Belgian programme on radioactive waste management

The PRACLAY in situ Experiment

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

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ONDRAF/NIRAS & EURIDICE

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27th Exchange Meeting

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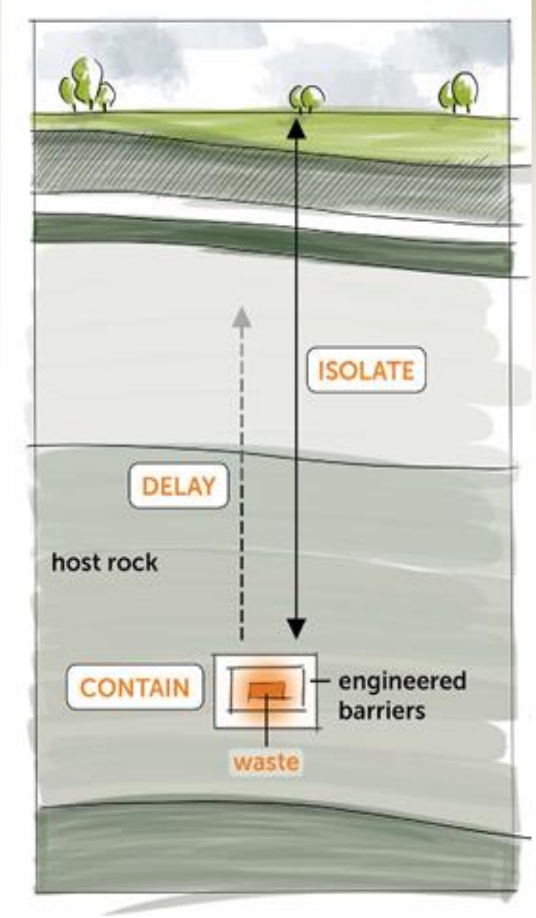
PRACLAY 2025
CLOSING THE HEATING CHAPTER, OPENING THE COOLING PHASE

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

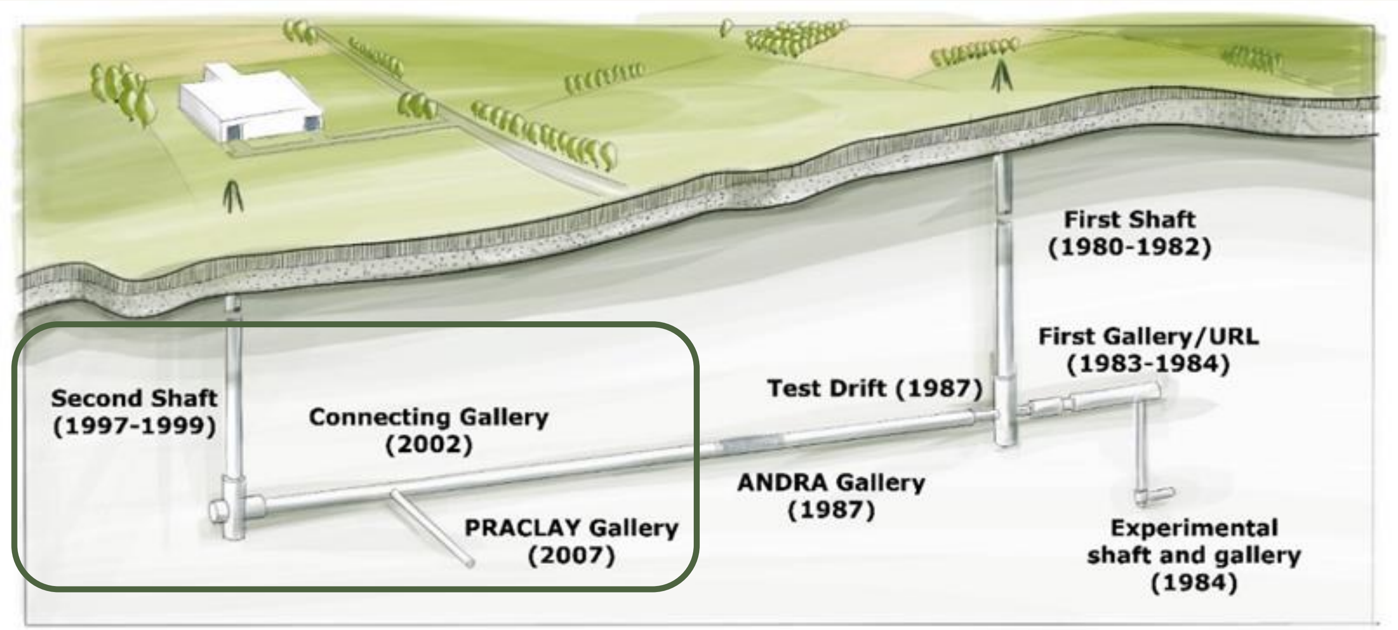


- **Current concept (generic)**
  - in poorly indurated clays (about 50 years of research on Boom Clay)
  - reference depth between 200 and 600 m
- **Multi-barrier system**
- Heat-emitting waste: C waste (vitrified HLW or SF)
  - Full containment during the thermal phase (a few hundreds to a few thousands' 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)

