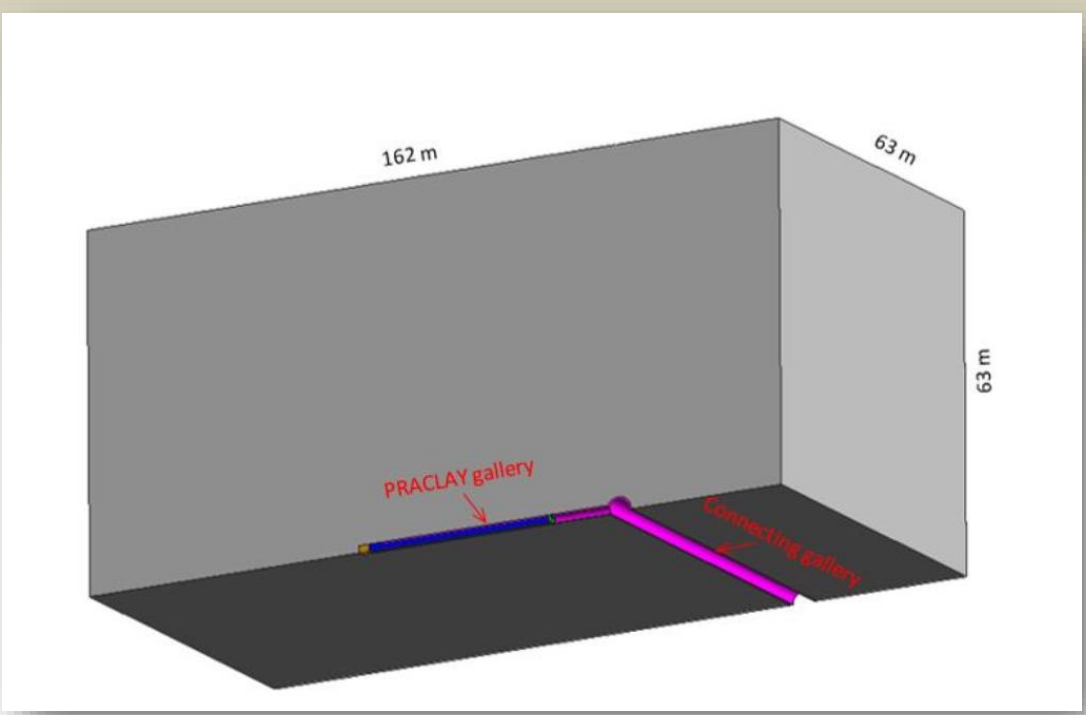
- Including effects of the Connecting Gallery

  ➔ Dissipation of heat/ water flux in all directions

  ➔ Anisotropic properties OK

  ➔ All components of the PRACLAY experiment

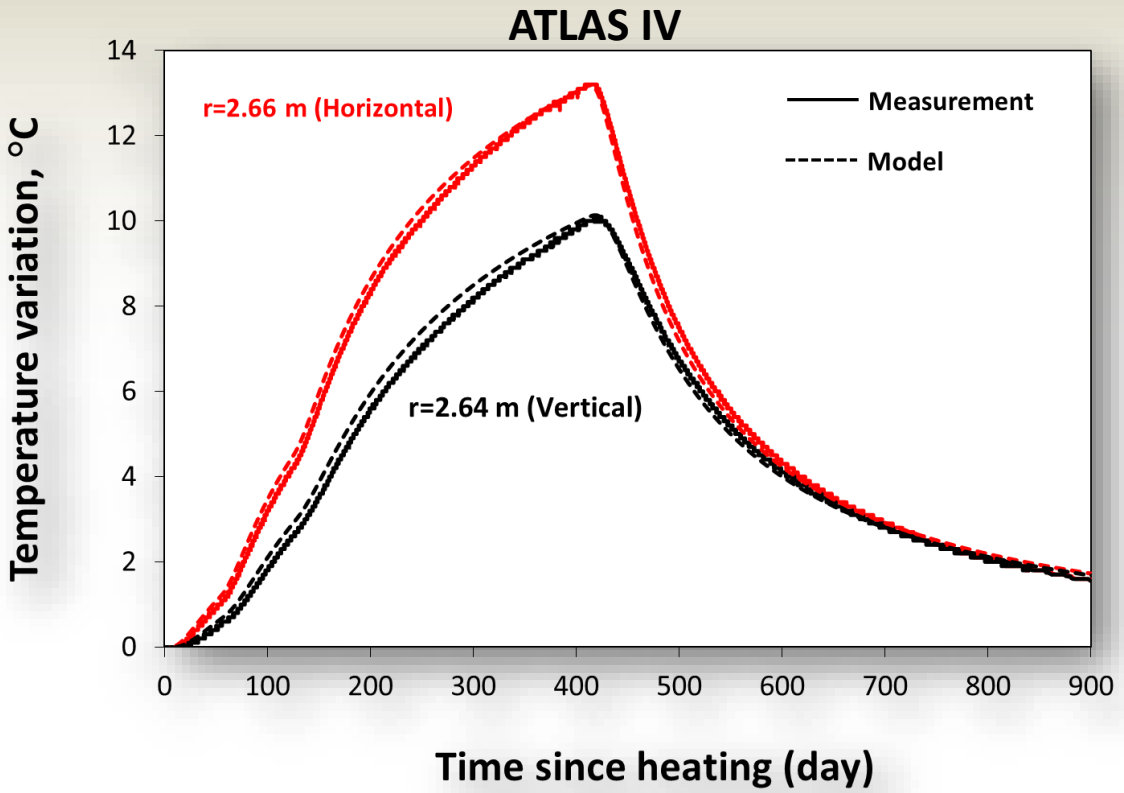
  ➔ Very heavy to realise for a fully coupled THM analysis

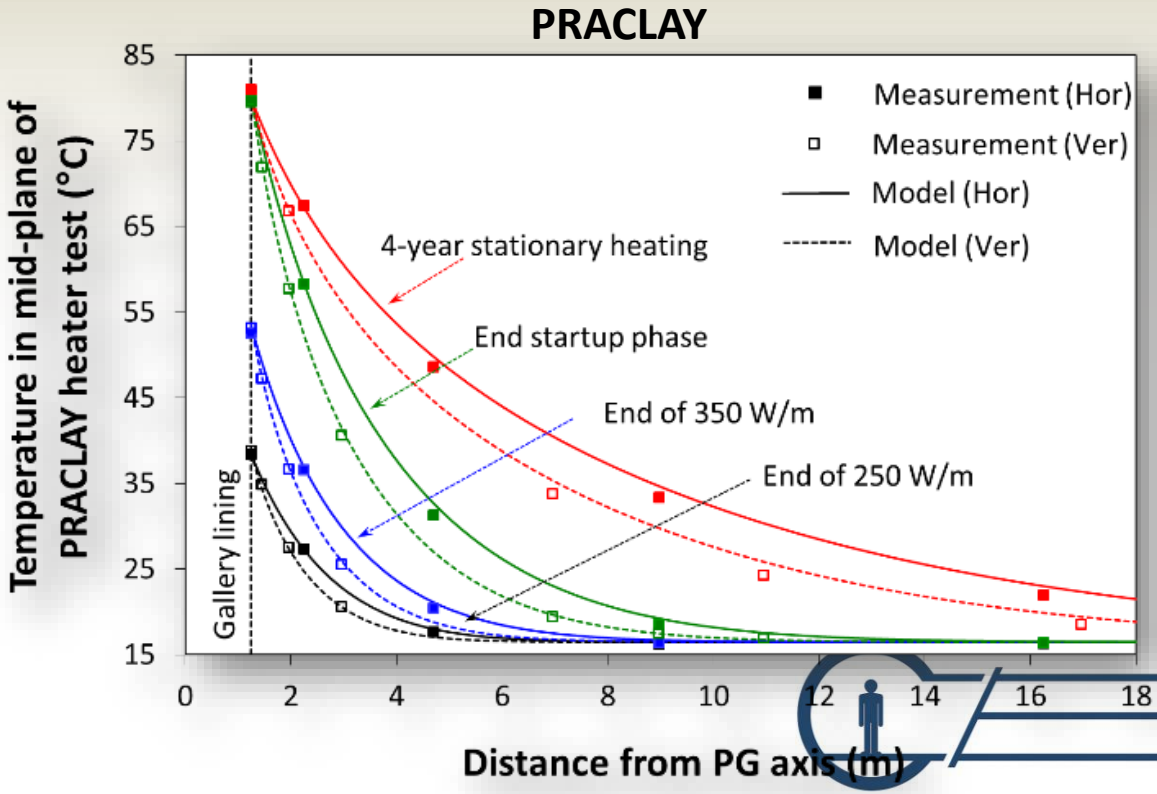


PRACLAY Heater test – 3D thermal modelling

3D model – Thermal analysis

- Thermal conductivity assessment: λ_h = 1.9 W/(mK) / λ_v= 1.20 W/(mK)





