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# Assessing the performances of engineered barrier systems and rock masses from large scale in situ tests at the Tournemire underground research laboratory

IRSN MEMBER OF ETSON

EUROSAFE 2019

# Context - A TSO operated URL

## Good expertise requires adequate training/experience

- Nothing replaces direct contact with rocks and underground conditions
- Few labs available worldwide, even less in clay rocks in Europe

## Having its own facility provides independence and leaves more freedom

- Research program can be freely defined and modified
- Clear distinction between TSO and WMO

### Rationales for Independent R&D in support to Expertise Function

- To investigate specific safety issues that require an independent knowledge from the reviewer to perform a contradictory review and check assumptions taken by the implementer with respect to safety,
- To analyse uncertainties and sensitivity of processes,
- To analyse issues that are not considered (or not sufficiently) by the WMO, and require a particular attention from the reviewer

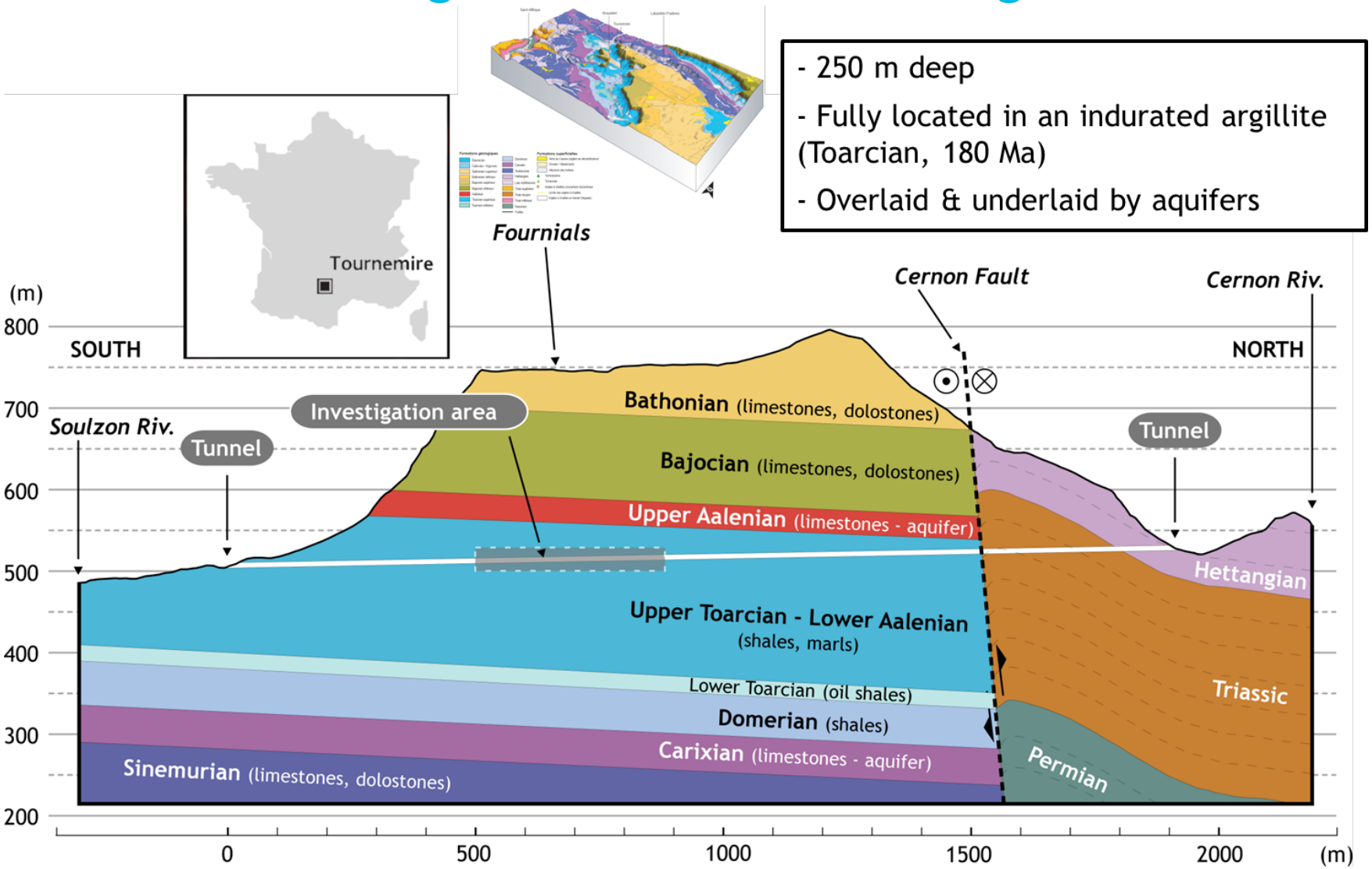
## Comprehensiveness is not required!