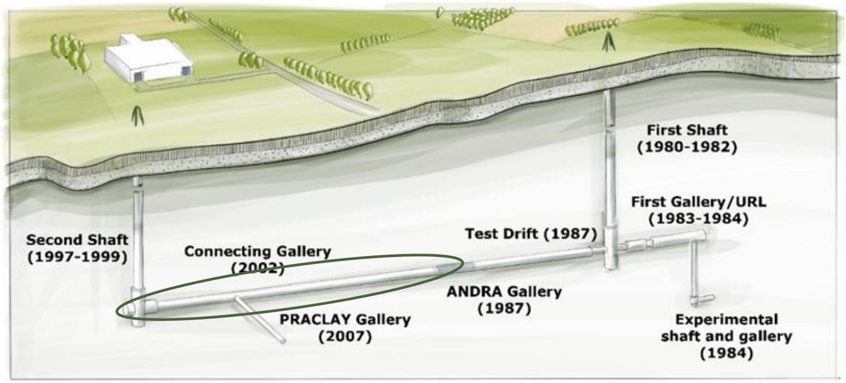


Demonstrate feasibility with industrial techniques

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)



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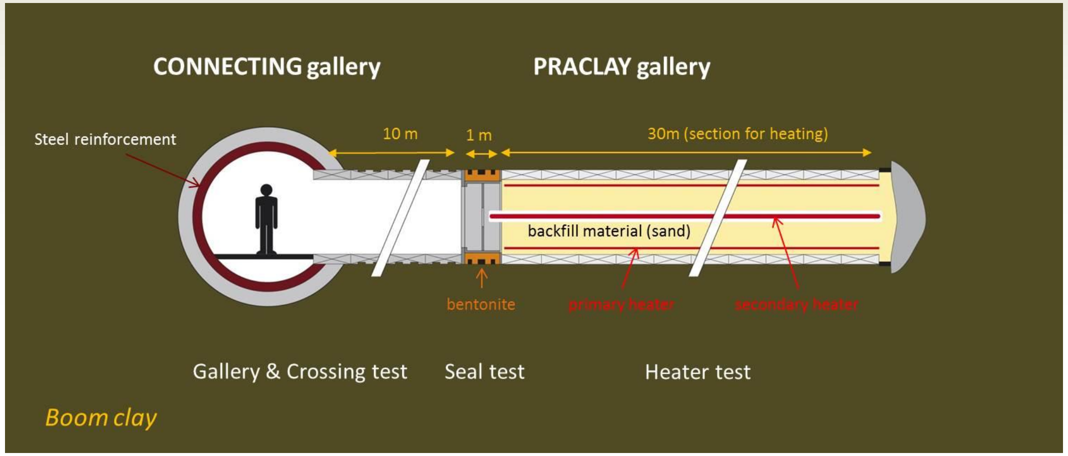
External diameter: 4.8m
Internal diameter: 4.0m
Concrete C75/90

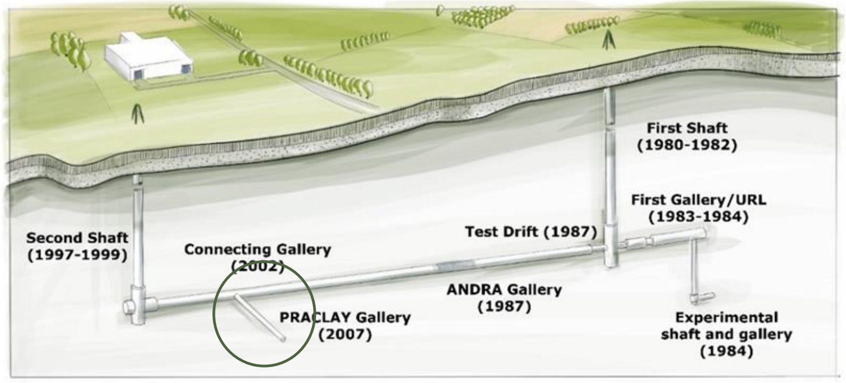
Demonstrate feasibility with industrial techniques

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)