Chen et al., 2022, Acta Geotecnica

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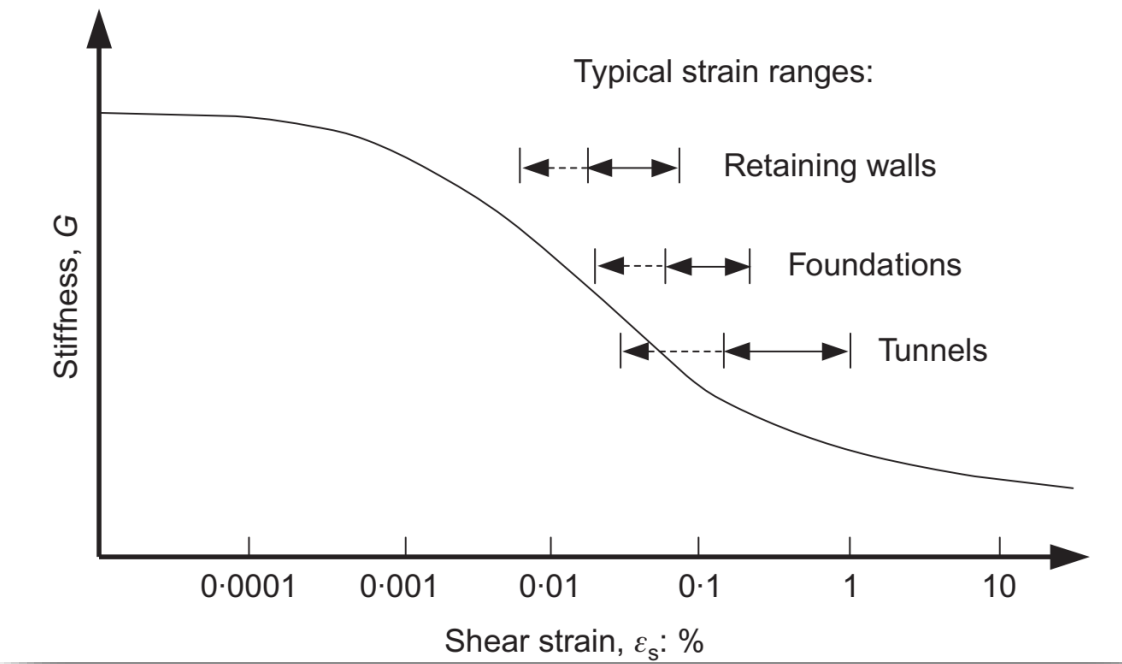
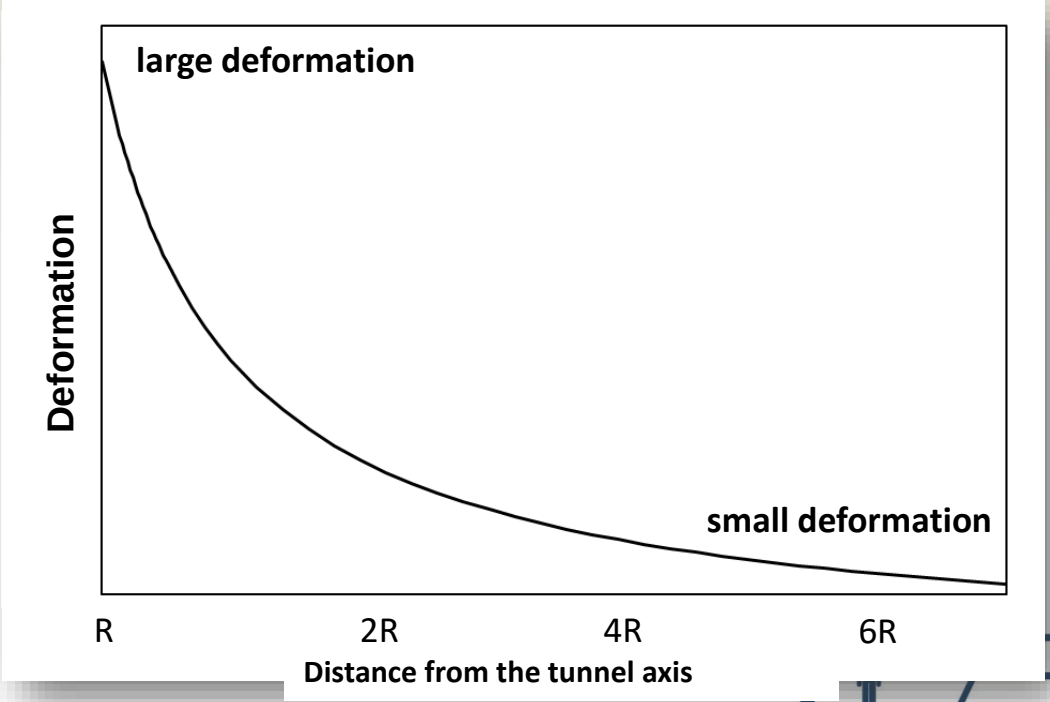
PRACLAY Heater test – 2D Plane strain

2D Plane Strain – THM analysis

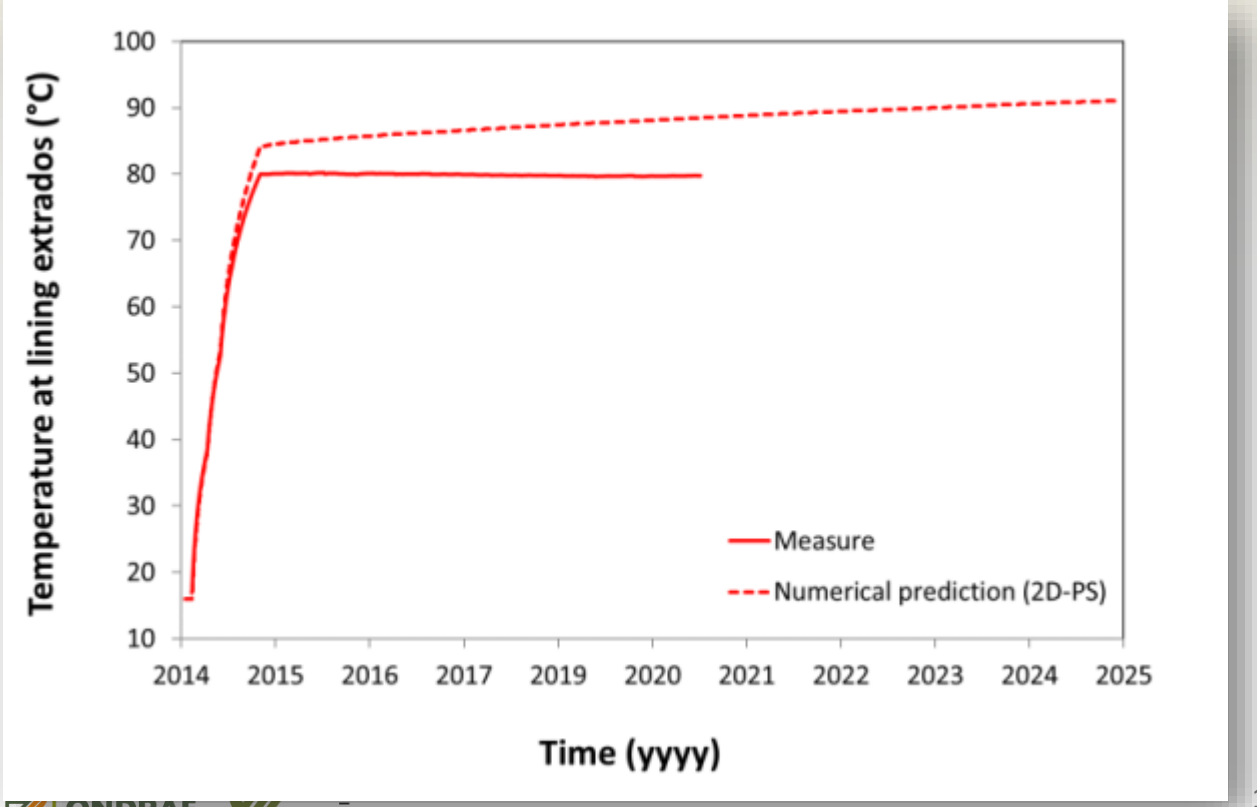
- Additional mechanisms to consider the degradation of the shear modulus with strain
  ➔ transition near-field / far-field

