Modern2020

The Long Term Rock Buffer Monitoring (LTRBM) in situ test, assessing under realistic conditions the performances of monitoring devices developed in Modern2020

Pierre Dick[1], José Luis García-Siñeriz[2], Susana Tuñón Valladares[2], María Rey Mazón[2], Bruna De Carvalho Faria Lima Lopes[3] Héctor Luis Abós Gracia[4], Thomas Schroder[5], Guillaume Hermand[6], Radwan Farhoud[6], Jiri Svoboda[7], Joonas Jarvinen[8], Johan Bertrand[6], and Juan Carlos Mayor[9]

1-IRSN, 2-AMBERG, 3-University of Strathclyde, 4-ARQUIMEA, 5-NRG, 6-Andra, 7-CTU, 8-VTT, 9-ENRESA

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This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n° 662177

Long-Term Rock Buffer Monitoring experiment (LTRBM)

Objectives: LTRBM experiment is intended to test new monitoring solutions developed in WP3 of Modern2020 to assess their performance under real in situ conditions, e.g. inside an Engineered Barrier System (EBS), to demonstrate a full wireless data transmission from the EBS borehole to the earth's surface and to assess commercial sensors that have never been tested in a bentonite buffer

Contribution from WP 3.2 (wireless devices), WP 3.4 (new sensors), WP 3.5 (geophysical methods) and WP4 : AMBERG, Andra, ARQUIMEA, Czech Technical University (CTU), ENEA, ENRESA, EURIDICE, IRSN, NRG, University of Strathclyde, VTT

The in situ field test design is based on previous experience gained from SEALEX project (nearly 9 years of feedback) and uses existing infrastructures of these in situ tests (Tournemire URL, DAS, etc.)

