

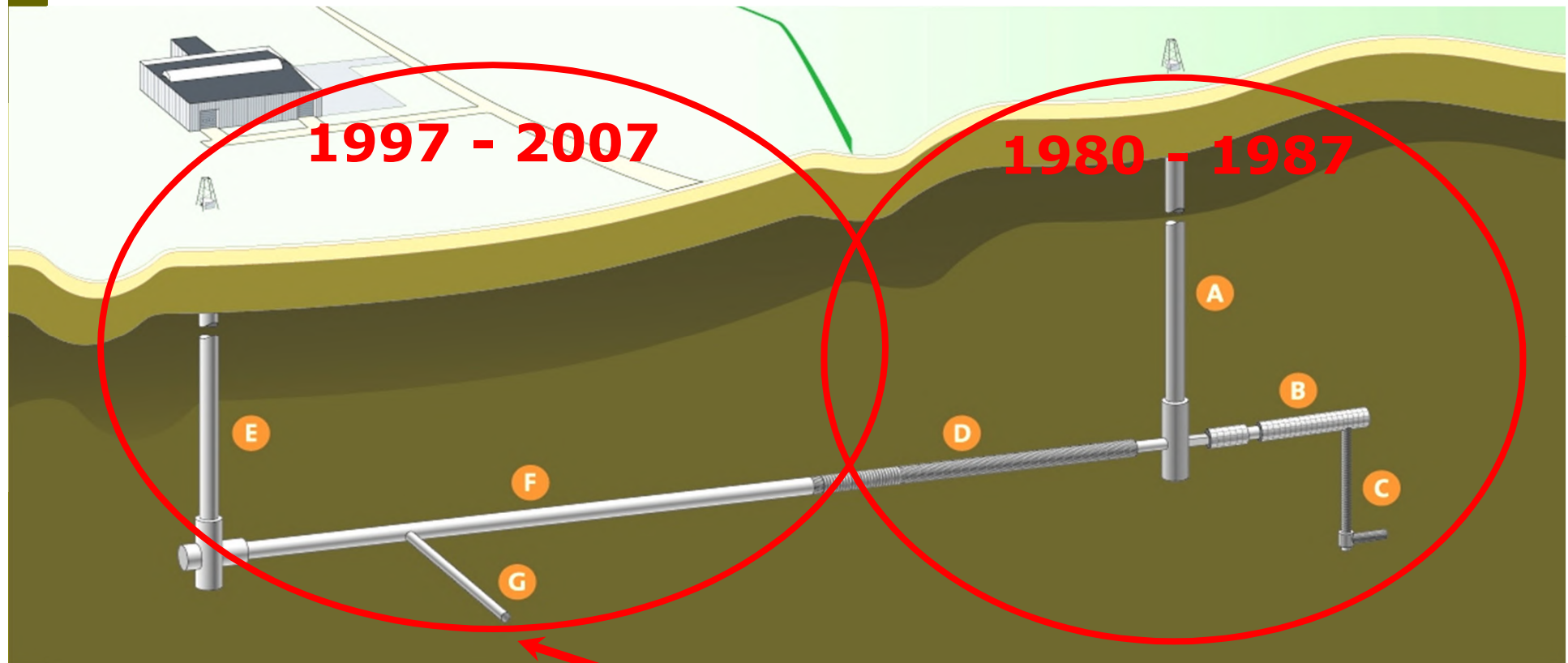
Status of the PRACLAY SEAL & HEATER experiment

16th Exchange Meeting
November 25, 2010

A long way ...

- The PRACLAY project and the creation of the EIG PRACLAY (1995) and the EIG EURIDICE (2000)
 - The idea of a large scale demonstration project since the beginning of the nineties – post SAFIR (1989)
 - The extension of the URL HADES in the period 1997 – 2007 as part of the PRACLAY project
 - Safety requirement of second shaft for extended underground infrastructure
 - Use of excavation and construction technology at an industrial scale – world-wide « première »
 - Gallery crossing

HADES Underground Research Facility



PRACLAY gallery

A long way ...

□ SEAL & HEATER experiments

- The evolution from a disposal demonstration project to a large scale R&D confirmation experiment
- Final part of the PRACLAY project (1995 – > 2020)
- **Confirmation** of our scientific knowledge base, e.g. w.r.t.
 - Combined mechanical and thermal disturbance of clay
 - Thermal properties of the clay
 - THM behaviour of the clay
 - ...

A long way ...

- SEAL & HEATER experiments
 - CERBERUS (1986 – 1998) – heating & irradiation experiment (m scale)
 - BACCHUS
 - ATLAS – still ongoing experiment

- PRACLAY heater phase 2011 - ...
 - 10 years of heating
 - Post-mortem analysis

A central element of the national programme

- **NIRAS/ONDRAF National waste plan**
 - Comments on the continued RD&D programme
 - Overall quality of the programme
 - Remaining uncertainties vs. a decision « now »
 - Visibility of the PRACLAY SEAL & HEATER experiment w.r.t. remaining uncertainties
- **Next milestones – Safety and Feasibility Cases I & II**
 - SFC I: decision to start siting
 - SFC II: decision to confirm 1 site
- **PRACLAY SEAL & HEATER**
 - First confirmation input for SFC I
 - Final confirmation input for SFC II

Next year - 2011

- EURIDICE will start the heating phase
- EURIDICE will organise with SCK•CEN and ONDRAF/NIRAS, an international event:

“HADES, 30 years underground research laboratory”

The changing role of URL's in radioactive waste disposal research.

23, 24 & 25 May 2011

Antwerp, Belgium

Status of the PRACLAY SEAL & HEATER experiment

16th Exchange Meeting
November 25, 2010

The design of the PRACLAY Heater and Seal tests and the role of the Hydraulic Seal

Xiangling Li
EIG EURIDICE
Exchange Meeting
25 November 2010



ONDRAF/NIRAS



EGV EURIDICE GIE



STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

Introduction

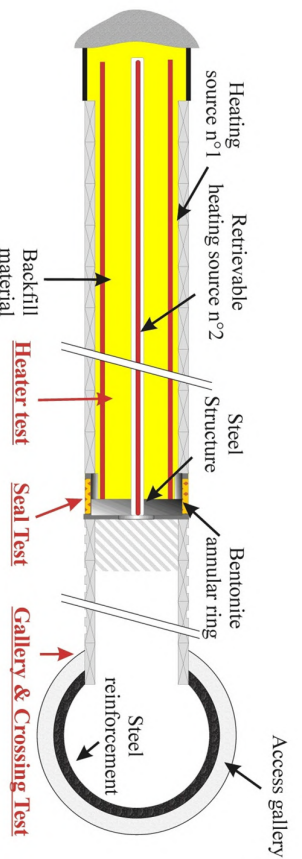
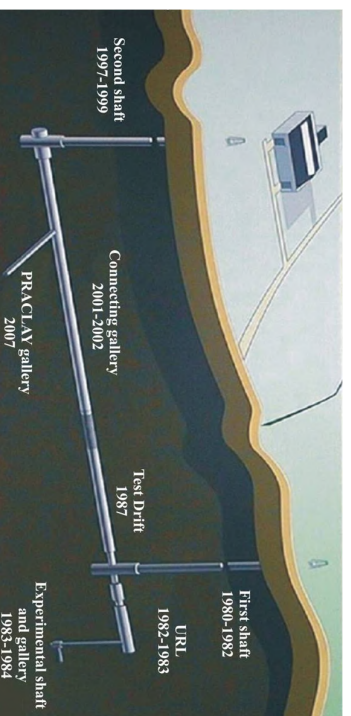
Design

Summary

Conclusions

PRACLAY in-situ Experiment

- Gallery & Crossing Test
- **Heater Test**
- **Seal Test**



Objectives of PRACLAY Heater test

➤ **simulating the disposal of heat-emitting high-level waste in a geological repository in clay**

Introduction

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Conclusions

- to study the combined effect of the EDZ and the TDZ
- to improve our knowledge of the THM/C behaviour of Boom Clay
- to demonstrate that the thermal load does not affect the performance of the Boom Clay as main barrier
 - ✓ configuration similar to a real repository
 - ✓ at a large scale :
 - o results will not be affected with local heterogeneities
- to study the effect of the thermal load on the stability of the liner

Objectives of PRACLAY Seal test

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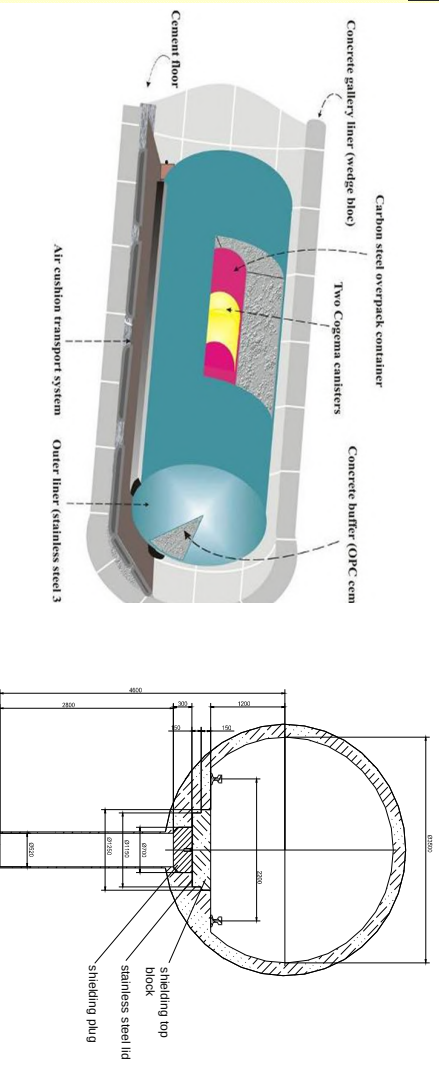
Conclusions

- to provide suitable hydraulic boundary condition for heater test (cf. later)
- to test the feasibility to cut-off hydraulically any preferential pathway to the main access gallery through the EDZ and the lining with a seal in a horizontal drift in Boom Clay.

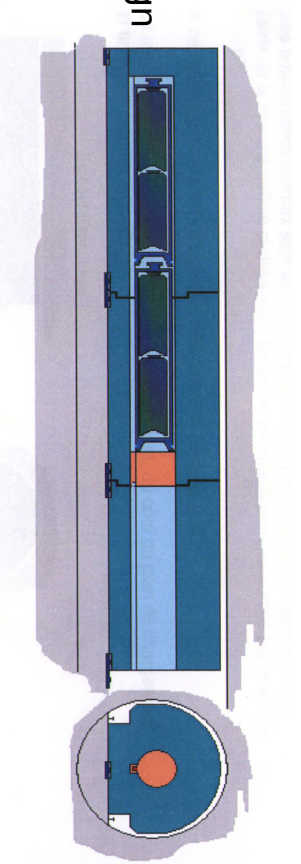
Three alternatives for geological disposal of HLLW

Supercontainer design

Borehole design



Sleeve design



Introduction

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Introduction

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Supercontainer design is the reference option, but ... choices have to be kept as flexible as possible to get the possibility to reorient parts of the design towards another alternative at minimal cost.

=>

PRACLAY Heater test results should be applicable to all possible disposal designs

=>

PRACLAY Heater test should be developed as **disposal design-independent** as possible to accommodate possible future changes in the reference disposal design.

First questions :

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1. Disposal design - independent ?
2. Heat source terms ?
3. Heated length ?
4. Hydraulic boundary condition ?
5. Stability of the lining ?
 - ✓ Dismantling of PRACLAY experiment !
 - ✓ Retrievability ?

➤ THM boundary conditions control ?

Introduction

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- Different time scale : short heating period (~10 years)
- Different spatial scale
- Different heat source term
- Different boundary conditions
-

The test has some limitations with respect to a real repository :

⇒ **The Heater test aims at imposing the most penalising**

THM conditions that are reasonably achievable to

reproduce in a conservative way the *most critical*

phenomena that could occur in the host rock (THM)

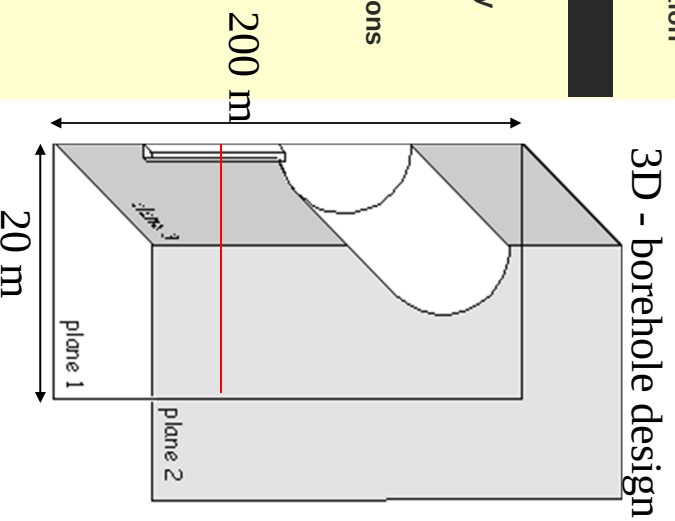
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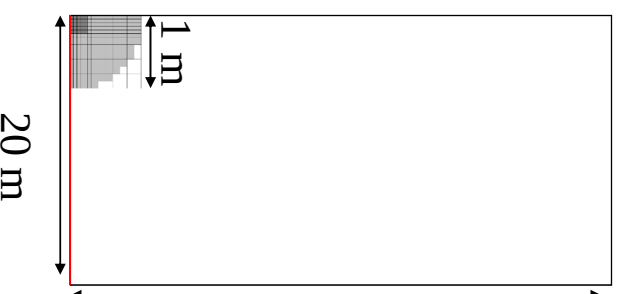
Summary

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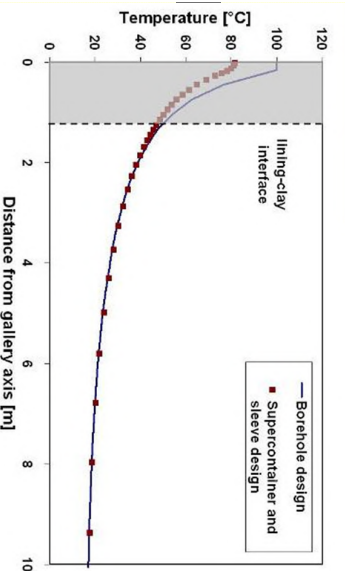
1. Disposal design – independent ?



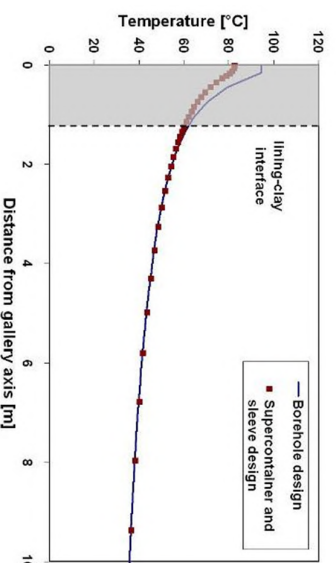
2D SC and sleeve design
2 canisters
per 5 m
(201 W/m)



1. Disposal design - independent ?



after 1 year of heating



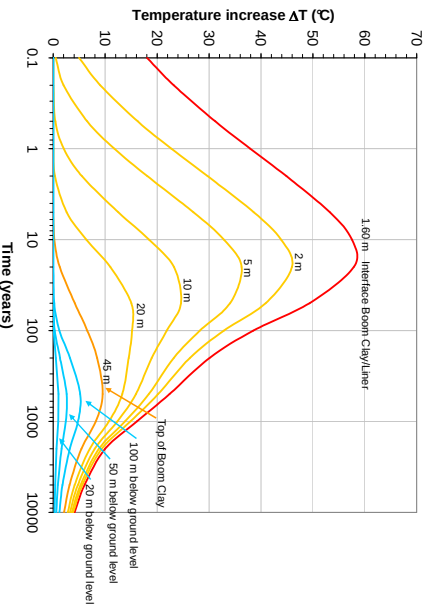
after 20 years of heating

For radial distance > 2 m, the influence of the design on T° is very limited

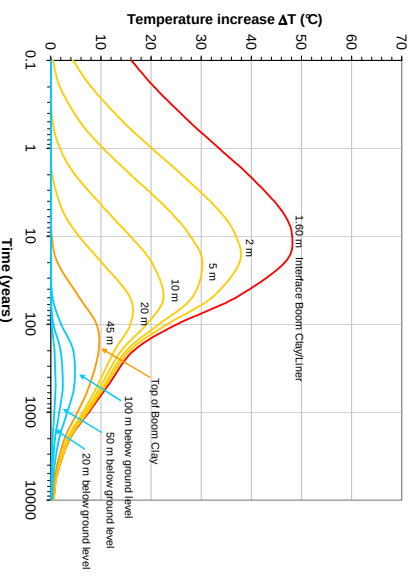
⇒ PRACLAY Heater test results are applicable to all possible designs !
⇒ “Disposal design- independent” !

2. Heat Source terms ?

PRACLAY Heater test vs. real repository cases (SC design, O/N 2006)



spent fuel



vitrified waste

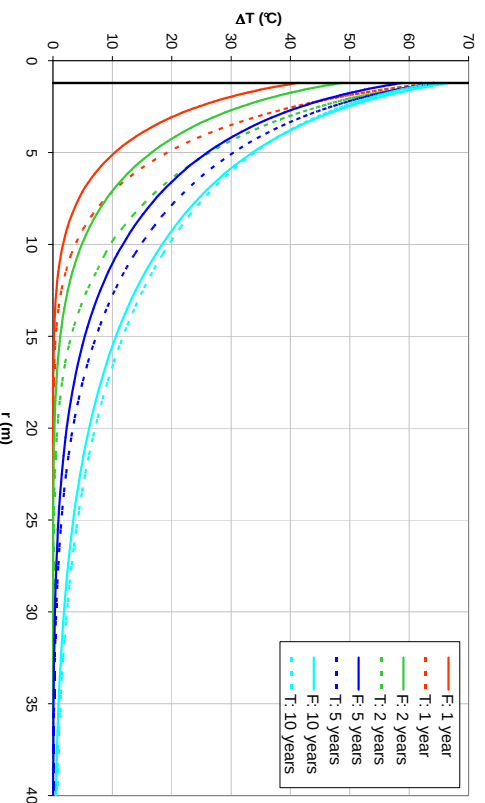
PRACLAY Heater test :

$T_{max} = 80\text{ °C}$ ($\Delta T\ 64\text{ °C}$) at interface liner / Boom Clay, higher than real cases

=> More penalising condition !

2. Heat Source terms ?

Constant Flux (250 W/m) or Constant Temperature (80°C) ?



Constant Temperature is more efficient :

- Higher T and gradient T ! Larger volume heated !
- Boundary condition is better defined for THM modelling !