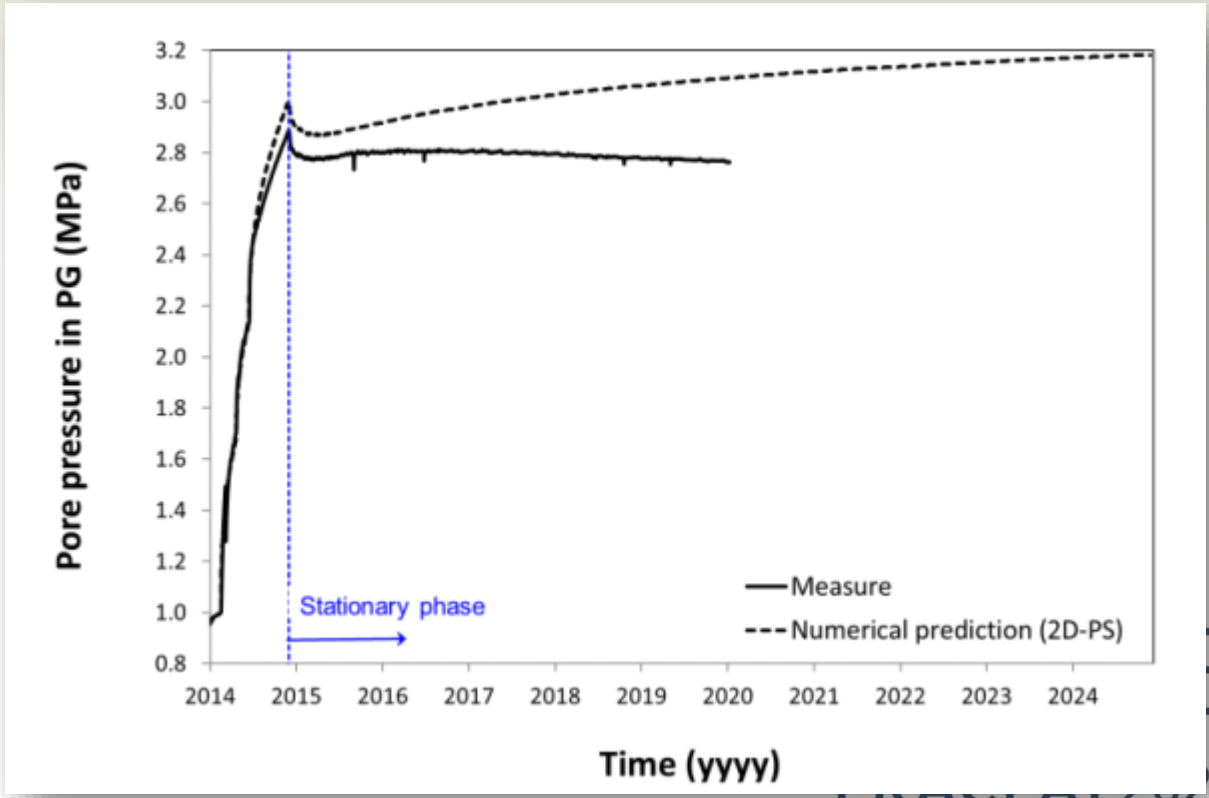




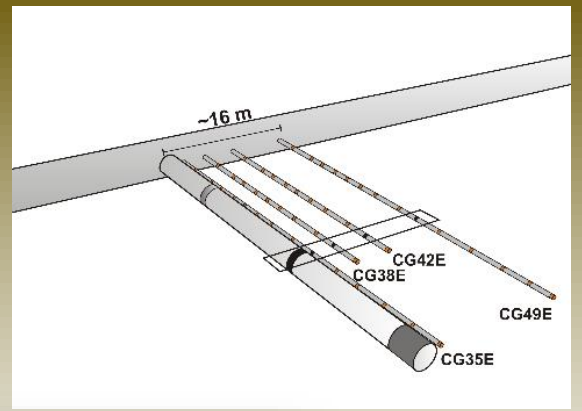
2D Plane Strain – THM analysis

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

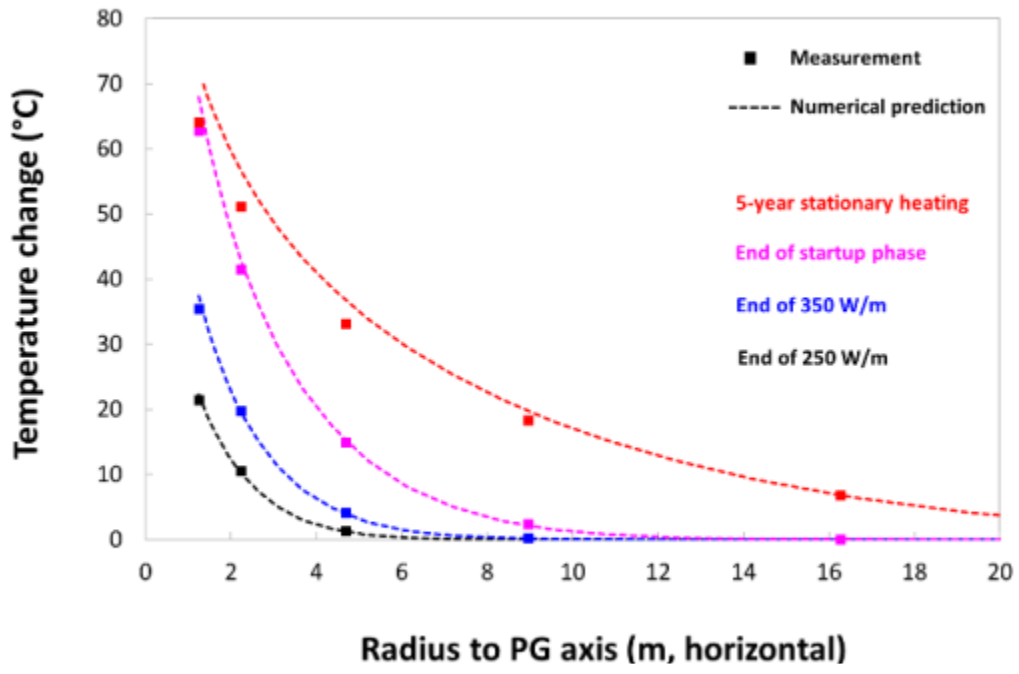




Temperature in the Boom Clay

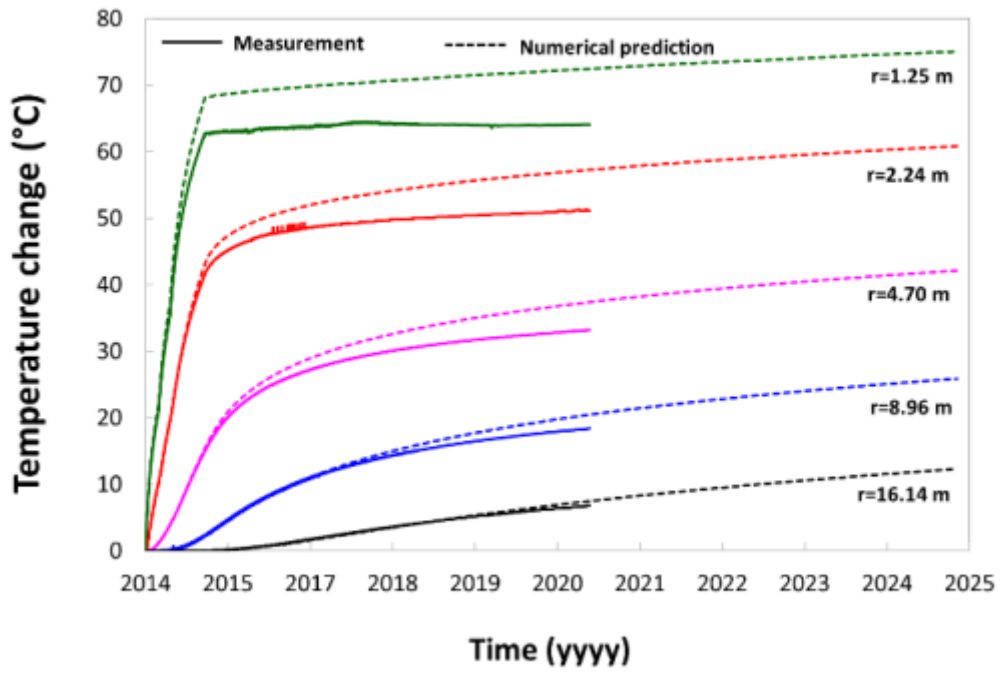


Temperature profiles



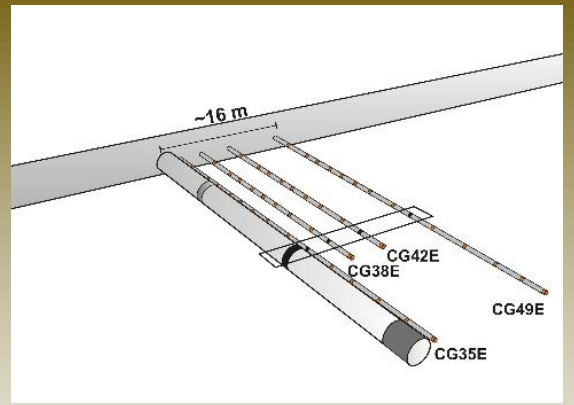
(a) T-ı

Temperature evolution

