Poster introductions

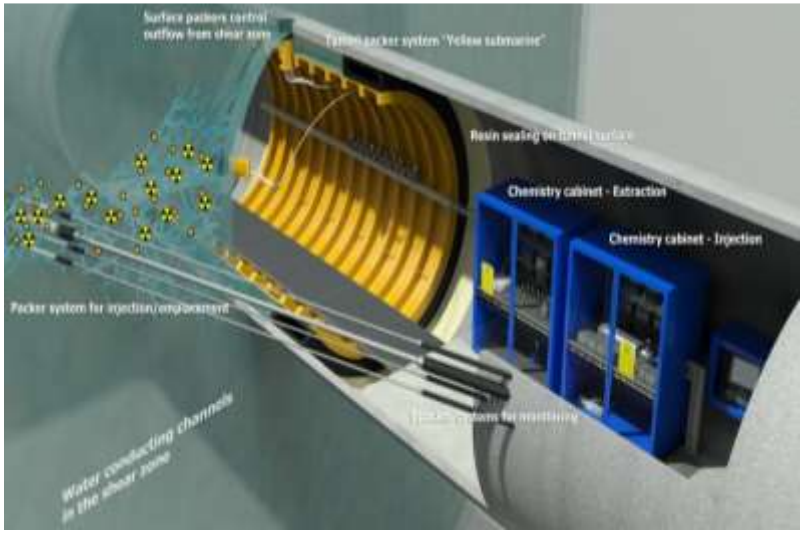
Poster introductions

HYDRAULIC EVOLUTION OF THE LONG-TERM IN-SITU TEST AT THE GRIMSEL TEST SITE AND SUPPORTING EXPERIMENTS	Rinderknecht (KIT INE)
APPROACHES FOR SIMULATION OF PROCESSES IN THE ENGINEERED BARRIERS OF THE RADIOACTIVE WASTE REPOSITORY	Balvin (TU Liberec)
SWELLING PROPERTIES OF MX-80 BENTONITE MATERIALS	Bernachy-Barbe et al (CEA)
DENSITY REDISTRIBUTION IN COMPACTED BENTONITE EXPOSED TO EXTERNAL WATER PRESSURE DIFFERENCE	Birgersson (Clay Technology)
LARGE SCALE GAS INJECTION TEST (LASGIT): HYDRATION AND HYDRAULIC TESTING	Harrington (BGS/SKB)
THE CZECH CONSORTIUM'S PLAN FOR THE BEACON PROJECT	Hausmannova (SÚRAO)
RESEARCH ACTIVITIES AT RWMC ON THE BENTONITE RE-SATURATION PROCESS (1) OVERVIEW	Ishii (RWMC)
RESEACH ACTIVITIES AT RWMC ON THE BENTONITE RE-SATURATION PROCESS (2) LABORATORY AND NUMERICAL EVALUATION	Ito, Tachibana (Kobe U/ RWMC)
PROTOTYPE REPOSITORY – MASS REDISTRIBUTION IN THE BUFFER AND THE TUNNEL BACKFILL	Johannesson et al (SKB)
SWELLING PRESSURE AND HYDRAULIC CONDUCTIVITY - INFLUENCE OF SALINE SOLUTIONS	Karnland (Clay Tech)
BLOCK-PELLET HOMOGENIZATION IN KBS-3V BUFFER – LABORATORY SCALE TEST	Lavikainen et al (Posiva)
BUFFER AND BACKFILL INTERACTION	Luterkort et al (SKB)
ROCK STRESS- AND TIME-DEPENDENCY IN OVERPACK DISPLACEMENT AND BENTONITE PRESSURE BY CENTRIFUGE PHYSICAL MODELLING TEST IN PREDICTING FUTURE OF NEAR-FIELD	Nishimoto (Criepi)
LEI - STATUS OF WASTE MANAGEMENT IN LITHUANIA, ONGOING WORK AND WORK PLANNED IN BEACON	Poskas, Justinavicius (LEI)
HETEROGENEOUS DRY DENSITY OF GRANULATED BENTONITE MIXTURES EMPLACED BY SCREW FEEDERS: A DIRECT MEASUREMENT USING A DIELECTRIC METHOD	Sakaki/LEUPIN (Nagra)
HANDLING OF THE MECHANICAL EVOLUTION OF THE BENTONITE BUFFER IN THE SR-SITE SAFETY ASSESSMENT	Sellin (SKB)
MOCK-UP-CZ	Svoboda et al (CTU, Surao)
MOCK-UP-JOSEF	
LABORATORY DATA FROM PERMEAMETERS (WATER IN-FLOW AND SWELLING PRESSURE EVOLUTION ON BENTONITE SAMPLES – USEFUL FOR MODEL VALIDATION AS THEY CAPTURE SATURATION & PRESSURE EVOLUTION ON CONFINED, INITIALLY DRY SAMPLE)	
HETEROGENEITIES AND HYDRO-MECHANICAL BEHAVIOR OF BENTONITE-BASED STRUCTURE: LESSONS LEARNT FROM LARGE SCALE EXPERIMENTS	Talandier (Andra)
THM MODELLING OF BENTONITE: AN APPROACH TESTED ON MX-80 AND FEBEX BENTONITE	Thatcher (Quintessa)
HYDROMECHANICAL MODELLING OF BENTONITE HOMOGENISATION	Åkesson (Clay Technology)
IN-SITU PRACLAY SEAL TEST IN URF HADES, BELGIUM	Chen (Mol team)
CODE COMPARISON OF COUPLED THM PROCESSES IN ENGINEERED BARRIERS PERFORMED WITHIN THE TASK FORCE ON ENGINEERED BARRIER SYSTEMS	Schäfers et al (BGR)
SPATIAL DISTRIBUTION OF BENTONITE BARRIER DRY DENSITY AND WATER CONTENT AFTER 5 AND 18 YEARS OPERATION	Villar et al (CIEMAT)

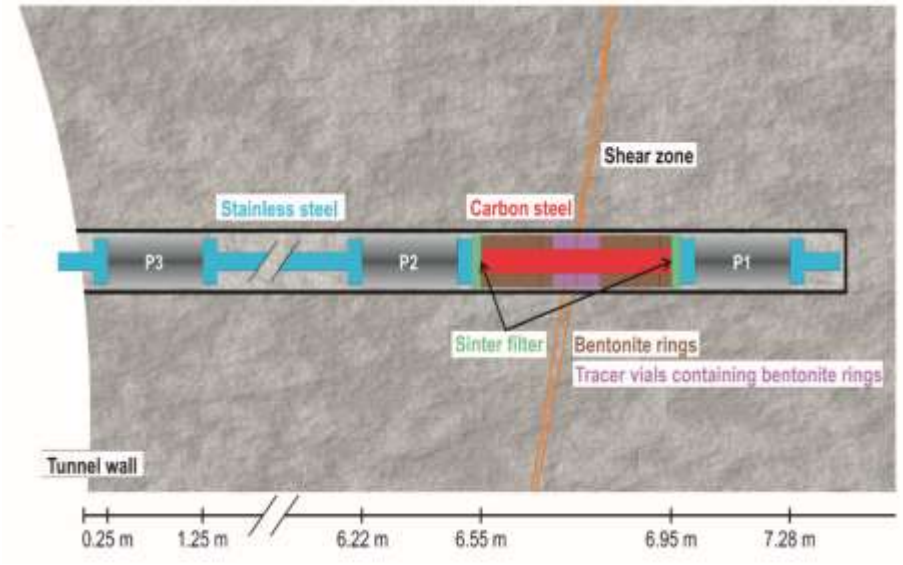
Long-term In-situ Test (LIT) at the Grimsel Test Site and supporting laboratory studies

- **Rinderknecht F., Kraft S., Huber F., Geckeis H., Schäfer T.,** KIT-INE
- **Lanyon B.,** Fracture systems Ltd.
- **Blechschmidt I**., Nagra

Karlsruhe Institute of Technology - Institute for Nuclear Waste Disposal (KIT-INE)

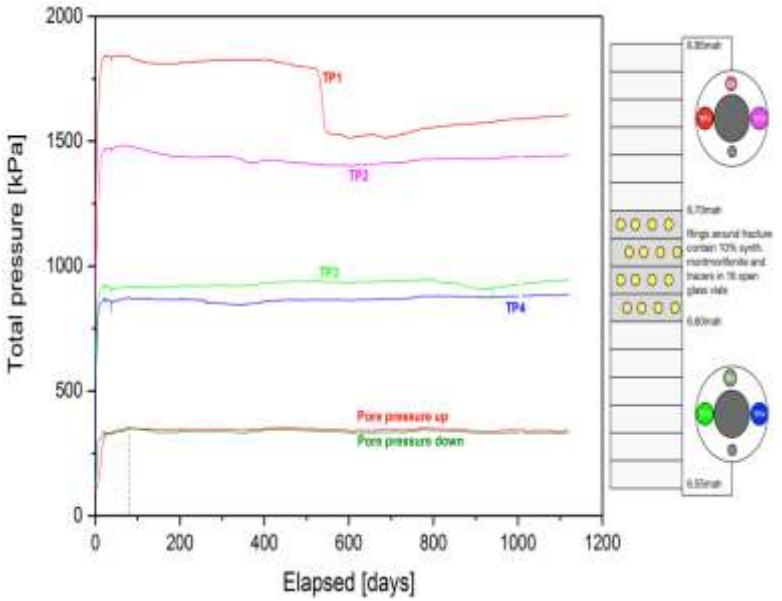


Long-term In-situ Test



Schematic LIT layout (inclination of 19°)

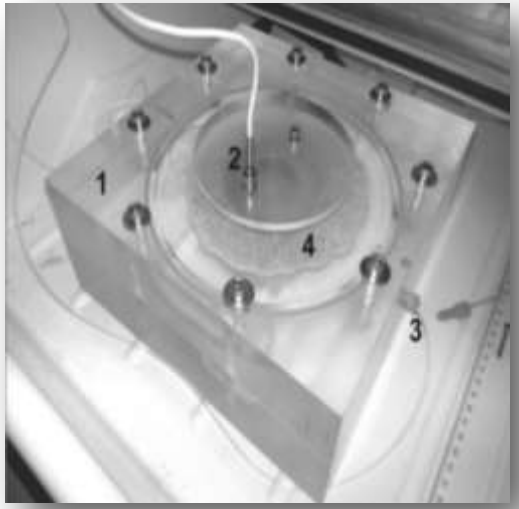
- Bentonite (total mass 2.6 kg, ρ=1.41 ± 0.05 g/cm^3) in fractured zone under repository relevant constant flow conditions since May, 2014.
- In-situ saturation, colloid generation with radionuclide interaction and migration under controlled low flow conditions.
- Total pressure stable despite pressure drop after ~550 days (TP1, homogenization)
- Swelling pressure between 0.6 MPa (TP3, TP4) and 1.1 MPa (TP1, TP2)



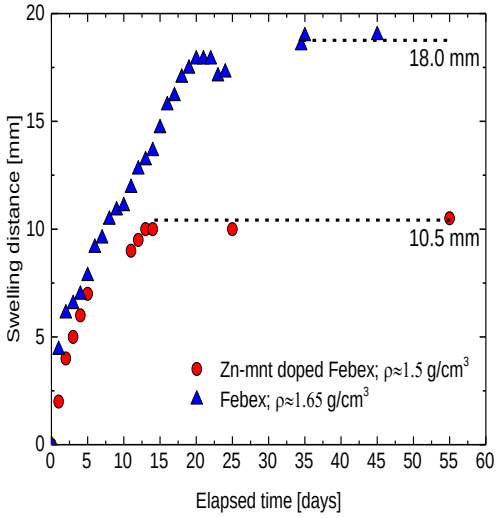
Online pressure data

Supporting mock-up tests

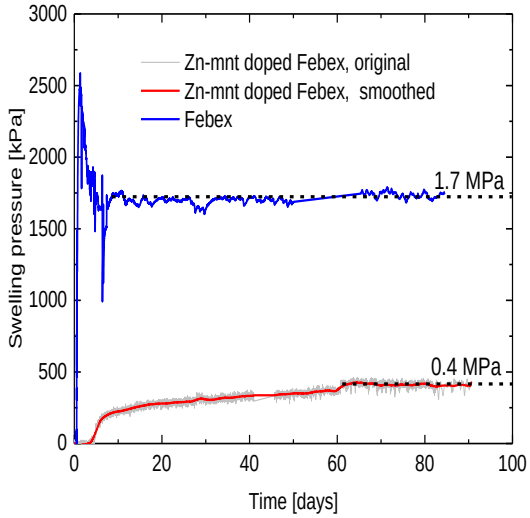
- Artificial 1 mm horizontal fracture aperture set-up
- Bentonite sample composition and dimensions, contact water and flow velocity identical to LIT



Experiment	Sample density [g/cm³]	Swelling presssure [MPa]	Swelling distance [mm]
LIT	1.41	0.6-1.1	-
Mock-up 2 (Febex + Zn montm.)	1.5	0.4	10.5
Mock-up 1 (Febex)	1.65	1.7	18.0