PRACLAY Heater test : Constant T = 80 °C at interface liner/BC

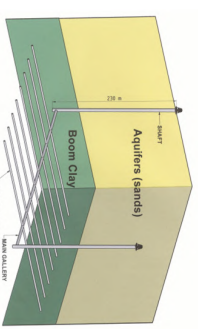
Challenge for heating system design (cf. presentation by Wlm)

Introduction

Design

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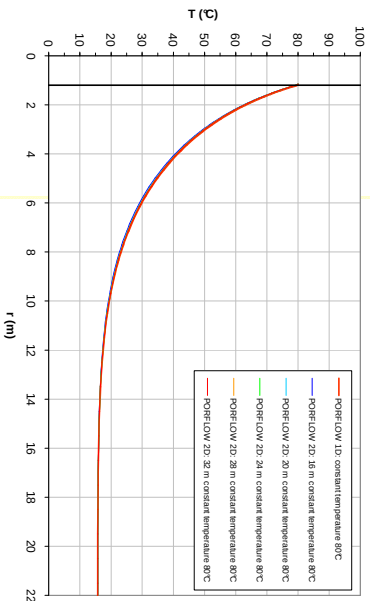


3. Heated length ?

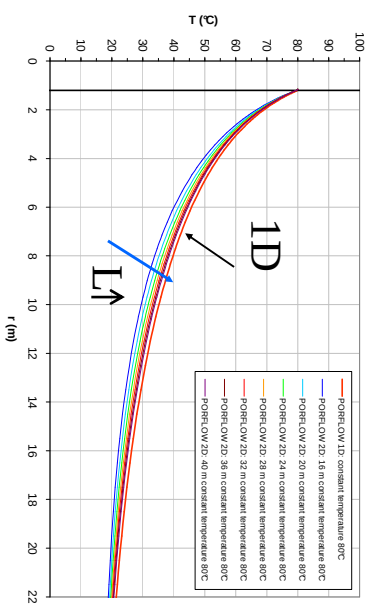
- 1D modelling : infinite length (most representative)
- 2D modelling : with different lengths L : % 1D ?

Introduction

Design



After 1 y of heating



After 10 y of heating

L > 28 m, length effect is limited !

PRACLAY Heater test : 30 m heated section !

4. Hydraulic boundary condition ?

THM responses

= f (hydraulic boundary condition)

Question ?

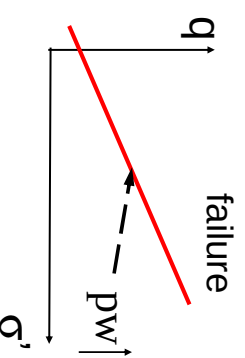
Under which hydraulic boundary condition, more critical THM responses will be reached ?

⇒ higher the pw build-up during heating

⇒ higher the risk of damage for host rock!

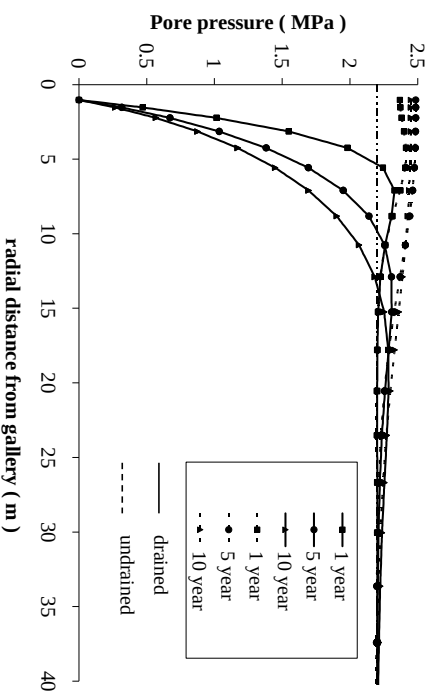
$$\sigma' = \sigma - p_w$$

⇒ more critical condition !



4. Hydraulic boundary condition ?

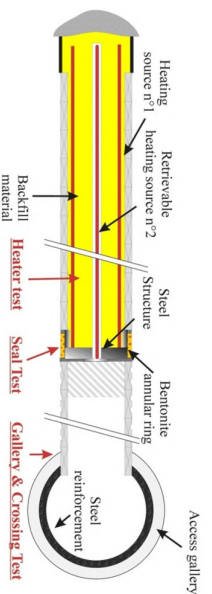
Numerical simulations assuming different hydraulic boundary conditions :



Undrained boundary condition,
 => higher pw build-up
 => More **critical** condition in terms of THM responses
PRACLAY Heater test :
 “undrained” condition within the limits of what is reasonable achievable

The “undrained” boundary condition will be realised by:

1. **Backfilling** the heated part of the gallery with saturated high permeable material, which allows to easily build-up the higher pw as expected by the undrained boundary condition



Additional requirements for backfill:

- higher thermal conductivity : λ backfill > λ BC/liner
- homogeneity :
avoid segregation to achieve isotropic conditions

Backfill material selected for Praclay gallery : Mol Sand !

n [%] : 47
k [m/s] : 10^{-4}
λ [W/m·K] : 2.3

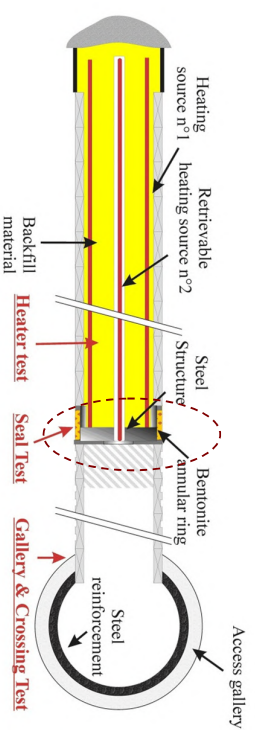
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- The “undrained” boundary condition will be realised by:
2. Installation of an **hydraulic Seal** at the intersection between the heated and the non-heated part of the gallery



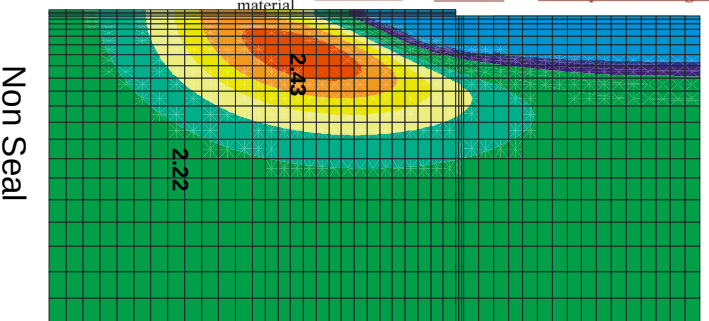
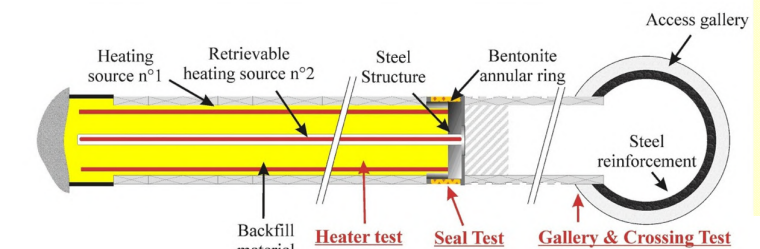
- It should be as impermeable as possible at its location on the interface seal/BC : $K_w \ll K_w \text{ of BC}$
- The Seal has to hydraulically seal the heated section of the gallery and its surrounding EDZ from the non-heated section.

Question : What is the required Seal length?

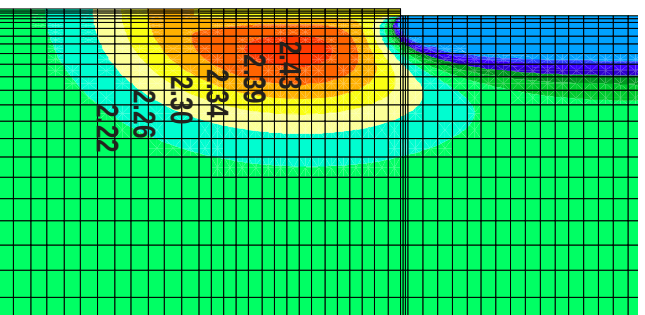
Length of Seal ?

Numerical simulations assuming different lengths of Seal

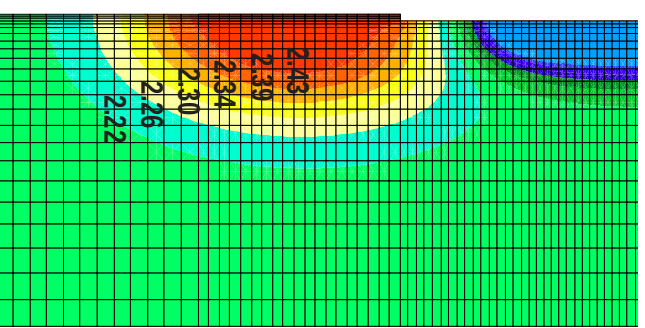
Pore water pressure distribution after 5 y of heating



Non Seal



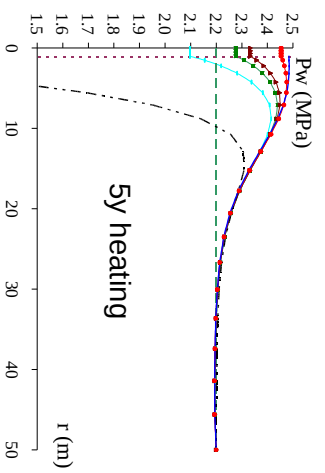
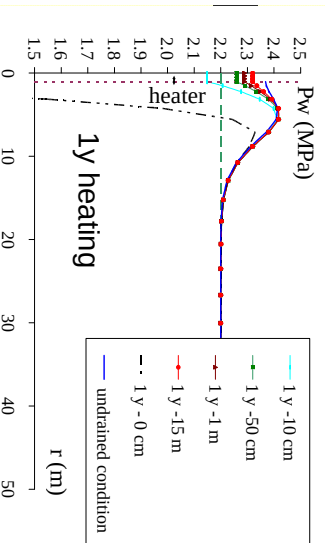
1m of Seal



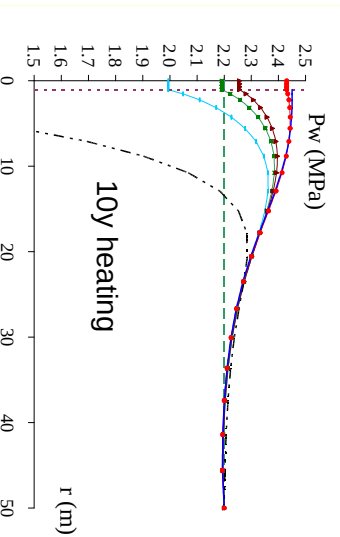
15 m of Seal

Length of Seal ?

Pore water pressure profiles in a midplane around the heated gallery



- the longer the Seal, the closer to undrained conditions
- 10 cm of Seal takes already effect



PRACLAY Heater test :
1m of Seal was installed !

Role of the Seal:

- As impermeable as possible at its location on the interface Seal/BC
 - $K_w \ll K_w$ of BC ($\sim 10^{-12}$ m/s)

- Able to seal/heal EDZ
 - swelling material
 - swelling pressure
 - ✓ Enough to seal / heal EDZ, etc.
 - ✓ not too big < lithostatic pressure (4 - 5 MPa)

→ PRACLAY Seal test

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Material choice for the Seal:

Introduction

Bentonites are good choice:

- swelling capacity
- lower Kw
- long term functioning

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PRACLAY Seal test : MX 80 is selected

Material choice for the Seal : **why MX 80 ?**

Introduction

- Na-bentonite is compatible with the Boom Clay environment, whose water chemistry is sodium dominated (14 mM NaHCO₃)

Design

- When compacted to a **suitable dry density** (Chen's presentation)
 - suitable swelling pressure
 - desired low permeability

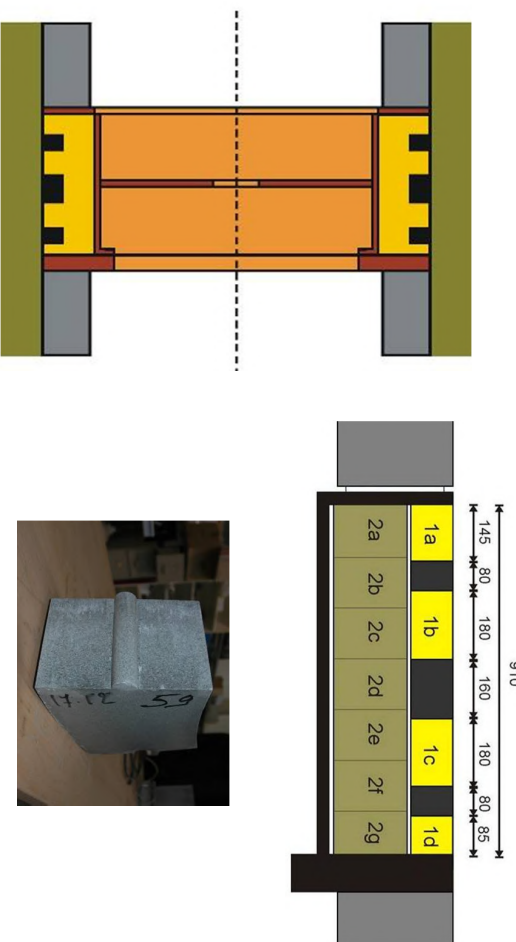
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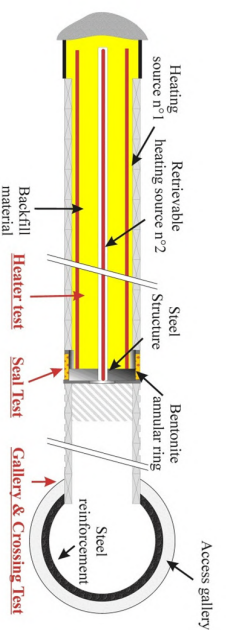
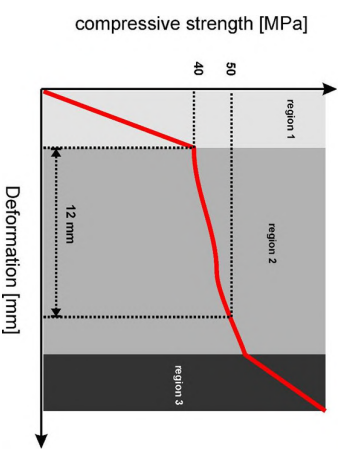
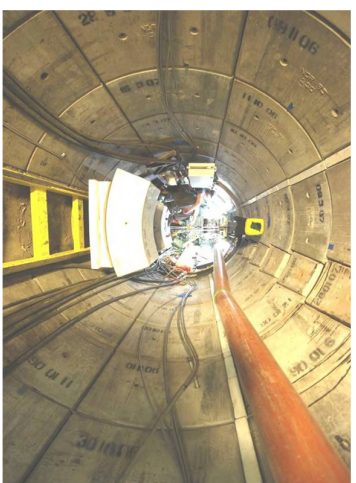
- MX80 is most studied in the world
 - a lot of existing THM lab test results
 - a lot of THM parameters obtained
 - scoping calculations for seal design
 - modelling for interpretation

PRACLAY Seal (Philippe's presentation)

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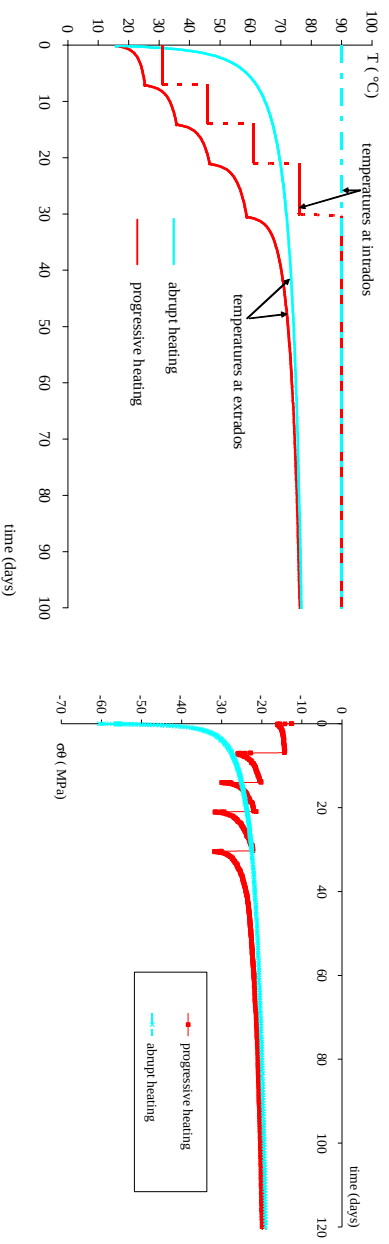
5. Lining stability ?



Compressible materials are inserted in the lining to release stresses during heating phase

Introduction
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5. Lining stability ?



Moreover, temperature will be increased progressively to the target T

=> to minimise the ∇T => to minimise the $\Delta \sigma\theta$

Summary

- Design criteria for PRACLAY Heater test
 - heated part = 30 m
 - $T = 80^{\circ}\text{C}$ at the gallery extrados
 - heating step by step (Wim's presentation)
 - “undrained” condition by:
 - hydraulic Seal
 - backfilling and saturating the gallery
- Role of Seal : achieve the “undrained” boundary condition by
 - its low permeability
 - its swelling capacity

Conclusions

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- A successful experiment requires a good control of the test conditions, especially the boundary conditions
 - to interpret and understand the test results
- PRACLAY experiment will be carried out under well controlled THM boundary conditions (hopefully !)
- The consideration on the THM boundary control in the PRACLAY Heater test design constitute also key issues for the repository design.
- The PRACLAY experiment will constitute an important milestone in the Belgian programme for HLW disposal.