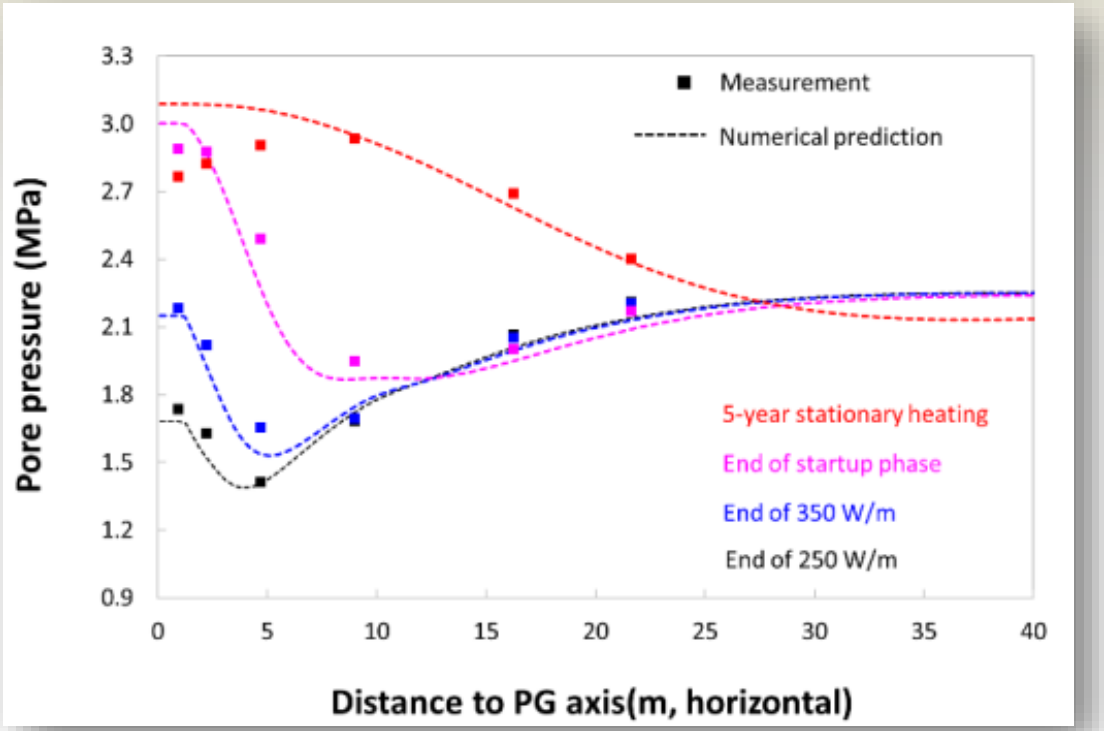


(b) T-t

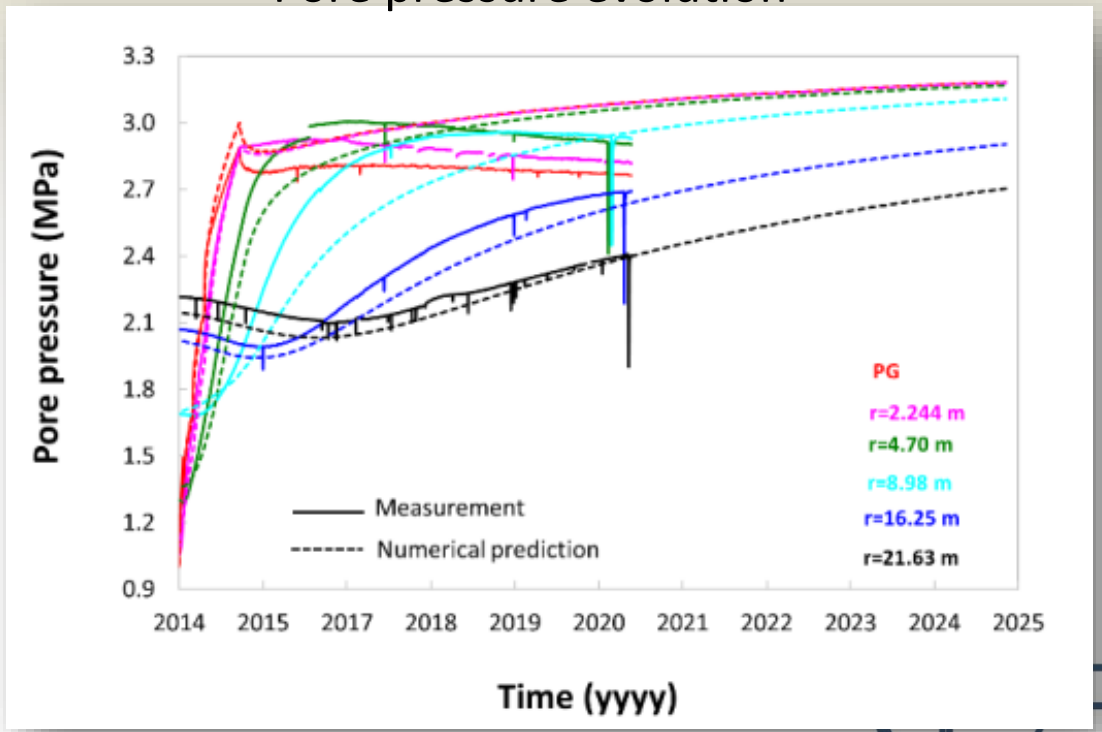
Pore water pressure in the Boom Clay



Pore water pressure profiles



Pore pressure evolution



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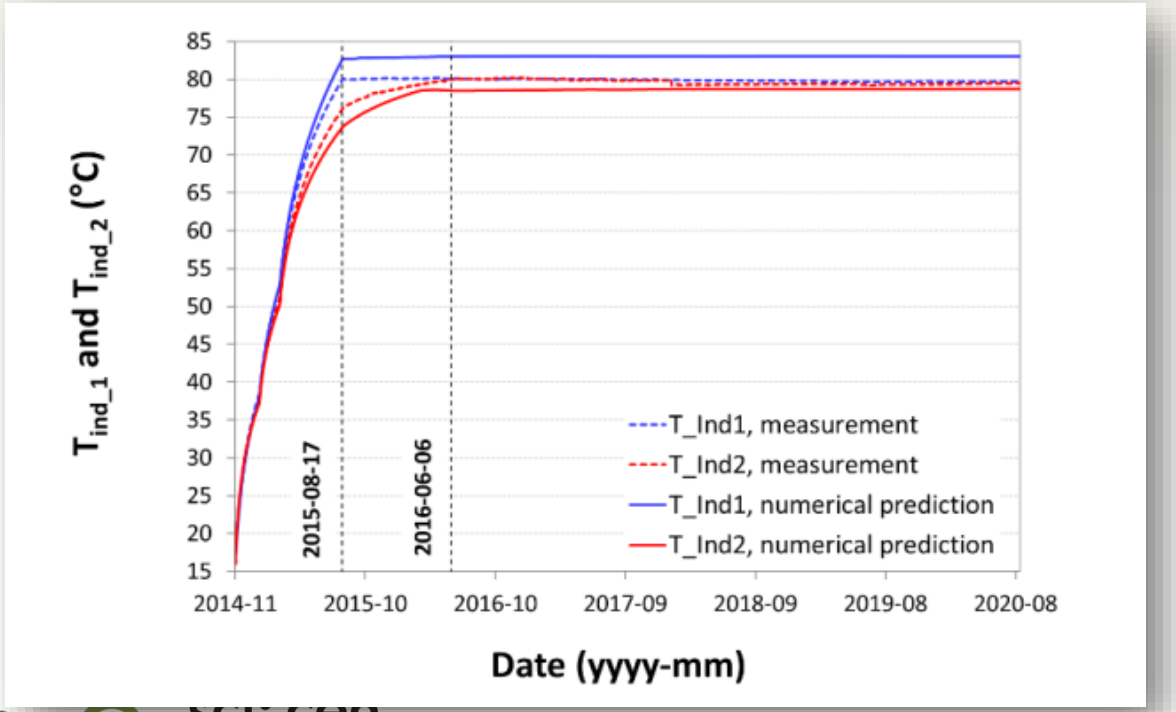
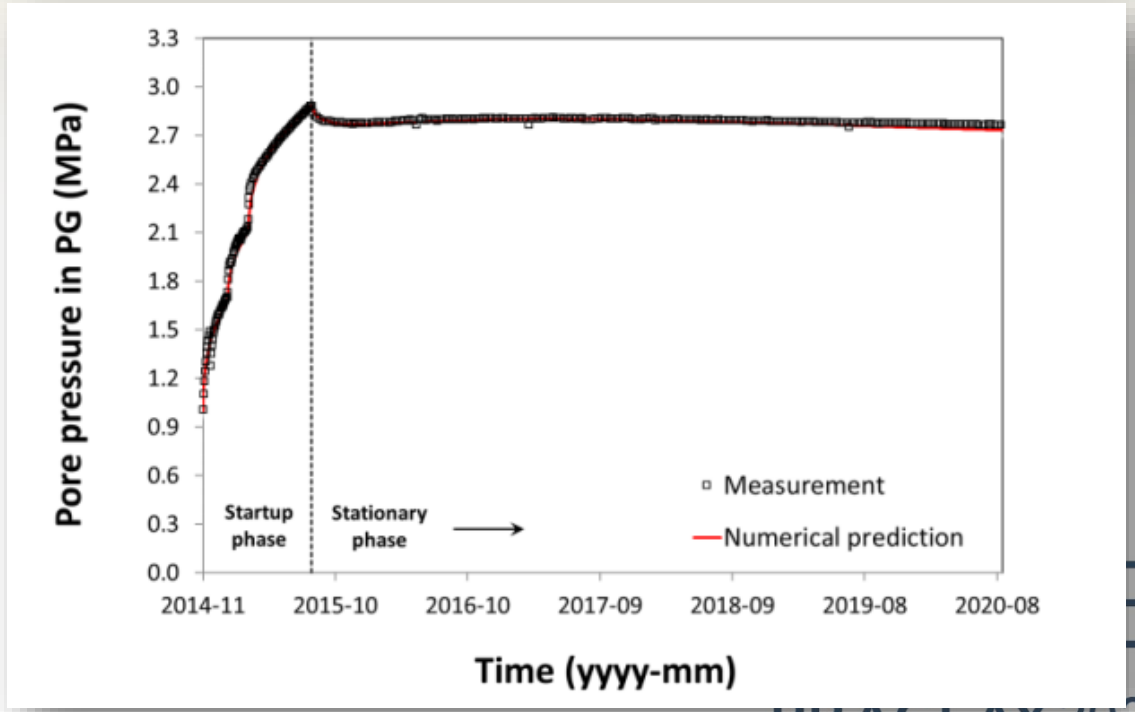
PRACLAY Heater test – 2D Axisymmetric model