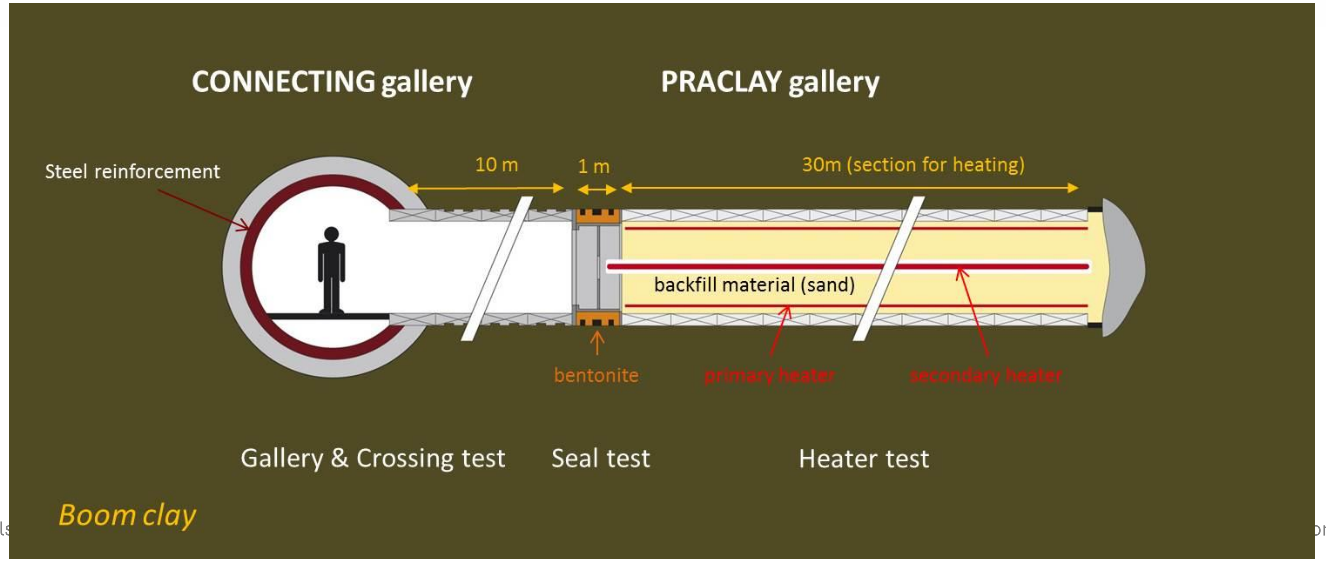


Series of demonstration tests
- the Gallery & Crossing Test
- the Heater Test
- the Seal Test

→ **Important milestones in the stepwise confirmation of a GDF feasibility**

PRACLAY in situ experiment – Timeline

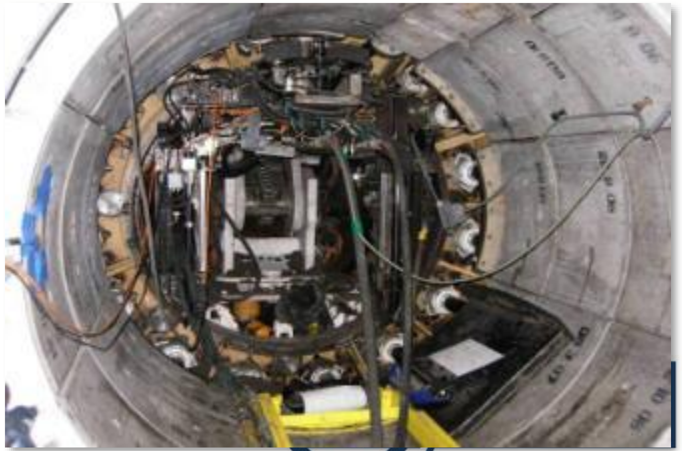
- **PG excavation** – Oct 2007
- **Seal installation** – Feb 2010
- **End of heater test installation** – 2012
- **Start heating** – Nov 2014
- **Stationary phase (10 y)** – Aug 2015
- **Start cooling** – Oct/Nov 2025



Gallery & Crossing Test (2007)

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

- **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.



Gallery & Crossing Test (2007)

<u>Scientific Lessons</u>

- **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

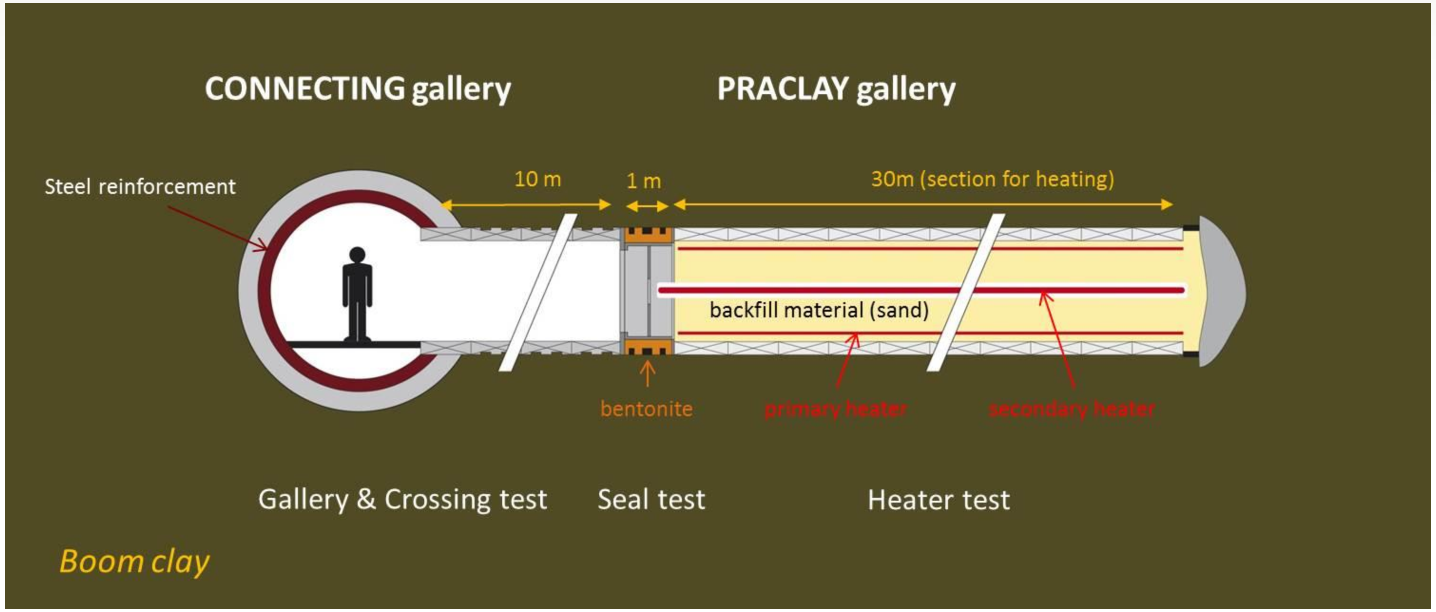
- **Enhanced knowledge of the hydromechanical behaviour of the EDZ in Boom Clay** (during and after excavation)
  - Confirmation of observations made during excavation of Connecting Gallery
  - Observation of EDZ fractures reactivation in the crossing zone