Acknowledgements

- EURIDICE team :
 - Scientific team
 - Technical team
- Weetjens Eef, Volckaert Geert
- Sillen Xavier
- Bernier Frédéric, De Cannière Pierre

Installation of the PRACLAY Hydraulic Seal

Philippe Van Marcke
EIG EURIDICE
Exchange Meeting
25 November 2010



ONDRAF/NIRAS



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Design

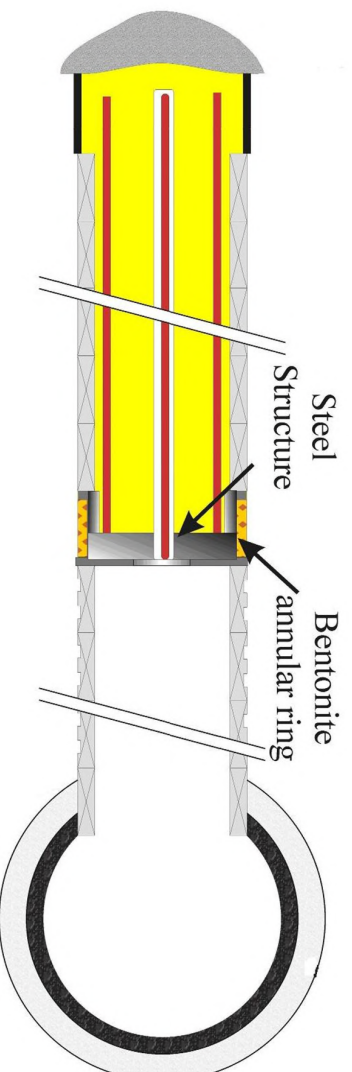
Construction

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Goal PRACLAY Hydraulic Seal

- undrained hydraulic boundary for Heater Test
- examining feasibility of installing a seal



Design PRACLAY Hydraulic Seal

- ULg
- TRACTEBEL Engineering
- EURIDICE

Introduction

Design

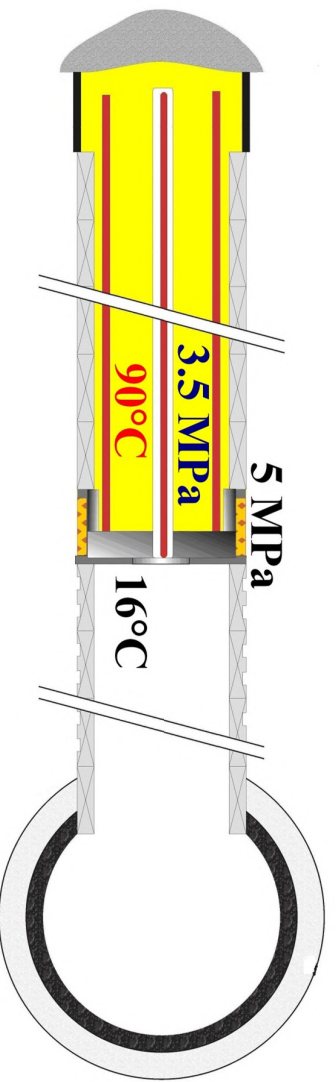
Construction

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Design criteria for steel structure

- bentonite pressure: 5 MPa
- upstream water pressure: 3.5 MPa
- upstream temperature: 90°C



Introduction

Design

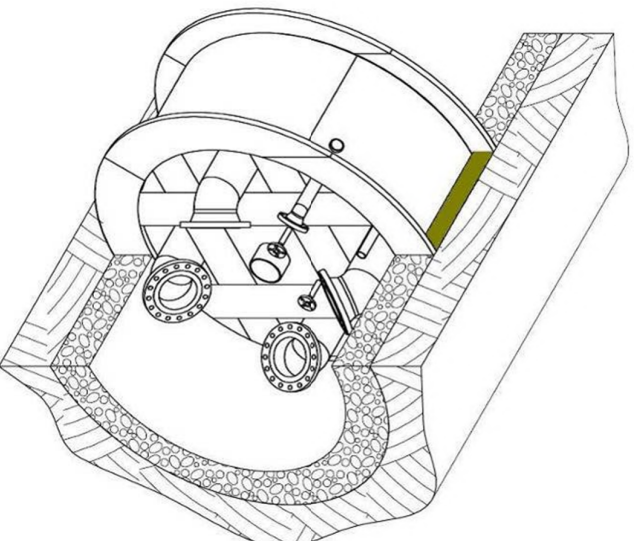
Construction

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First design

- placement bentonite ring (170 mm)
- assembly 4 parts of annular ring by welding



Design

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Second design

- thicker bentonite ring (310 mm)
- less in-situ welding

Design

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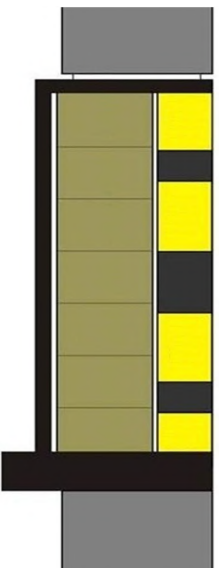
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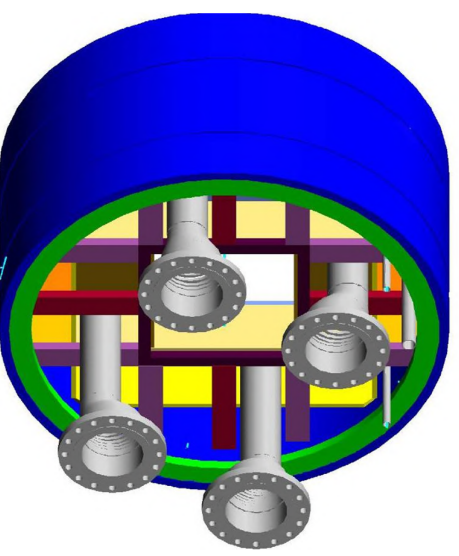
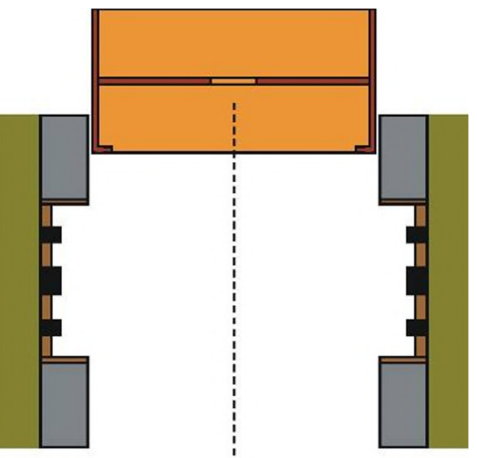
Second design

- thicker bentonite ring (310 mm)
- less in-situ welding



Second design

- thicker bentonite ring (310 mm)
- less in-situ welding



Introduction

Second design

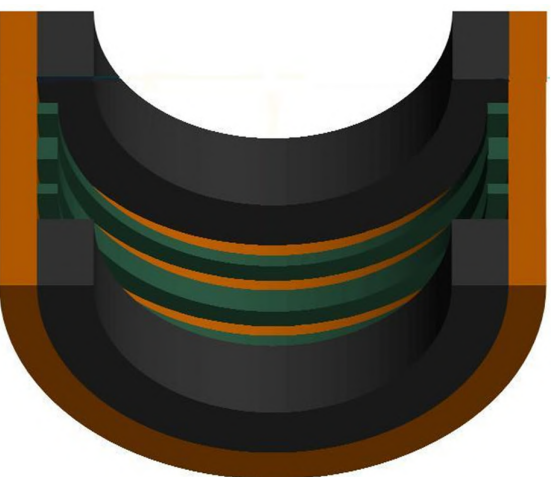
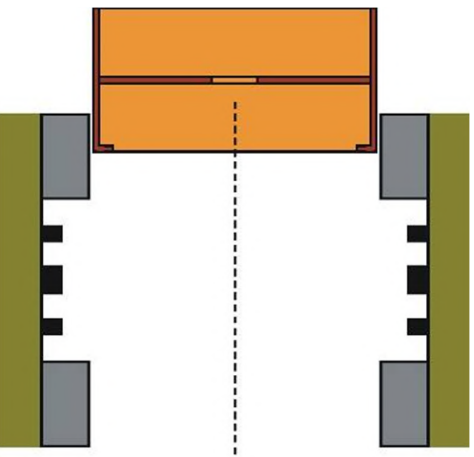
- thicker bentonite ring (310 mm)
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Design

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Second design

- thicker bentonite ring (310 mm)
- less in-situ welding

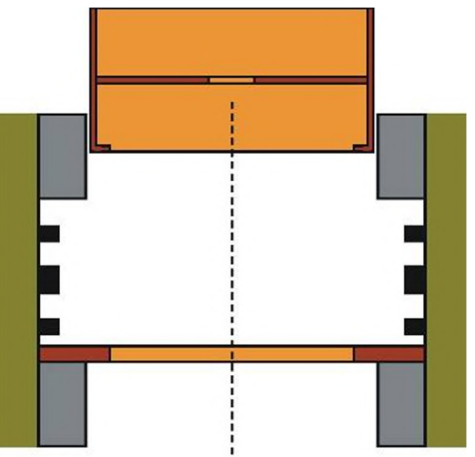
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Introduction

Second design

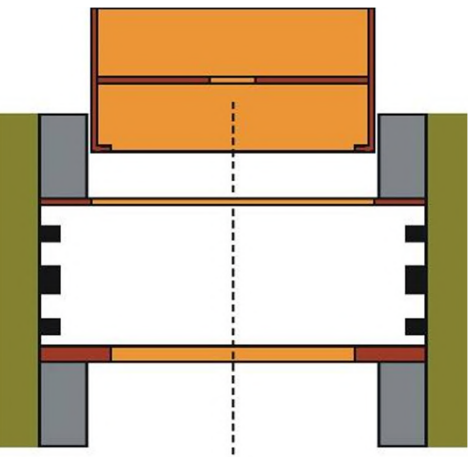
- thicker bentonite ring (310 mm)
- less in-situ welding

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Second design

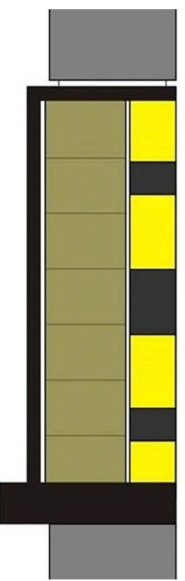
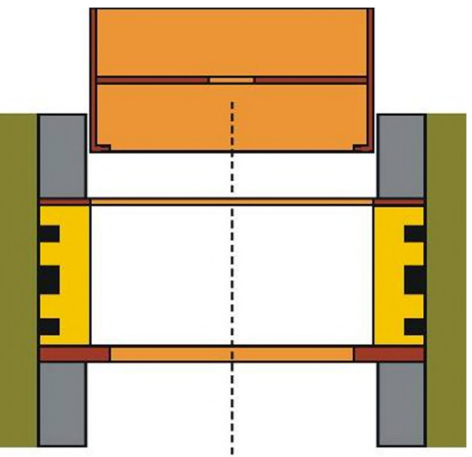
- thicker bentonite ring (310 mm)
- less in-situ welding

Design

Construction

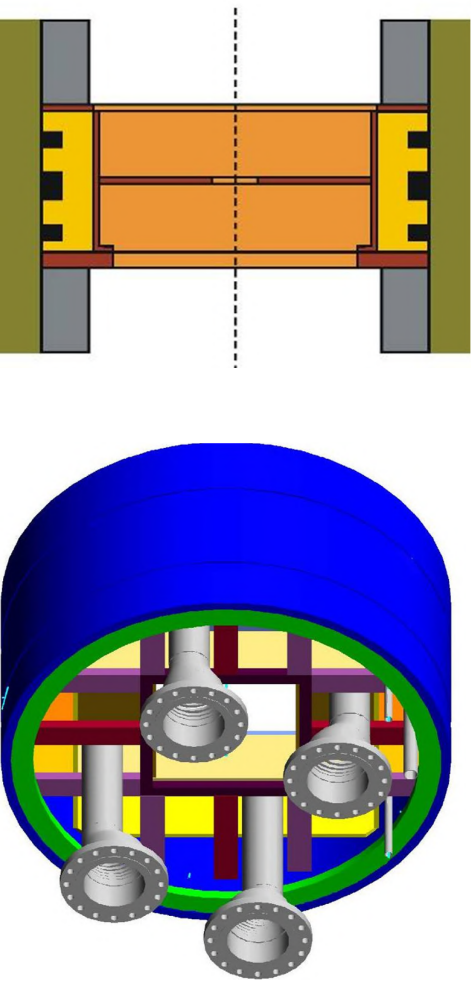
Installation

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Second design

- thicker bentonite ring (310 mm)
- less in-situ welding



Design

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Second design

- thicker bentonite ring (310 mm)
- less in-situ welding
- bentonite instrumentation
 - 35 thermocouples
 - 26 total pressure cells
 - 21 piezometers
 - 13 relative humidity sensors
 - 3 thermal conductivity probes
 - 2 extensometers

Design

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Construction and installation of the PRACLAY Hydraulic Seal

Introduction

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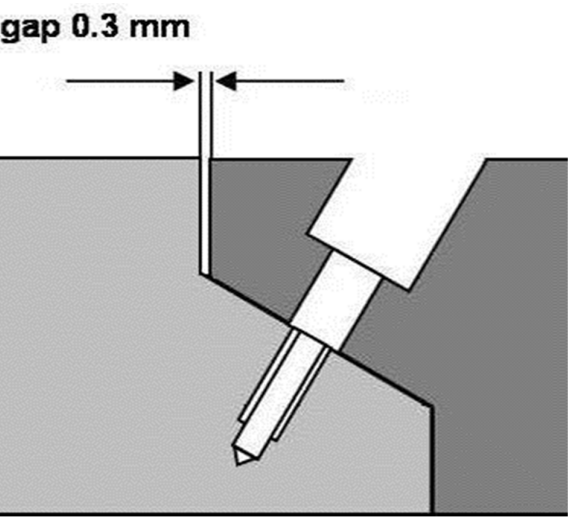
Installation

Conclusions

- SMET-Tunnelling
- Stork
- EURIDICE
- TRACTEBEL Engineering

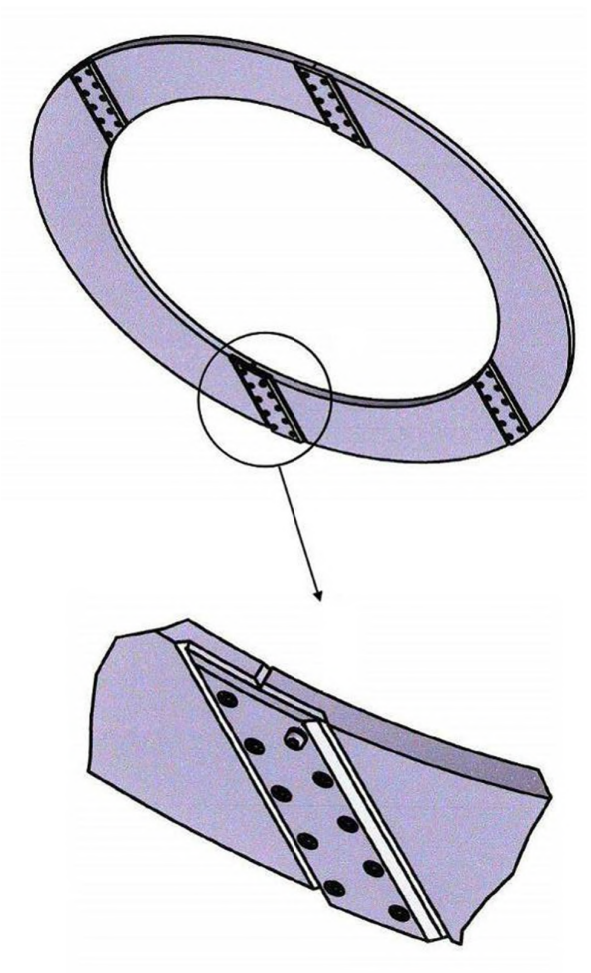
Downstream flange

- 4 segments
- assembly by bolting and sealing resin



Upstream flange

- 4 segments
- assembly by bolting (and minor welding)



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Cylinder

- assembly to downstream flange by bolting



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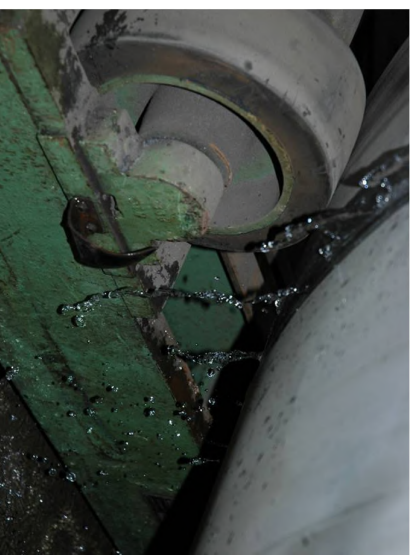
Installation

Conclusions

- assembly to upstream flange by welding

Cylinder

- filters at extrados for artificial bentonite hydration



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Installation works

- introduction cylinder in gallery



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Installation works

- removal wood in alternative lining

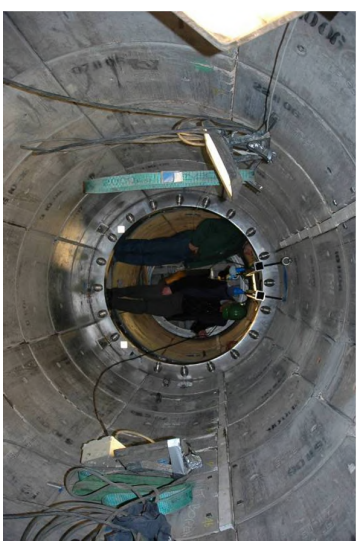
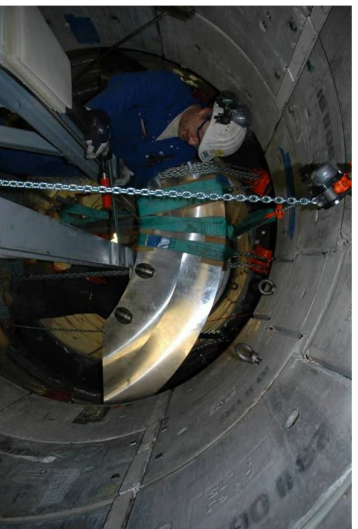


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Installation works

- installation downstream flange

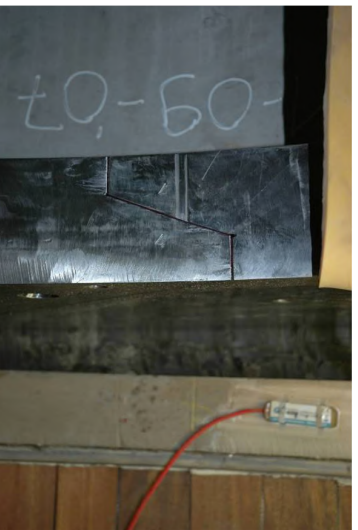
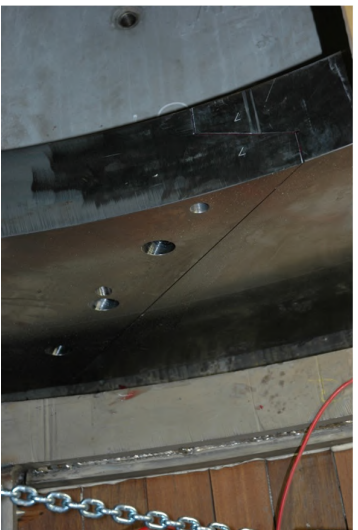


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Installation works

- installation downstream flange

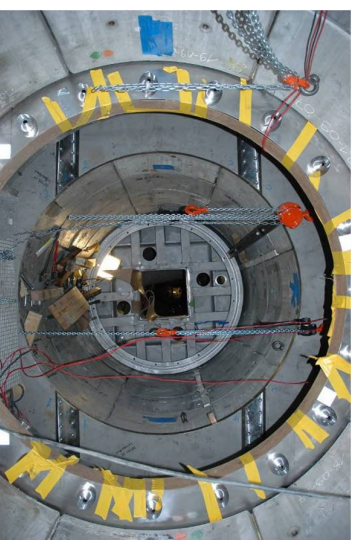
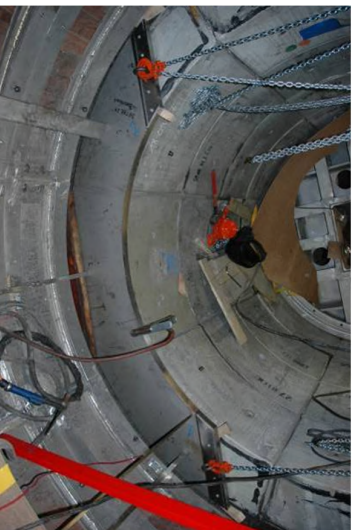