- Focus on key points from safety perspective

- Focus on “weaknesses” of WMO’s project

- Take benefit of the Tournemire URL specificities

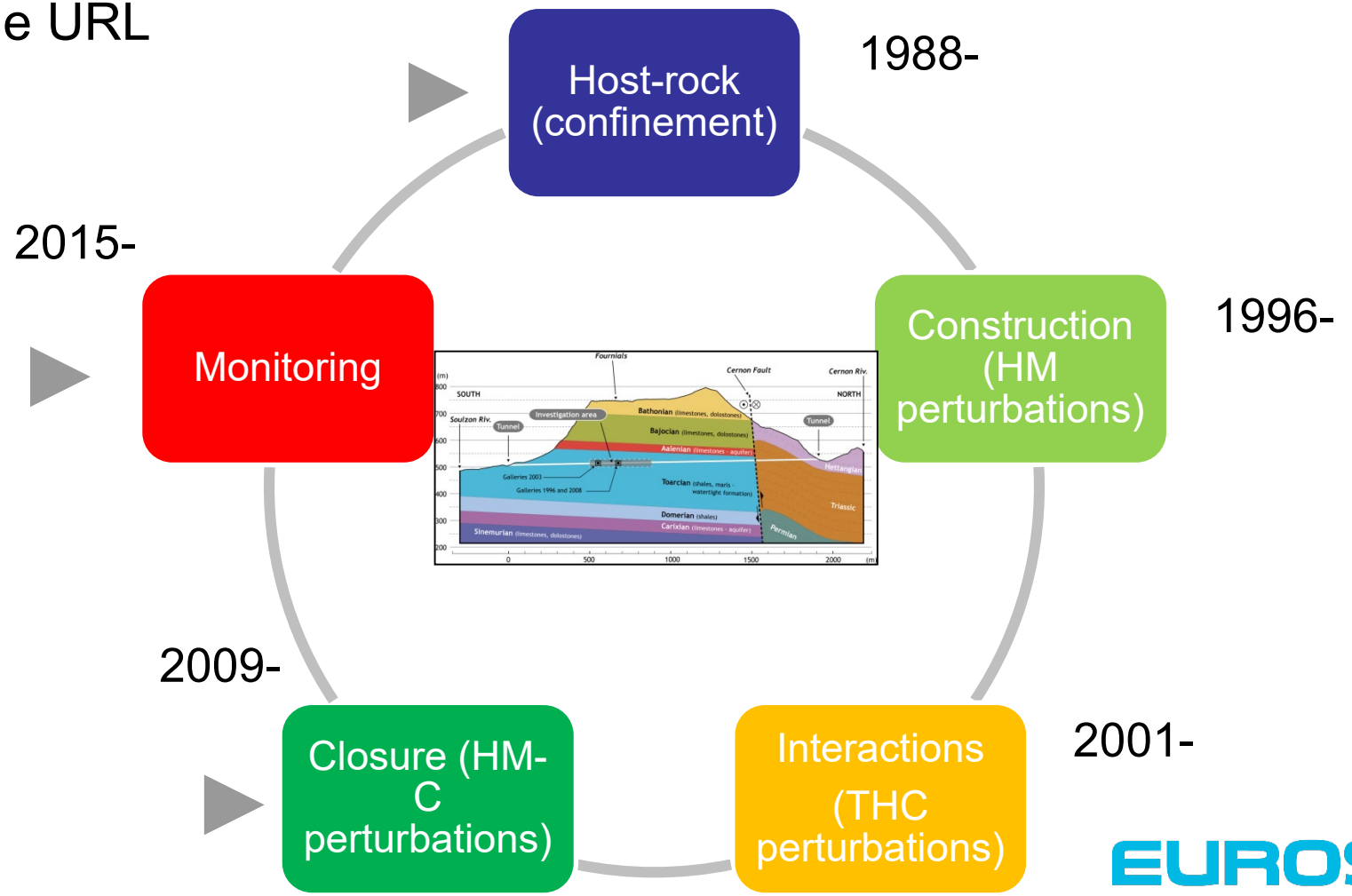
# Context - Geological cross-section along the main URL tunnel




- Original tunnel excavated from 1882 to 1888 (railway tunnel)
- New drifts excavated in 1996, 2003 & 2008
- More than 500 boreholes (cumulated length > 5000 m, 1 to 300 m long, 48-1000 mm Ø)
- Used as a scientific tool to support expertise (generic URL)

# R&D lifetime evolution @ Tournemire URL

- Starting from pre-siting… a long story with evolving fields of R&D activities carried out at the URL



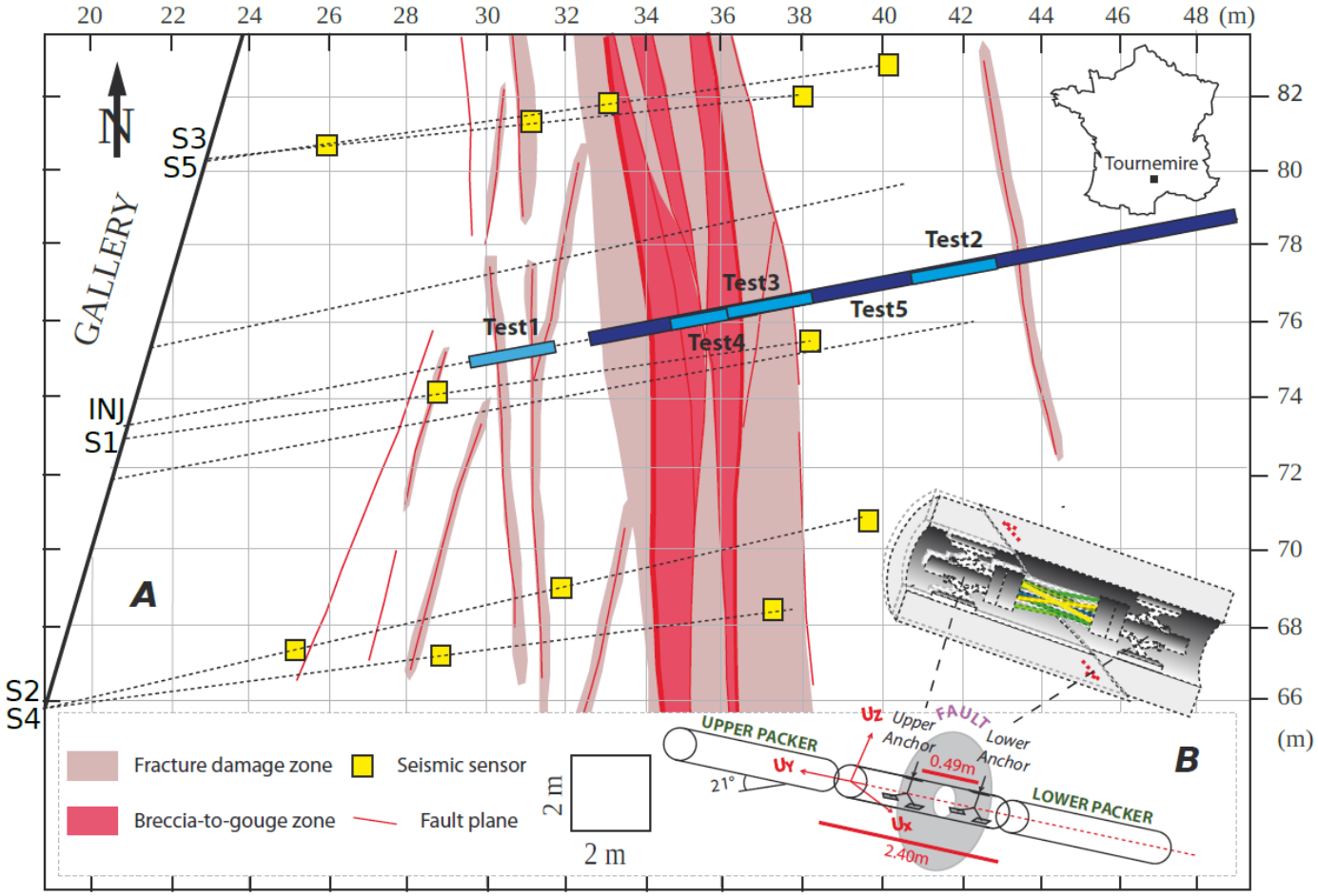
# Site characterization & evolution – Clay host rock as a natural barrier