Swelling distance evolution



Swelling pressure evolution

The approaches for simulation of processes in the engineered barriers of the radioactive waste repository

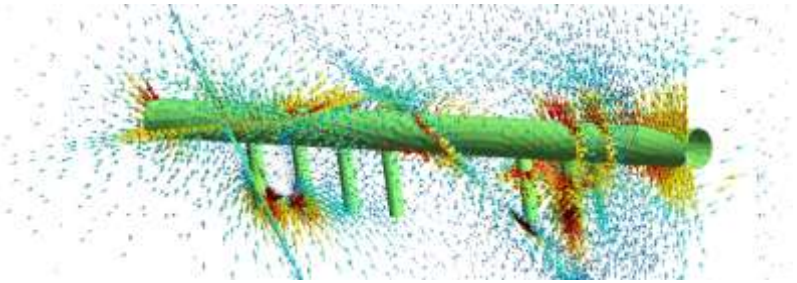
Aleš Balvín, Ilona Hančilová, Milan Hokr

BEACON, Kaunas, Lithuania

19-20 June, 2017

The poster summarizes our modelling approaches and example problems connected with processes in bentonite:

- **Multidimensional conception (Flow 123d)**
  - hydraulical models (flow in saturated and partly saturated medium with discontinuities)
  - thermal models
  - implementation based on mixed-hybrid formulation of FEM
  - the fractures are represented by the lower dimensions elements
  - software Flow 123d (developed at TUL)

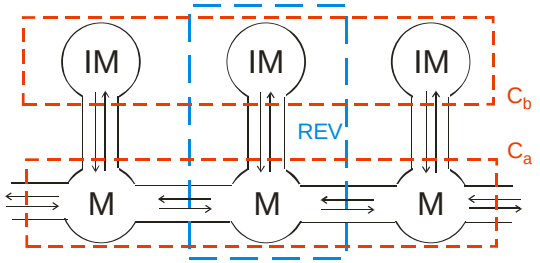


example: model of tunnel inflows in the Prototype Repository experiment (saturated rock with fractures)

- **Richards' equation (COMSOL Multiphysics)**
  - standard (H) and non-isothermal (TH) formulations of Richards' equation
  - advective flow of liquid water + diffusive flux of water vapour
  - implemented in user-defined PDE interface of COMSOL Multiphysics

example: models of bentnite saturation of Prototype Repository experiment (H and TH problems)

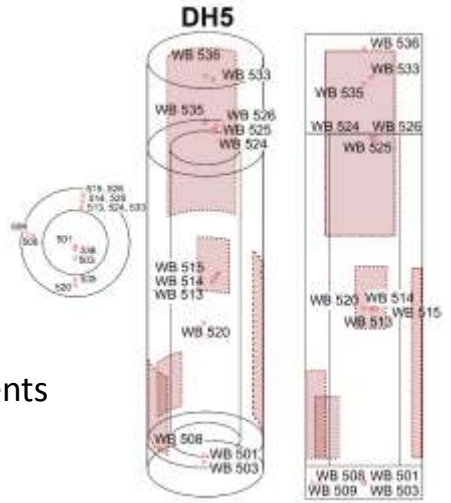
- **TH conception (ISERIT)**
  - coupled transport of the heat and water vapour
  - water is distributed into two phases: the vapour in the pores and liquid water in the solid grains
  - non-equilibrium interaction between both phases
  - software tool: ISERIT developed at TUL



examples: benchmark TH models according to laboratory experiments within project Task Force on Engineered Barrier System

- **Diffusion conception (ANSYS)**
  - hydraulical problems
  - approximation of Richards' equation by diffusion equation with nonlinear diffusivity
  - degree of saturation is unknown variable (negative pressure levels only)
  - computational tool: ANSYS
  - possibility of simplified coupling (TH and HM problems)

examples: models of bentonite saturation according to laboratory and in situ experiments (Prototype Repository, Bentonite Rock Interaction Experiment, Water Uptake Test, ...)



DE LA RECHERCHE À L'INDUSTRIE

cea den

Swelling properties of MX-80 bentonite materials for Andra's repository engineered barriers

Fabien Bernachy-Barbe

Laboratory for the Study of Concrete and Clays

Beacon Initial Workshop - Kaunas, Lithuania – 19/06/2017

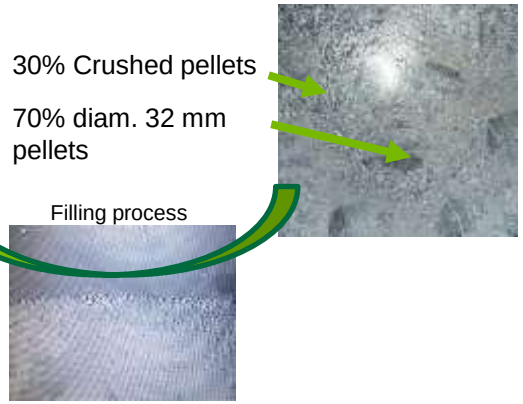
ISSUES (1/2)

DOPAS-FSS (full scale seal) mock-up

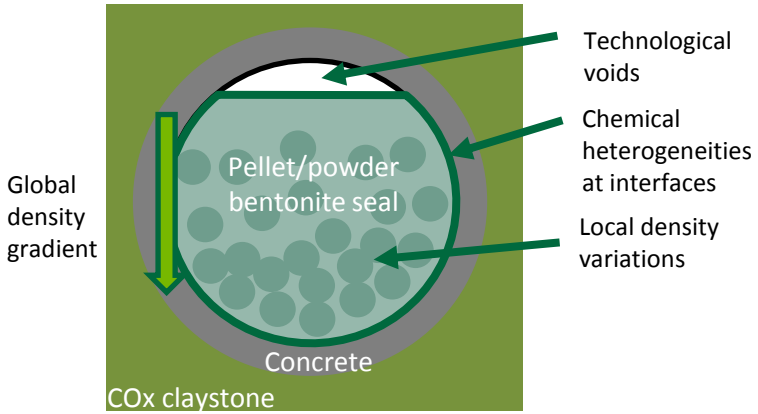
30% Crushed pellets

70% diam. 32 mm pellets

Filling process

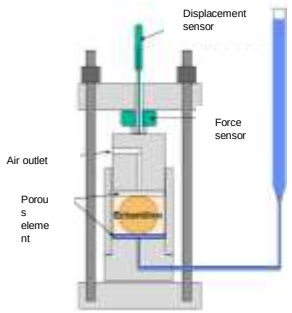


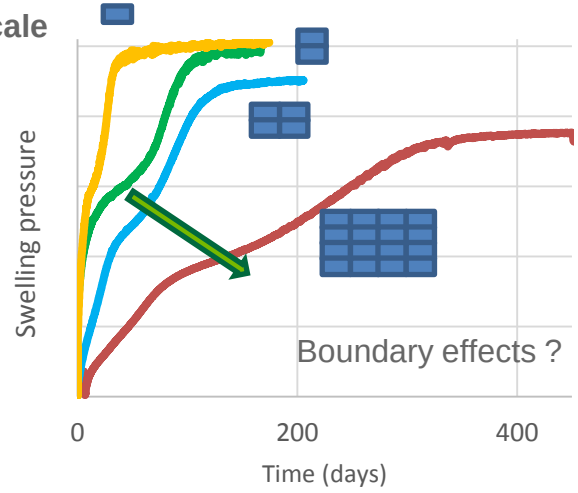
Heterogeneities at different scales :



Representative volume element for these granular materials ?

Centimeter scale





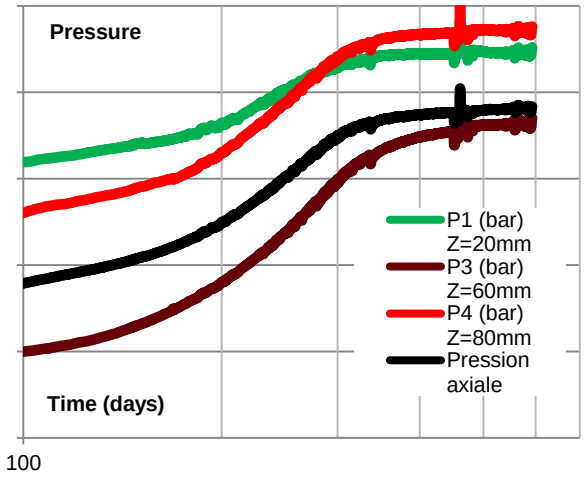
Metric scale ?

ISSUES (2/2)

Residual local pressure heterogeneities ?

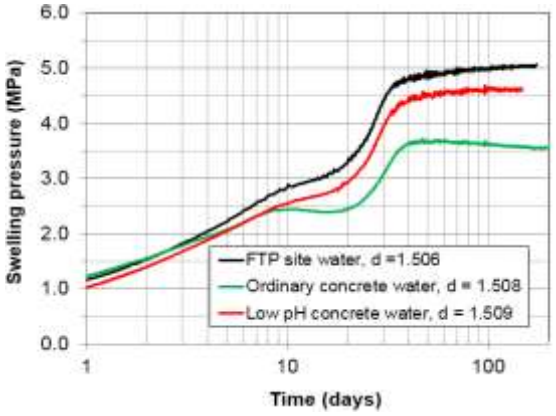
dm scale test :

- Hydration of φ 240 mm, h=105 mm sample (124 pellets)
- Radial force and THR sensors



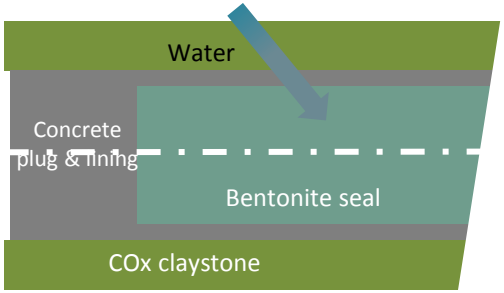
20% « final » local pressure variability, do not seem to resorb

Effect of concrete porewater on swelling properties ?



In the tested (specific) conditions :

- Lower swelling pressure, unstable at short-term
- Hydraulic conductivity ×10
- Though, effect decreasing with sample size (boundary layer effect)



Lasgit (Large scale gas injection test)

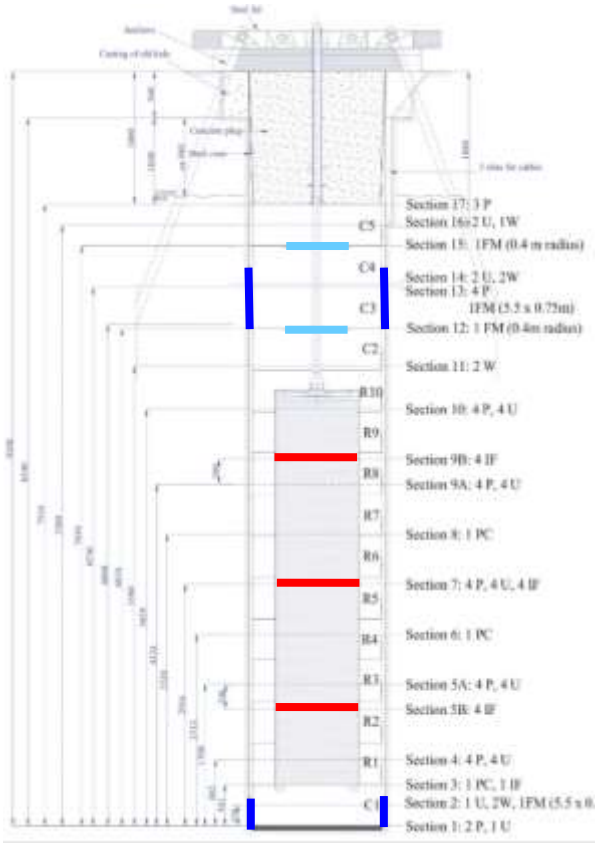
Jon Harrington, Rob Cuss and Patrik Sellin

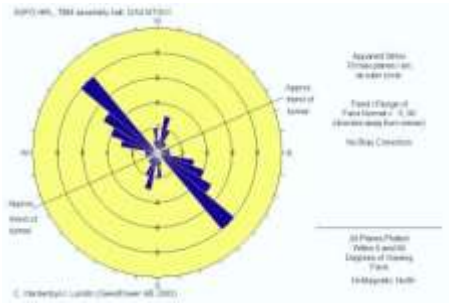
Test comprised a number of stages:

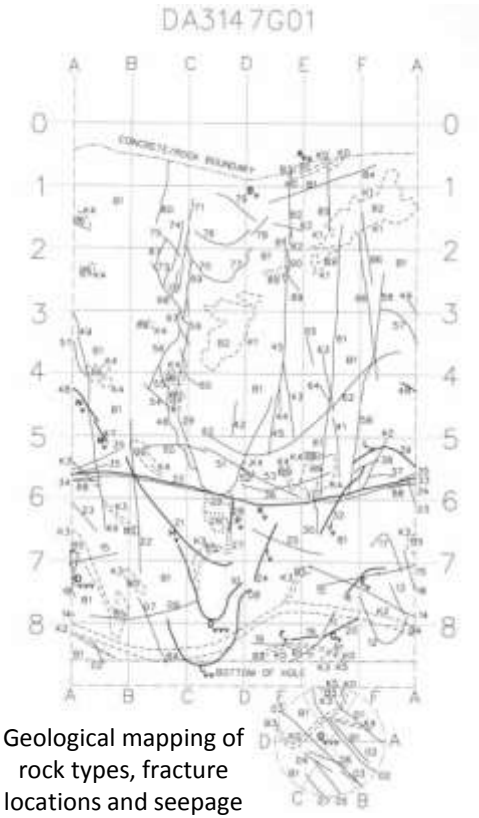
1. Evaluation and characterisation
2. Hydration
3. Hydraulic testing
4. Gas testing
5. Repeat…

A highly instrumented, isothermal test

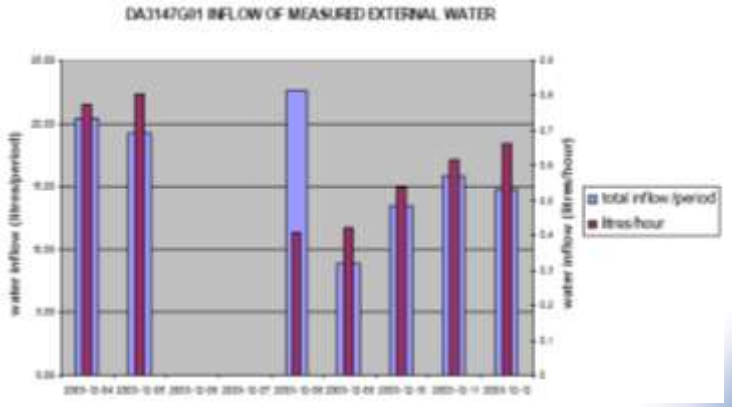
Test site





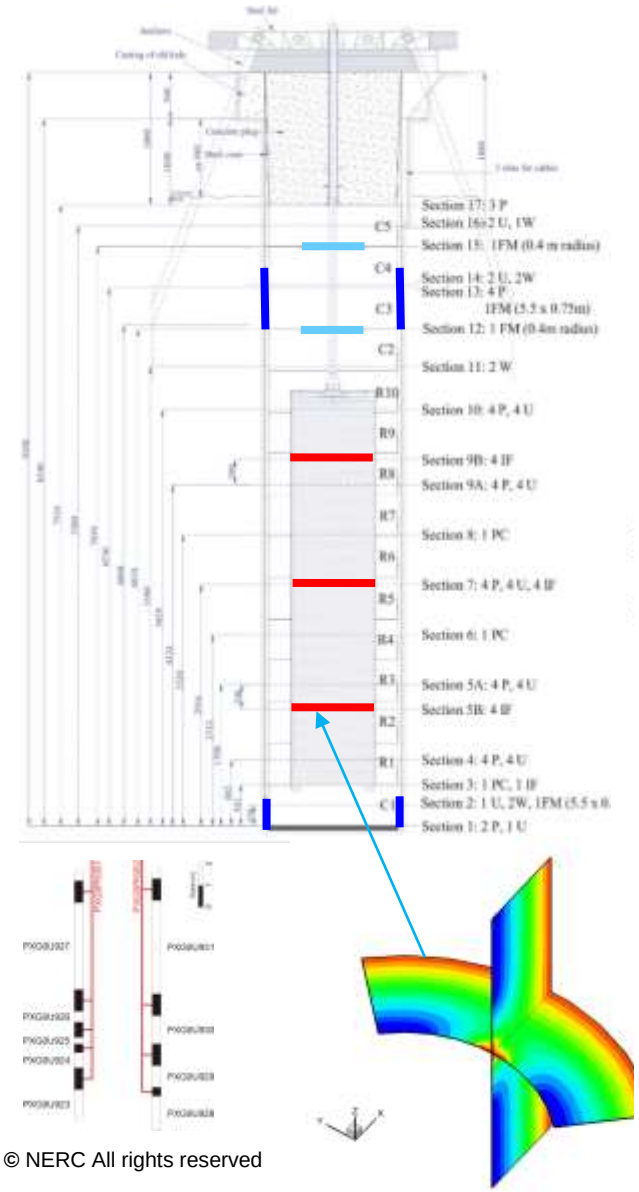


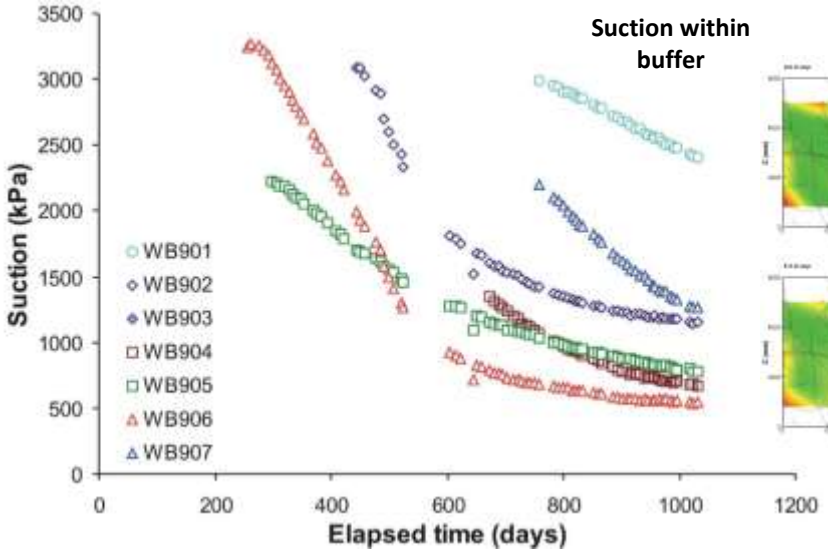
Geological mapping of rock types, fracture locations and seepage

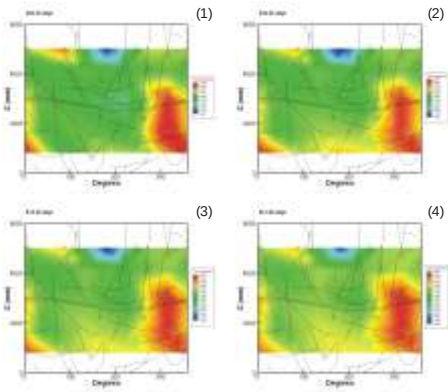


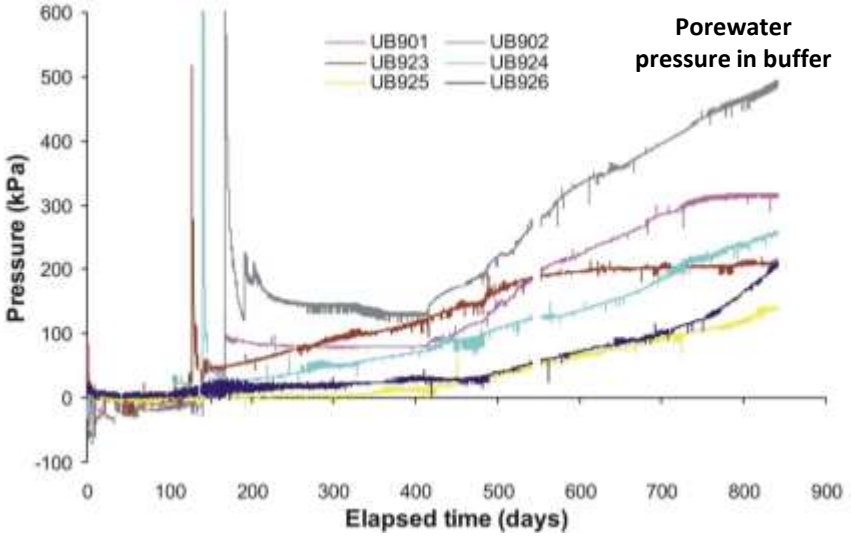
Surface packer system to measure EDZ (BGR)

Hydration and hydraulic testing









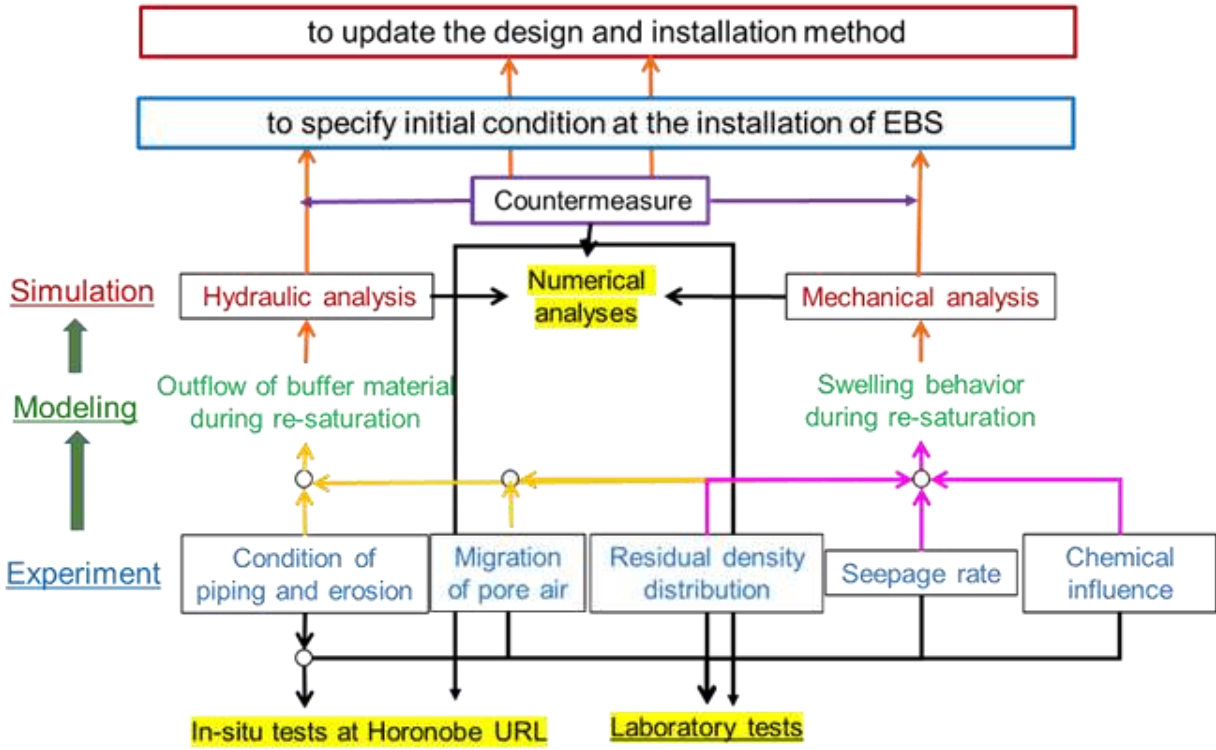
RESEARCH ACTIVITIES AT RWMC ON THE BENTONITE RE-SATURATION PROCESS (1) Overview

Tomoko Ishii (ishii.tomoko@rwmc.or.jp), Minoru Emori,
Radioactive Waste Management Funding and Research Center

This research is part of the Development of Advanced Technology for Engineering Components of HLW Disposal initiative, and is conducted with a grant from the Japanese Ministry of Economy, Trade and Industry (METI).

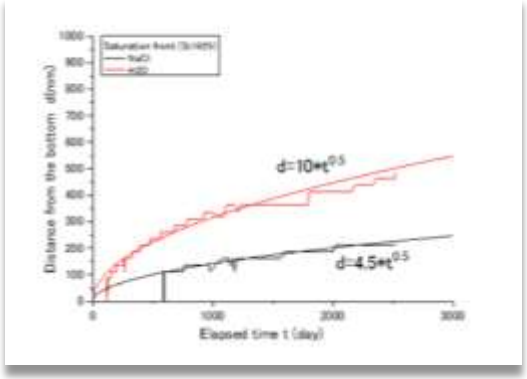
RWMC's bentonite research

RWMC has been focusing on the period during re-saturation process by underground water after the installation of the buffer material. And examines mainly the mechanical behavior of buffer material.