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Installation works

- installation upstream flange



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Installation works

- installation bentonite blocks



Introduction

Design

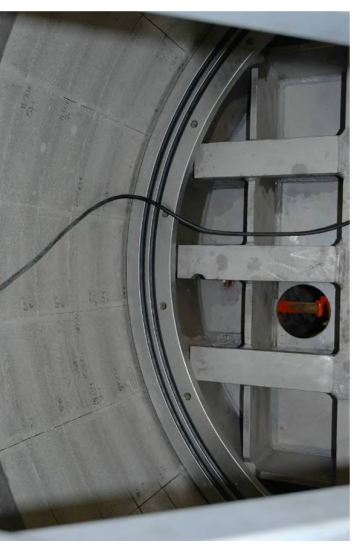
Construction

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Installation works

- positioning and assembly of cylinder



Introduction

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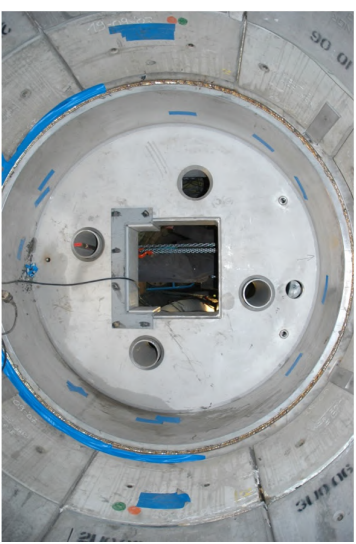
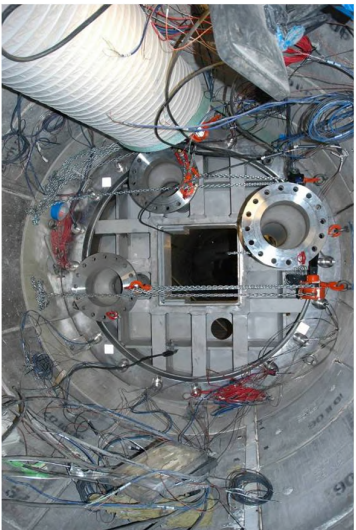
Installation

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Installation works

- feed-through instrumentation



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Conclusions

- goals
 - undrained hydraulic boundary for Heater Test
 - examining feasibility of installing a seal
- design
 - steel structure with annular bentonite ring
 - minimising in-situ welding
 - use of bolts, gaskets and sealing resin
- are the goals met?
 - in-situ assembly of large and heavy parts successful
 - technological void bentonite: 7-8%
 - bentonite hydration on-going
 - performance evaluation before and during Heater Test

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Scoping calculations for PRACLAY Seal design

Initial dry density of MX80 bentonite

Chen Guangjing & Xiangling Li

EIG EURIDICE

Exchange Meeting
25 November 2010



ONDRAF/NIRAS



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STUOIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

- ### Main criteria to design the Seal:
- o Maximum swelling pressure: 4~5 MPa
 - o K_w : 1~2 orders lower than Boom clay

Introduction

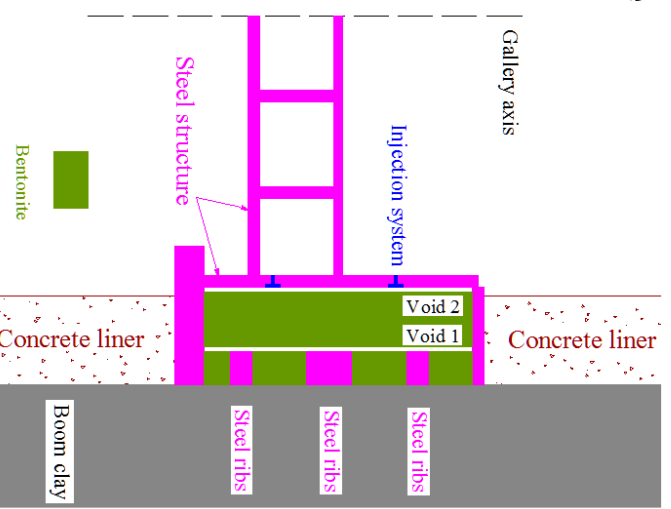
MX80 bentonite

Modeling

Conclusions

Main factors controlling swelling pressure:

- o Initial dry density of MX80 bentonite
- o Technological void ratio
- o Boundary conditions
 - ✓ Boom clay
 - ✓ Steel cylinder



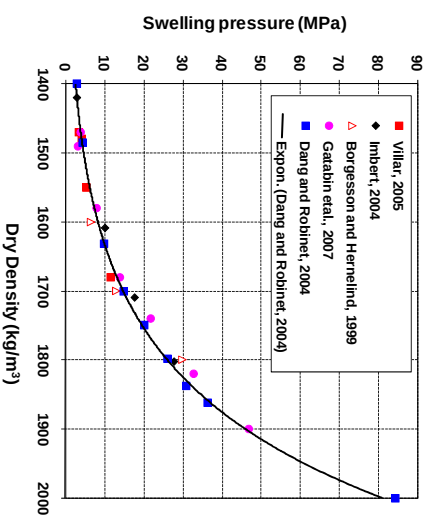
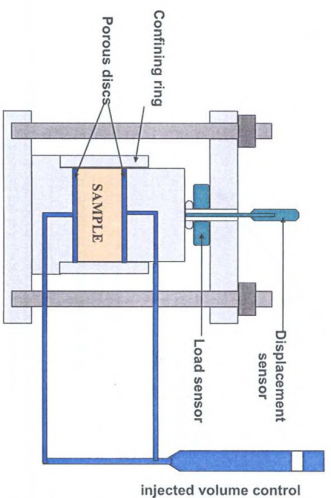
Swelling pressure is a function of dry density

Introduction

MX80 bentonite

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(Under constant volume)

o For dry density 1700kg/m³: 14~15 MPa

o For dry density 1800kg/m³: 29~30 MPa

Swelling pressure is a function of

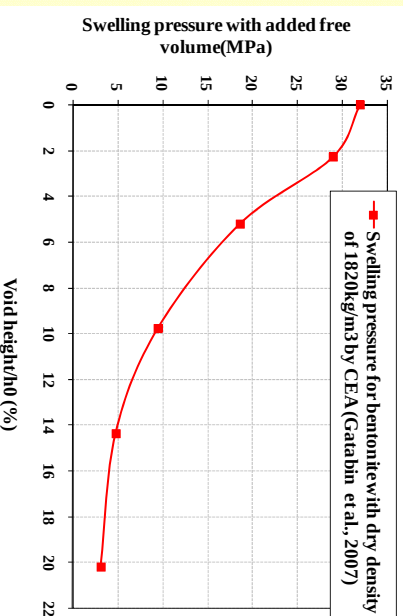
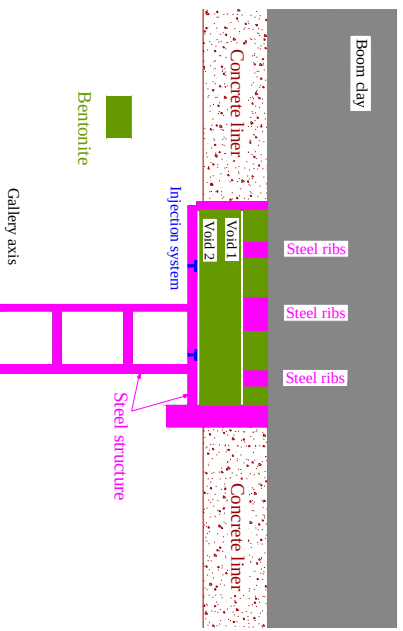
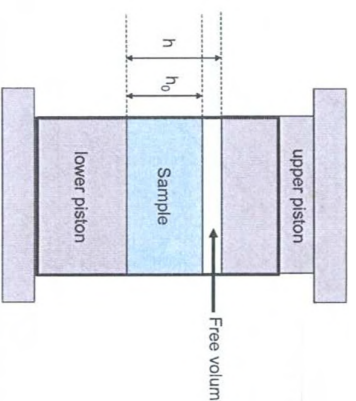
technological void ratio and boundary condition

Introduction

MX80 bentonite

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Swelling pressure for bentonite with dry density of 1820kg/m³ by CEA (Gatabin et al., 2007)

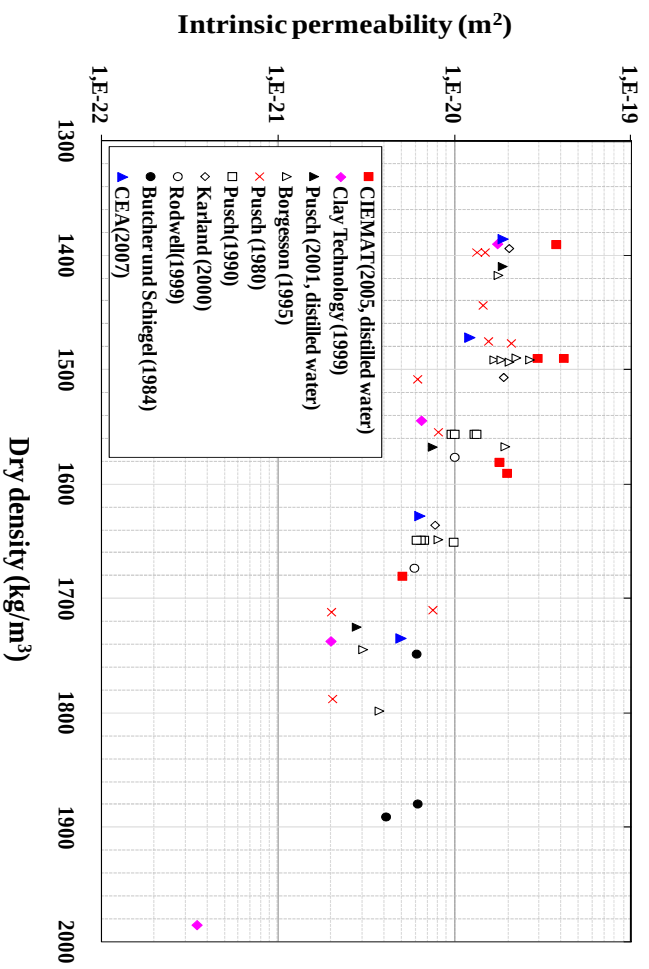
o Simple CEA test is designed to simulate Seal test

o Seal test is more complex:

- ✓ Boom clay is an elastoplastic material
- ✓ At least 2D problem
- ✓ Steel ribs exist between bentonite & Boom clay
- ✓ etc.

Intrinsic permeability is a function of dry density

Introduction
MX80 bentonite
Modeling
Conclusions



For dry density 1800kg/m³: 2 orders lower than Boom clay.

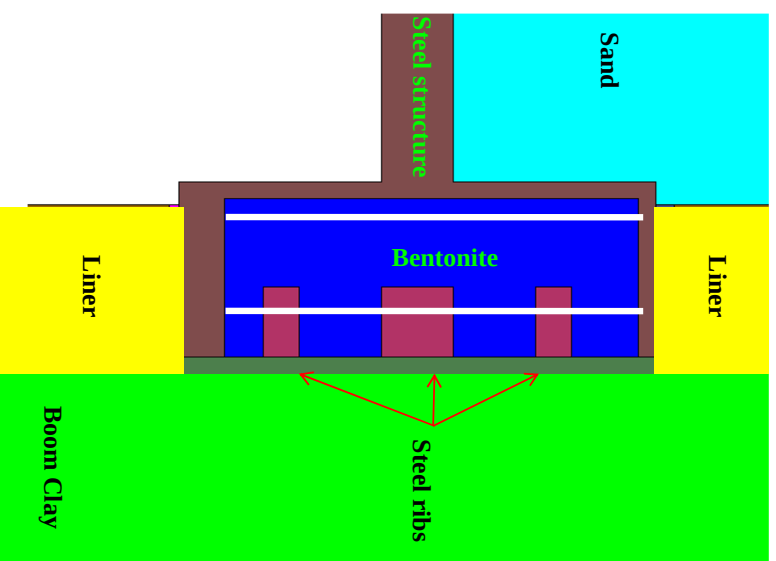
Modeling approach

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- ❖ Finite element method using code “Code_Bright”
- ❖ Bentonite/Boom clay are multi-phase and multi-species materials
- ❖ Many THM phenomena are considered
 - ✓ Heat conduction, advection (T)
 - ✓ Water advection, vapor diffusion (H)
 - ✓ Thermal expansion, swelling of bentonite, elastoplasticity of Boom clay etc. (M)
 - ✓ THM coupling
- ❖ Take into account interaction Boom clay/Bentonite/steel structure
- ❖ Follow the real test procedures as much as possible
- ❖ 1D model, 2D axisymmetric model, & 2D plane strain model
- ❖ A large number of THM parameters and constitutive models are obtained and validated based on lab tests & in-situ tests.

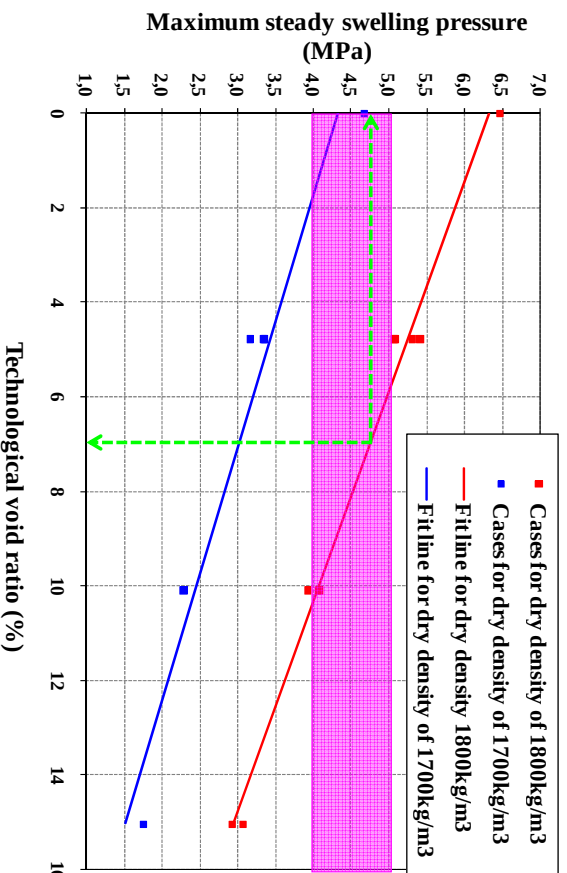
Modeling test procedure

- ❖ **Excavation & installation of liner**
Nov. 2007
- ❖ **Drainage:**
Nov. 2007~Feb. 2010
- ❖ **Remove wood**
Jan. 2010
- ❖ **Install bentonite & steel**
Feb. 2010
- ❖ **Inject water**
Apr. 2010~Jan. 2011
- ❖ **Backfill & saturate sand in gallery**
Jan. 2011
- ❖ **Praclay heater test**
Sept. 2011~Sept. 2021



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Modeling results



steady swelling pressure ~ tech. void ratio, for different dry density

For initial dry density $r_d=1800\text{kg/m}^3$, when technological void ratio: **6 ~10 %:**

=> swelling pressure : **4~5 MPa** (target swelling pressure)

	❖ Initial dry density of 1800kg/m³ is selected, with - Water content: 16.5% - Saturation degree: 83.8% - Suction : 59 Mpa
Introduction	
MX80 bentonite	❖ Initial technological void ratio of 6.9% is obtained after installation
Modeling	❖ At final state, the estimated intrinsic permeability: 6~10×10⁻²¹m², nearly 2 orders lower than Boom clay
Conclusions	<i>Modeling also checks many other aspects:</i> - o <i>Effect of artificial water injection on the saturation process</i> - o <i>Interaction between heater test and seal test</i> - o <i>Effect of non-saturation of Praclay gallery on the THM responses of Boom clay</i> - o <i>Influence of earlier backfilling in gallery on the seal saturation process</i> - o <i>Effect of unlocking the steel ribs on the homogeneity of swelling pressure</i> - o <i>Influence of upstream joint, downstream joint on the efficient of the seal</i> - o <i>etc.</i> <i>Modeling keeps updating based on the measured data and real test conditions</i>

PRACLAY Seal

Instrumentation & Sensor Data

Jan Verstricht
EIG EURIDICE
Exchange Meeting
25 November 2010



ONDRAF/NIRAS



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STUDIECENTRUM VOOR KERNENERGIE
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Seal Instrumentation Plan

Monitoring objectives

- hydraulic performance
 - hydraulic cut-off effectively realised
 - transmissivity (water&gas) along interface
- evolution of hydration/saturation
 - availability of clay water
- evolution of swelling pressure
- displacement at bentonite-host rock interface
- temperature field
- T → HM (swelling pressure, pore pressure)

Introduction

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Measured Quantities and Sensor Types

Overview

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- saturation → suction/humidity
- porewater pressure, permeability
- swelling pressure → total pressure
- mechanical response → deformation
- temperature

Measured Quantities and Sensor Types

Saturation

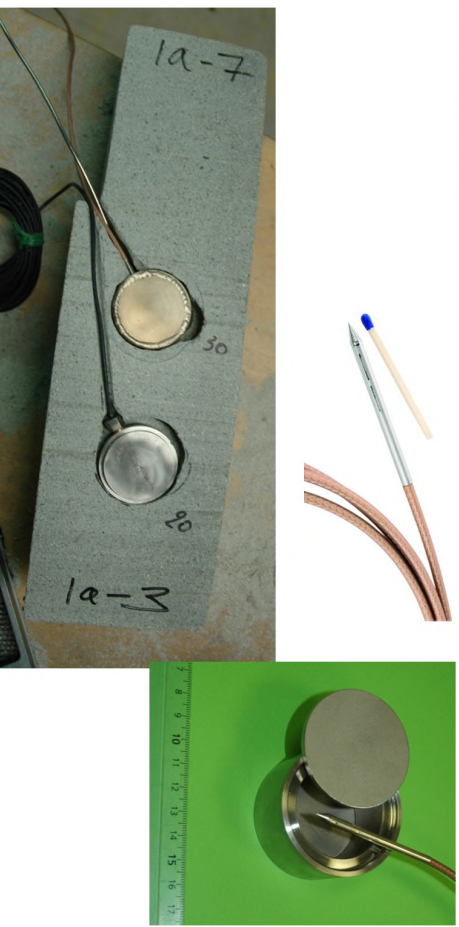
- suction through relative humidity $\psi = f(RH)$
 - capacitive RH sensor
 - psychrometer →
- tensiometer
- moisture sensors
 - TDR
- indirect: thermal conductivity
 - non-steady state probe



Measured Quantities and Sensor Types

Saturation

- RH sensor preferred over other sensors
 - previous experiences, confined space
 - ! doesn't like (liquid) water
- Miniature capacitive sensor (*Rotronic HC-C04*), integrated in piezometer filter



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Measured Quantities and Sensor Types

Porewater pressure, Permeability

- piezometer filters with one tube
 - 1 μ pore size (nominal) to avoid possible clogging in bentonite (5 μ in Boom Clay)
 - 4 x twin tube for gas permeability tests (FORGE)

Temperature

- stainless steel sheathed thermocouples
 - “multicouples” (3 x TC in one cable) to limit wiring
- thermistors integrated in vibrating wire sensors

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Measured Quantities and Sensor Types

Total pressure

- flatjack cells with vibrating wire pressure sensor
 - Geokon 4800 (Ø 100 mm flatjack disc)



- piezoresistive soil pressure cell

- Kulite 0234



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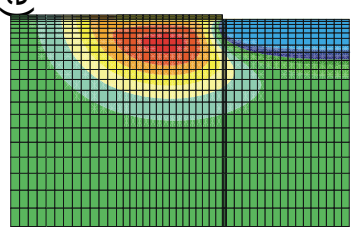
Measured Quantities and Sensor Types

Displacement

- recompression Boom Clay at interface with Seal
 - inductive transducer, hermetically sealed
 - connected to steel cylinder throughout the bentonite