PRACLAY Gallery (2007)

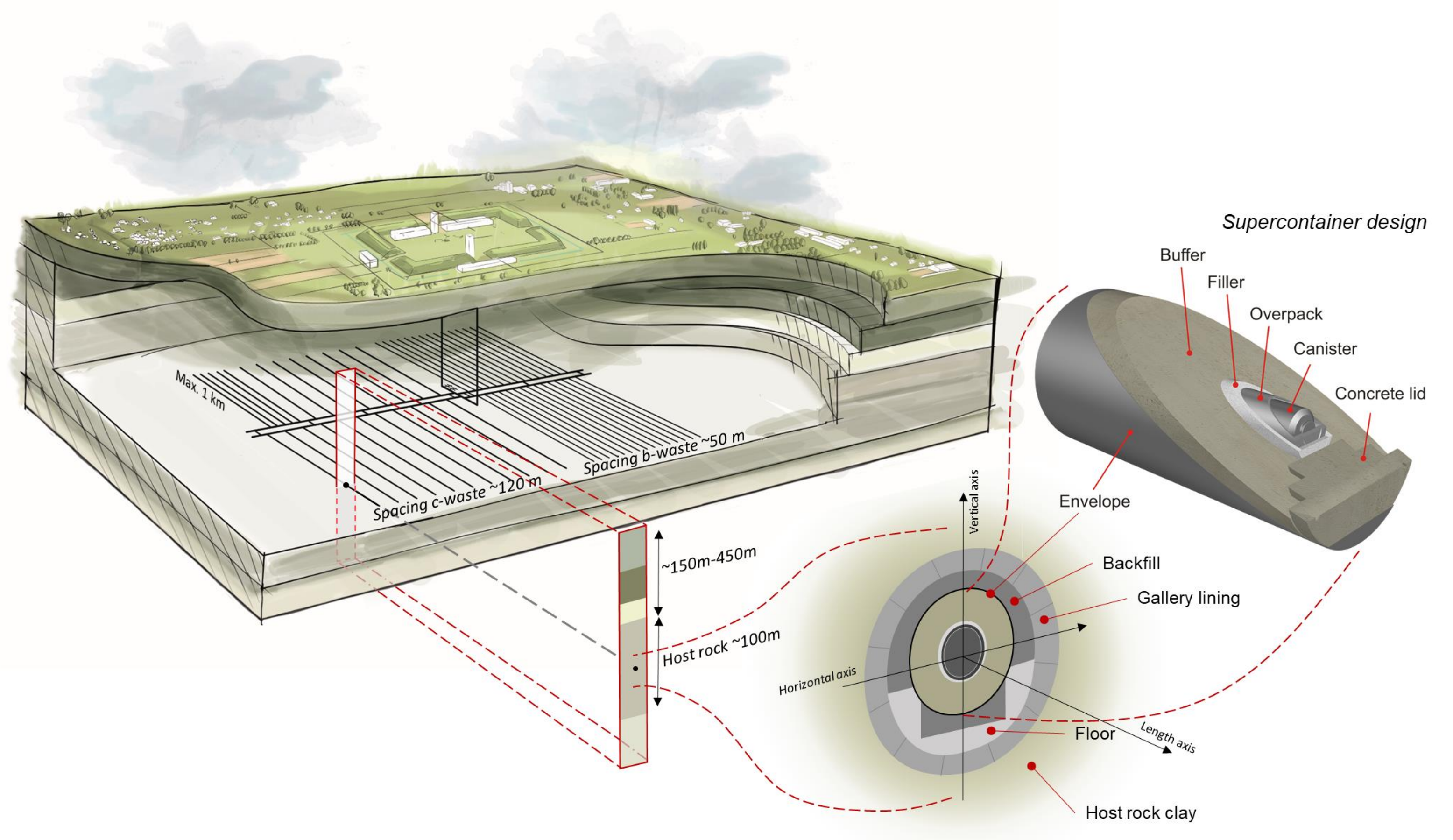
PRACLAY Heater Test (since 2014)