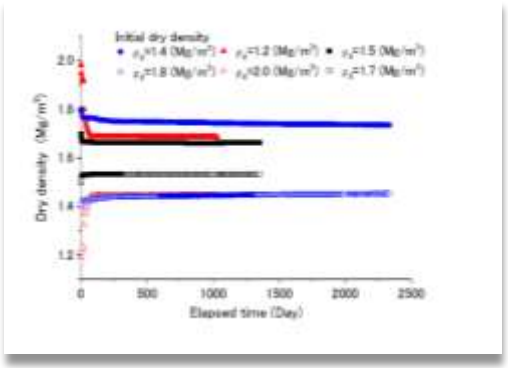


Objectives and study policy

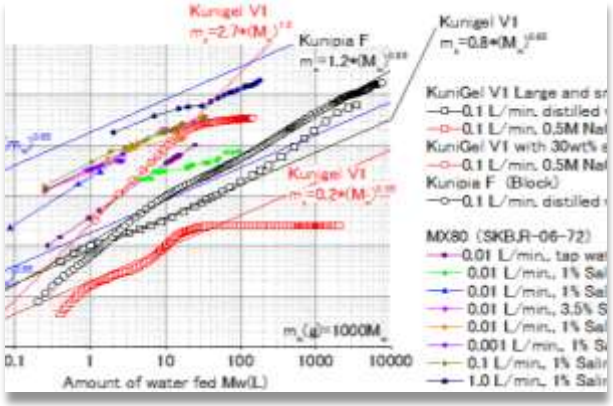
Tests on mechanical behavior of buffer material during re-saturation by RWMC



Seepage rate



Residual density distribution

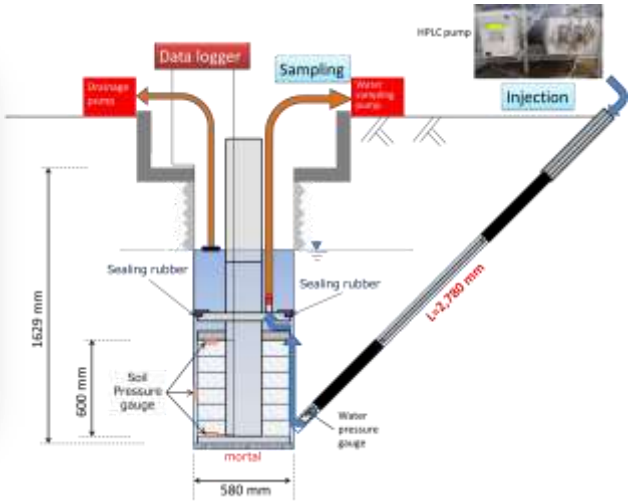


The results of Lab. tests

Migration of pore air

Chemical influence

(Fe-bentonite interaction)



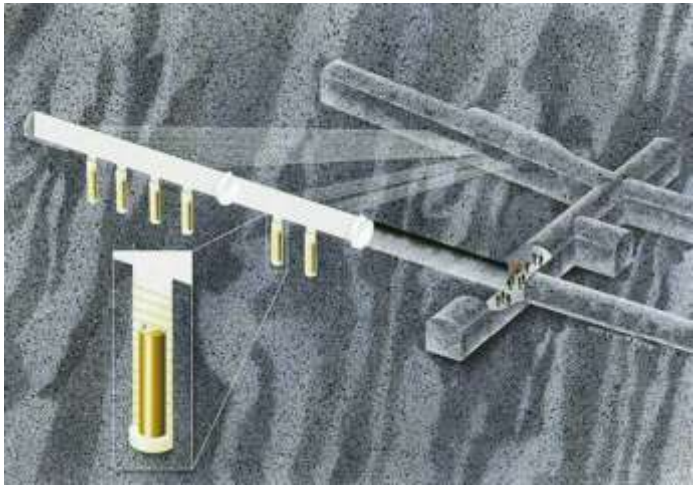
The design of URL tests

Piping and erosion

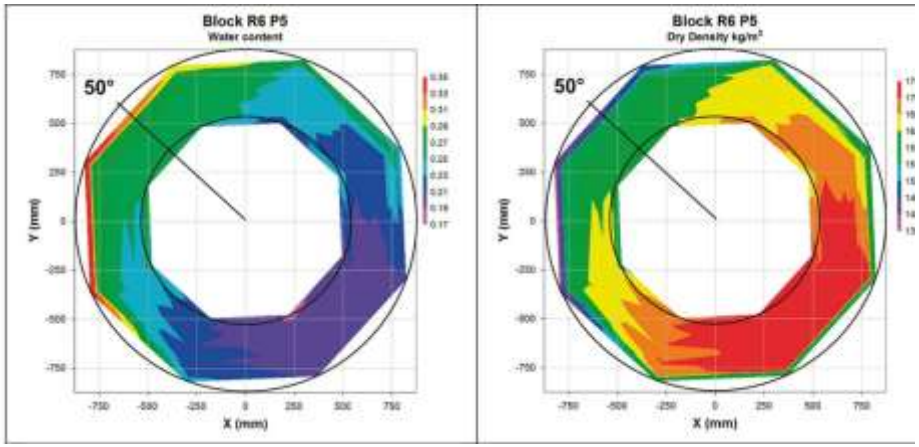
Prototype Repository – Mass redistribution in the buffer and the tunnel backfill

Lars-Erik Johannesson, Patrik Sellin, David Luterkort, Peter Eriksson
Swedish Nuclear Fuel and Waste Management Co (SKB). Solna, Sweden

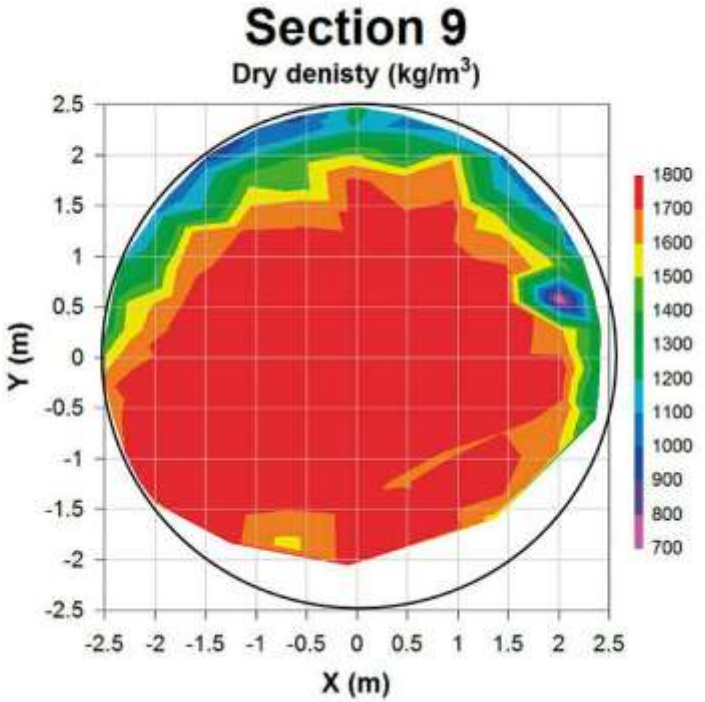
Mass redistribution in the buffer and the tunnel backfill



Mass redistribution in the buffer and the tunnel backfill



Buffer in deposition hole
Mx-80 Bentonite



Tunnel backfill
(bentonite/crushed rock 30/70)

This project receives funding from the Euratom research and training programme 2014-2018 under grant agreement No 745942

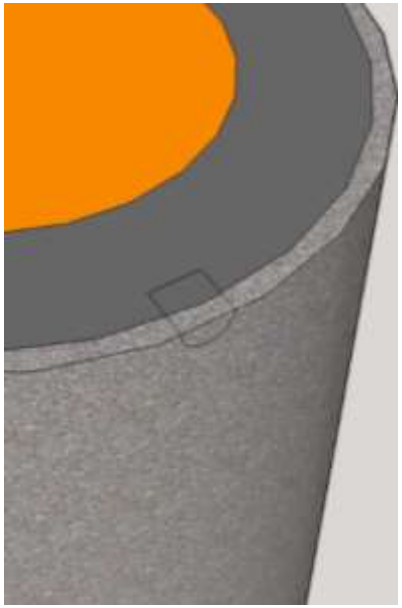
BLOCK–PELLET HOMOGENIZATION IN KBS-3V BUFFER – LABORATORY SCALE TEST

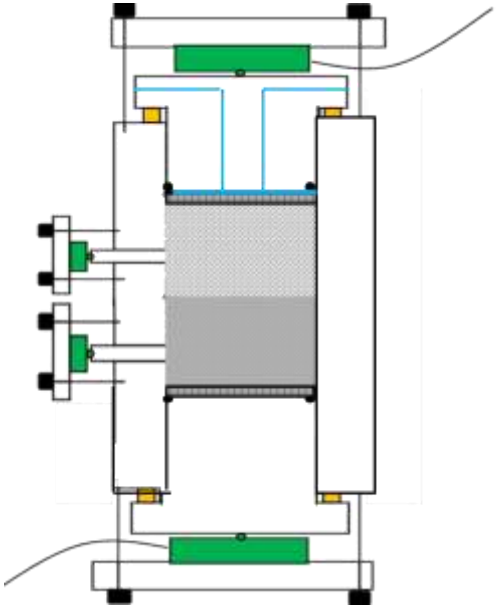
Poster presentation
Beacon 1st workshop
19th – 20th of June 2017

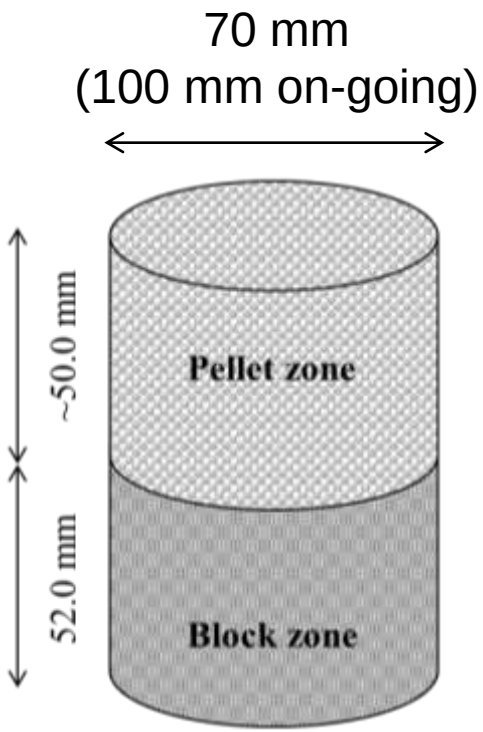
Lasse Lavikainen (presenter), Posiva Oy
Jari Martikainen, Saanio & Riekkola Oy
Teemu Laurila, Saanio & Riekkola Oy

POSIVA

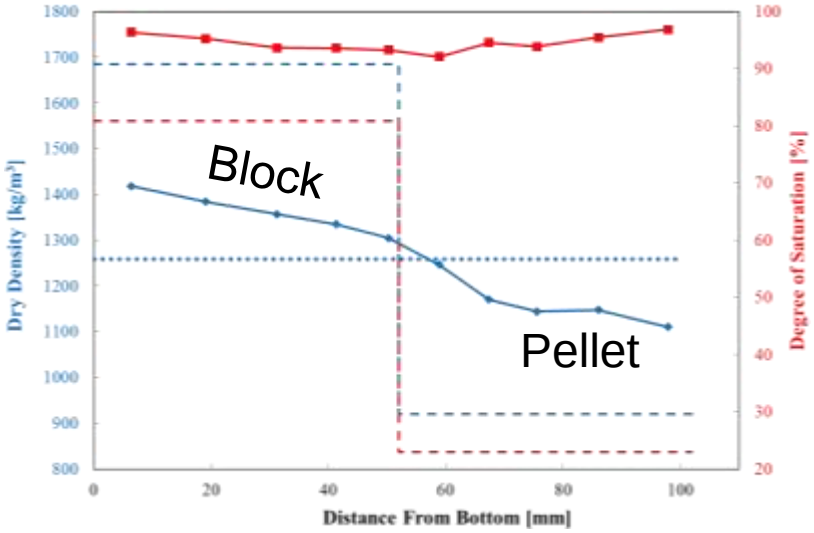
Introduction







Results & Outlook



Recorded swelling pressures (SP) [kPa]

	⌀ = 70 mm	⌀ = 100 mm*
SP(block, avg)	~1150	~1500
SP(pellet, avg)	~400	~850
Δ(SP, avg)	~750	~650

*on-going test!