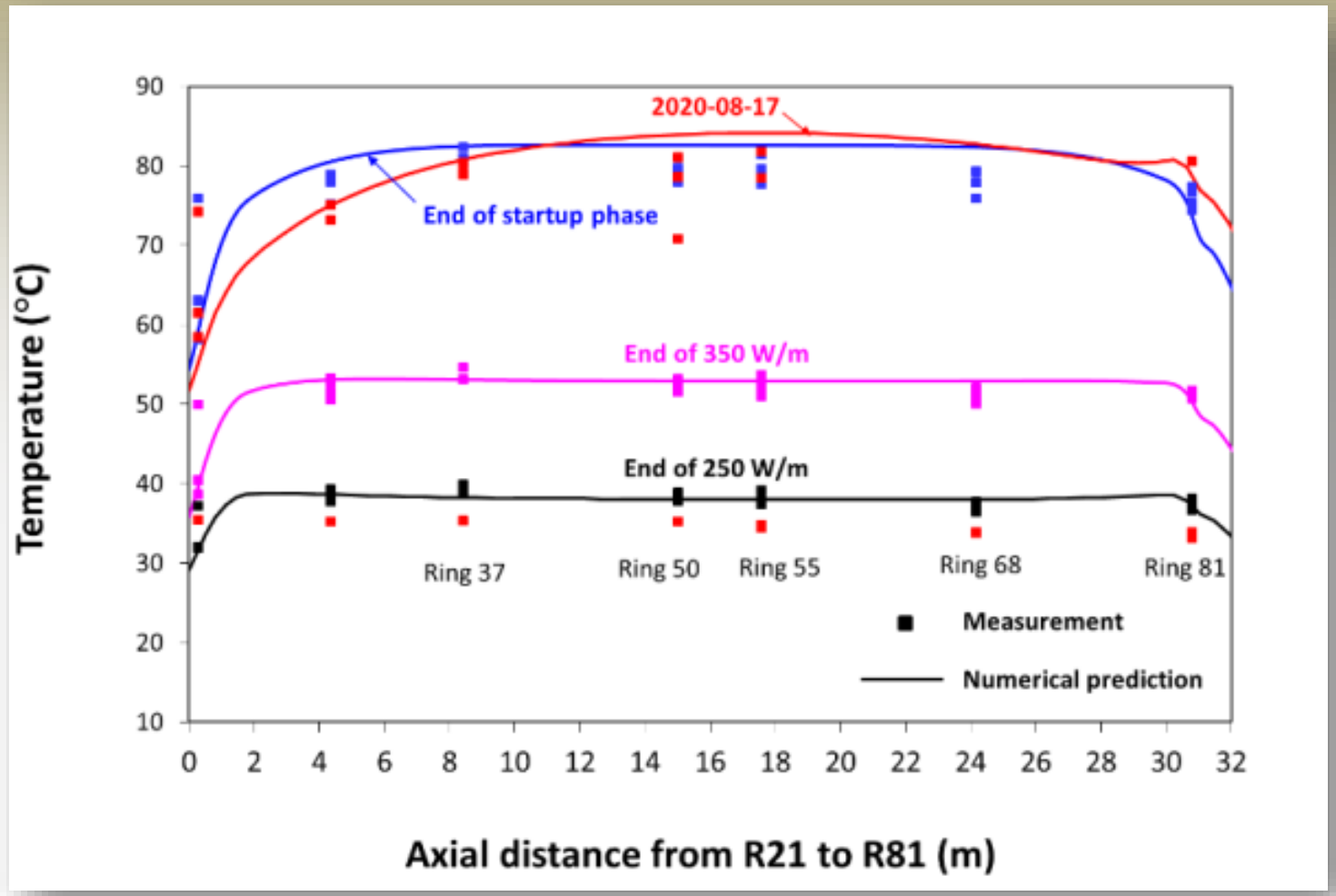
2D Axisymmetric – THM analysis

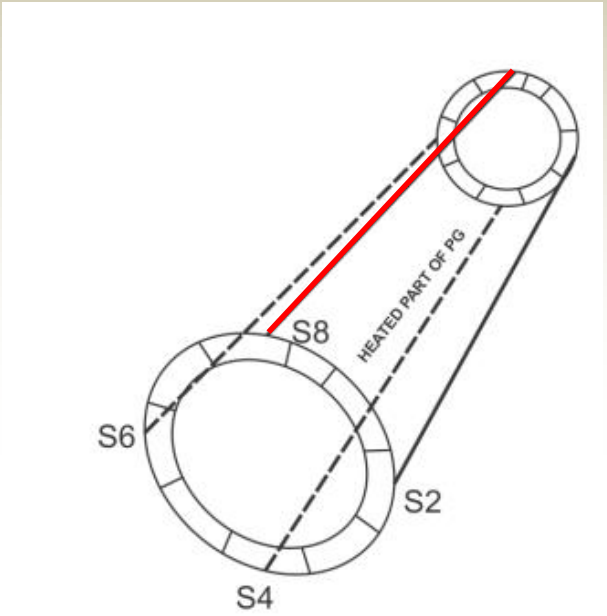
- Steering parameters:
  - Temperature evolution - lining / Boom Clay interface
  - Pore water pressure evolution in PRACLAY gallery



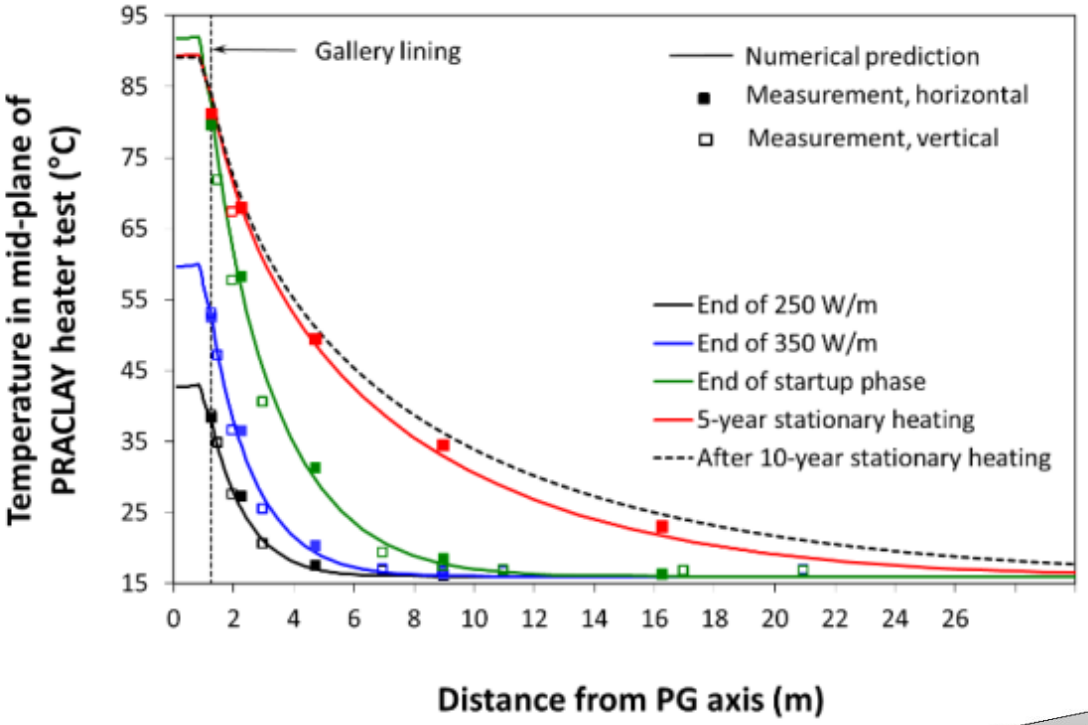


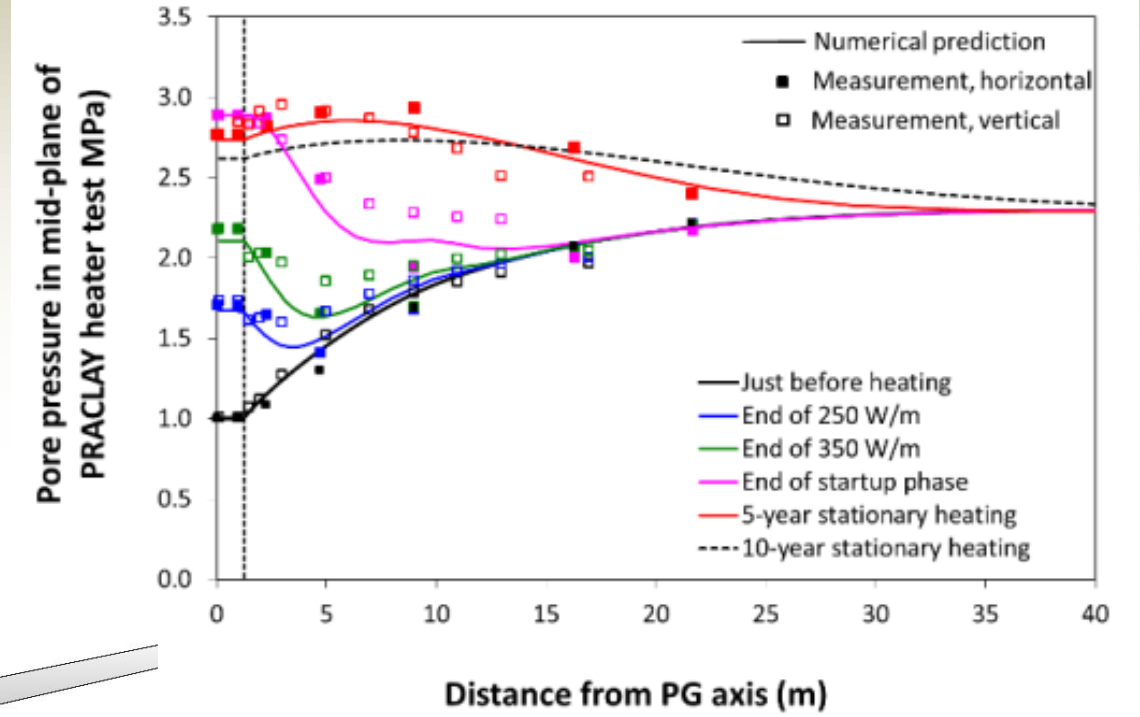
Temperature profiles - lining / Boom Clay interface

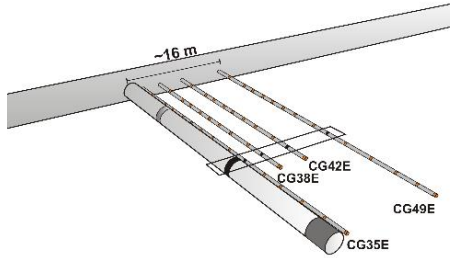




Temperature and pore water pressure profiles







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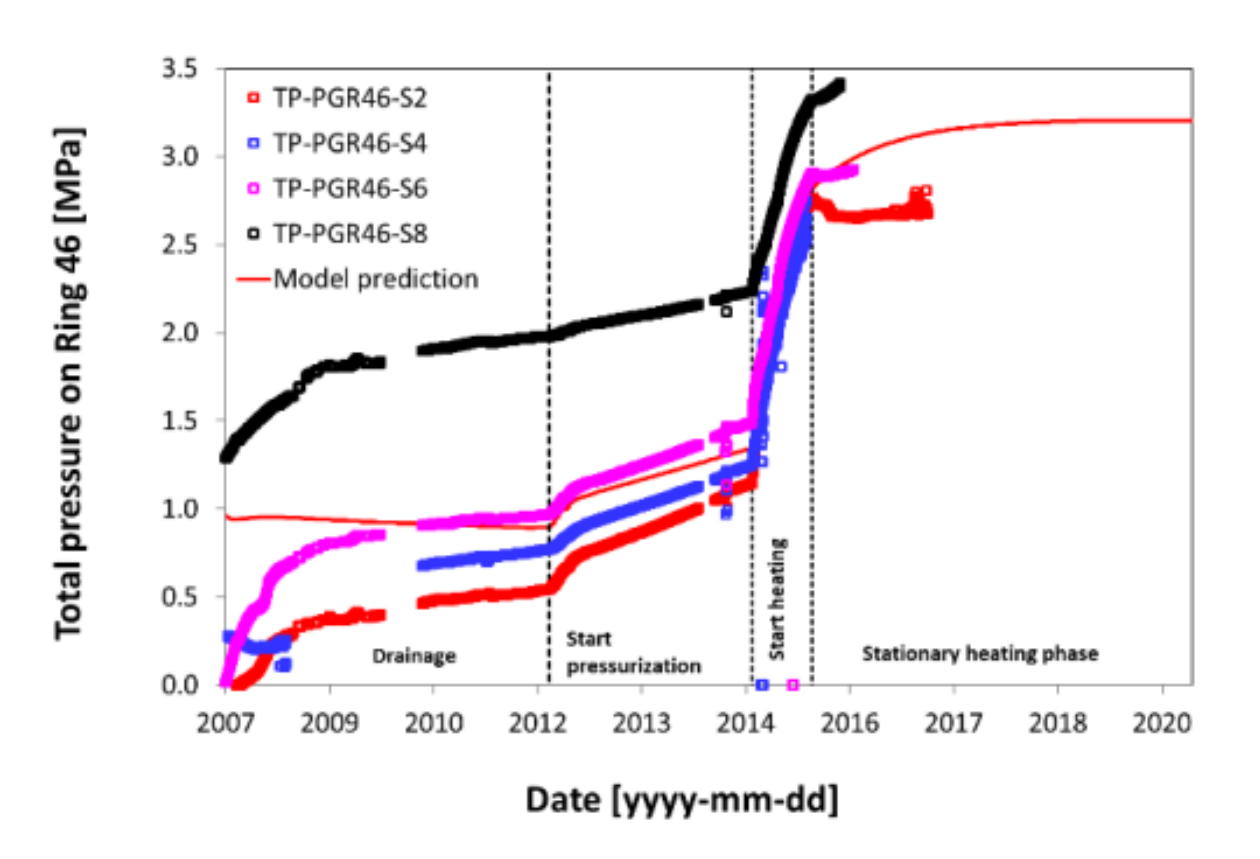
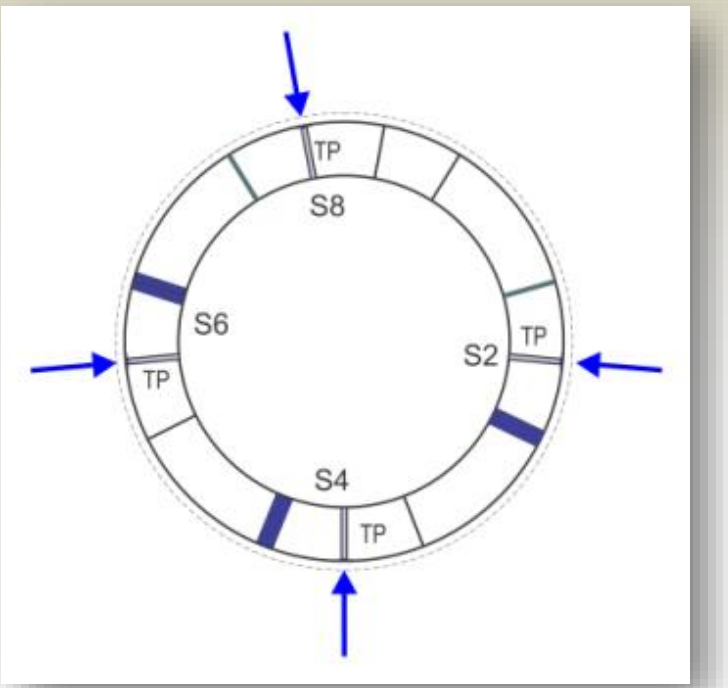
Total pressure acting on the lining