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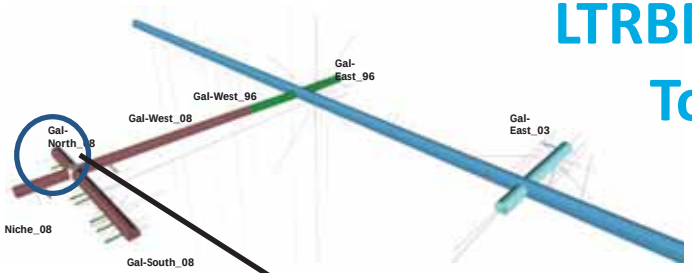
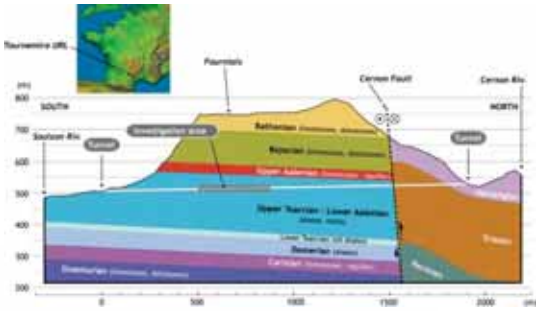
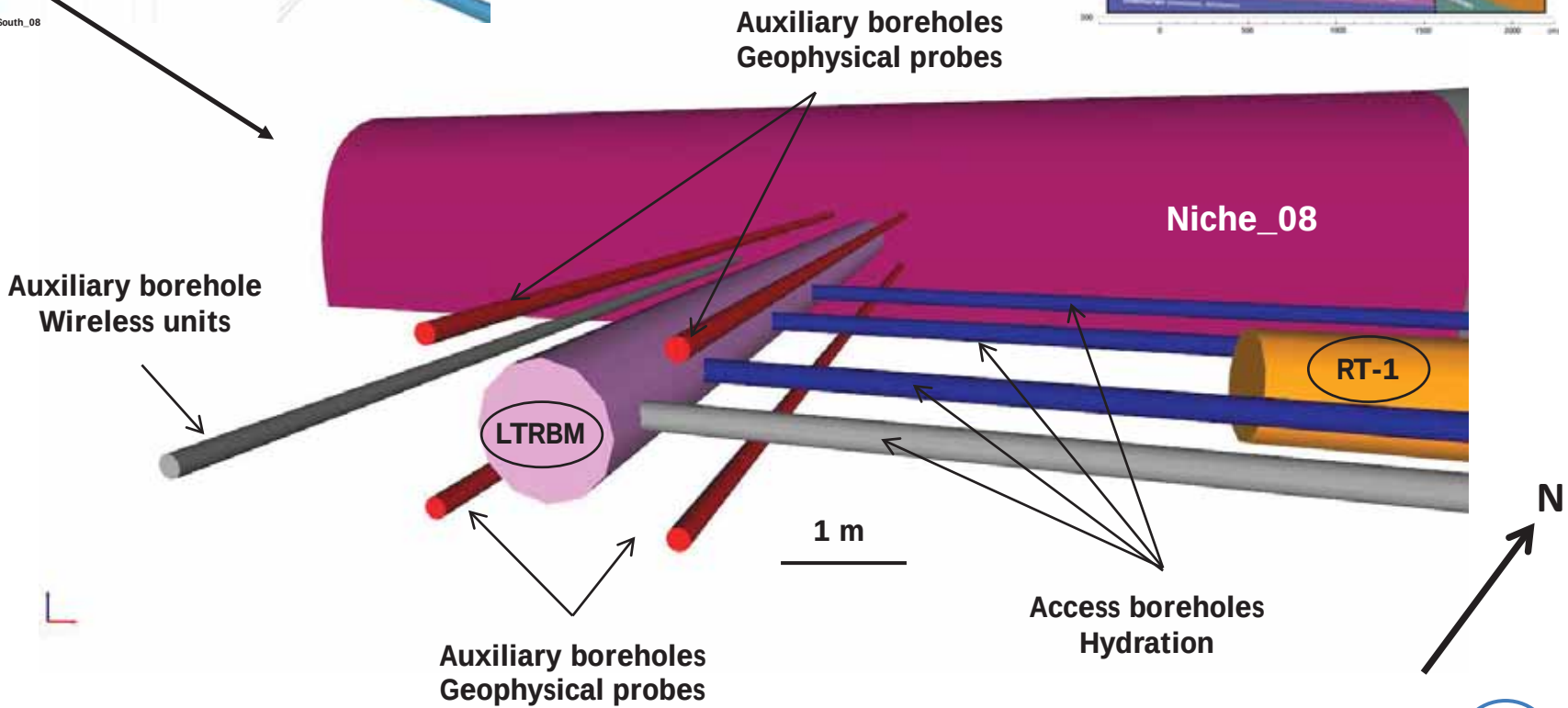
The Long Term Rock Buffer Monitoring (LTRBM)

LTRBM borehole layout
Tournemire URL







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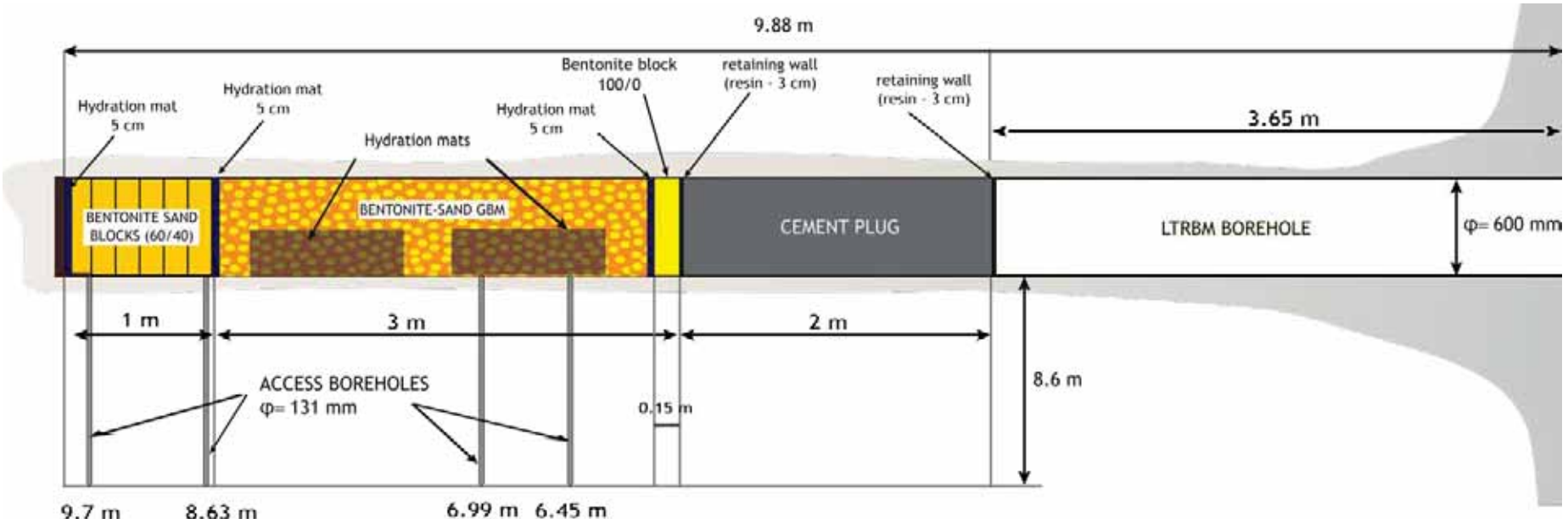
The Long Term Rock Buffer Monitoring (LTRBM)