Kiitos

Thank you

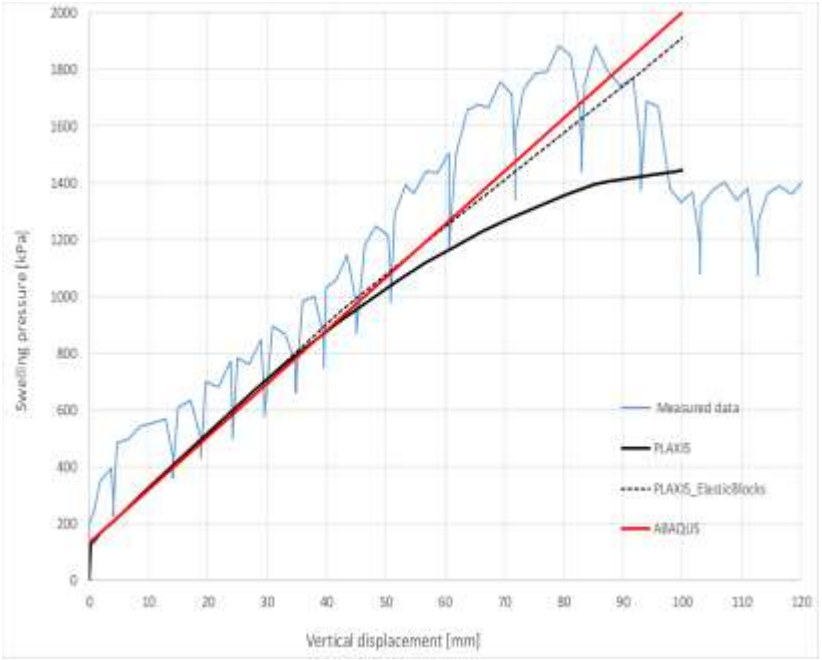
Buffer and Backfill Interaction

David Luterkort, Swedish Nuclear Fuel and Waste Management Co (SKB).

Lennart Börgesson, Clay Technology AB

Buffer and Backfill Interaction

Models for predicting the upward swelling off buffer and compression of the dry tunnel backfill has been further developed and used as a tool for updating buffer and backfill design



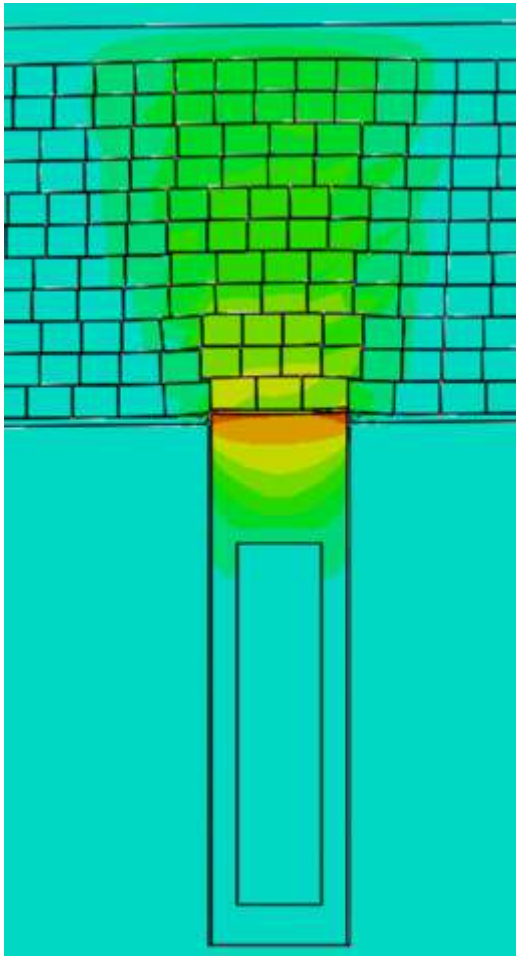
The modelled results agreed well with the measured up to about 8 cm displacement when the backfill blocks started to crack

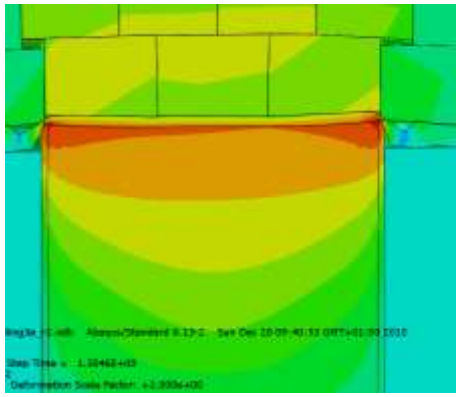
General conclusions

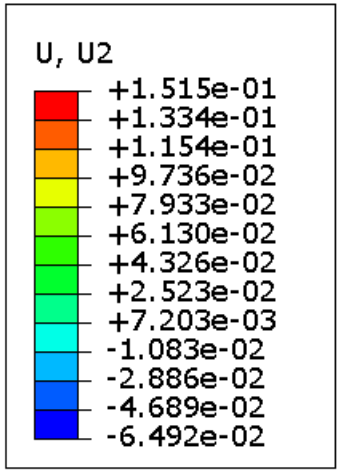
A few cases were also simulated using a 3D model. The comparison with the 2D model showed that the 2D model gives more pessimistic results, i.e. larger upward swelling.

General conclusions:

- The tested models could simulate the deformation of the backfill until diffused failure of the blocks occurred
- The reference design results in acceptable upward swelling
- The stiffness and thickness of the pellet filling in the floor and roof are the factors most sensitive to changes
- Only low density buffer (starting values close to the limit) causes problems for the buffer.







ROCK STRESS- AND TIME-DEPENDENCY IN OVERPACK DISPLACEMENT AND BENTONITE PRESSURE BY CENTRIFUGE PHYSICAL MODELLING TEST IN PREDICTING FUTURE OF NEAR-FIELD

Central Research Institute of Electric Power Industry (CRIEPI, Japan)

Soshi NISHIMOTO

The first Beacon international scientific workshop on Mechanical Properties of Bentonite Barriers

Jun. 19, 2017

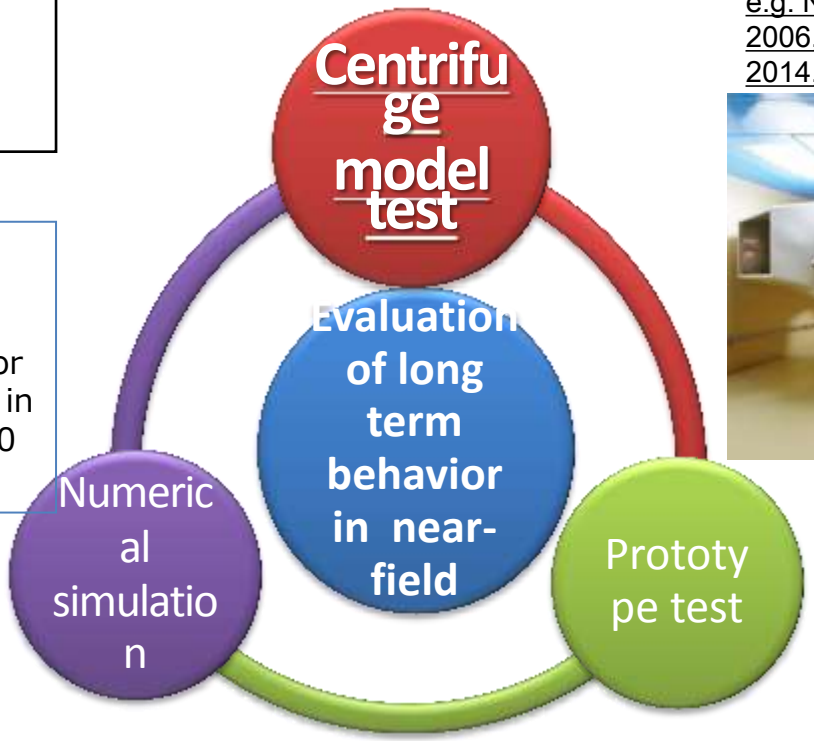
CRIEPI
Central Research Institute of Electric Power Industry

Improvement of reliability of future prediction of HLW disposal repository

OUR POINT
- Based on **a centrifuge scaling law,** the future behaviors are predicted by the **time-acceleration** model tests.
- These results are reflected in the improvement of the reliability in the analysis.

[Scaling law] model size: 1/N and acceleration (G) : N
-> time: 1/N²
(e.g. The behavior in **100 years** for the actual near field can be tested in about **6 weeks** by 30 (G) and 1/30 model.)

*The equivalent elapsed time for the migration of underground water that satisfies Darcy's law, the stress due to consolidation and swelling, and the distribution of elastic strain can be shortened, compared with the full-scale elapsed time



O Equivalent data of a long-term behavior can be obtained in lab.
X Limitation coming from small size.
[in CRIEPI]
e.g. Nakamura & Tanaka (2004, 2006, 2009), Nishimoto et al. (2012, 2014, 2016)

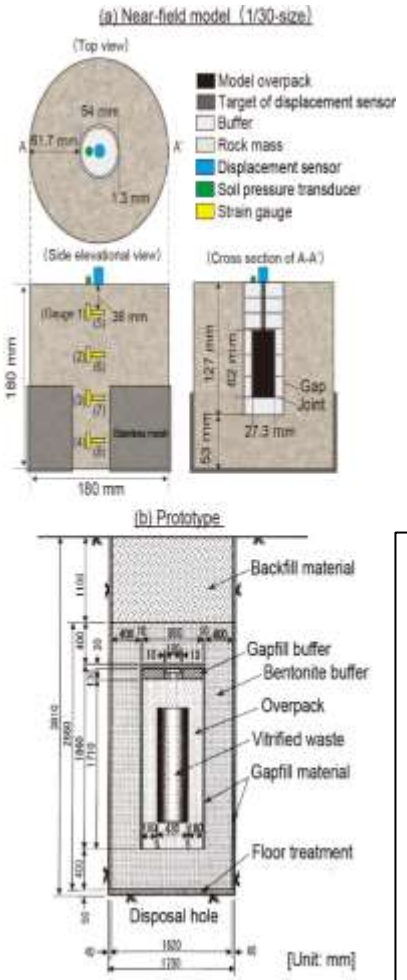
O Long-term behavior can be analyzed.
X Necessity of a verification of the applicability of the model.
[in CREPI]
e.g. Sawada et al. (2006, 2010, 2012, 2017)

O Similar actual behavior can be observed
X Test time is very short (~20yr.)
[in CREPI]
e.g. Okada et al. (2009, 2012)

Example of results: Stress & time dependency of bentonite pressure

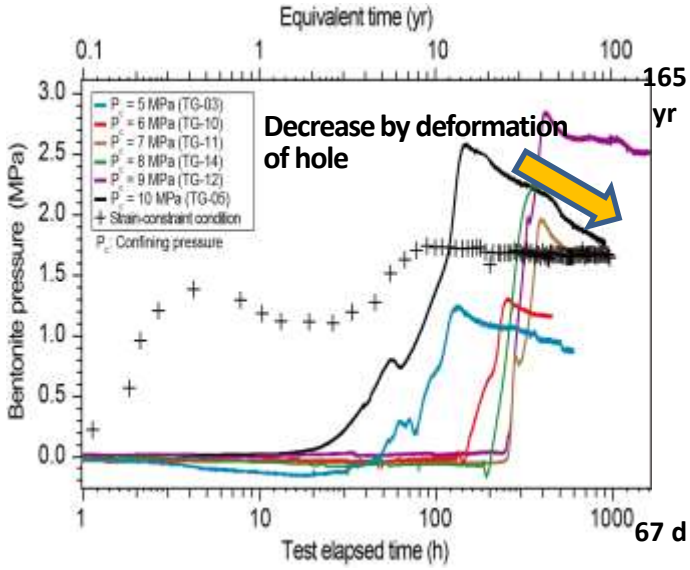
(and, rock strain and overpack displacement)

(a) Near-field model
(b) Target HLW disposal repository.

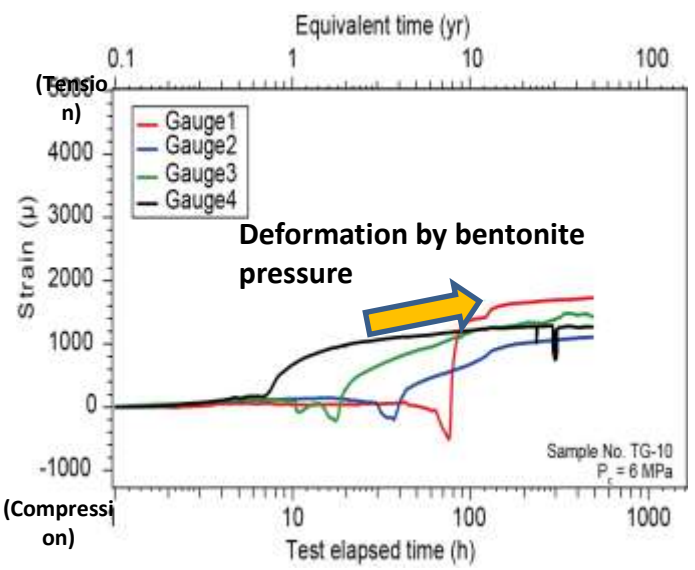


Example of results

(Bentonite pressure)



(Rock strain)



- **Stress dependency**

In the test of "**stress-constraint condition**" (bentonite surroundings is **sedimentary rock mass,** and surrounding **DEFORMS**), the values of local maximum are different in response to the loaded the confining pressures. On the other hand, the local maximum value is almost same the in the test of "strain-constraint condition" (bentonite surroundings is **stainless steel** ,and surrounding **DOES NOT deform**) as long as density of bentonite is the same.