**Fluids and Faults project: An in-situ test of fault seal integrity**

- Better understanding of hydromechanical coupling processes within a fault zone in a sealing formation
- Evolution of fault zone permeability with fluid pressure near critical conditions
- Identify flow pathways and strain distribution during injection within a fault zone
- Role of discontinuities
    - Fractures, cemented and uncemented
    - Core zone/damage zone

# Site characterization & evolution - Fluids and Faults (F&F)

- Toarcian shales
- >50 % clay
- Porosity (volume water content) 10-14 %
- Permeability 10-0.1 nD
- Polyphased strike-slip fault zone, active Cretaceous- Eocene (Pyrenean compression), steeply dipping W
- Currently transtensive stress state
- Expected normal left-lateral reactivation
- Poorly oriented



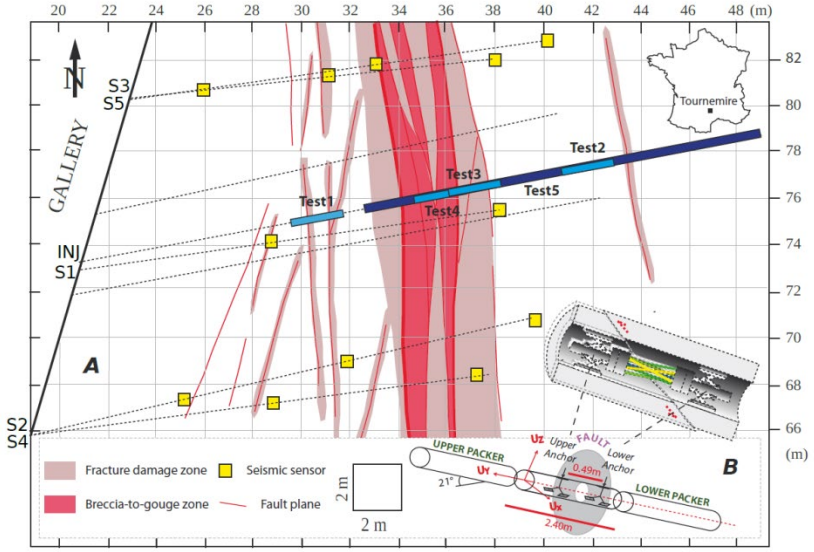

**F&F experimental layout (2013-2014)**

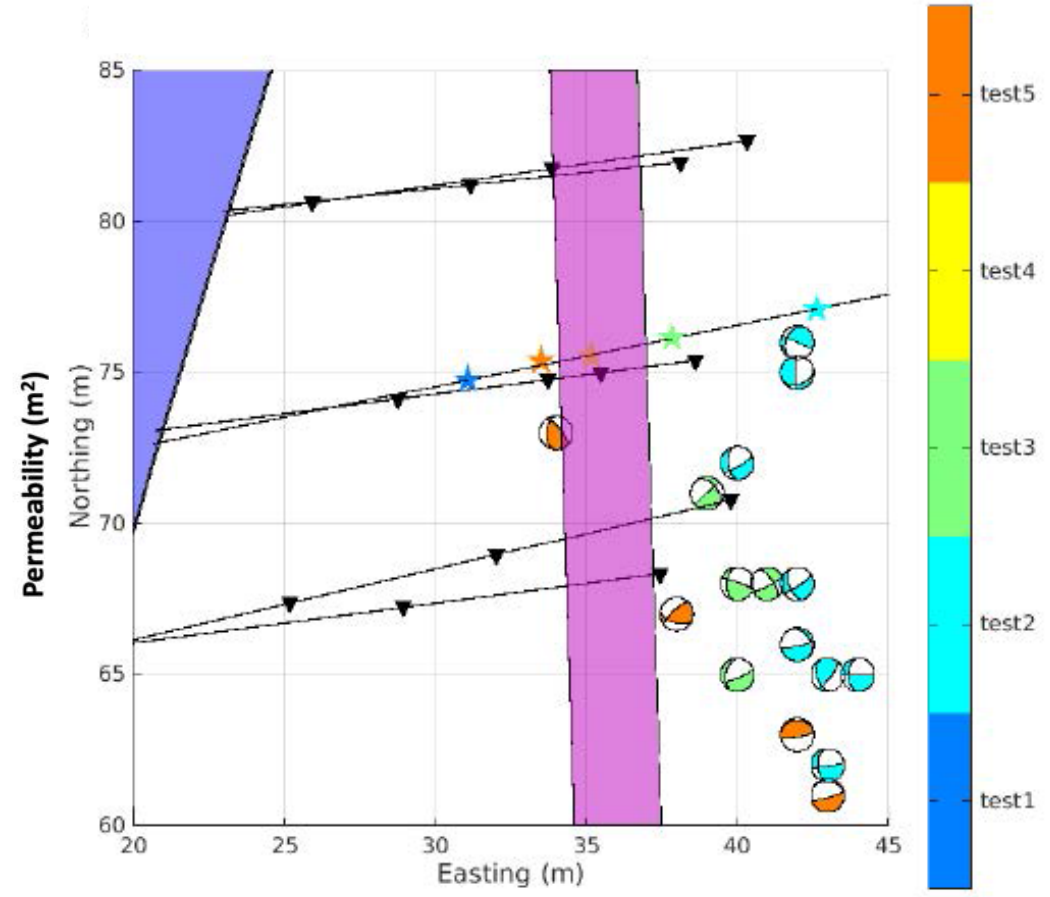
*Current state of stress (Cornet, 2000)*

σ1 = 4,0+- 2,0 Mpa - N162°
σ2 = 3,8 +- 0,4 Mpa - N72°
σ3 = 2,1 +- 1,0 Mpa – N72°

# Site characterization & evolution – Fluids and Faults (F&F)

- Permeability and micro-seismic monitoring




- Induced seismicity is very low and occurs as a consequence of stress transfer from strain induced in the fluid-injected zone (De Barros et al., 2016, 2018)
- Different permeability-effective pressure laws at low and high fluid pressure
- Transition at F.O.P. could correspond to shear activation

# Site characterization & evolution – Fluids and Faults (F&F)

- Conclusions

Strain is not only localized on major discontinuities (e.g. core/damage zone boundary) but also occurring in a distributed way in the damage zone and within the core zone.