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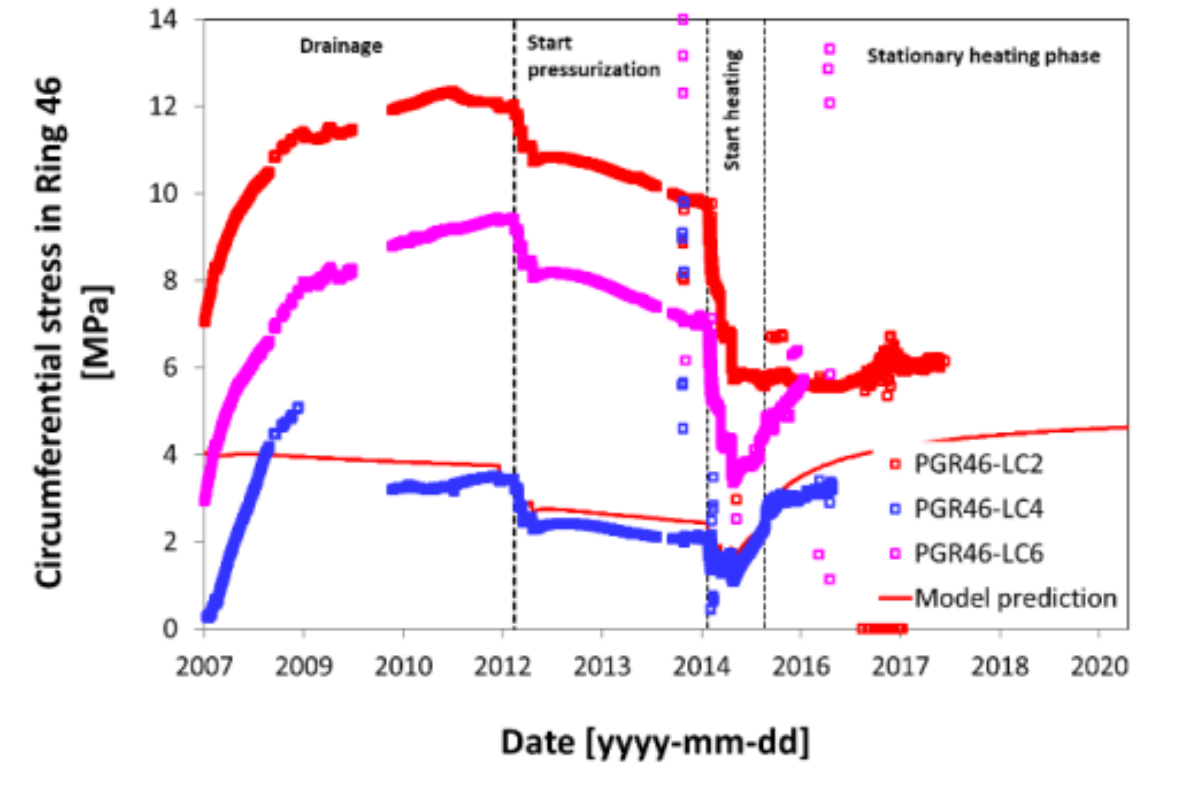
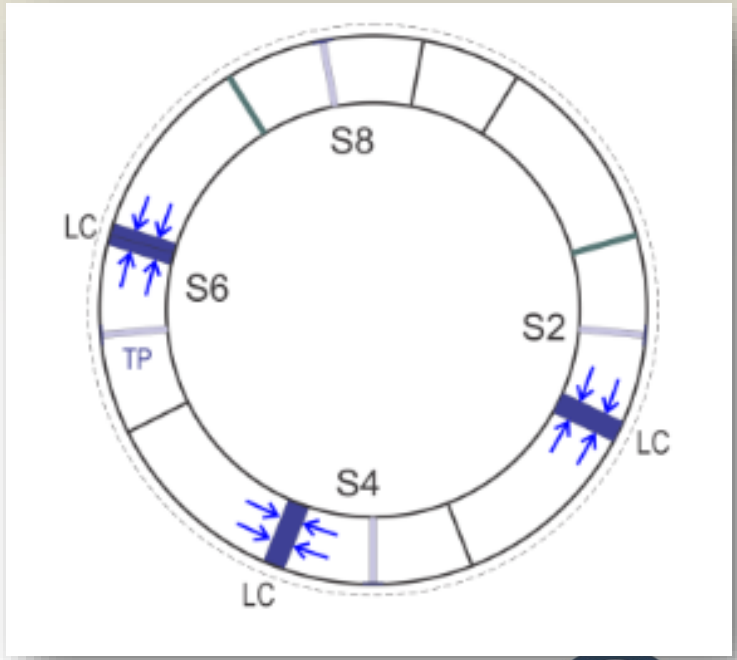
Stresses inside the segmental lining





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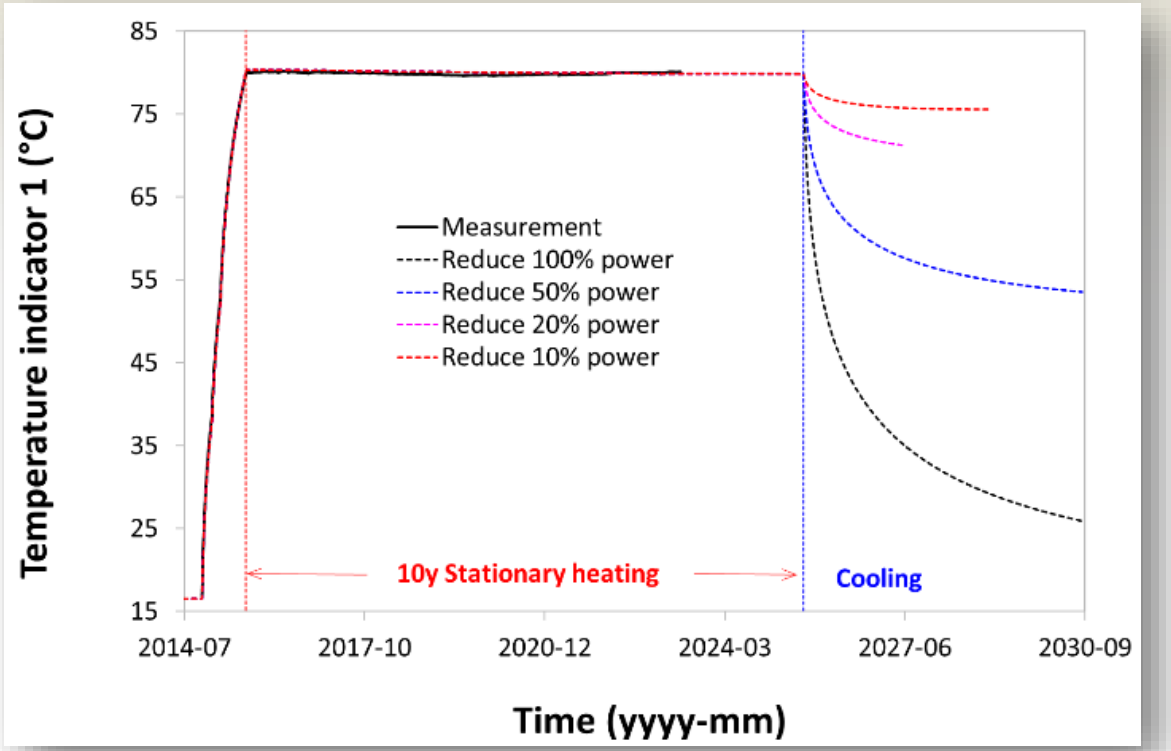
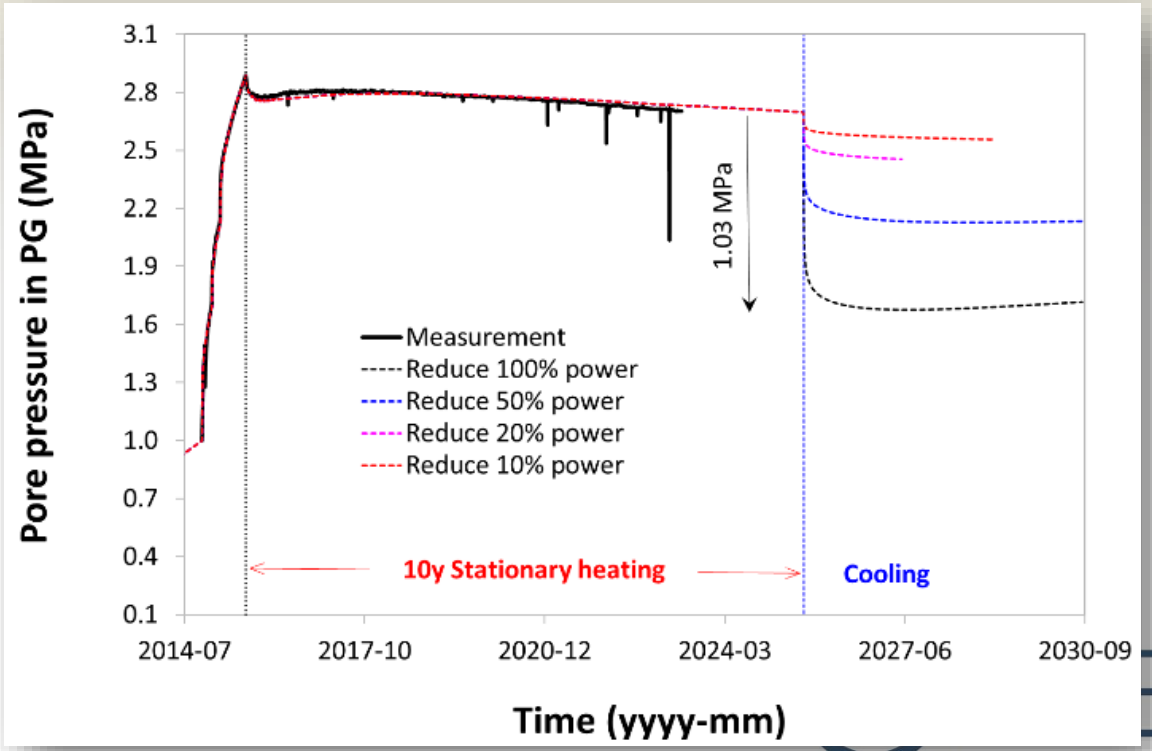
PRACLAY Heater test – Cooling phase