- **Time dependency**

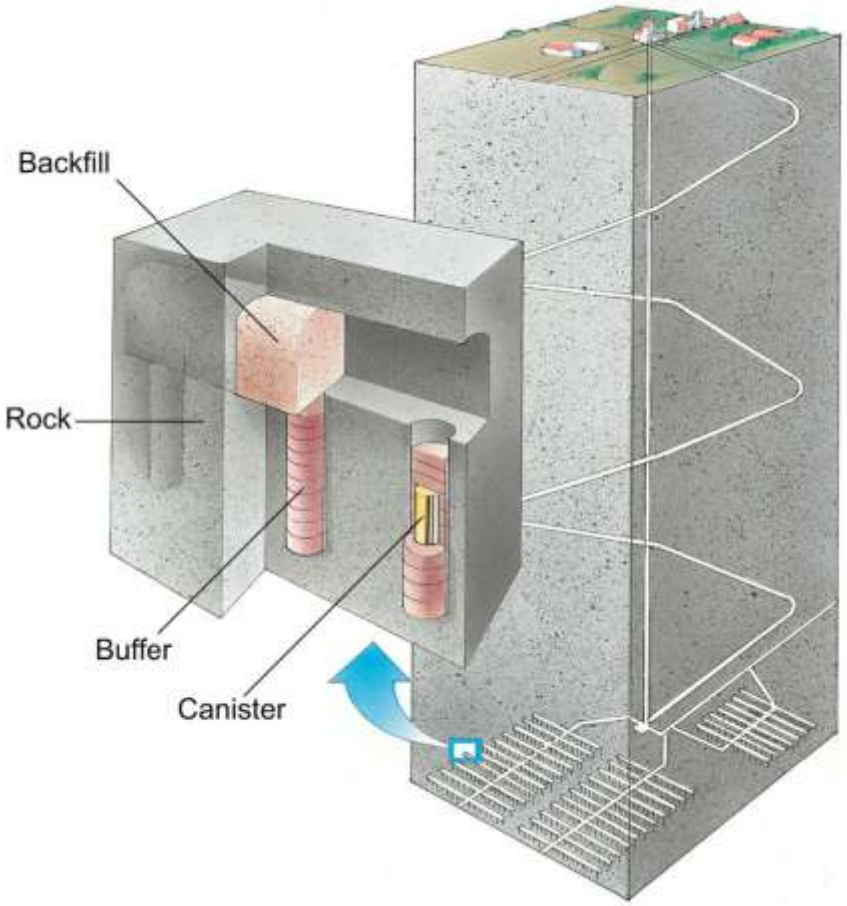
In the test of "stress-constraint condition", the values of soil pressure were continuing to decline after the local maximum were measured. They did not converge after 165 equivalent years elapsed. On the other hand, the value of the "strain-constraint condition" converged after 20 to 30 equivalent years elapsed.

Handling of the mechanical evolution of the bentonite buffer in the SR-Site safety assessment

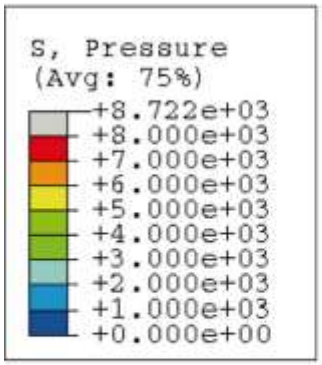
Patrik Sellin, Swedish Nuclear Fuel and Waste Management Co (SKB). Solna, Sweden

Bentonite Mechanical Evolution

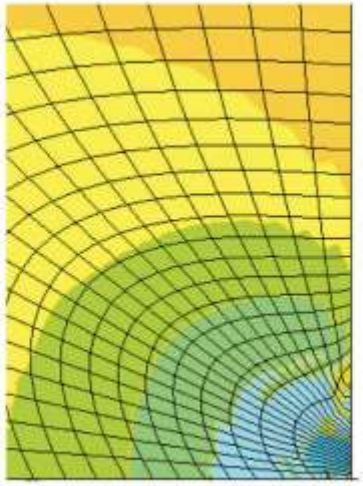
- The excavation and operation phases
  - Piping damage
- The initial period of temperate climate after closure
  - Buffer homogenisation
  - Buffer upward expansion
  - Movement of the canister in the deposition hole.
- The remaining part of the reference glacial cycle
  - Homogenisation after loss of bentonite mass



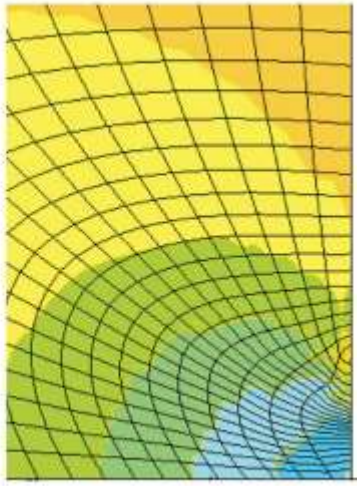
Eroded half donut. Base case. Pressure.



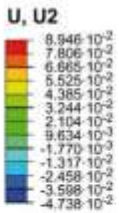
Scale (kPa)

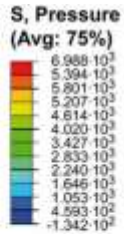


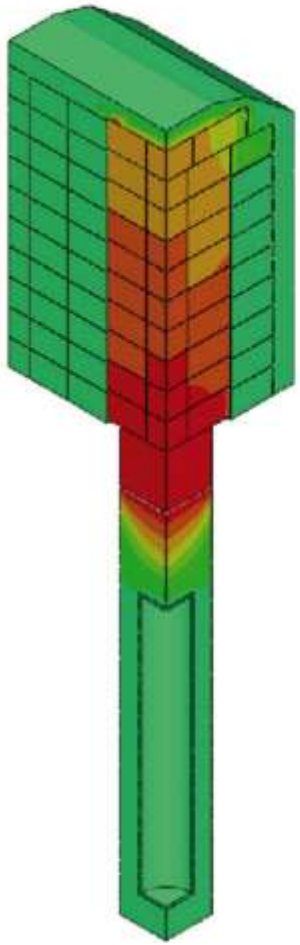
Case2_2c2

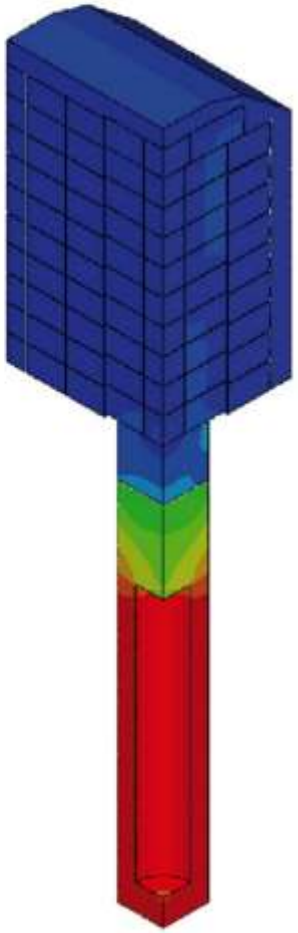


Case2_2c3

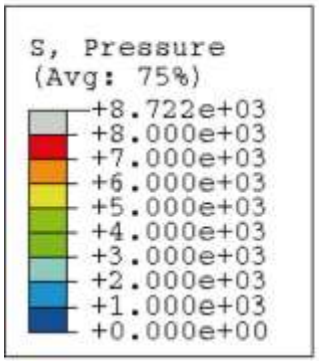




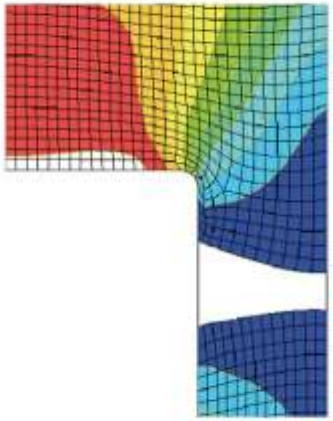




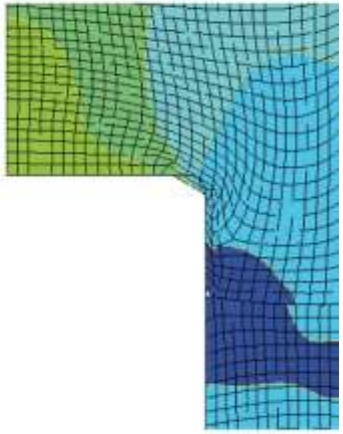
One missing bentonite ring. Base case. Pressure.



Scale (kPa)



1 year

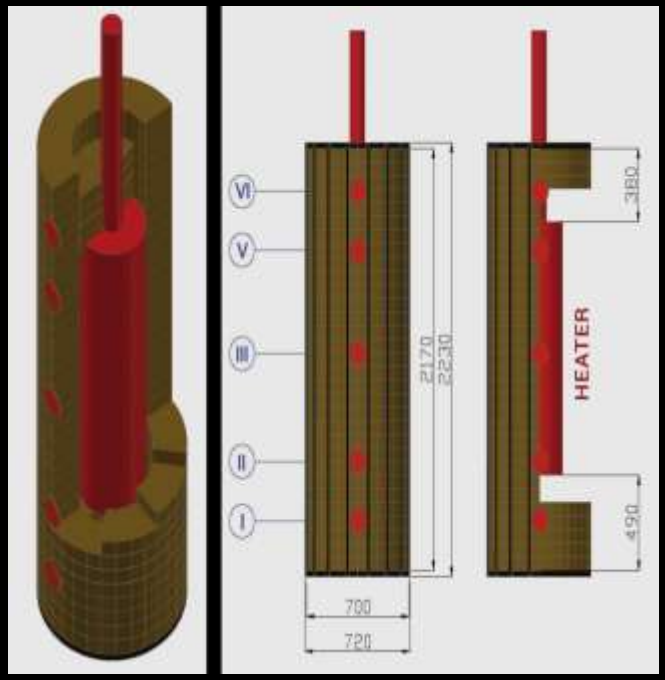


54 years (completed)

Mock-Up Josef
In-situ experiement

Irena Hanusová, Lucie Hausmannová, Nikol Novotná, Jiří Šťástka, Jiří Svoboda

- ✓ scale ½ (diameter 720mm, length 2230mm)
- ✓ 1st in-situ experiment to be performed at this scale using Czech Ca-Mg bentonite
- ✓ 105 sensors
  - temperature
  - total pressure
  - relative humidity
- ✓ sampling availability throughout the experiment



Conclusions

- swelling pressure developed almost immediately following the placement of the supercontainer in the well
- the saturation of the bentonite barrier is not homogeneous (observed from values measured by total pressure sensors and the evaluation of the bentonite core samples)
- the highest total pressure value was obtained from below the heater
- heating immediately influenced total pressure within the barrier

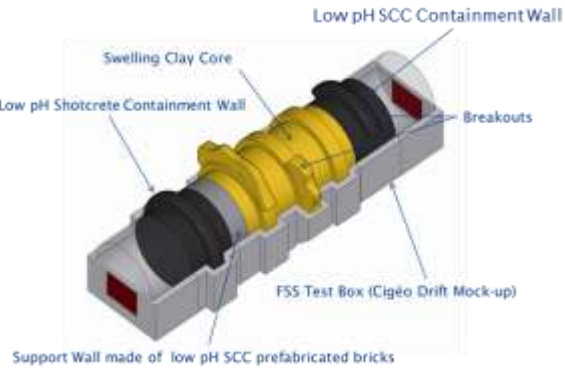
HETEROGENEITIES AND HYDRO-MECHANICAL BEHAVIOR OF BENTONITE-BASED STRUCTURE: LESSONS LEARNT FROM LARGE SCALE EXPERIMENTS

Jean Talandier, Rémi de La Vaissière, Jacques Wendling

Workshop Beacon 19-20 june 2017

Lessons from several experiments at different scales

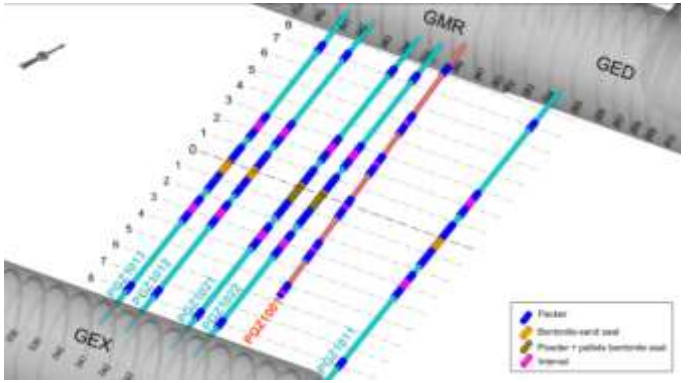
The FSS Experiment (Full Scale Seal)



Demonstrating the industrial capacity to emplace large volumes of bentonite & low pH concrete

Pellets (32mm)/crushed pellets mixture

The PGZ2 Experiment (URL)