LTRBM layout (top view)



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 (moulds from SEALEX PT-N2)

- 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

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Components : Bentonite buffer

LTRBM jointed blocks

Charging of the screw conveyor tank with GBM

Bentonite-Sand compacted blocks (moulds from SEALEX PT-N2)

- Diameter φ=560 mm, divided in 4 sections, length 1 meter
- Composition: 60% bentonite (MX 80) and 40% sand. Dry density 1.88 (1.5 for pure bentonite). ¼ weighs 19.3 kg (16.1 kg for pure bentonite)

Granular Based Bentonite-Sand Material (GBM)

- Length 2.8 m, composition: 75% bentonite (MX 80-Expangel SP7) pellets and 25% sand. Dry density pellets + sand:1.41 g/cm3 (WTB)

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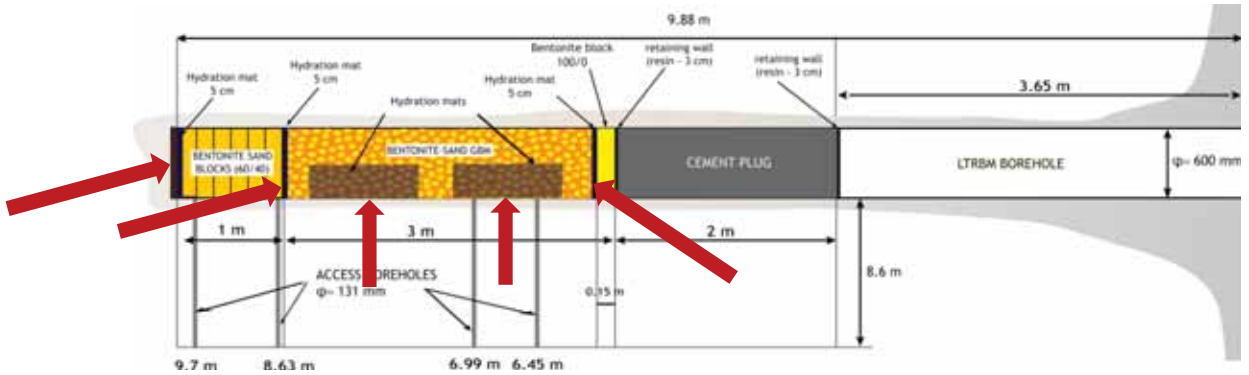
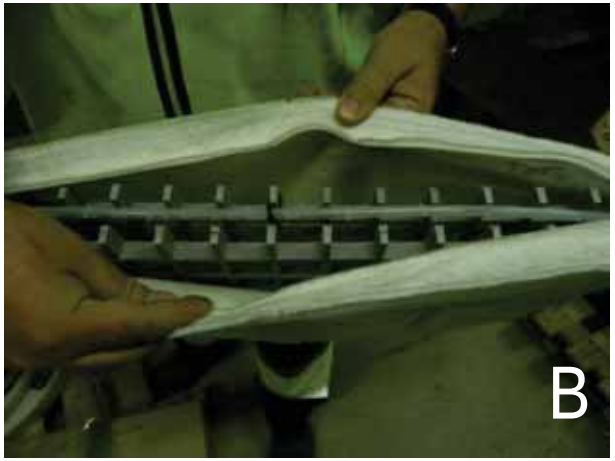
The Long Term Rock Buffer Monitoring (LTRBM)