Flow is channelled within the fracture network in the fracture damage zones as well as along the major discontinuities.

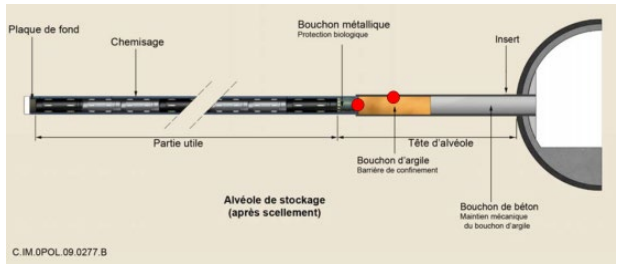
Flow rate and permeability increase exponentially with fluid pressure above a pressure threshold (F.O.P. for Fracture Opening Pressure) that seems to depend on local mechanical conditions.

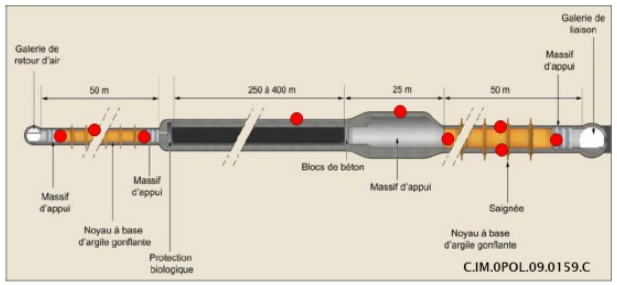
Flow channels typically open with small, largely reversible strains and channelized flow probably results in highly heterogeneous fluid pressure distribution on fault planes. This opens the possibility of transient flow along a fault zone without mechanical destabilization at the larger scale.

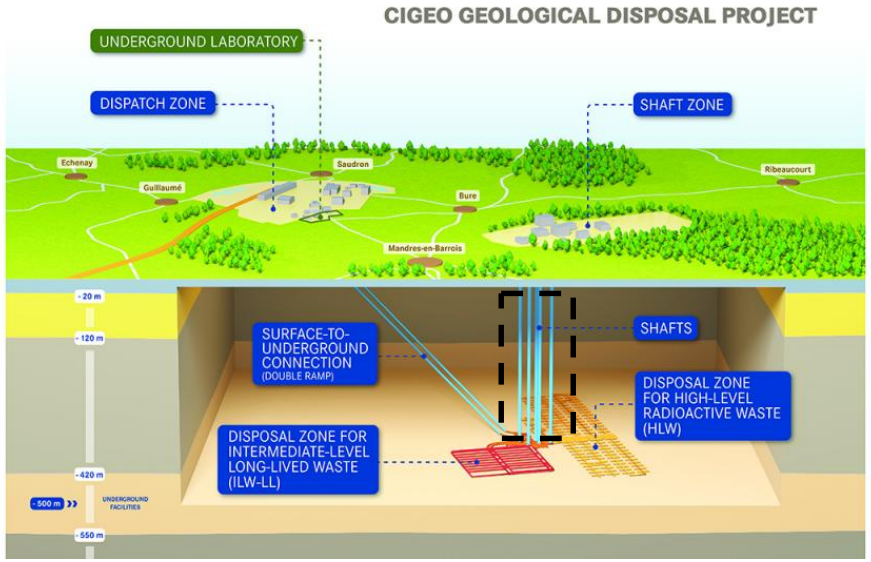
# R&D lifetime evolution @ Tournemire URL: Closure (HM-C perturbations)

## Questioning with regards to seals

- defaults in horizontal sealing (**SEALEX**)
- behaviour of vertical sealing under adverse water & gas resaturation (**VSEAL**)

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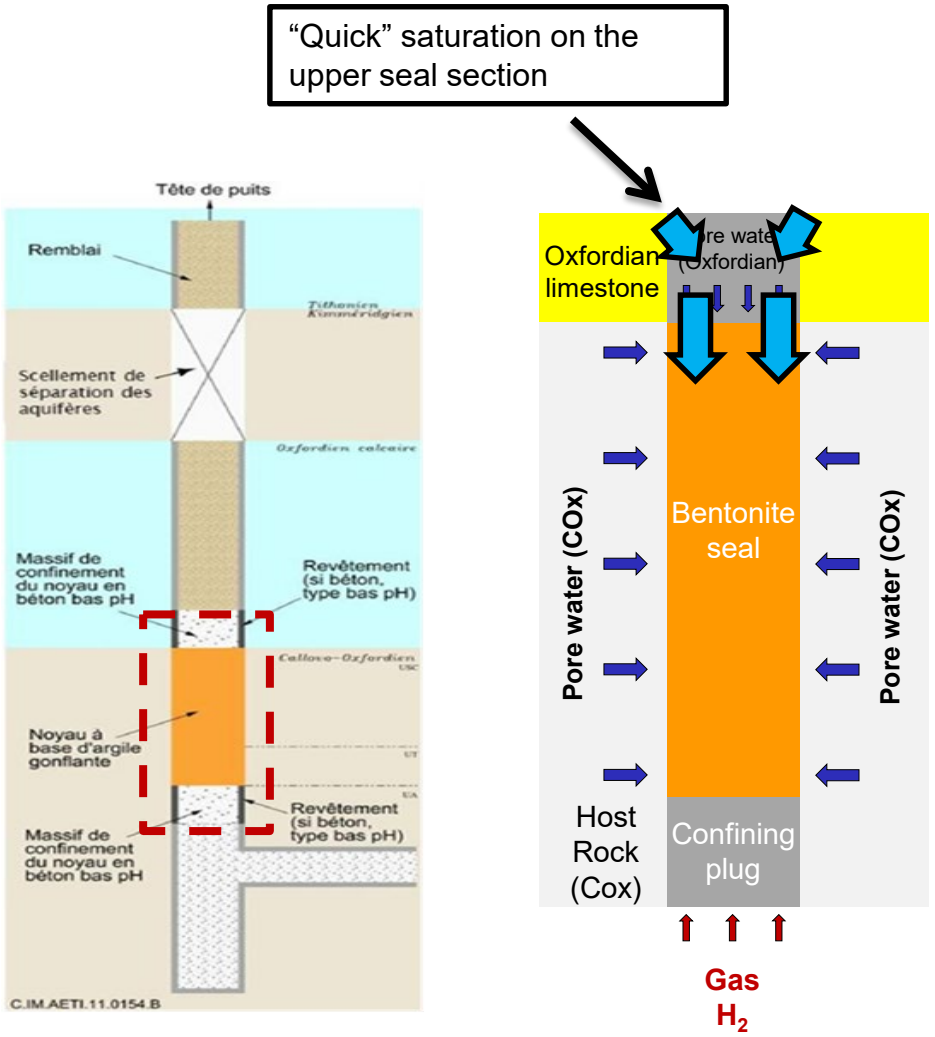
Influence of main parameters with respect to the overall hydraulic performance of swelling clay cores, at long-term:

- ❑ In nominal situations for different core compositions (pure MX80, sand/MX80 mixtures)?
- ❑ For different technological choices (impact of intracore geometry, construction joints)?
- ❑ In altered situations (loss of mechanical confinement)?
- ❑ Do we really observe a long-term homogenization of dry density and swelling pressure fields in bentonite-based materials?

# R&D lifetime evolution @ Tournemire URL: Closure (HM-C perturbations)

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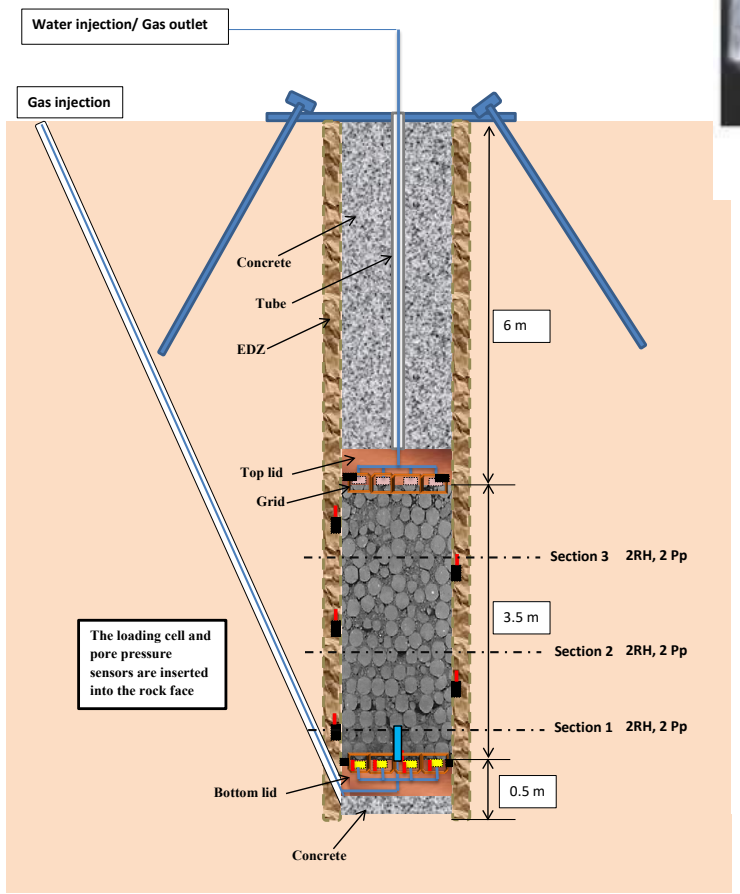
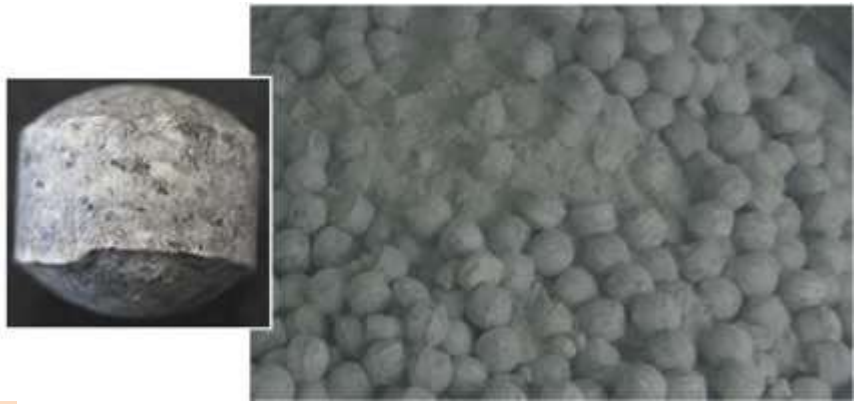
The impact of gas during saturation of the bentonite seal

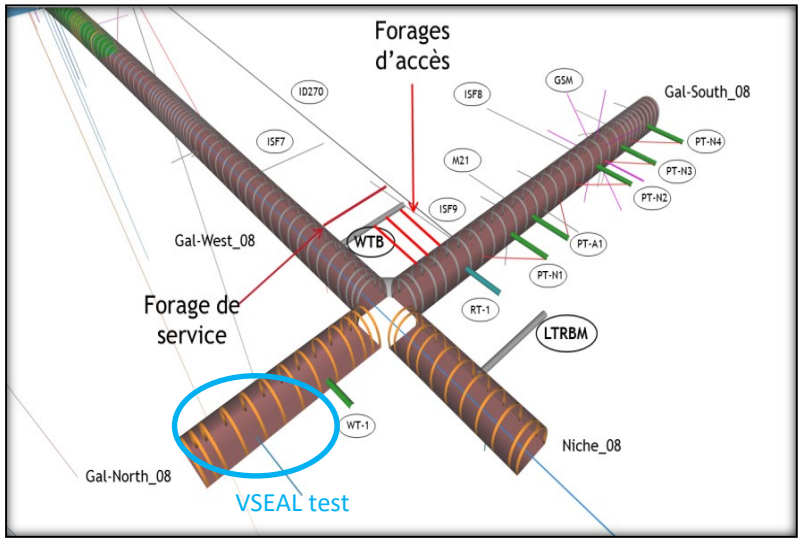
Gas migration processes through the saturated bentonite core (preferential flow paths, role of interfaces…).