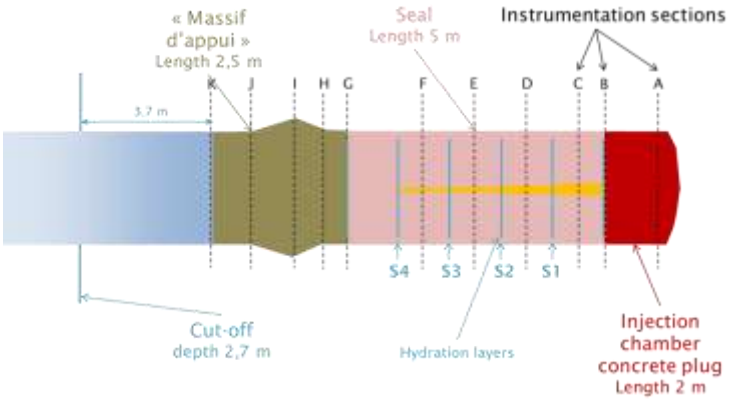
Dedicated to gas transfer properties of seals and water saturation of bentonite plugs

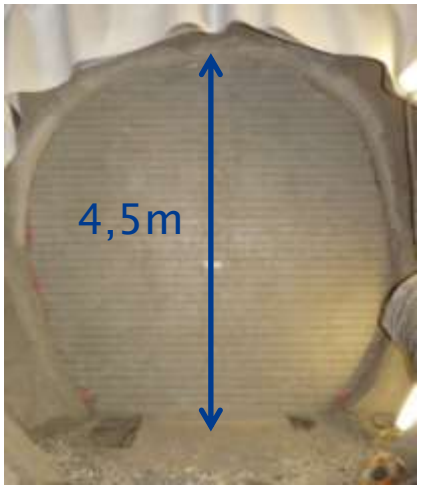
Pellets (7mm)

Compacted cylinders bentonite/sand

Lessons from several experiments at different scales

The NSC experiment (URL)





Pre-compacted bentonite/sand (40%/60%) +pellets/powder mixture

Testing hydraulic efficiency of a seal after full water saturation (artificial hydration)

Main learning points concerning bentonite homogenization / mechanical evolution and relevance for the project

- Initial heterogeneities in bentonite structure can't be avoided
- Water hydration of bentonite depends of the environment conditions
  - ➢ Total pressure and swelling pressure are not uniform in bentonite during water saturation phase
- Hydro-mechanical equilibrium is long to obtain
  - ➢ Performances expected are reached before a complete homogenization

THM modelling of bentonite: an approach tested on MX-80 and FEBEX bentonite

Kate Thatcher and Alex Bond

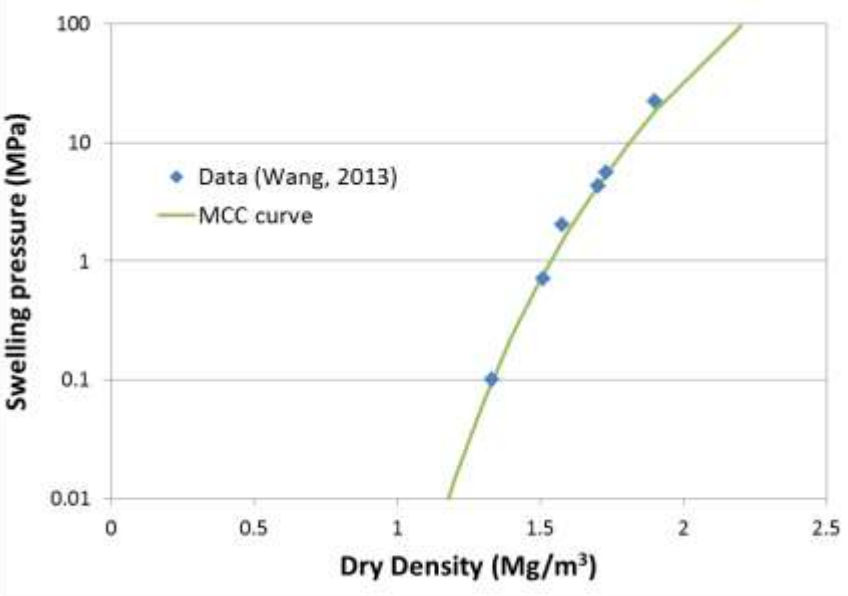
Date: 19th June 2017

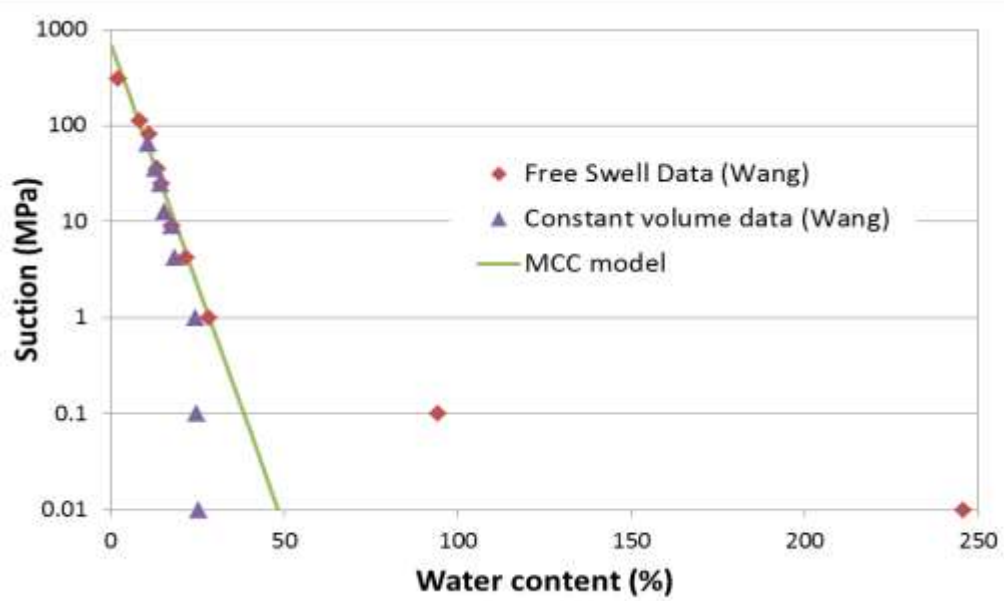
Radioactive Waste Management

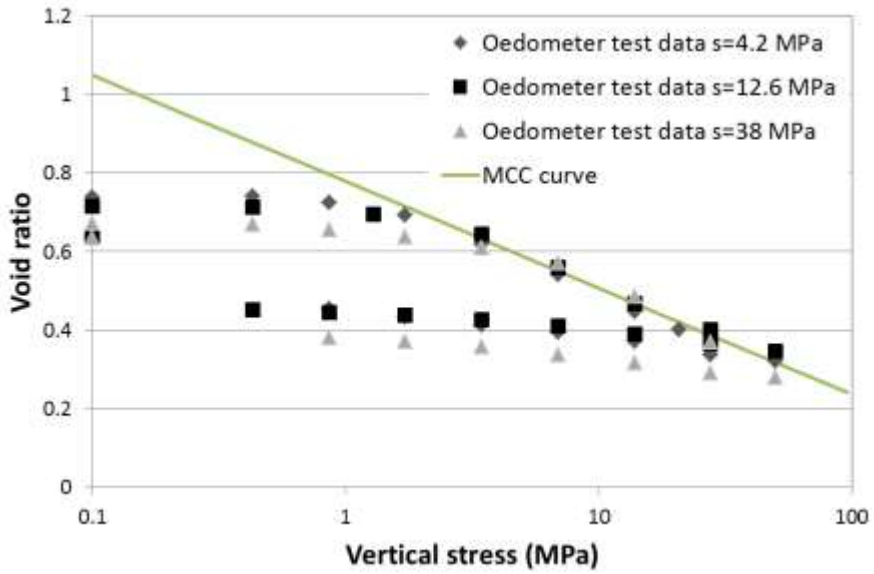
Quintessa

Internal Limit Model

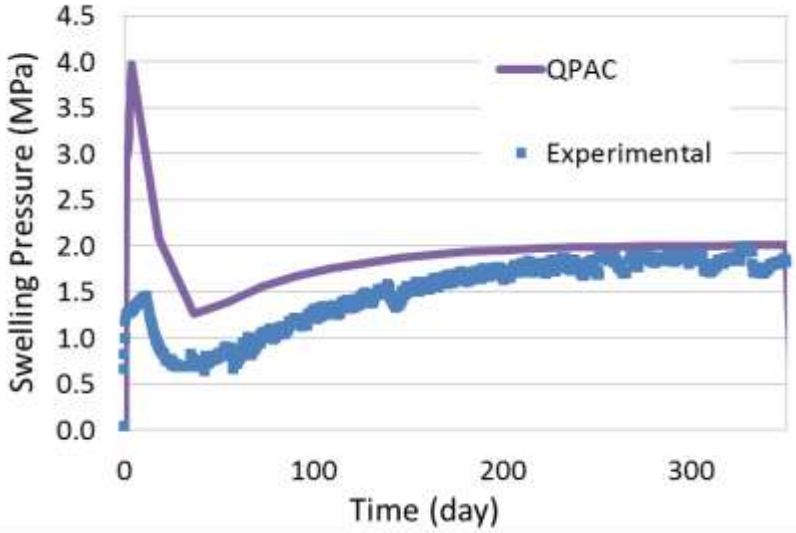
- Observed that in the SEALEX data, a single equation could be fit to:
  - The water retention data
  - The swelling pressure versus dry density
  - The plastic failure curve in oedometer tests

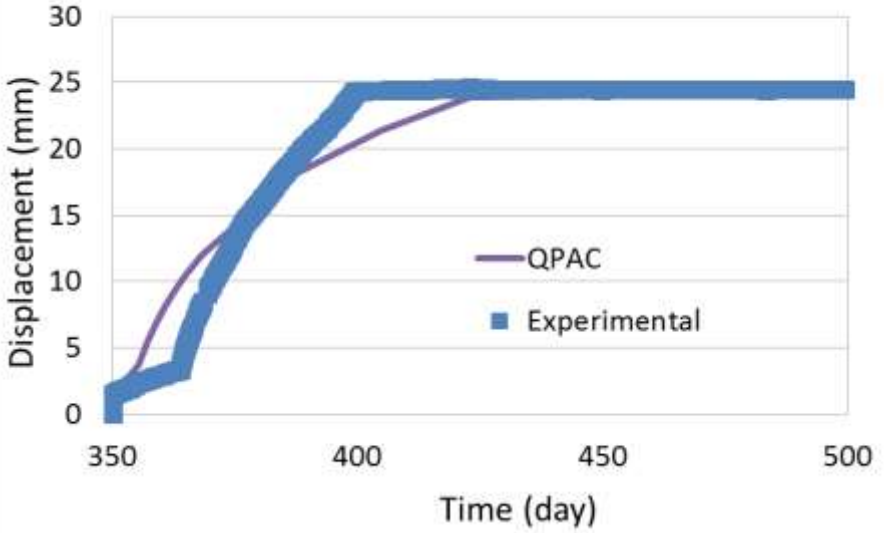




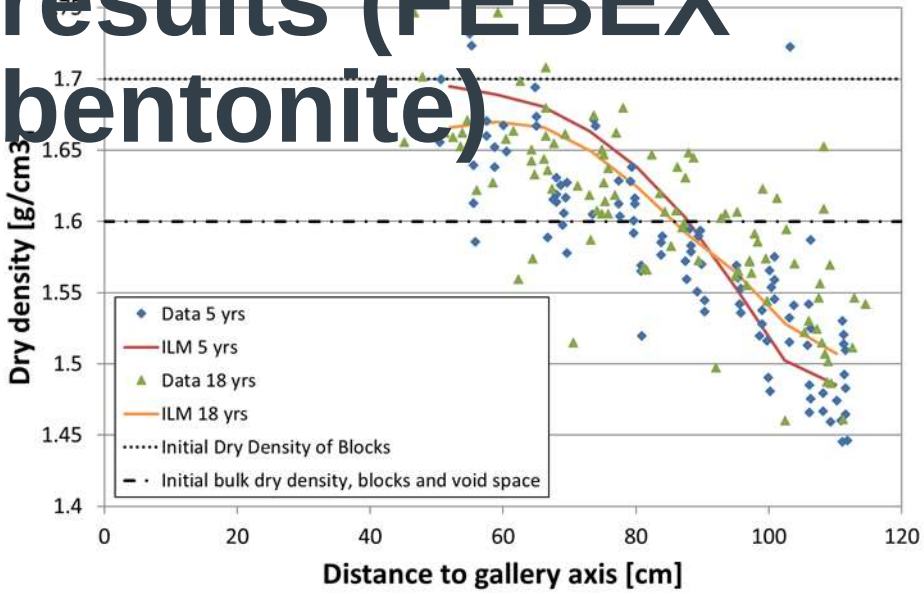


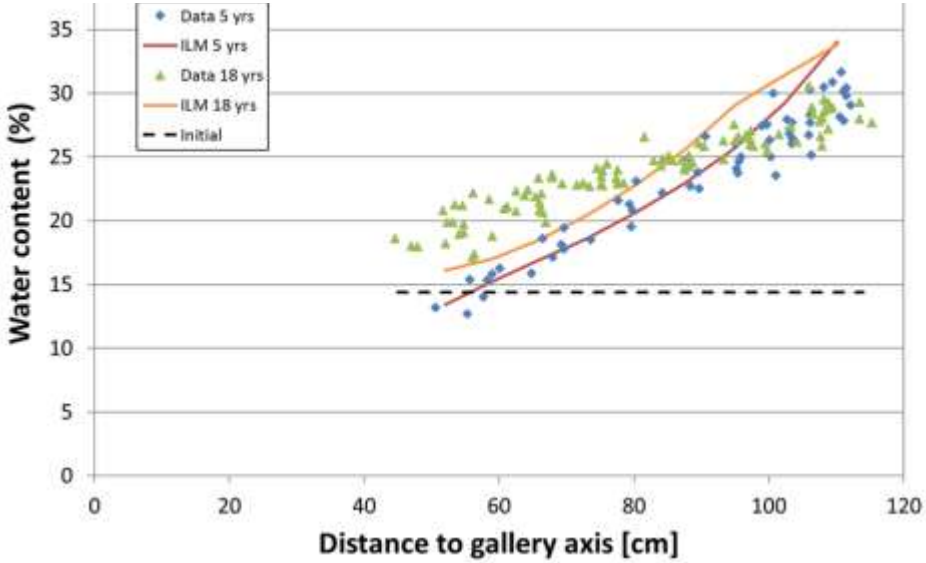
SEALEX results (MX-80 bentonite/sand mixture)