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 ©

Vertical cross-section of the disposal gallery for C-waste

Thermal pre-design requirements

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

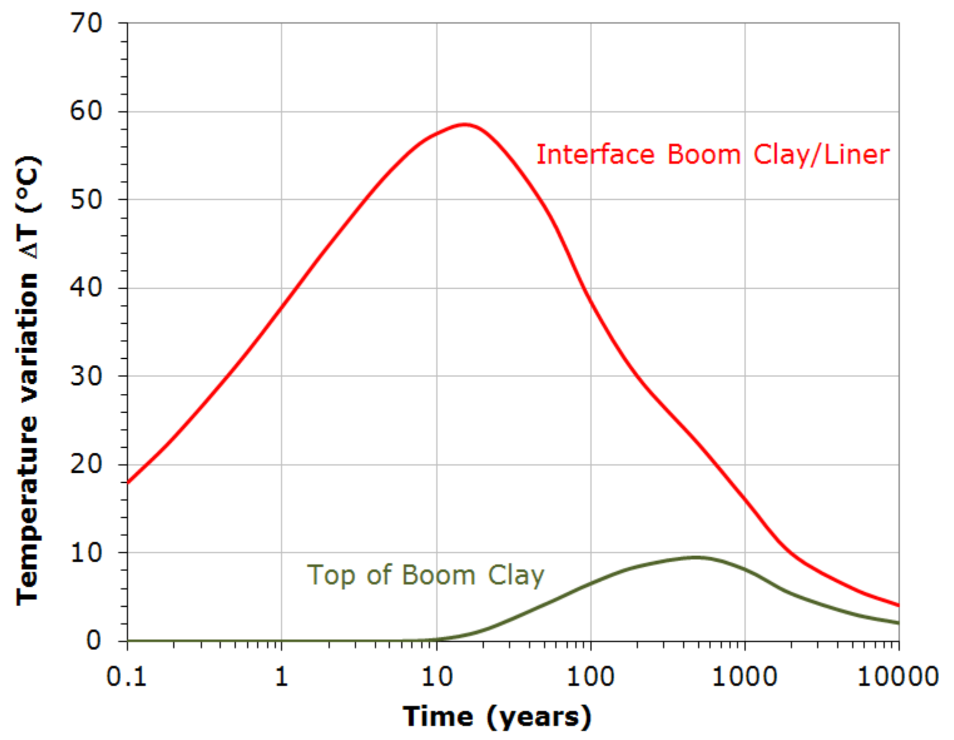
Design parameters to accommodate the heat output

- 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

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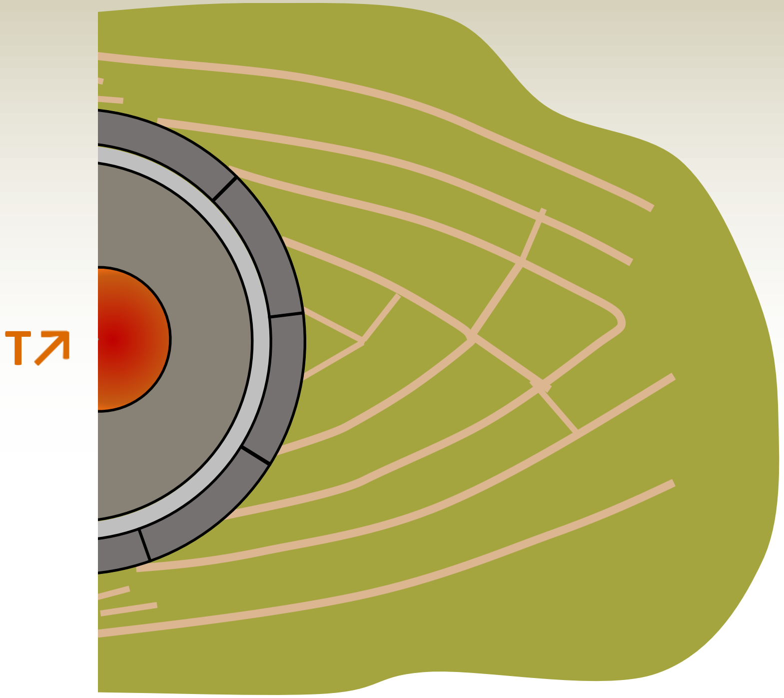
Disposal of heat-emitting waste: current design

- **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



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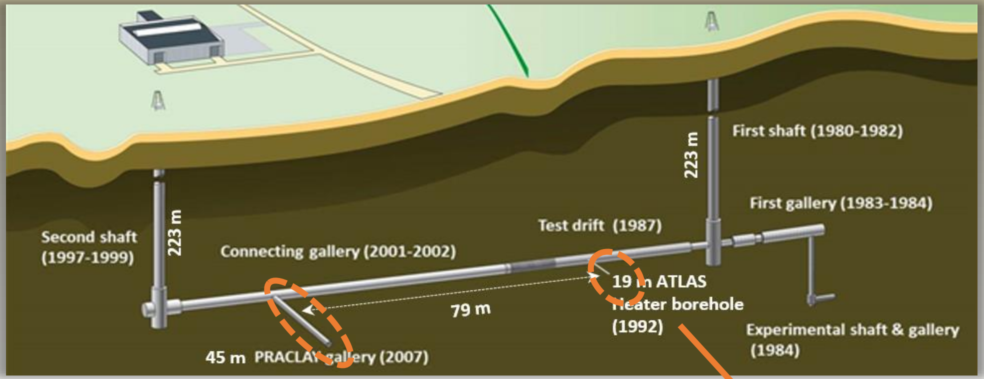
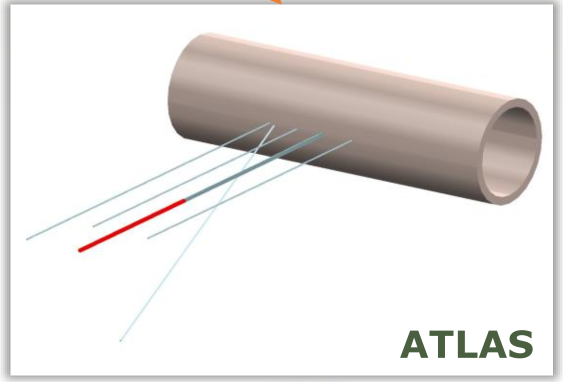
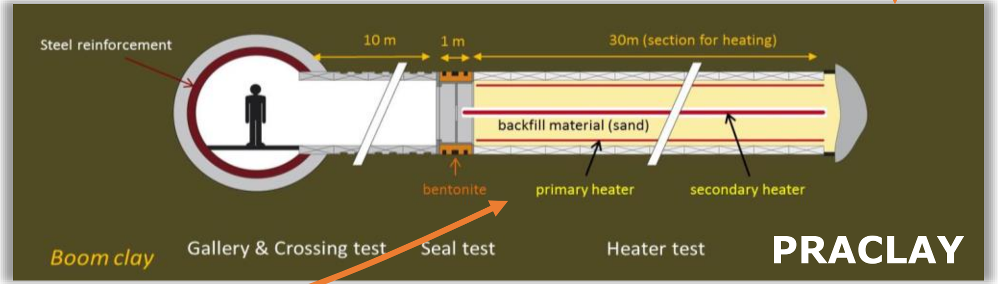
Disposal of heat-emitting waste: current design