Sensor lay-out principles



- Seal Geometry
 - longitudinal
 - hydraulic & thermal gradient
 - radial (hydration evolution)
 - circumferential (anisotropy – stress state)
- Technical issues
 - confined space → combined sensors, cabling limitations
 - precompacted bentonite blocks
- Instrumentation around Seal
 - instrumented boreholes (P30E, P35E)
 - instrumented segments (R20, R21)

Introduction	Measurands & Sensor Types	Sensor lay-out	Experimental Phases	Sensor Data	Performance Testing	Conclusion
Introduction	Measurands & Sensor Types	Sensor lay-out	Experimental Phases	Sensor Data	Performance Testing	Conclusion

Main locations and parameters

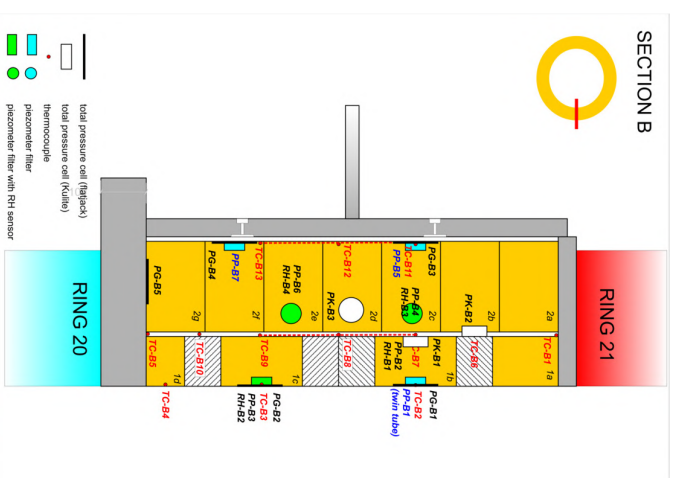
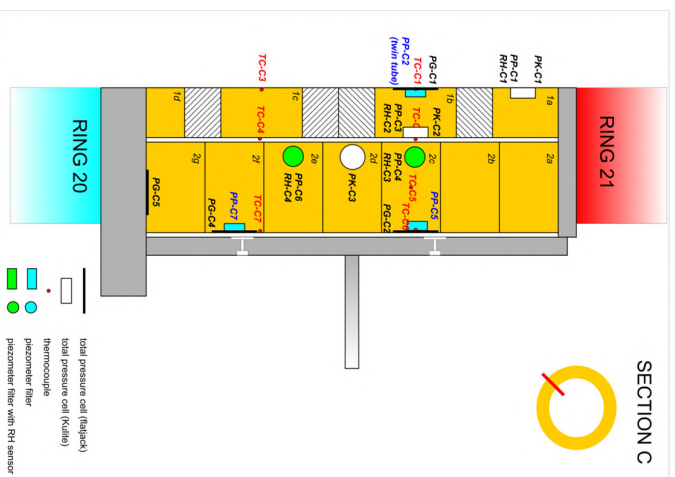
	suction/ moisture (unsat)	porewater pressure (sat)	total - swelling pressure	temperature	displacement / deformation
interface host rock	X	X	X	X	X
bentonite	X	X	X	X	
interface steel structure		X	X	X	(X)

interface bentonite - host rock

- boundary conditions
- most important zone (preferential pathway)
- displacement

Other instrumented sections

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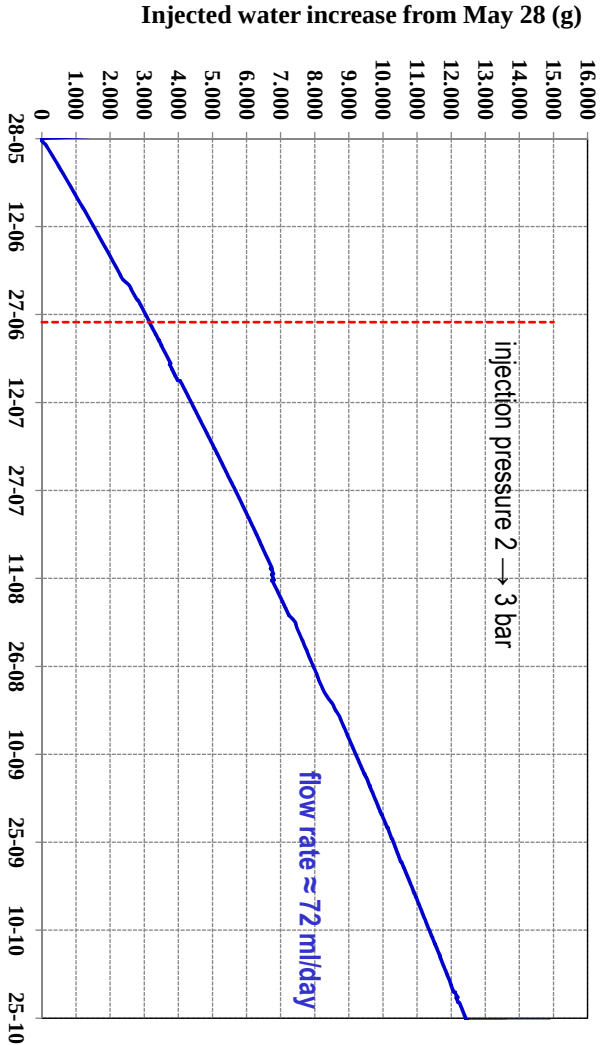
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Experimental phases after construction

- natural hydration (Feb 1, 2010)
- hydration through injection filters (April 7, 2010)
 - “slow” injection to fill voids
 - sealing of joints along cables,...
 - avoid differential swelling bottom – top bentonite
 - current injection pressure 3 bar
 - total volume for saturation ≈ 95 l
- performance testing (preparations)
 - October 2010

Artificial hydration through injection filters

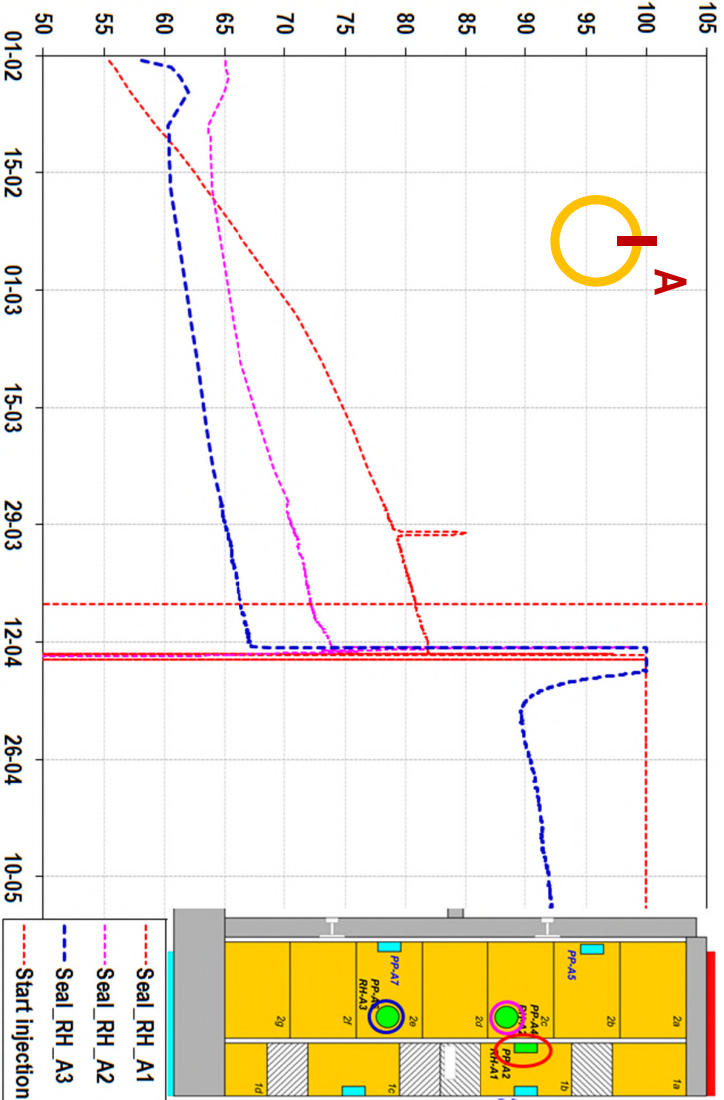
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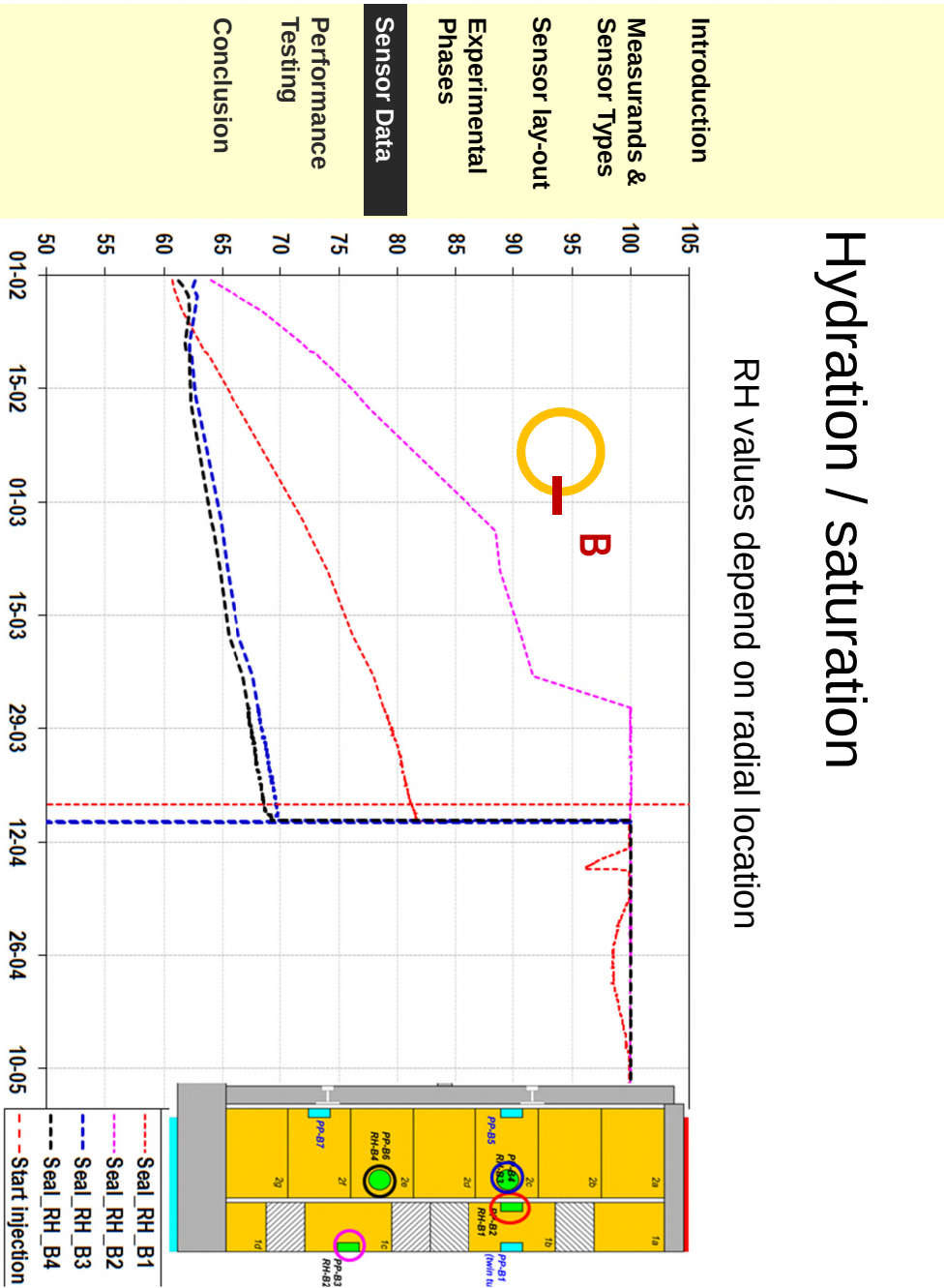
Hydration / saturation