Components: Hydration mats





A & **B** - Hydration mats, two are located on either side of the precompacted bentonite blocks and one between the GBM and the pure bentonite precompacted block. The thickness of each mat is 5 cm.
C - Hydration mat, lining ½ of the bottom borehole within the GBM section

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Instrumentation

1. New measuring
2. Standard meas
3. Instrumentatio

check performance of new sensors]

r test evolution

1. New measuring instruments from partners

- ***Chemical sensor*** *based on measurements of potential difference between an ion-selective electrode and a reference electrode (measuring electrodes pH, Eh and Cl^-) provided by* ***VTT_WP3***
- ***Thermocouple Psychrometers*** *(measures suction using dew point method) attached to a wireless transmitter provided by* ***ARQUIMEA*** *(4 units)_***WP3**
- ***THMC smart sensor*** *(measures total pressure, pore pressure, temperature and relative humidity) provided by* ***CTU_WP3***
- ***Total pressure*** (based on fibre optic technology) *provided by* ***Andra*** *(4 units)*
- ***Pore water sensors*** *(vibrating wire for pore pressure measurements and electrical resistivity for temperature) attached to a wireless transmitter provided by* ***Andra*** *(2 units)*

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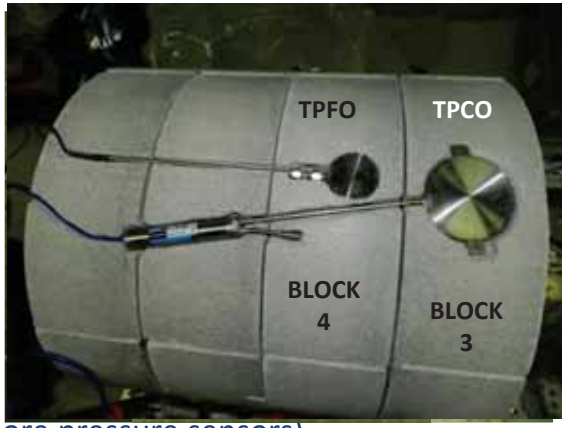
Instrumentation



2. Standard measuring instruments (commercial)

- ***Piezoresistive total pressure cells (5 units)***
  - Measures the swelling pressure of the bentonite core
- ***Miniature piezoresistive pore pressure sensors (5 units)***
  - Measures the pore water pressure in the bentonite buffer (near the new pore pressure sensors)
- ***Capacitive type hygrometers (4 units)***
  - Custom made based on commercial chip, will measure RH&T.
- ***Automatic tensiometers (3 units)***
  - Measure bentonite suction
- ***FDR type water content sensors (3 units)***
  - Measure water content in bentonite based on frequency domain reflectometry (FDR)
- ***Psychrometers (2 units)***
  - Measure bentonite suction (standard psychrometric method)
- ***TDR's in the buffer (7 units)***
  - Time Domaine Reflectometry (TDR) soil probes, will measure moisture the volumetric water content in GBM
- ***Fiber optic (deformation & temperature)***
  - Measure displacement, retraction of the cement plug