- **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 – …)







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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→HM coupling in Boom Clay at a scale representative of a disposal gallery + estimate possible upscaling effect

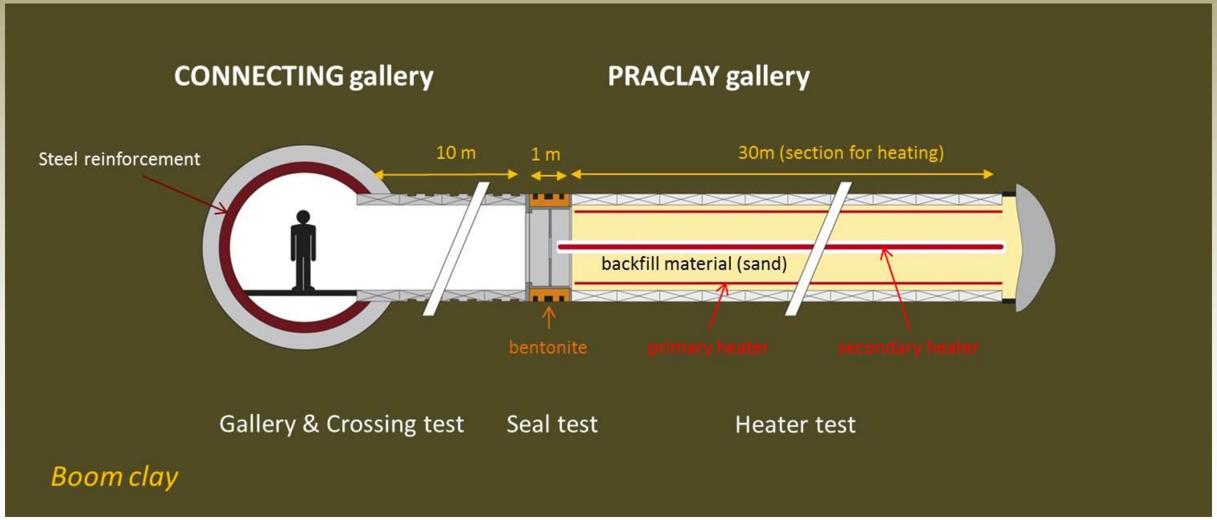
- “Simple” THM experiment
  - Main focus is on Boom Clay
  - Independent of a particular design

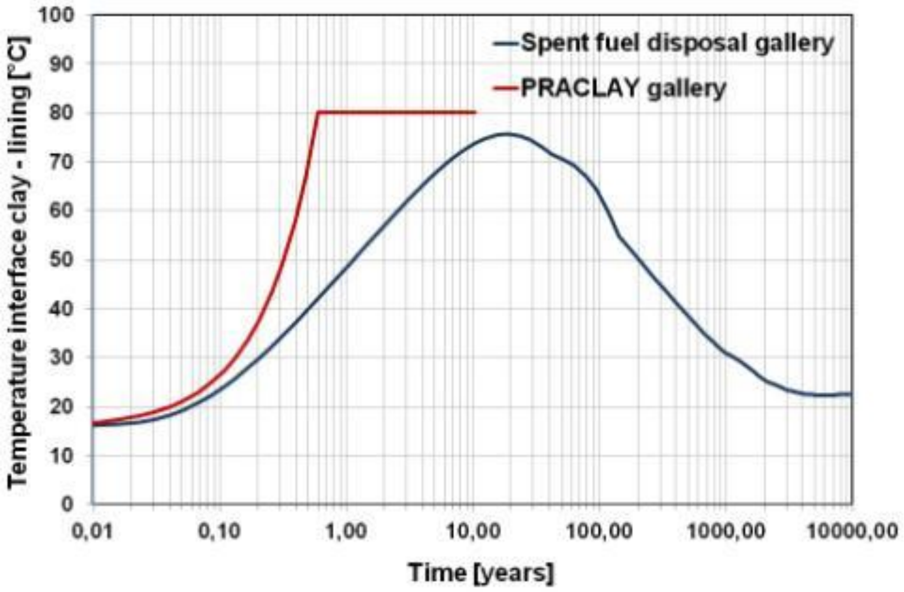
Verifying that the Boom Clay can withstand the thermal transient up to the time of maximum near field temperature