RH values depend on radial location



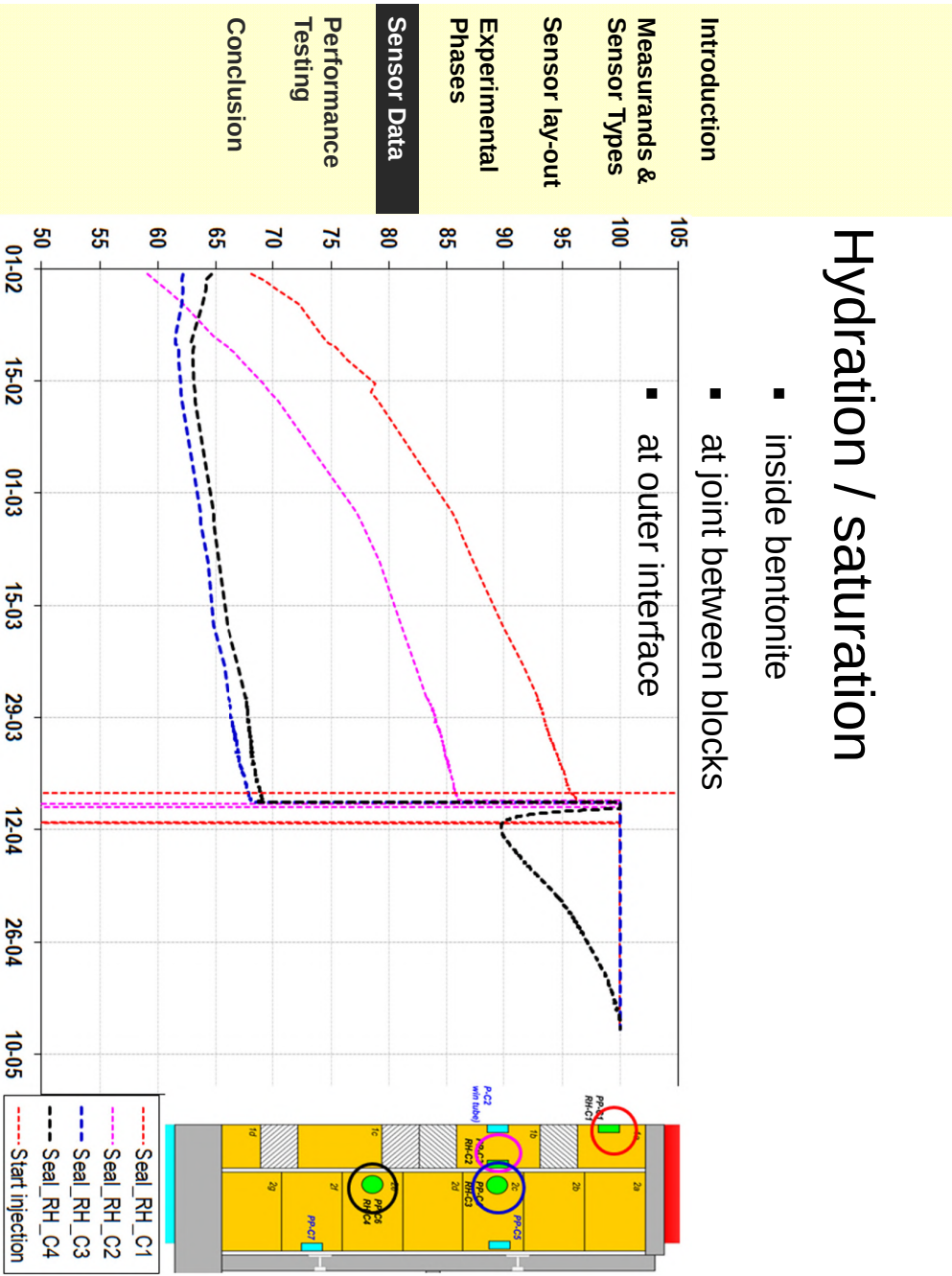
Hydration / saturation

RH values depend on radial location



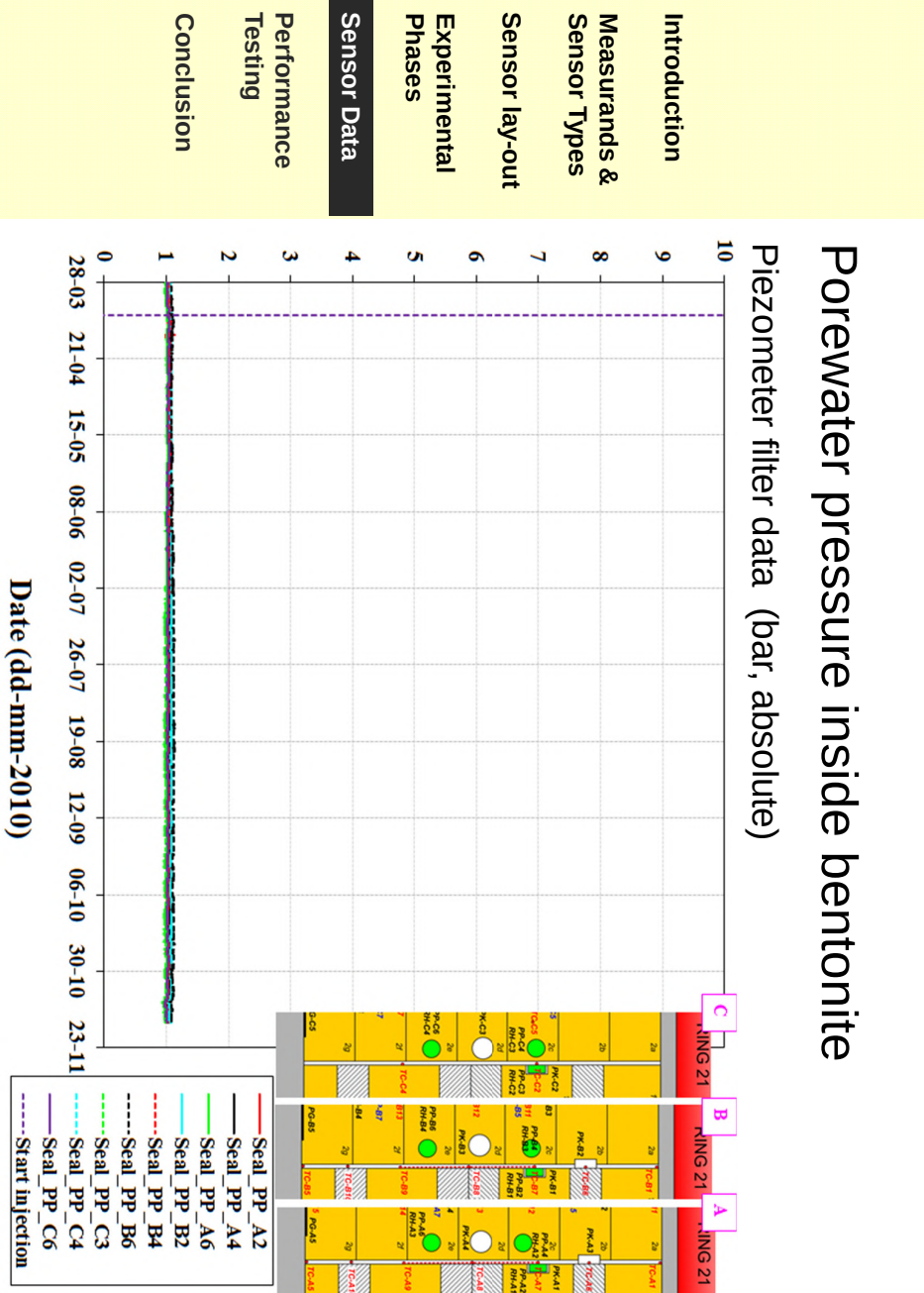
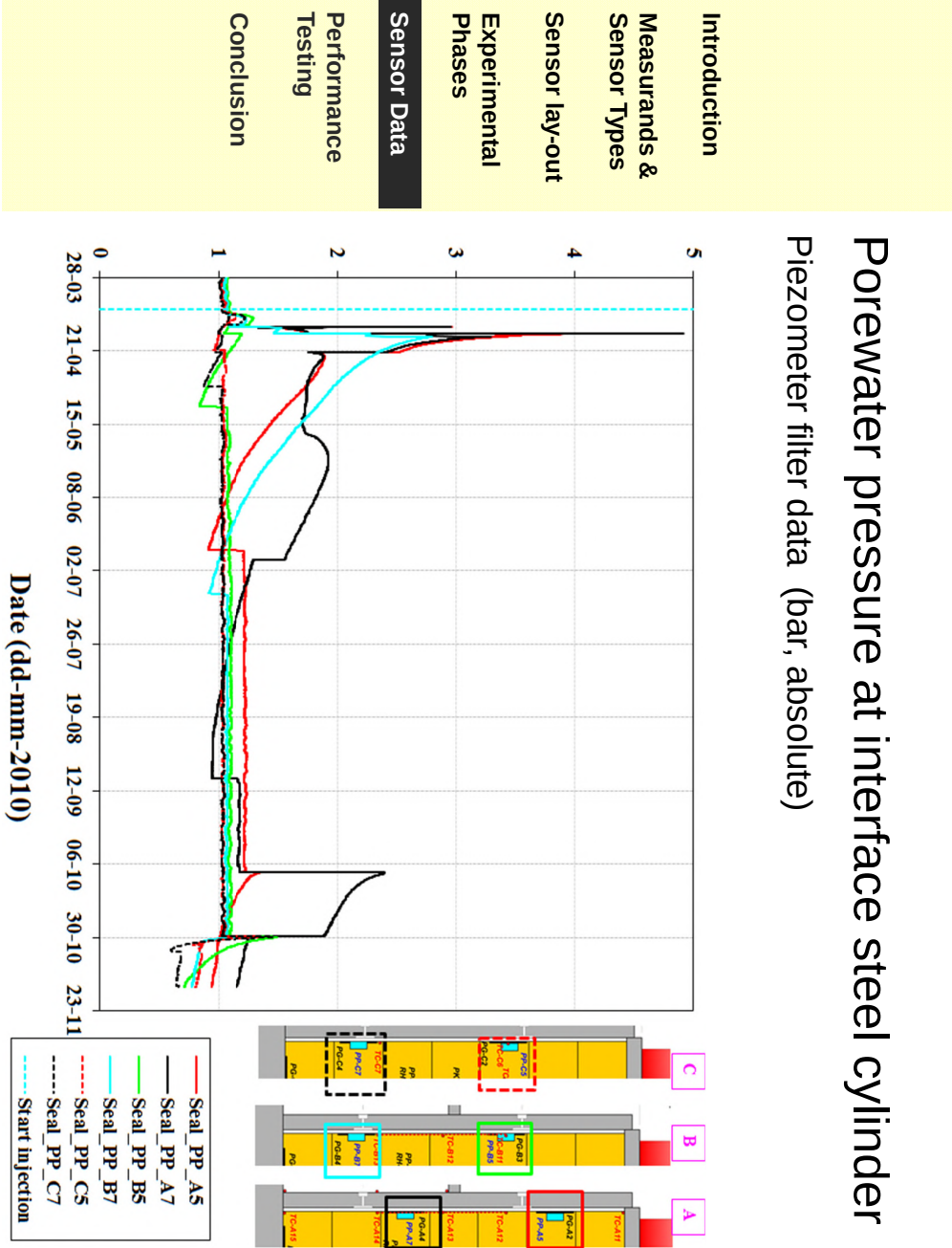
Hydration / saturation

- inside bentonite
- at joint between blocks
- at outer interface



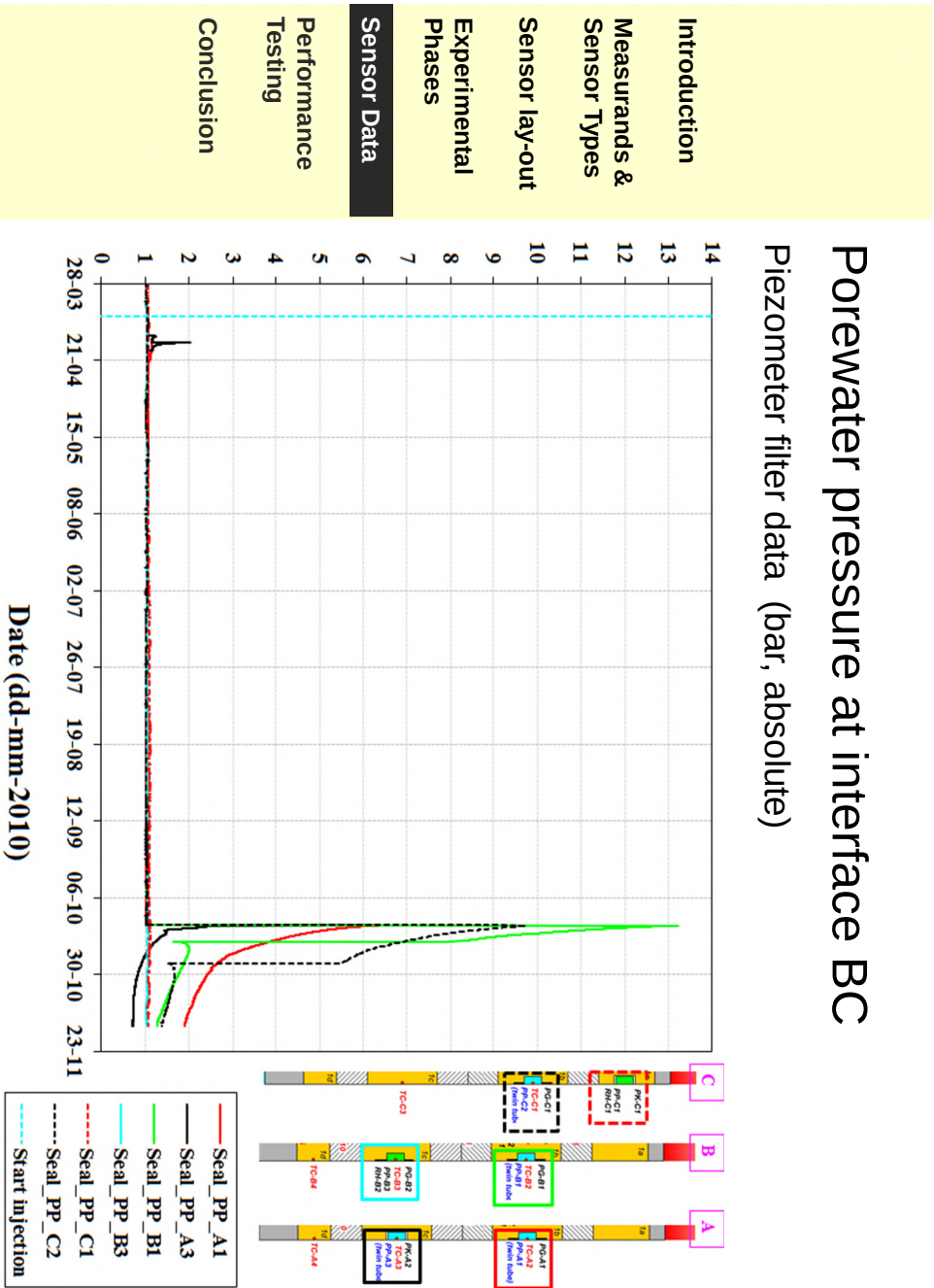
Porewater pressure at interface steel cylinder

Piezometer filter data (bar, absolute)



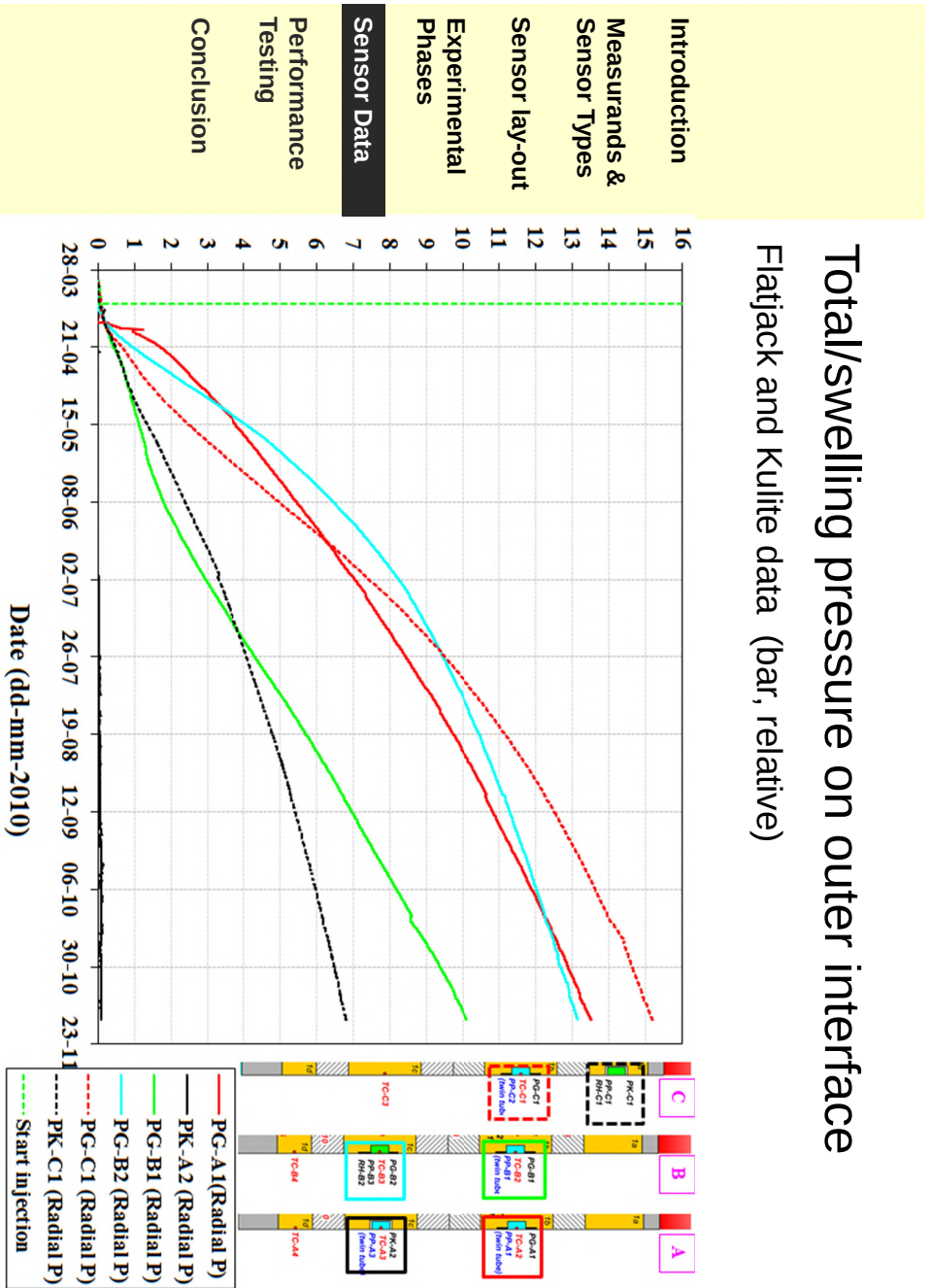
Porewater pressure at interface BC

Piezometer filter data (bar, absolute)



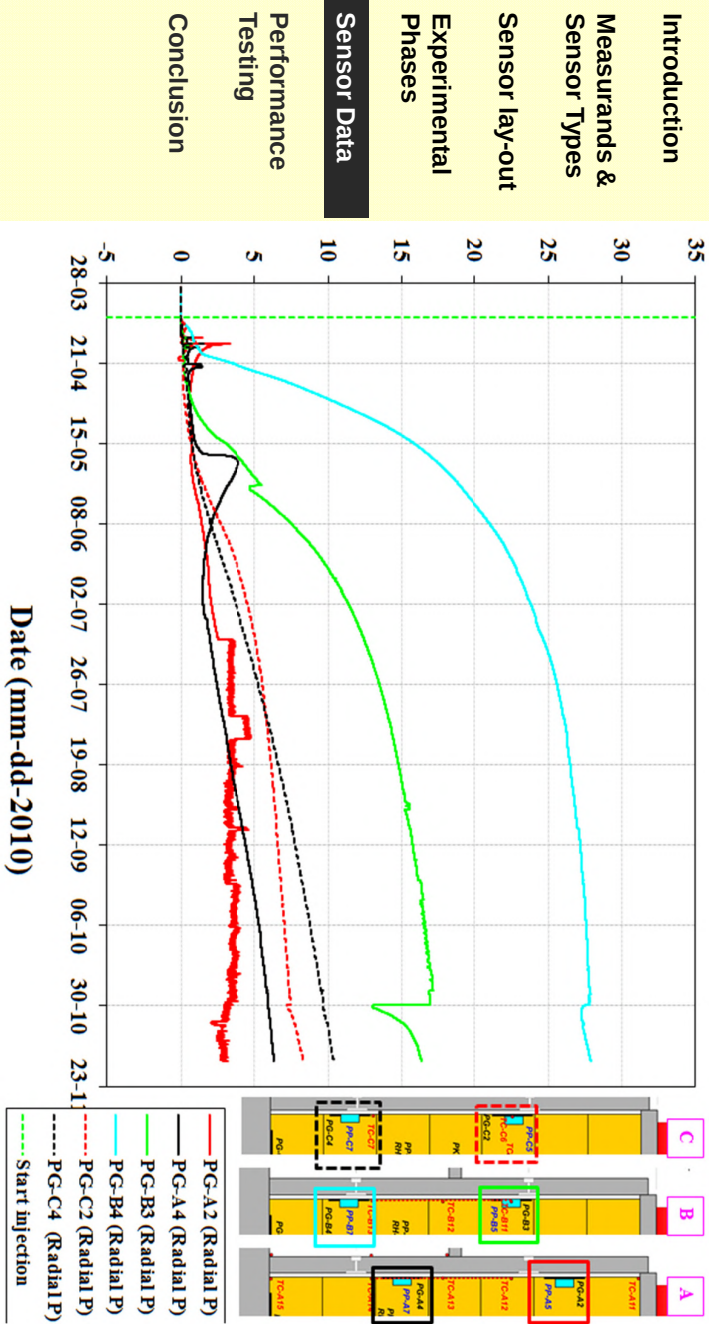
Total/swelling pressure on outer interface

Flatjack and Kulite data (bar, relative)



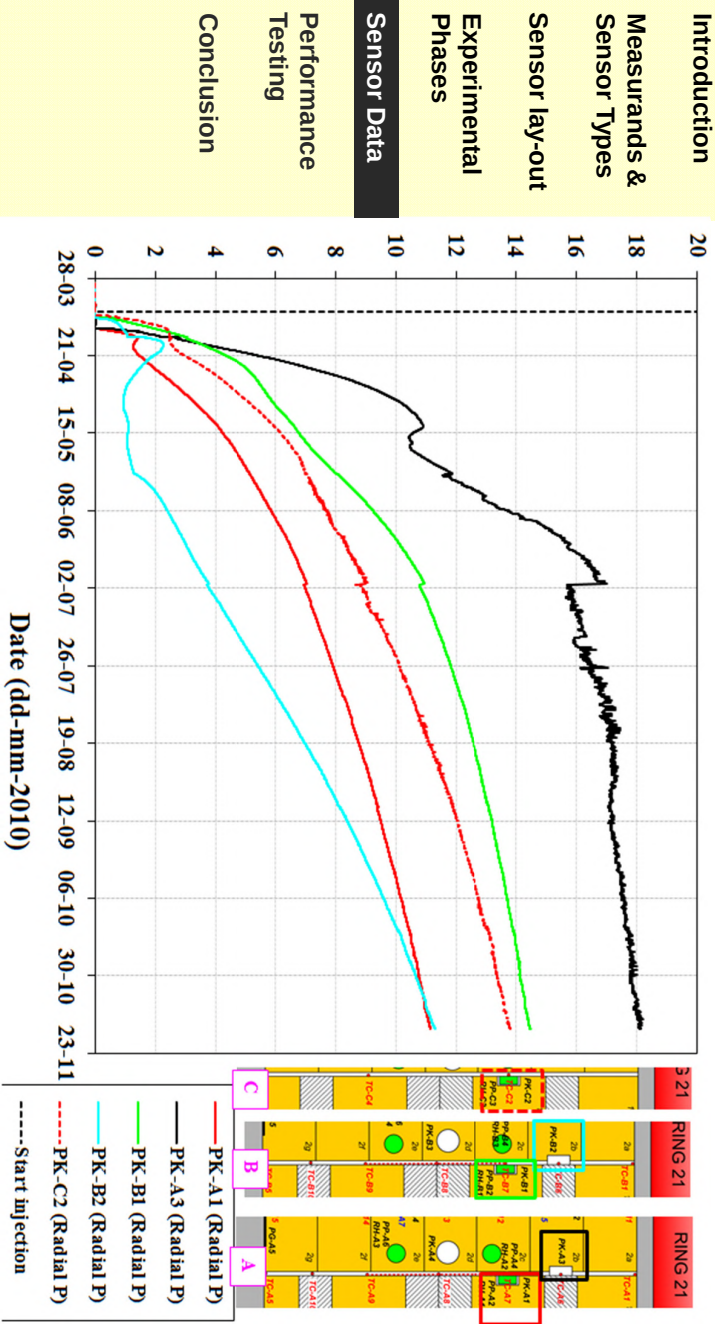
Total/swelling pressure on steel cylinder

Flatjack data (bar, relative)