# R&D lifetime evolution @ Tournemire URL: Closure (HM-C perturbations)

## VSEAL in situ layout






➔ **Mixture of MX80 Pellets (32 mm) /powder bentonite**

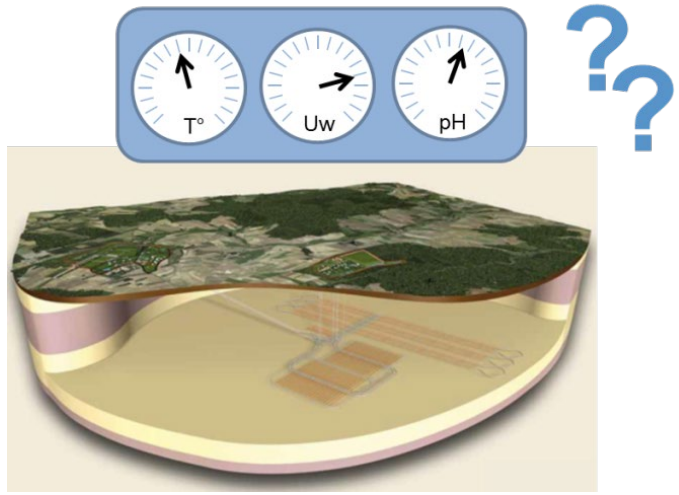
➔ **<u>2 tests:</u>**

**VSEAL1: hydration, gas injection after saturation**

**VSEAL 2: Several steps: Gas injections during the hydration and after the total saturation of the bentonite core**

# R&D lifetime evolution @ Tournemire URL: Operation & monitoring

- Mondern2020 European project (2015-2019)
  - Provide the means to develop and implement an effective and efficient repository operational monitoring programme
  - Focus on monitoring of the near-field during repository operations
  - Allow advanced national RW disposal programmes to design monitoring systems suitable for deployment when repositories start operating
  - Support less developed programmes and other stakeholders by illustrating how the national context can be taken into account in designing dedicated monitoring programmes tailored to their national needs

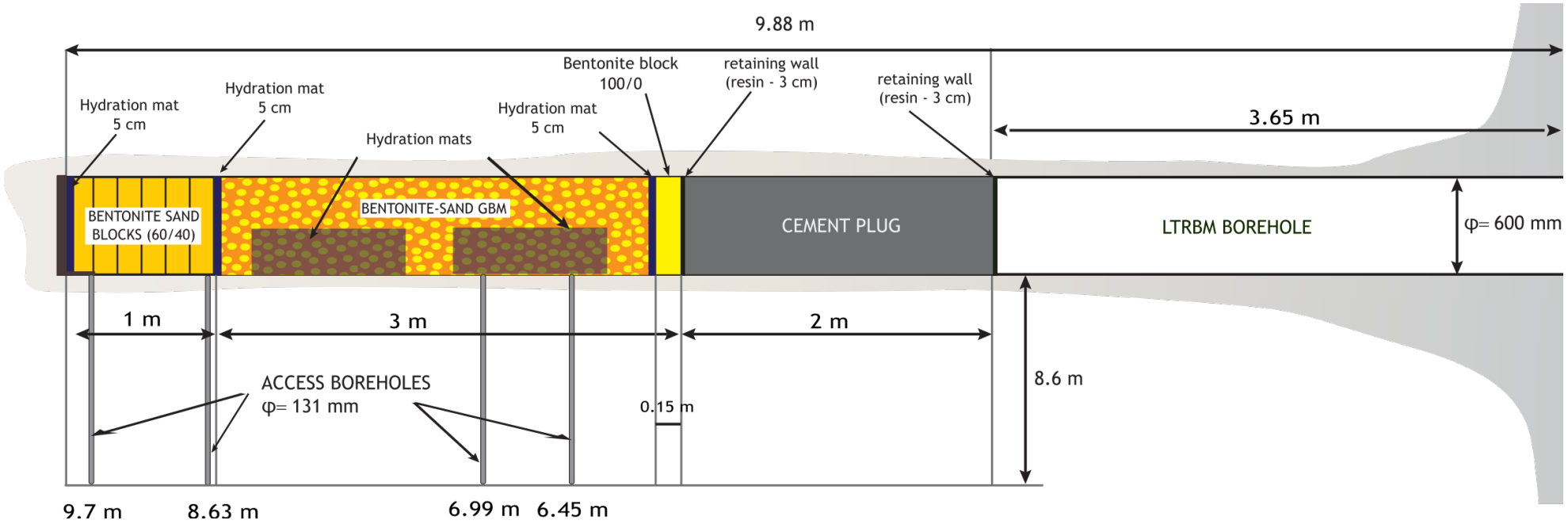


# R&D lifetime evolution @ Tournemire URL: Operation & monitoring

- 3 in situ tests at Tournemire
  - **Wireless Testing Bench (WTB)**
    - Improve existing short and long range wireless systems and evaluate the use of a combination of different range wireless systems
    - Improve propagation of radio waves across the repository media
    - provide the chance to evaluate the engineered barrier system (EBS) components in which the wireless units will be tested under realistically, representative conditions
  - **Long Term Rock Buffer Monitoring (LTRBM)**
    - Monitoring devices developed in Modern2020 as well as sensors that have never been tested in EBS will be installed to assess the real performance of the suggested solutions in realistic repository conditions
  - **Electrical Resistivity Tomography (ERT)**
    - Nonintrusive monitoring of an engineered barrier system

# R&D lifetime evolution @ Tournemire URL: Operation & monitoring

- LTRBM layout




**Granular Based Bentonite-Sand Material (GBM)**

- **Length 3 m**, composition: 75% bentonite (MX 80-Expangel SP7) pellets and 25% **sand**. Target dry density pellets + sand:1.4 g/cm$^3$

Cement plug

- 55% cement (Portland type IV) + 40% water + 5% bentonite (sodic)