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

PRACLAY Heater Test – Design

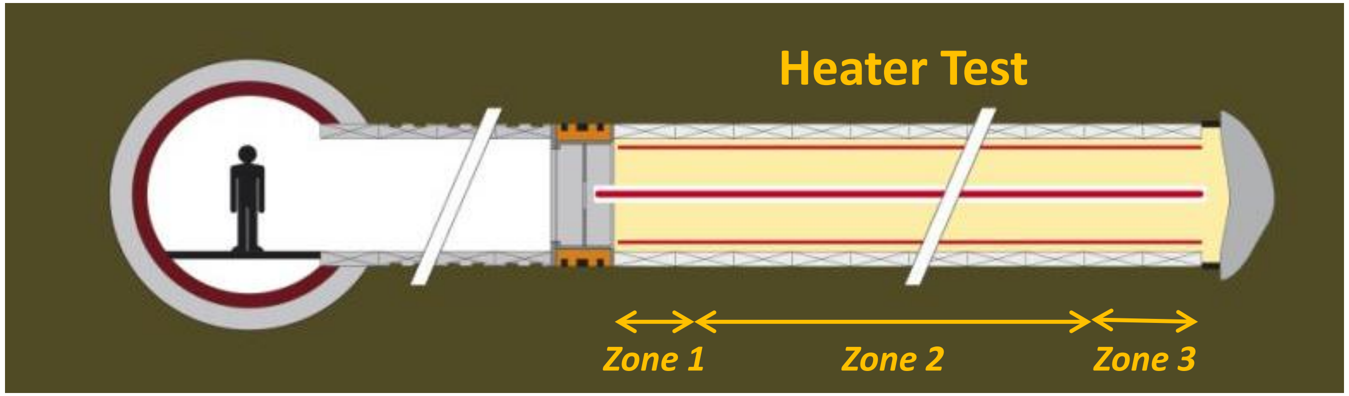
- **Thermal conditions**
  - Temperature at gallery extrados = 80°C
    - > real repository
  - Faster temperature increase
    - More penalising
  - Heating during 10 years
  - Heated gallery section = 30 m
    - No gain in test representativity by a longer section
    - Sufficiently far from the Connecting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





PRACLAY Heater Test – Design

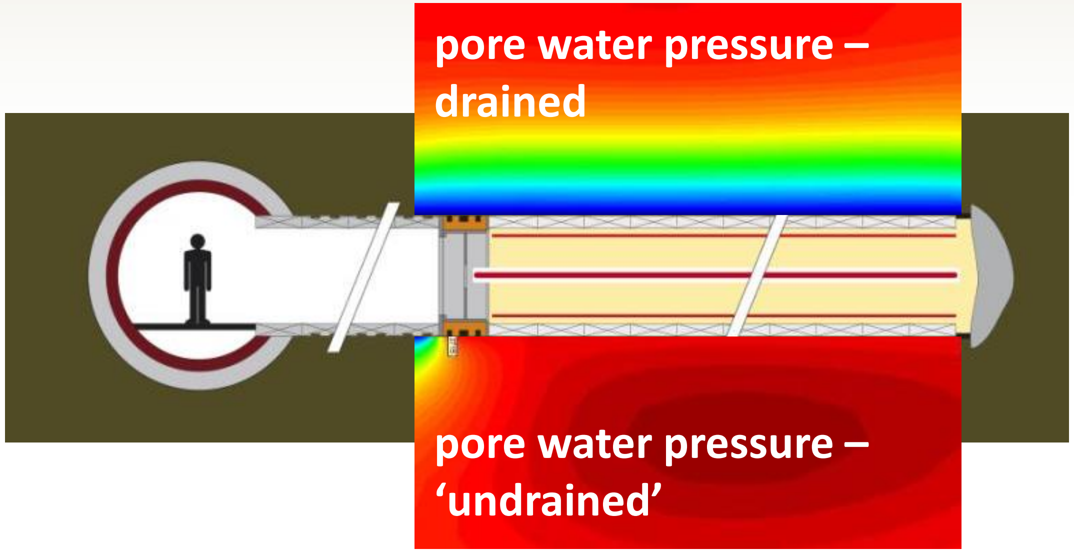
- Primary heater
  - Electrical heater cables close to the gallery lining split in 3 heating zones
  - Inaccessible during the Heater Test and therefore twice as much heater cables than necessary (100% redundancy)
- Secondary or backup heater
  - Electrical heater inside a central tube
  - Accessible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