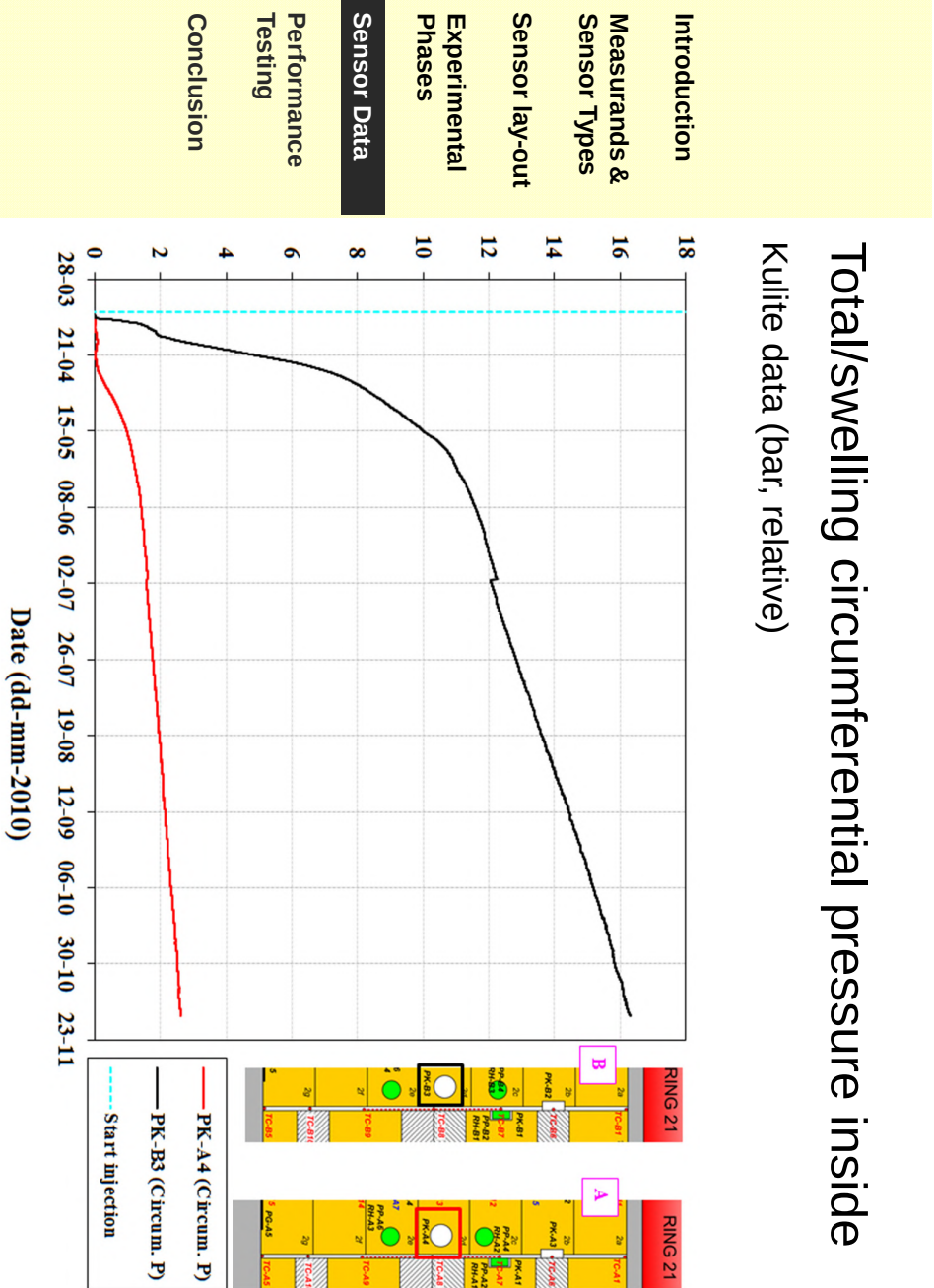
Total/swelling radial pressure inside bentonite

Kulite data (bar, relative)



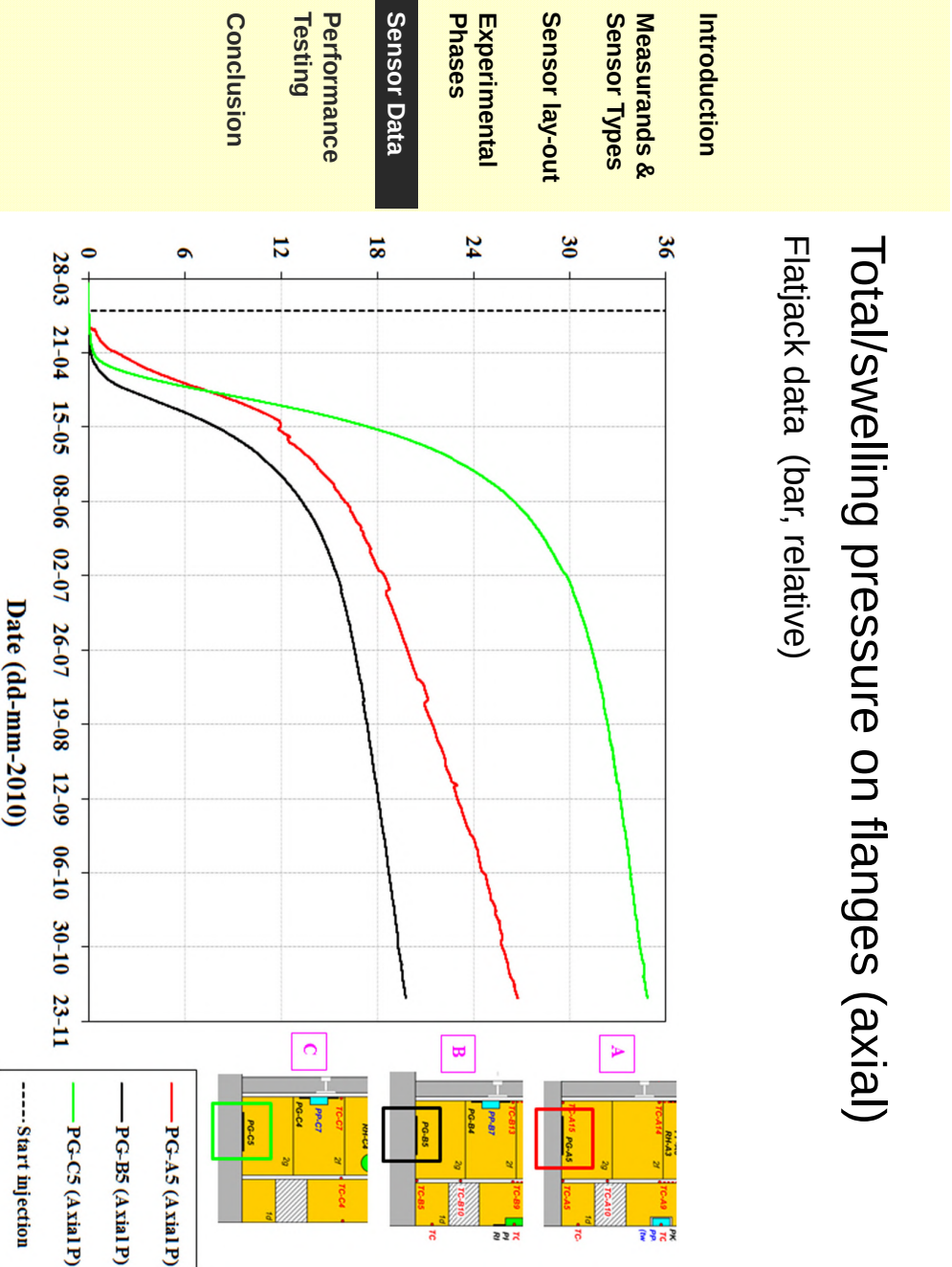
Total/swelling pressure on flanges inside

Kulite data (bar, relative)

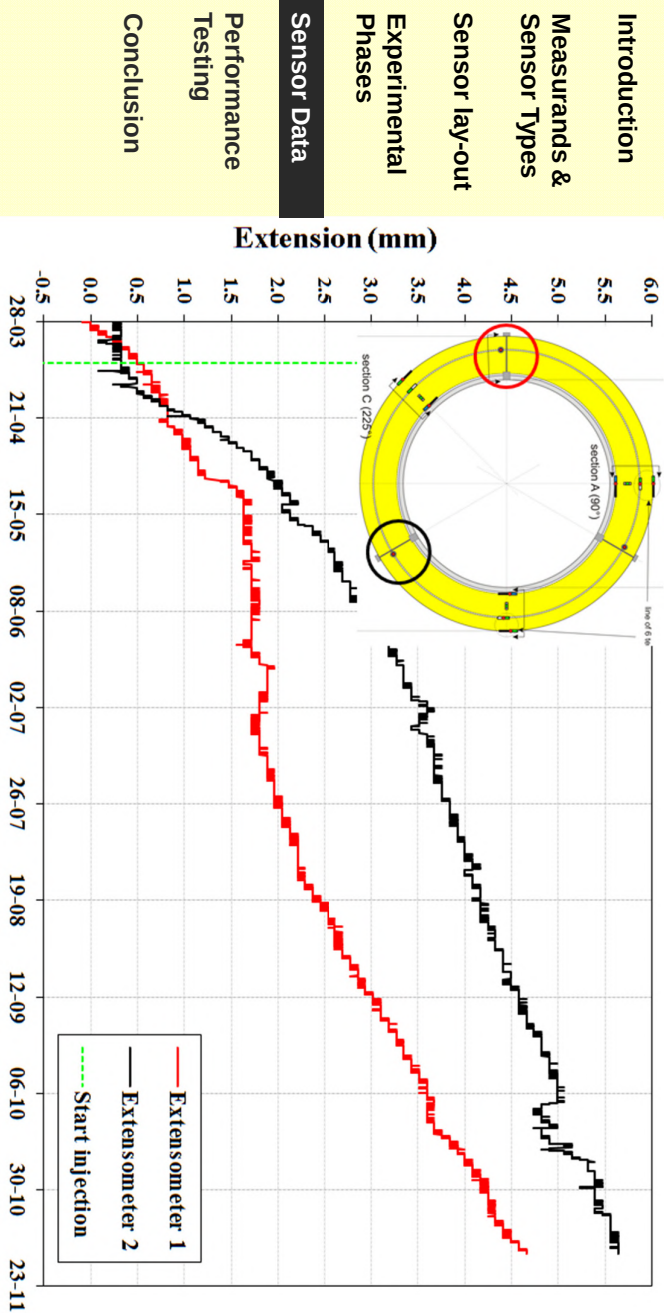


Total/swelling pressure on flanges (axial)

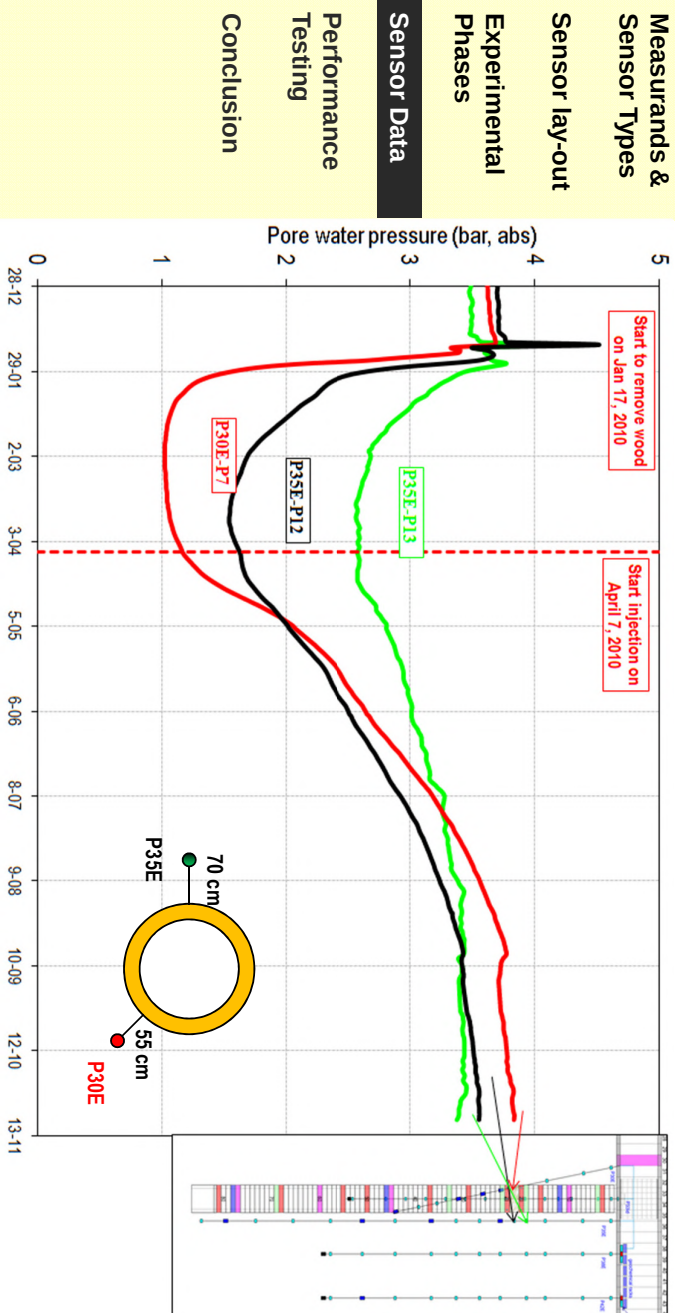
Flatjack data (bar, relative)



Displacement at bentonite – BC interface



Nearby piezometers show clear influence



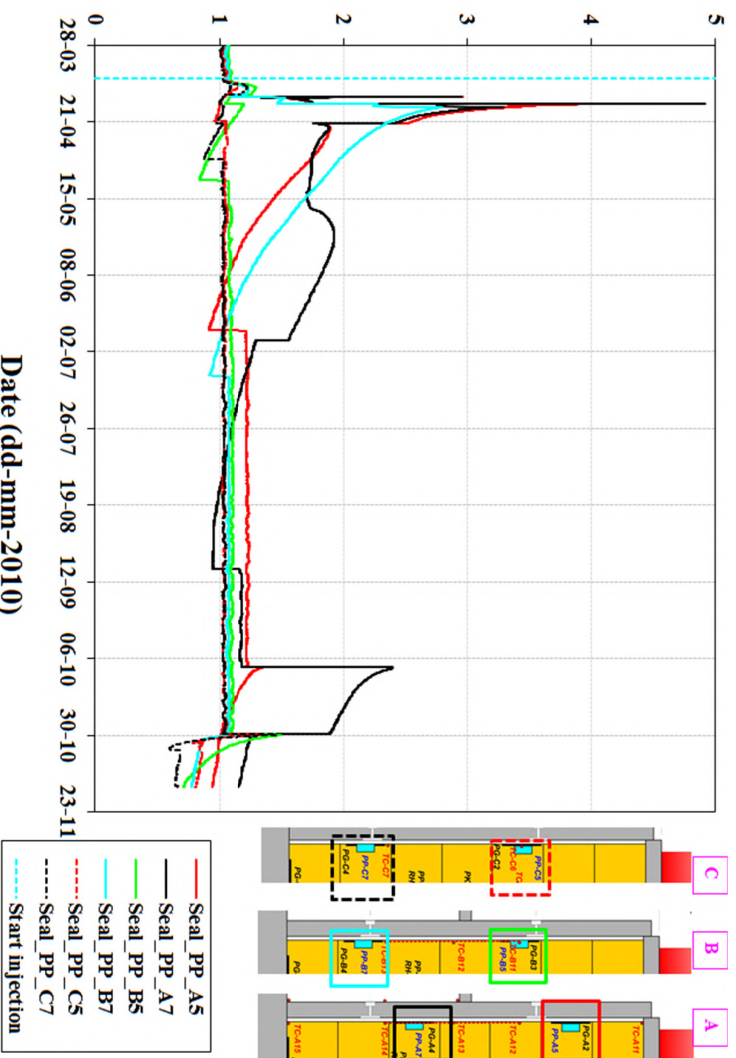
Performance Testing

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- Check of hydraulic behaviour around / between piezometer filters
- specific case: injection filter → piezometer on steel cylinder
- Current status: saturation of filters (w/o RH)
 - procedure:
 - removal air (vacuum pump)
 - injection of water (pressurised by CO₂)

Porewater pressure at interface steel cylinder

Piezometer filter data (bar, absolute)

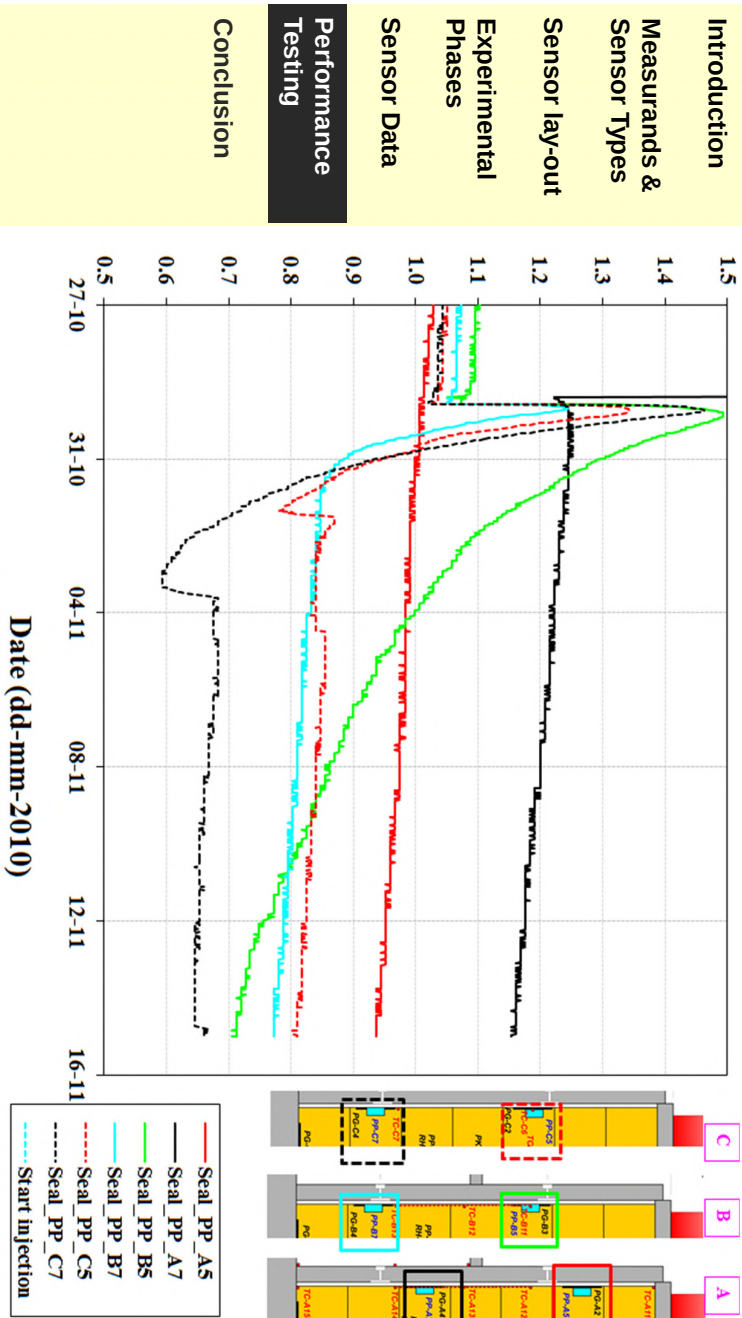


Date (dd-mm-2010)