What can we expect during the Cooling phase ?

- Definition of four scenarios of power decrease – 100% - 50% - 20% - 10%

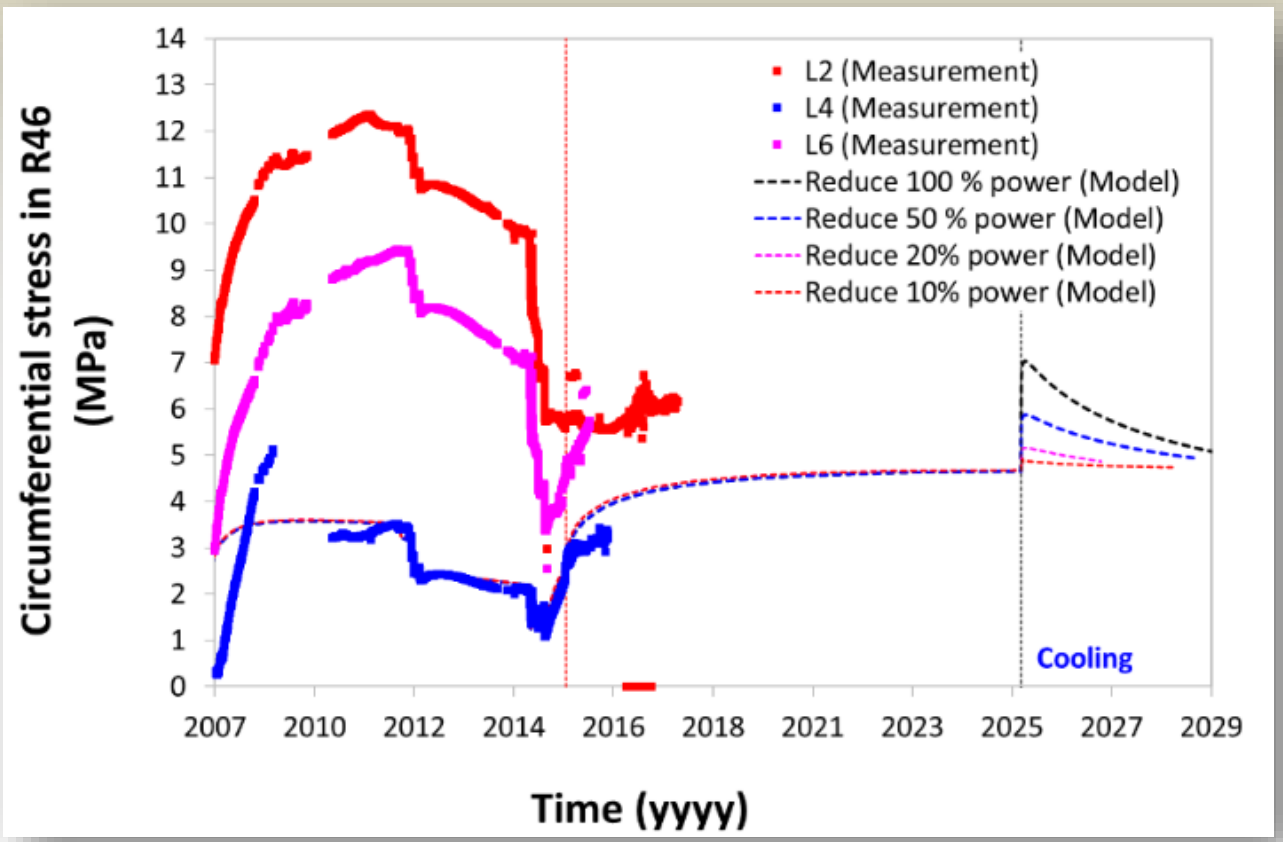
➔ Temperature and pore water pressure variation in clay and in the gallery

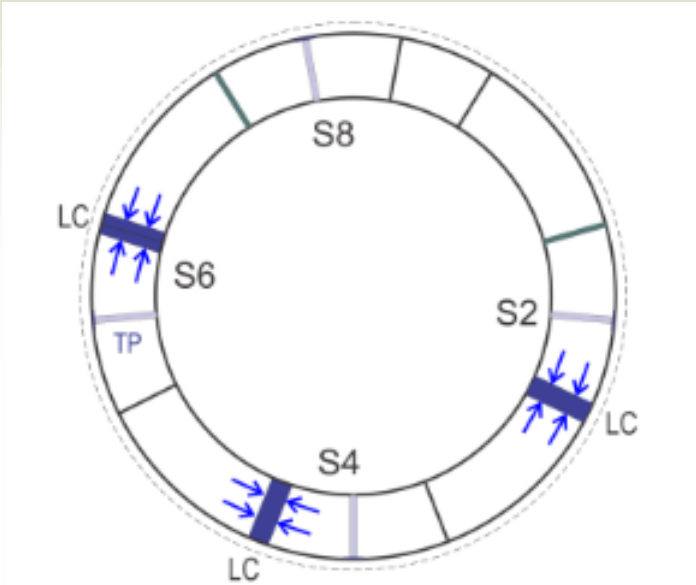




What can we expect during the Cooling phase ?

- Effect on the lining?