**Bentonite-Sand compacted blocks**

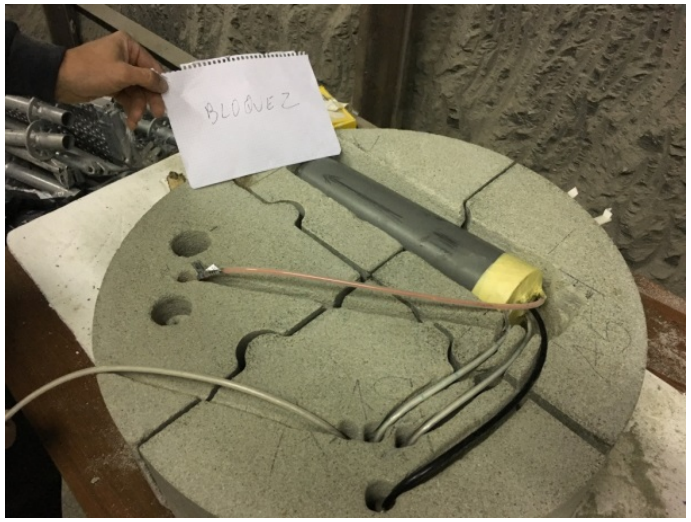
- Diameter φ=560 mm, divided in 4 sections, **length 1 meter**
- Composition: 60% bentonite (MX 80) and 40% sand. Dry density 1.88
- 1 block 100% bentonite with a dry density of 1.5 g/cm3

# R&D lifetime evolution @ Tournemire URL: Operation & monitoring

- LTRBM instrumentation: Wireless devices

Wireless receivers inside the main borehole

Wireless transmitter connected to a pore pressure sensor



Wireless transmitter connected to new psychrometers, conventional pore pressure and relative humidity sensors

# R&D lifetime evolution @ Tournemire URL: Operation & monitoring

- Preliminary results
  - WTB is running since 2016, it not only enables the development of wireless devices but also allows a better understanding of the transmission attenuation physics under different hydromechanical conditions.
  - LTRBM : Data recorded from the new sensors are in general close to the ones measured from the standard commercial ones. Two out of four wireless transmitters placed in the bentonite buffer worked continuously during the monitoring period (high vs. low frequency. Performance assessment of the sensors should be carried out during each step of the installation in order to prevent possible dysfunctions due to improper handling.
  - ERT: Promising first results, different materials within the installation are identifiable and changes in resistivity due to saturation and temperature increase are also visible.

# Conclusions

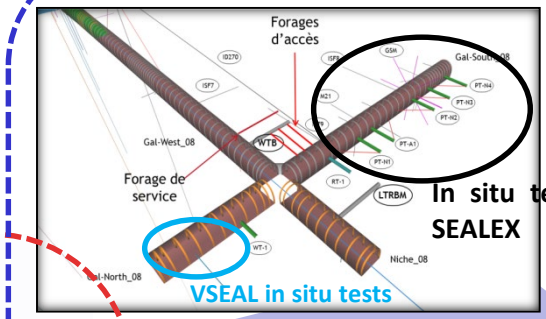
- Challenges for IRSN to assess Cigeo
  - **Challenge "Having timely knowledge and resources necessary to expertise the future nuclear facilities"**
  - **Project "Understanding and modeling the important phenomena for the geological disposal of HLLL waste, in order to apprise the safety of the nuclear facility“**
    - Research as support to expertise a
      - focused on safety issues and questions raised by the expert:
        - → understanding of the fundamental mechanisms that affect safety;
        - → explore the technical difficulties of implementation and asses their effectiveness
        - → With a methodological vocation to assess data quality.

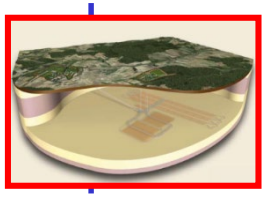
**Large scale experiments at the Tournemire URL have been (and still are) a very valuable tool for IRSN R&D (and to communicate with public as it increases confidence)**

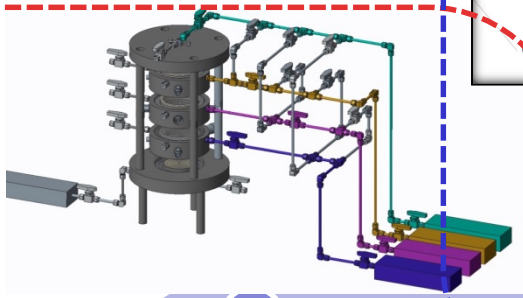
# Thanks for your attention

# R&D lifetime evolution @ Tournemire URL: Closure (HM-C perturbations)

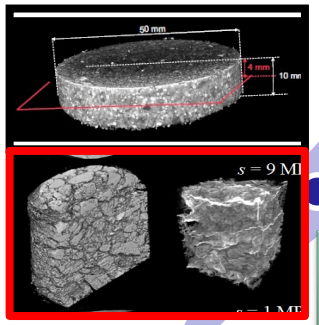
## Experimental and modelling multiscale approach





Bentonite mixture/ precompacted sand




Pellet mixture/bentonite powder

**Microscale:** Microstructure characterisation of materials

**Mesoscale :** HM tests on mock-ups (1/10 of in situ test), laboratory test

**Macroscale :** In situ tests Tournemire

In situ test modelling: predicting the long-term behaviour of constituent materials

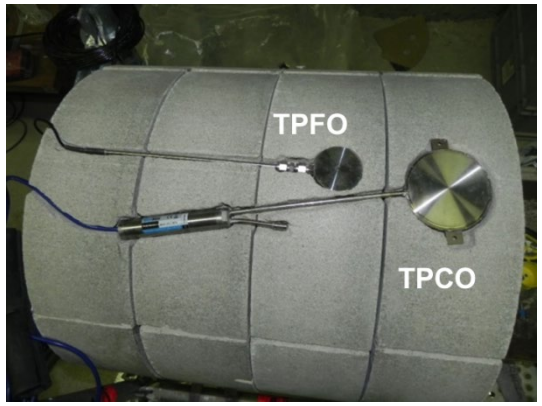
Upscaling

Developping HM models : calibration agains laboratory data results

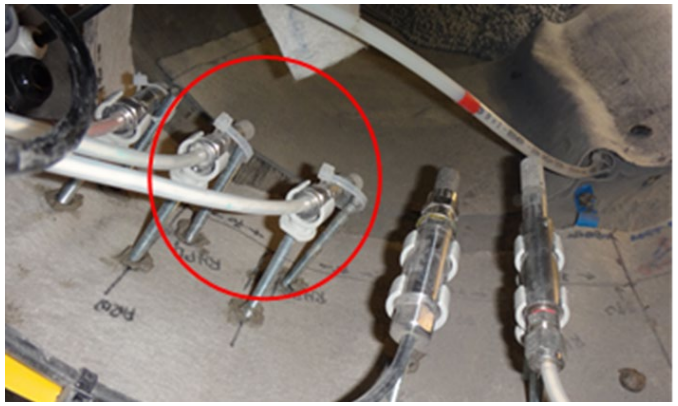
# R&D lifetime evolution @ Tournemire URL: Operation & monitoring