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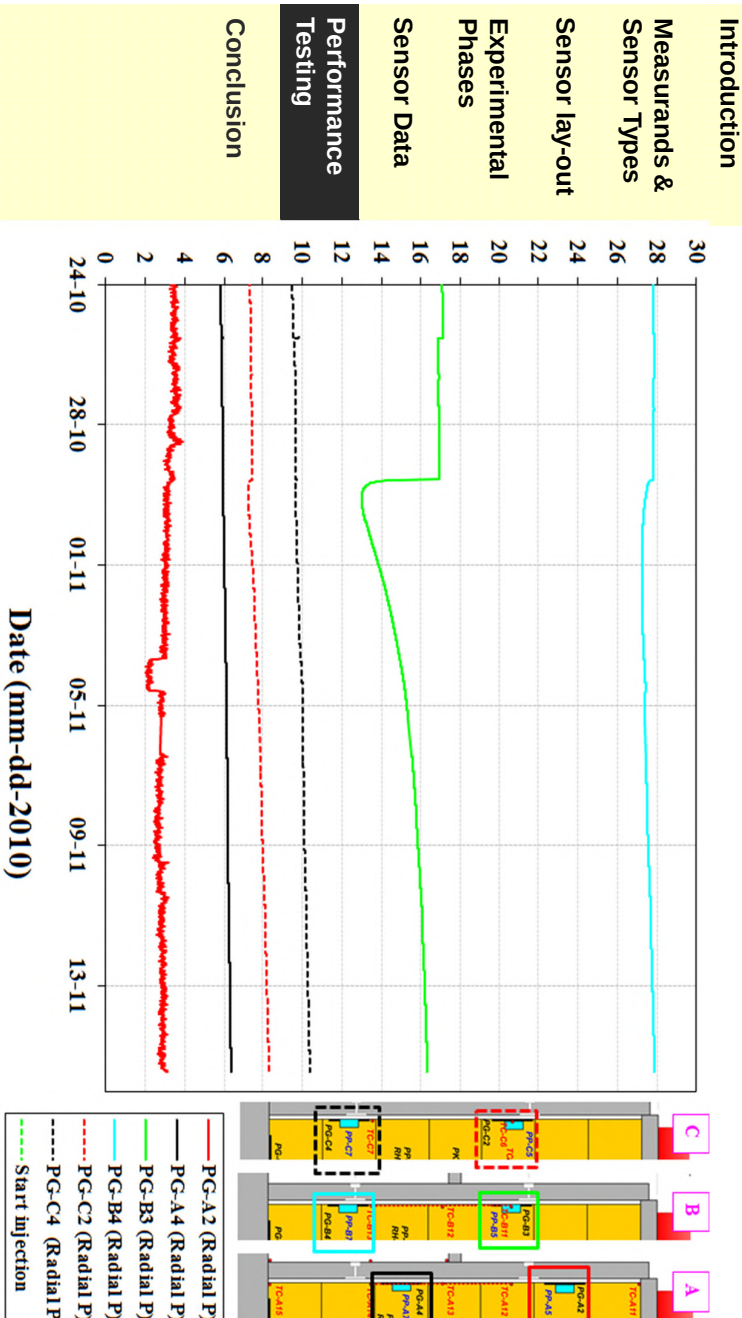
Porewater pressure at interface steel cylinder

Piezometer filter data (bar, absolute) – detail of last month



Reaction of total pressures on steel cylinder

Flatjack data (bar, relative) – detail of last month



Conclusions

- Natural hydration (before injection) well monitored
 - in line with modelling results
- Overall swelling, but no uniform behaviour yet
 - discrete nature of bentonite volume
- Unsaturated behaviour observed through piezometer filters
 - ? permeability testing in unsaturated media
 - interesting $H \rightarrow M$ interaction

Conclusion

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The heating system for the PRACLAY Experiment

Wim Bastiaens
EIG EURIDICE
Exchange Meeting
25 November 2010



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Outline

- Introduction
- Design
- Testing
- Installation
- Conclusions

Aim

- Heat experimental part of PRACLAY gallery ...
- ... following the defined heating strategy
 - C^{te} temperature: 80°C at gallery extrados
 - Progressive heating: 16°C → 80°C
- During 10 years

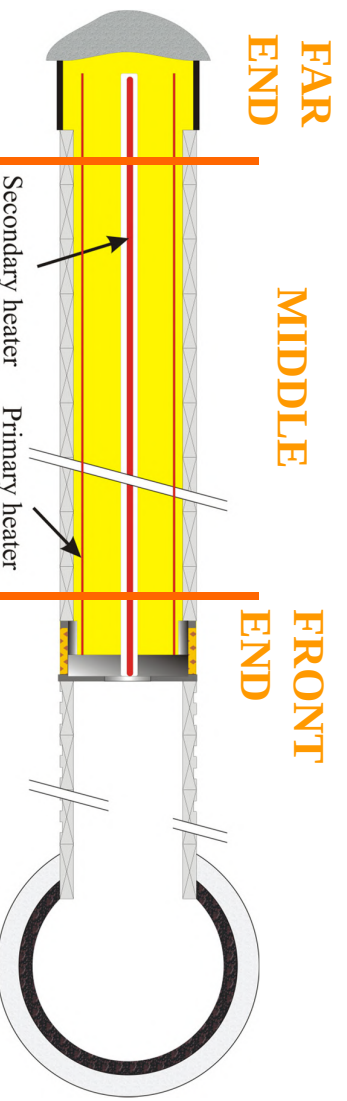
Define requirements of the heating system

- EURIDICE
- NRG (type of heater & general aspects)

Three sections

- Front and far end sections to limit side effects
- Each section is to be controlled separately
- Middle section is the representative part
- Maximise the length of the middle section

Primary and secondary heating systems



Main design requirements for the **heater** fixed by experimental conditions

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- water saturated (up to 35 bar) and hot
- mechanically robust & corrosion resistant
- life cycle overall system > 10 years
- heater at 10 cm from the lining intrados
 - protect concrete lining and instrument cables
- install with 100 % redundancy
- limit number of feed-throughs
- loops parallel to the gallery axis

Main requirements **control system**

During start-up

1. Temperature cables < 200°C
2. Max gradient concrete: 15°C
3. Temperature difference in middle section: < 7°C
4. Temperature difference total: < 10°C
5. Concrete temperature: < 95°C

During stationary phase

1. Temperature cables < 200°C
2. Max gradient concrete : 10°C
- 3a. Mean temperature middle section: 80°C +/- 2°C
- 3b. Local temperature middle section: 80°C +/- 3°C
- 4a. Mean temperature total: 80°C +/- 4°C
- 4b. Local temperature total: 80°C +/- 6°C
5. Concrete temperature: < 95°C

Be able to control secondary heater (C^{te} power)

Log heater output & generate alarms

Input control system

Introduction

- 7 lining sections inside the experiment were equipped with thermocouples

- 4 segments in each section

- 3 TC in each segment

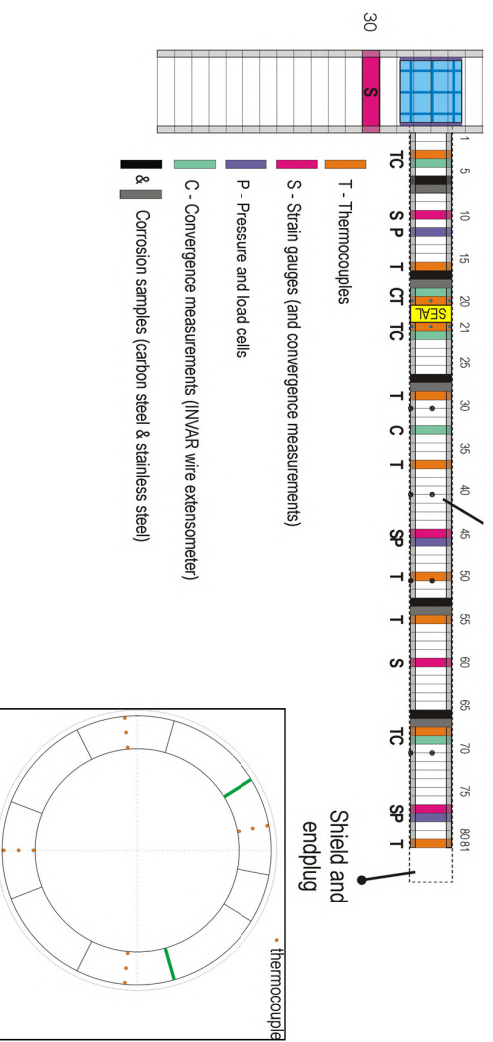
- Use intrados and extrados

- $7 \times 4 \times 2 = 56$ TC

Testing

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Contract by public procurement

- Technical specification described functional requirements

- Primary heater elements

- Control system

- Detailed design to be performed by contractant

- Tyco Thermal Controls (Oct 2009)

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Secondary heater elements: reuse ESDRED heater

Introduction

Design

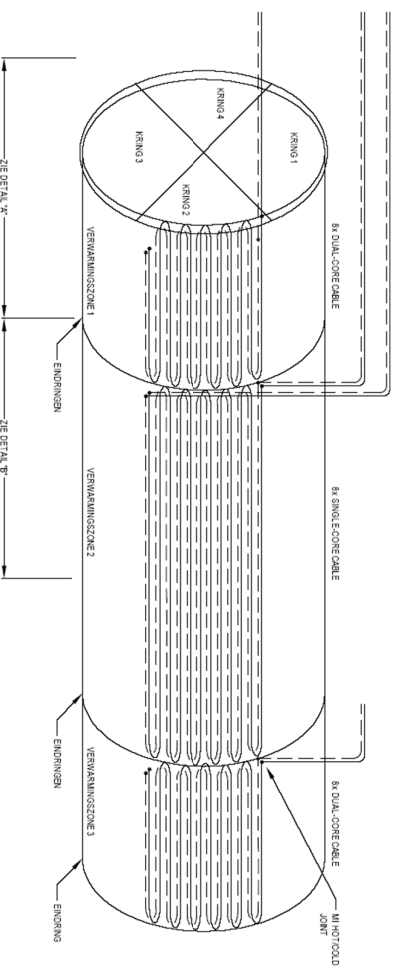
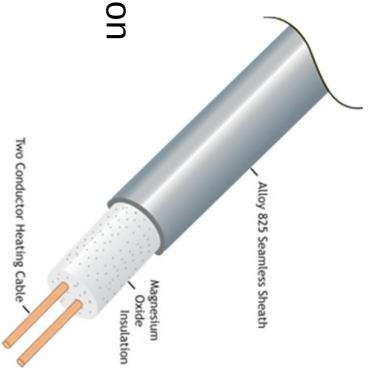
Testing

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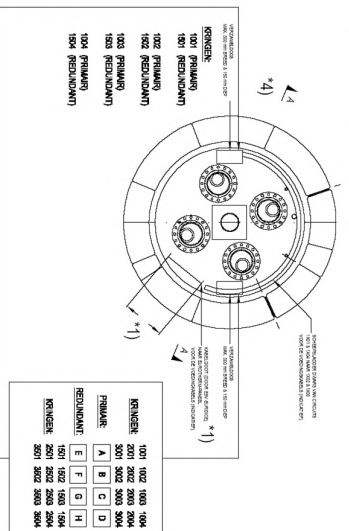
Conclusions

Design by Tyco

- Mineral Insulated elements
- Alloy 825 (Incoloy)
- Laser welded
- Three sections, four elements per section
- Power controlled separately
- 100 % redundant → 24 elements
- Switched every 24 hours
- Fixed on stainless steel support structures, cables may not touch each other

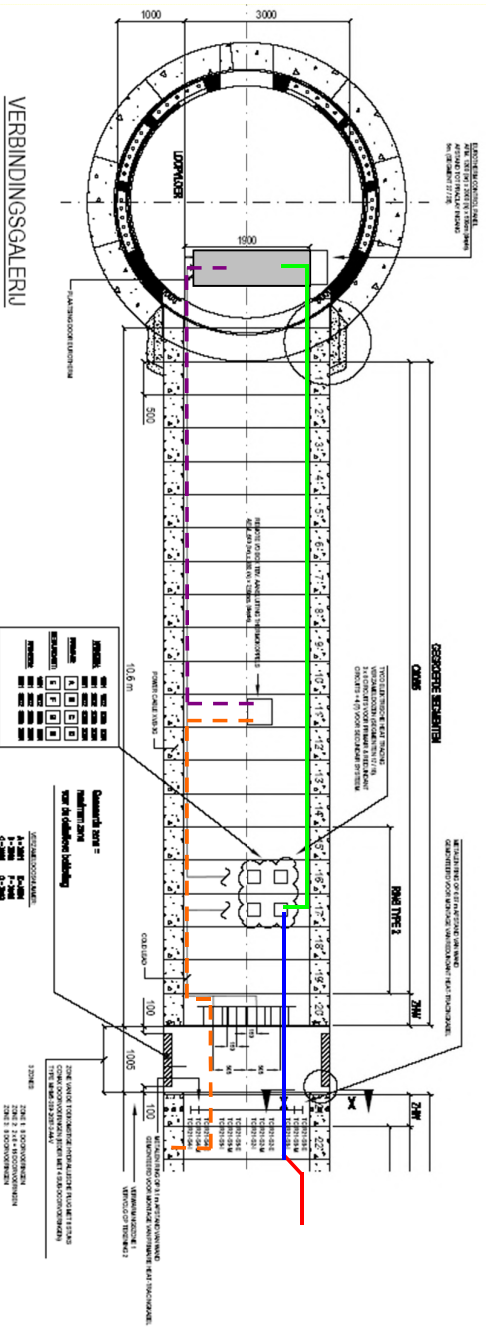


SCHAL 1.25
INSTALLATED DETAIL HT JUNCTION BOXES NABU HYDRAULISCHE SEAL



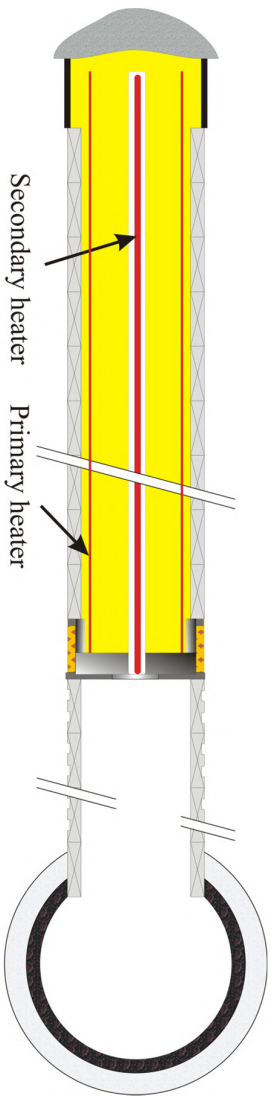
Heater - Setup

- Heater element & cold lead
- Power cable
- Thermocouple
- Data cable



Secondary heater

- Re-use ESDRED elements
- Four MI elements
- To be installed in central tube
- Accessible at all times during experiment
- Same control system as primary
- Constant power



Introduction

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Dummy element

- Elements are guaranteed up to 30 bar but PRACLAY pressure could reach 35 bar
- Design and manufacturing process are compatible with higher pressures → test
- Stepwise increase of pressure and temperature
- Megger: determine resistance between element sheet and element core ($> 50\text{ M}\Omega$)

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Temperature	Pressure	Result
Room temperature	30 bar	$> 200\text{ G}\Omega$
90°C	30 bar	$> 20\text{ G}\Omega$
90°C	35 bar	$> 20\text{ G}\Omega$
90°C	40 bar	$> 20\text{ G}\Omega$
Room temperature	40 bar	$> 200\text{ G}\Omega$

Installed elements

- Testing (Megger) is performed after each step
 - After production
 - On-site
 - Before installation
 - After installation
- Elements were immersed on-site during testing to detect defects → all OK

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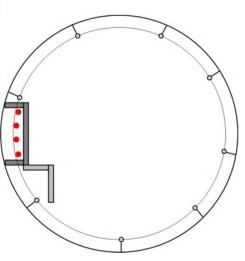
Support structure

- Stainless steel rings
- 10 cm distance from gallery intrados
- Spacing : 1 m

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Heater phase 1

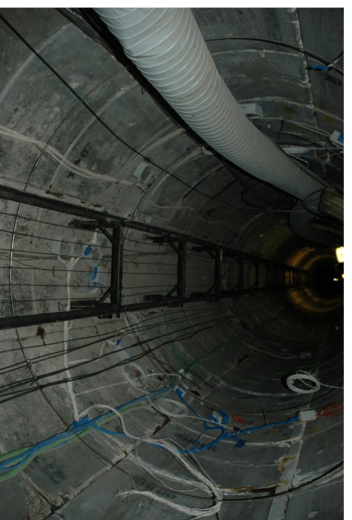
- Stainless steel cable ties



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Work platform



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Heater phase 2

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Testing

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Heater connections

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Control panel

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Central tube for secondary heater

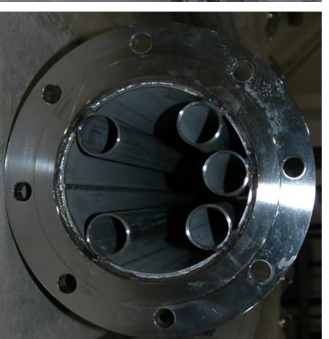
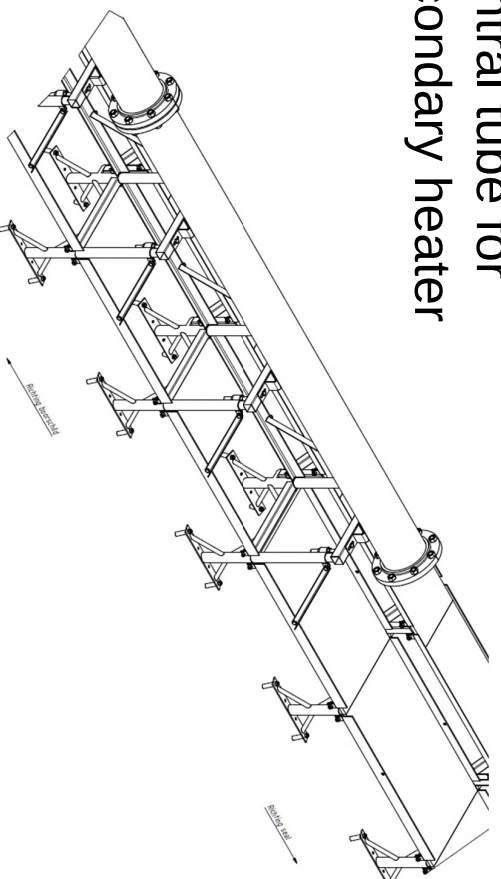
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Conclusions

- Primary heater installed and connected to i/o boxes according to design
- Test results on elements were satisfactory

Future work related to the heater system

- Install control system
- In-situ testing
 - Heater elements
 - Connections
 - Control system
- Install thermocouples on elements
- Install secondary heater
- Switch-on

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Future programme and planning of the PRACLAY Experiment

Xiangling Li
EIG EURIDICE
Exchange Meeting
25 November 2010



ONDRAF/NIRAS



EIG EURIDICE GIE



STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

PRACLAY In-Situ Experiment

- PRACLAY Gallery constructed: November 2007
- Hydraulic Seal installed : February 2010
(hydration: ongoing)

Actual state

- Primary Heater installed and connected : November 2010
- All (nearly) instruments were installed
- All materials were delivered (backfill sand, central tube,...)

Future work



PRACLAY In-Situ Experiment

Actual state

- Finish the heating system installation (start 2011)
 - ✓ control system
 - ✓ in situ testing
- Finish cabling and feed-through (start 2011)
- Install central tube (start 2011)
- Backfill the PRACLAY gallery (start 2011)
- Close the PRACLAY gallery (start 2011)
- Install the secondary heater (start 2011)
- Saturate the PRACLAY gallery (before switch on heater)
- Switch on heater !

- depending on the Seal evolution !
- => systematic Seal performance testing !

Future work

PRACLAY In-Situ Experiment

Seal performance testing :

- Through filters at interface BC/Bentonite
 - gas pressure build-up testing
 - pulse and response testing
 - hydraulic conductivity testing
 - etc.
- Through injection filters at interface bentonite/cylinder
 - pulse and response testing
 - etc.

Actual state

Future work