FEBEX-DP results (FEBEX bentonite)





Hydromechanical modelling of bentonite homogenisation

Åkesson M., Kristensson O., Malmberg D.
Clay Technology AB, IDEON Science Park, Lund, Sweden

Background

Engineered Barrier Systems composed of components with different initial dry density (eg bentonite blocks, pellets-filled slots).

The homogenization process: dry density differences tend to decrease with time.

Two material models

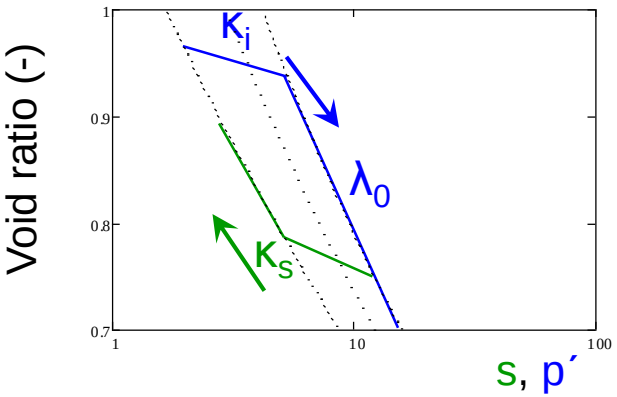
Thermoelastoplastic (TEP) laws implemented in Code_Bright. Used to analyse water unsaturated KBS-3 buffer and backfill.

Hysteresis based material model (HBM). Development motivated by homogenisation tests with water saturated bentonite specimens.

TEP

$$d\varepsilon_v^e = \frac{\kappa_i}{1+e}\frac{dp'}{p'} + \frac{\kappa_s}{1+e}\frac{ds}{s+p_{atm}}$$

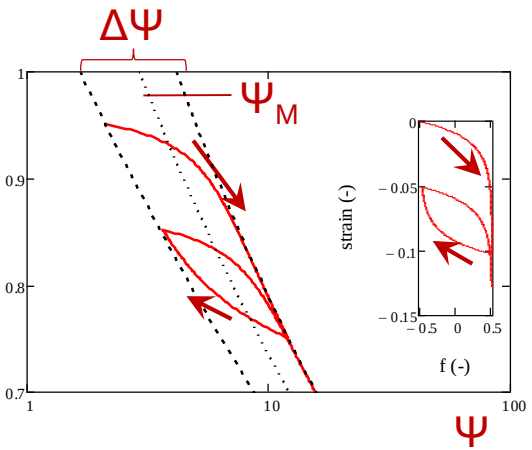
$$d\varepsilon_v^p = \frac{\lambda_0 - \kappa_i}{1+e}\frac{dp_0^*}{p_0^*}$$



HBM

$$s + \sigma^k = \Psi^k = \Psi_M(e) + \Delta\Psi(e)\cdot f^k(\varepsilon^k(t))$$

$$\frac{df^k}{d\varepsilon^k} = -\left(\frac{1}{2} + \delta(\varepsilon^k)\cdot f^k\right)\cdot K$$



Incorporation of swelling pressure and shear strength

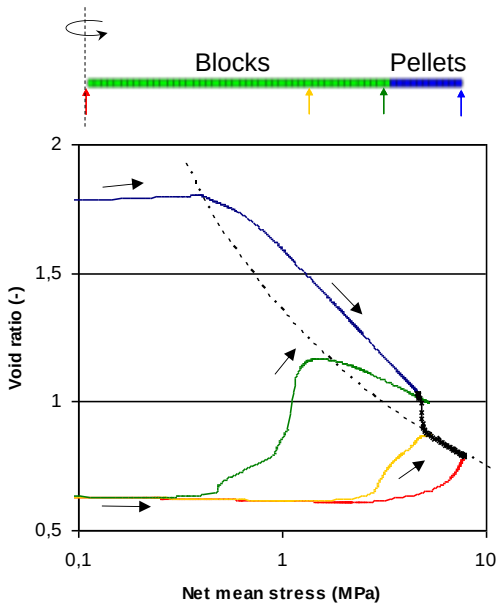
- TEP: adoption of plastic parameters for specific void ratios, and a void ratio dependence was introduced into the definition of the swelling module.
- HBM: fundamental properties are at the core of the material model and no parameter value adoption is needed for specific void ratios.

Examples and comparisons

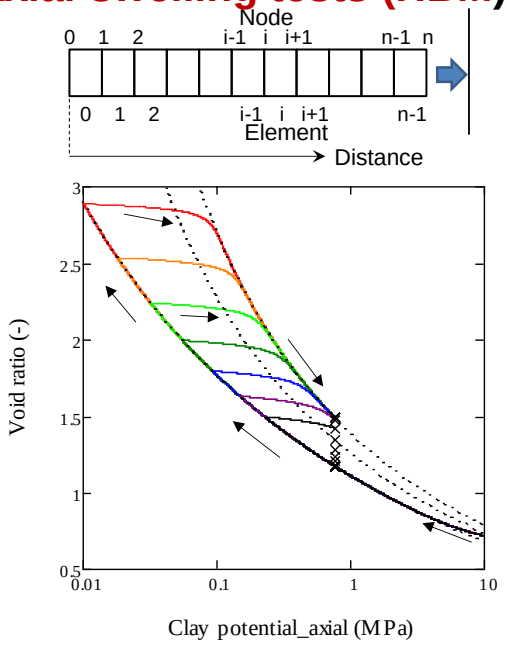
Both models results in:

- relevant build-up of stresses
- final states consistent with the defined swelling pressure curve
- remaining heterogeneities due to hysteresis effects.

Backfill homogenization (TEP)



Axial swelling tests (HBM)



PRACLAY Seal in-situ Test

in Mol, Belgium

Guangjing Chen

EURIDICE

Belgian Nuclear Research Center

June 19-20, 2017

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

ESV EURIDICE GIE

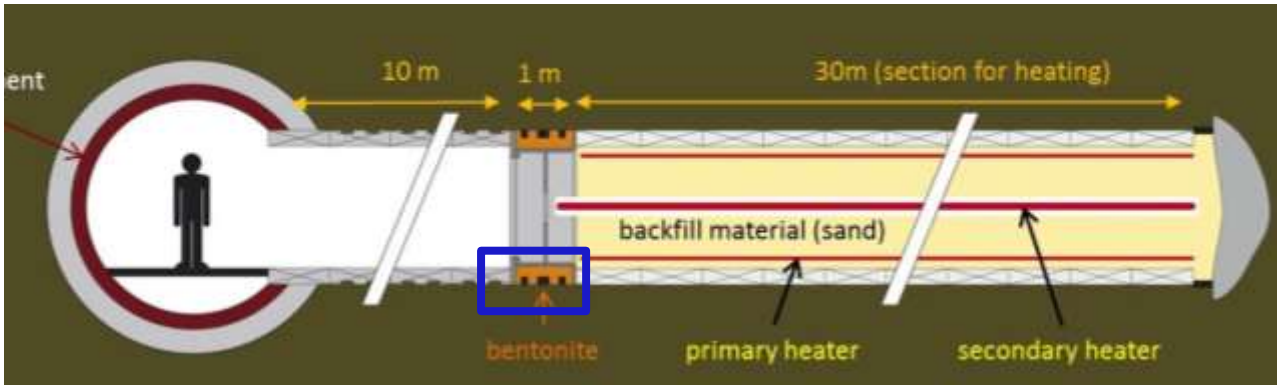
ONDRAF/NIRAS

PRACLAY Seal test

PRACLAY gallery:

1) Heater test

2) Seal test



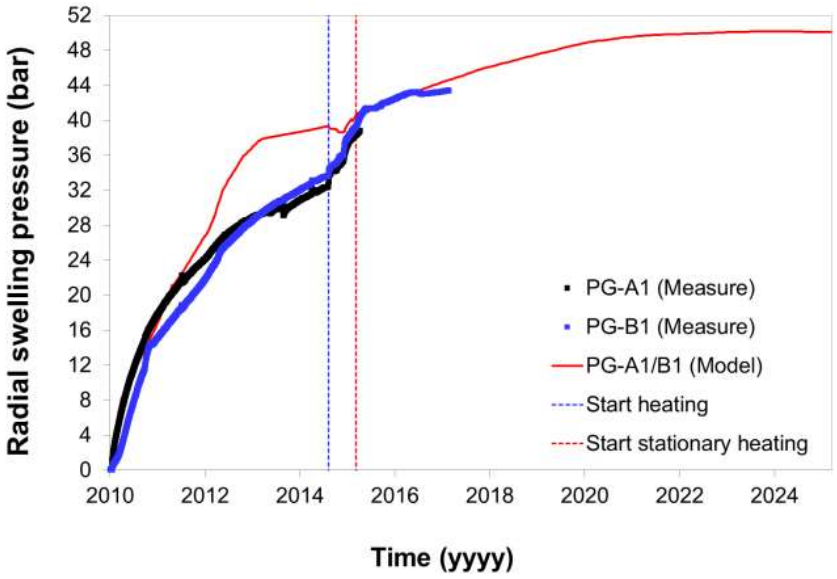
Seal:

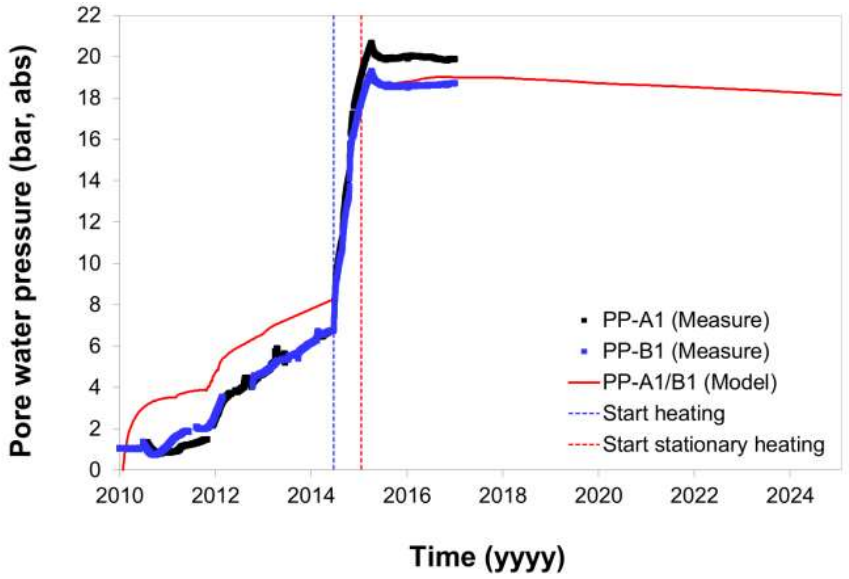
1) Steel structure

2) MX80 bentonite

Numerical interpretation and prediction

- 2D axisymmetric coupled THM model by Finite element code “Code_Bright”
- Hydro-mechanical responses of bentonite in the seal is evolving generally as predicted
- Reasonably good agreement highlights the capacity of the model





This project receives funding from the Euratom research and training programme 2014-2018 under grant agreement No 745942

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Poster introduction

This project receives funding from the Euratom research and training programme 2014-2018 under grant agreement No 745942