- LTRBM instrumentation
  - New sensors


THMC smart sensor (measures total pressure, pore pressure, temperature and relative humidity)




Total Pressure sensor, TPFO (5 units), installed next to the conventional total pressure sensors, TPCO (5 units)



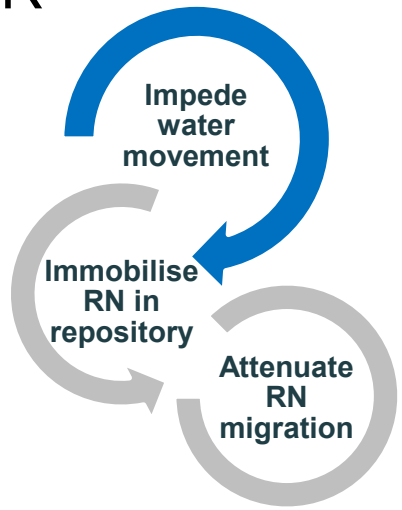
Thermocouple Psychrometers (measures suction using dew point method) attached to a wireless transmitter provided by ARQUIMEA (4 units).

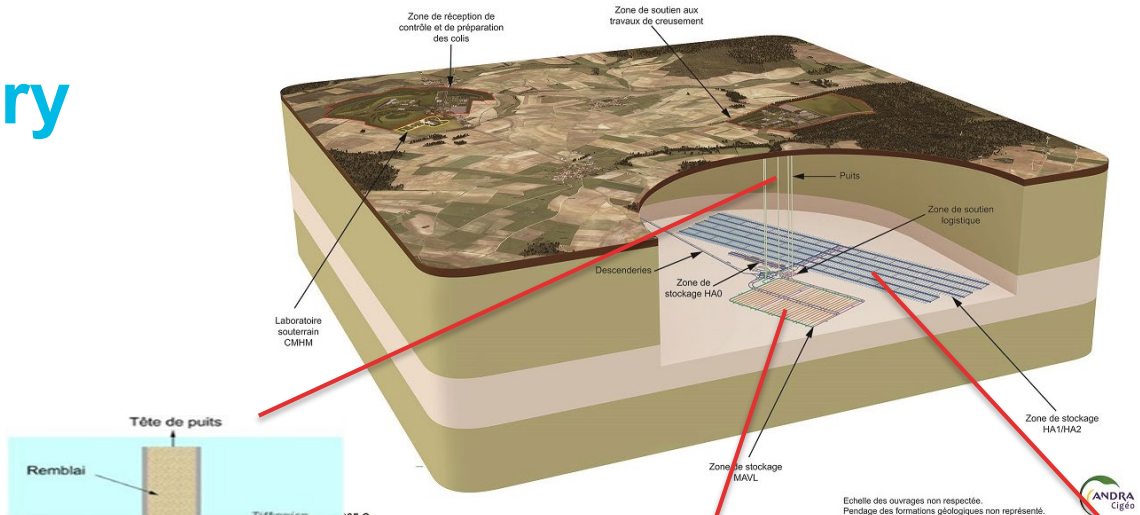
Chemical sensor based on measurements of potential difference between an ion-selective electrode and a reference electrode (measuring electrodes pH, Eh and Cl-)

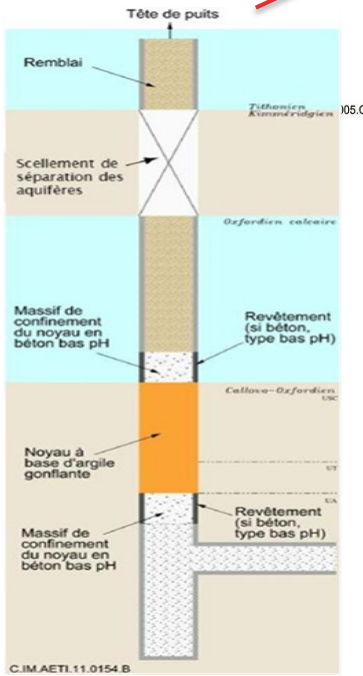
# R&D lifetime evolution @ Tournemire URL: Closure (HM-C perturbations)

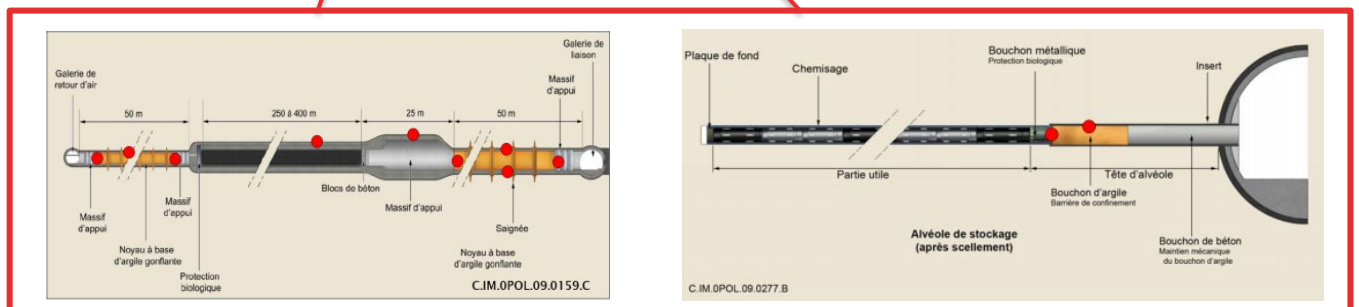
## The Cigeo repository after closure

- Numerous seals (bentonite based) foreseen to close the DGR




- Sealings :
  - defaults in horizontal sealing (**SEALEX**)
  - behaviour of vertical sealing under adverse water & gas resaturation (**VSEAL**)