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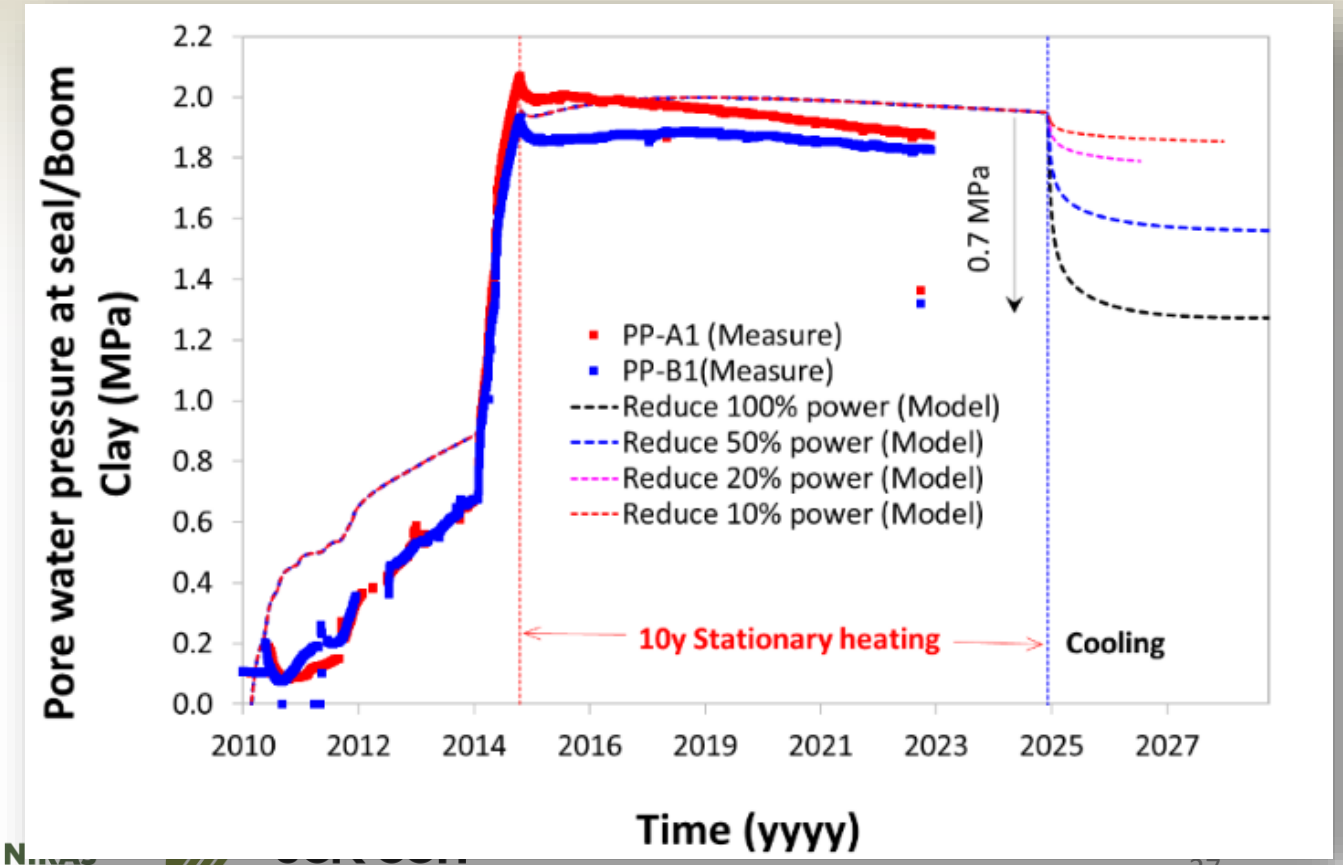
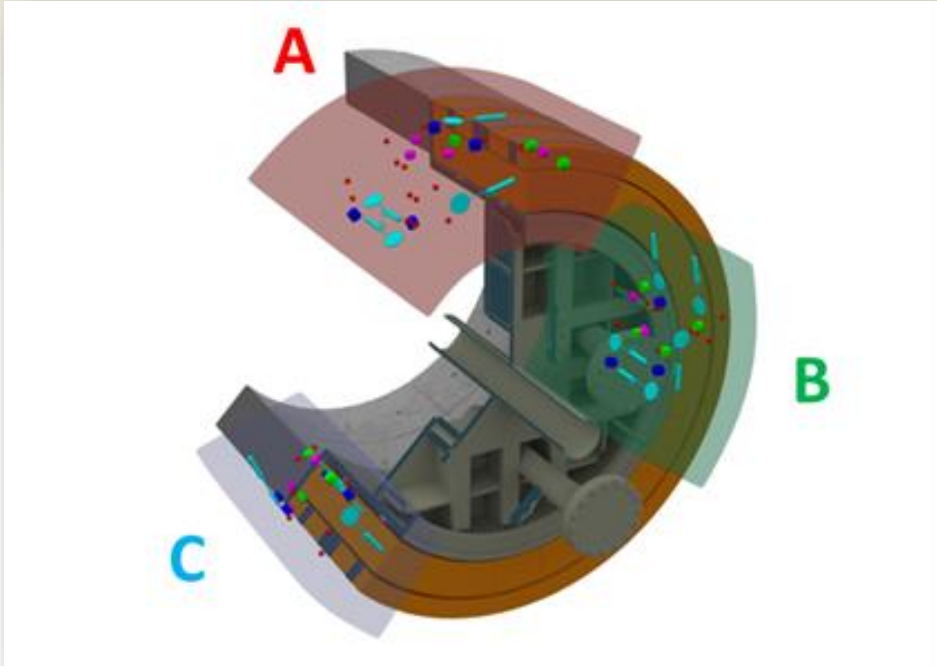
What can we expect during the Cooling phase ?

- Effect on the seal?





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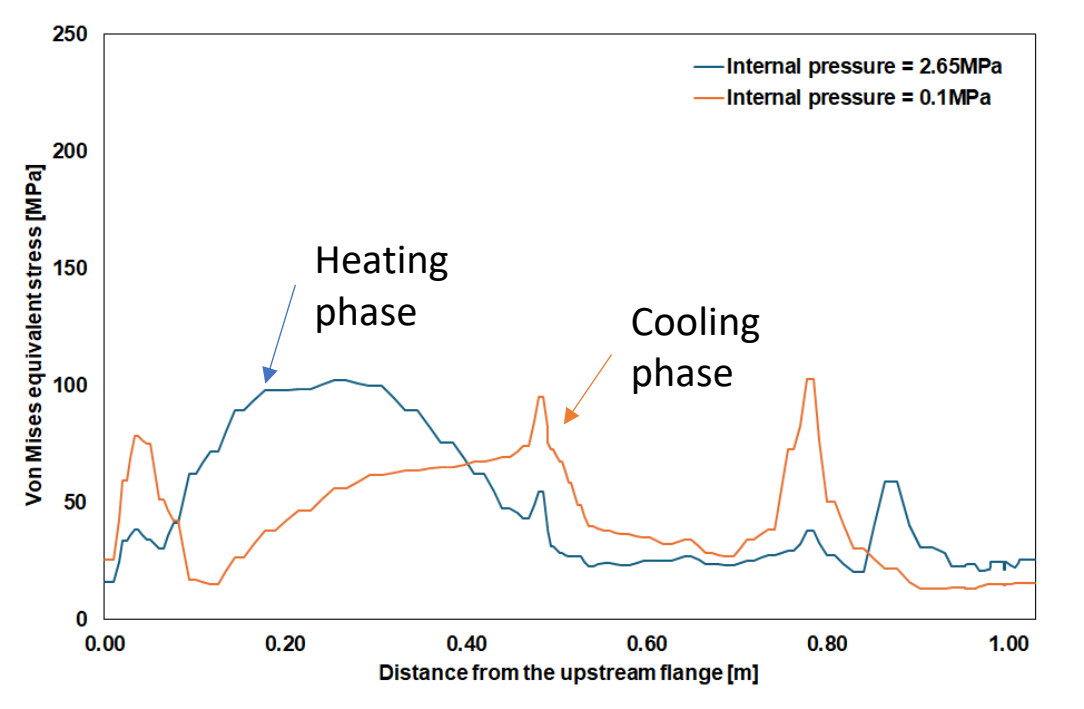
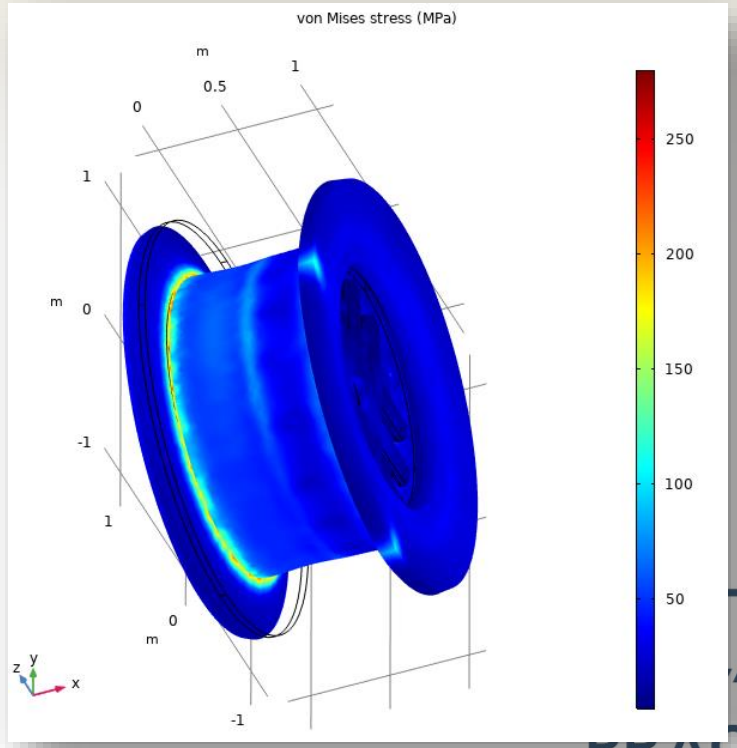
What can we expect during the Cooling phase ?

- 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



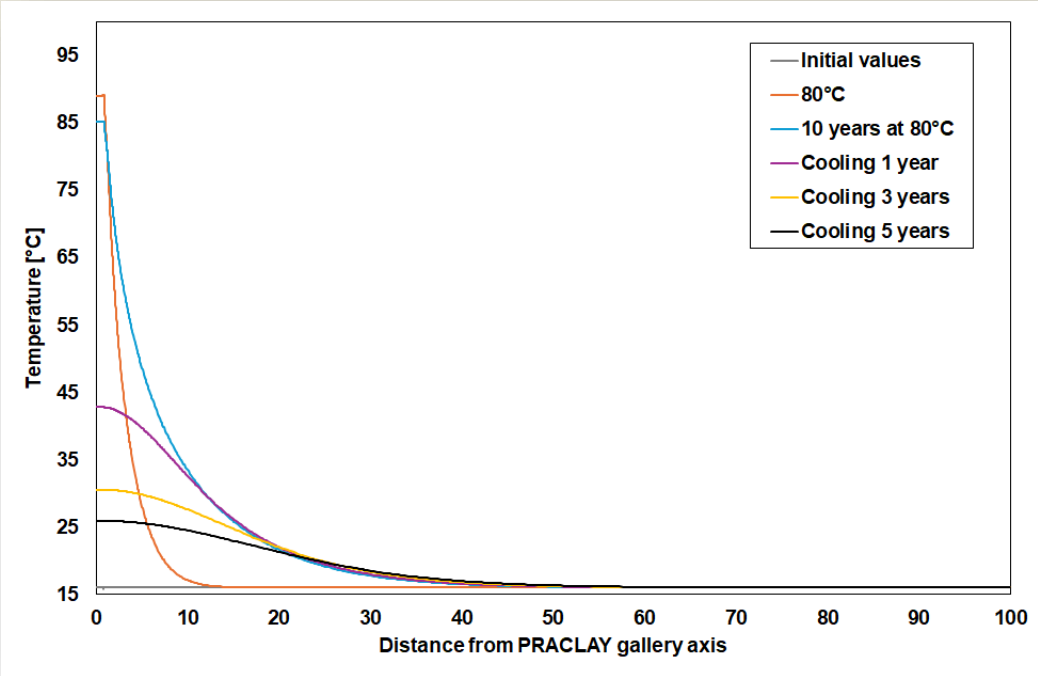


What can we expect during the Cooling phase?

- Chosen 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

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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
  - At least, 3 years before starting dismantling

To be continued…