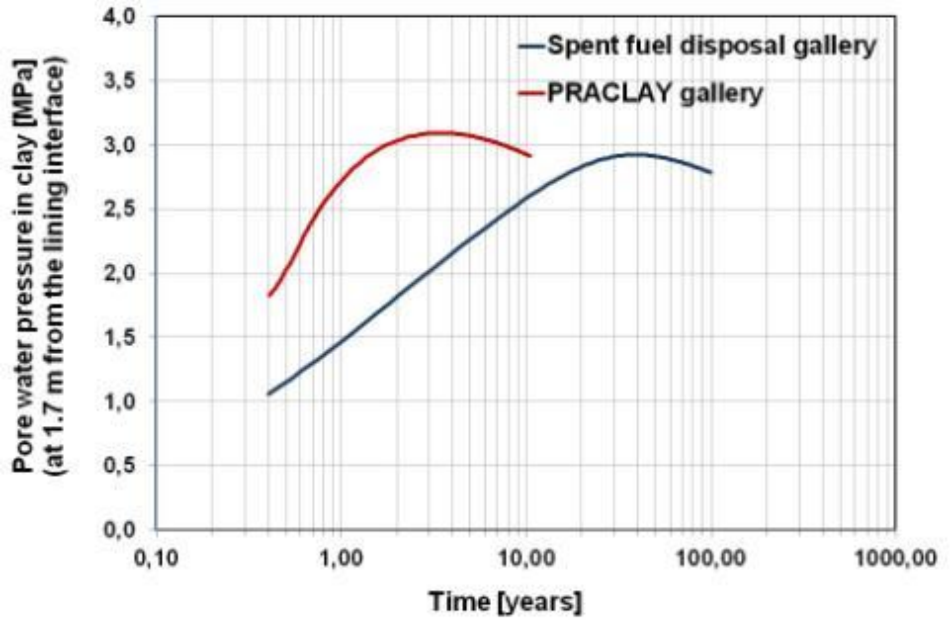


PRACLAY Heater Test – Design

- **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**

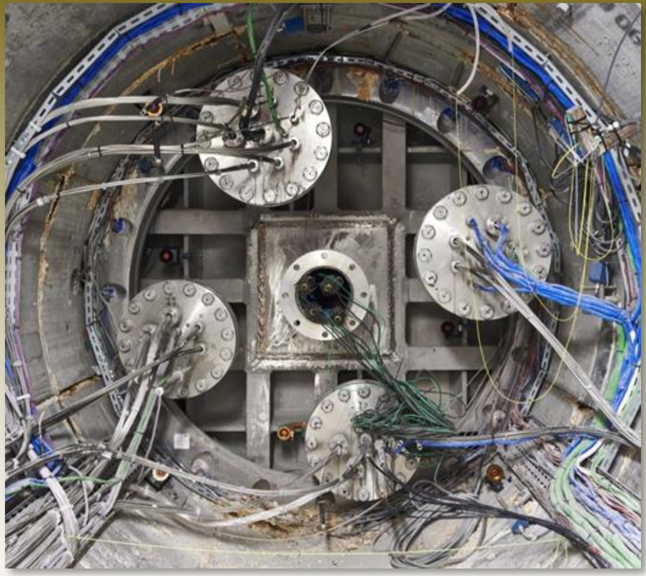
→ heating of Boom Clay in undrained conditions

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)

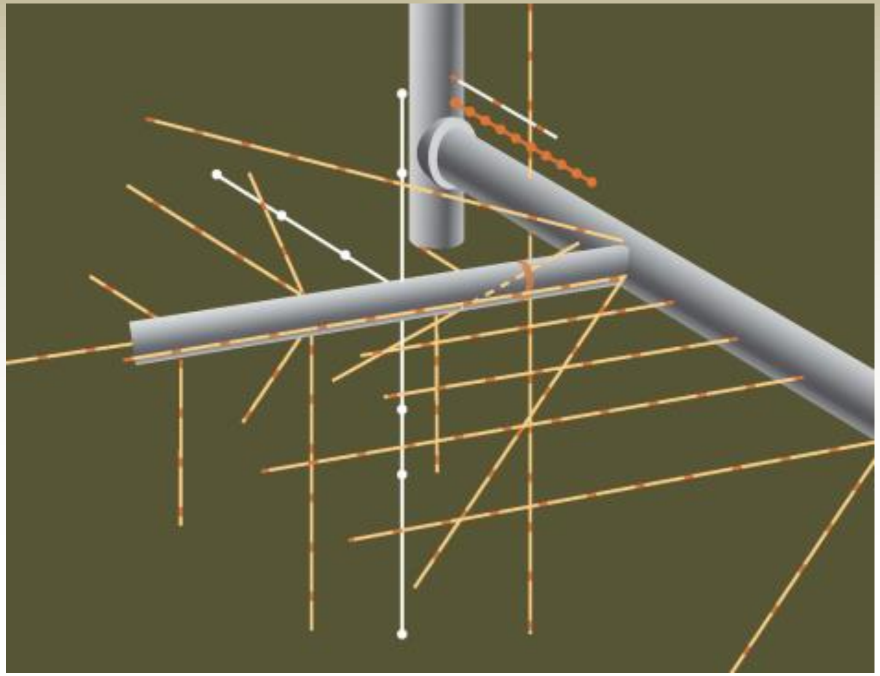
→ ***important lessons learned for the design of the seal of a real disposal gallery***

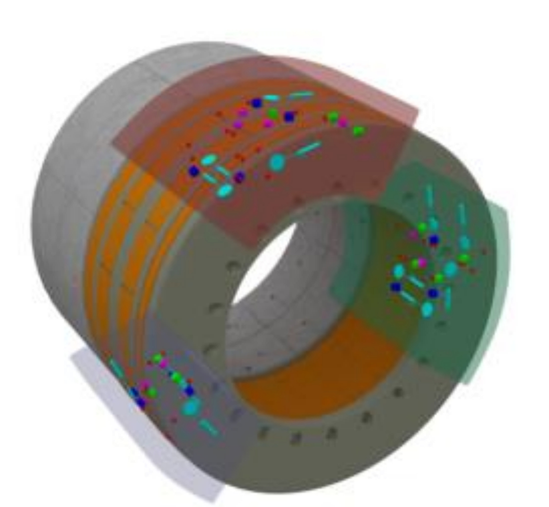
PRACLAY Heater Test – Design

- **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

PG excavation
Oct 2007

① Crossing is feasible

Feb 2010
Seal installation

② Lessons for seal design

End of heater test installation
2012

Nov 2014
Start heating

Stationary phase (10 y)
Aug 2015

Oct/Nov 2025
Start cooling

③ Validate THM knowledge at a scale representative of a disposal gallery → To continue during cooling phase

2028-2030
④ Dismantling & post-mortem analyses

Stepwise confirmation of a GDF feasibility

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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

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