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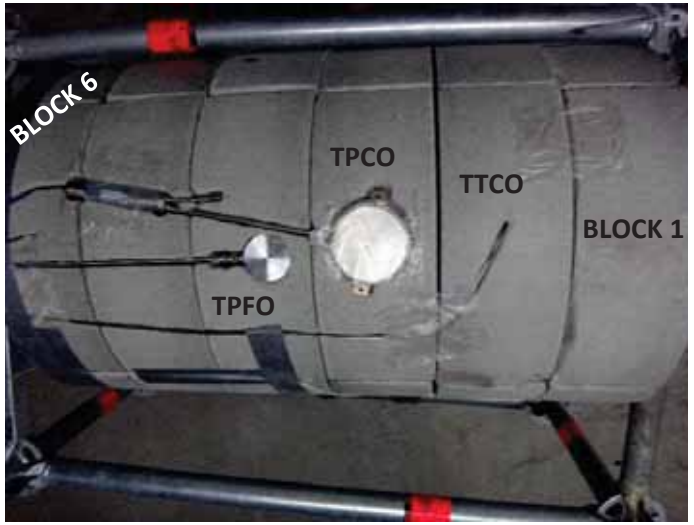
Instrumentation

3. Instrumentation required to control and monitor test evolution

- ***Displacement sensors (2 units)***
  - Installed perpendicularly to the concrete plug's face to measure potential movements
- ***Hydraulic pressure sensors (6 units)***
  - Conventional absolute pressure type transducers installed to measure the water pressure in the hydration system
- ***Weight sensor (1 unit)***
  - Measure tank level and water flow
- ***Temperature sensors (4 units)***
  - Located In the bentonite buffer



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Instrumentation

Wireless data acquisition system (WDAS)

The WDAS will extract part of the sensor's signal from the test section

- ***Within bentonite buffer***
  - 2 short range wireless transmitters for the new Thermocouple Psychrometers provided by **ARQUIMEA_WP3**
  - 2 short range wireless transmitters for pore pressure sensors provided by **Andra & Sakata Denki**
- ***Gallery***
  - Wireless receptor provided by **Andra & Sakata Denki**
  - Wireless receptor provided by **ARQUIMEA_WP3**
  - A long range wireless data transmitter provided by **NRG_WP3**
- ***Surface***
  - LRW data receiver provided by **NRG_WP3**

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Installation

Installation dates:

Drilling of auxiliary boreholes (ERT) December 4th to December 15th 2017

Drilling of main borehole (MB) from March 27th to April 27th 2018

Drilling of access boreholes from May 14th to June 6th 2018

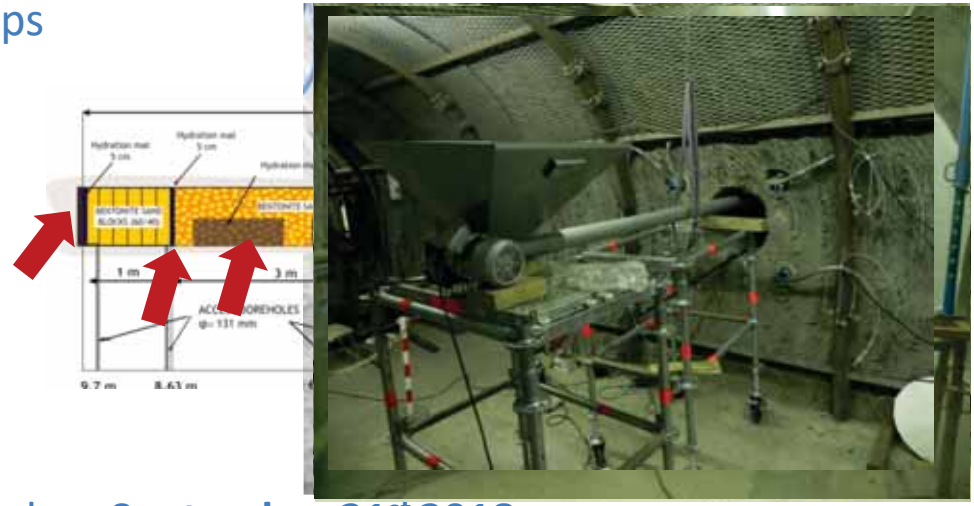
- Installation of EBS + sensors from **June 25 to July 20 2018**
- Installation can be divided in to two steps

1st 3 weeks (June 25 to July 13)

- Construction of the bentonite blocks (+sensors)
- Preparing the MB and access boreholes
- Installation of hydration panels
- Installation of data acquisition system (DAS)

2nd 1 week (July 16 to July 20)

- Insertion of the granular based material (GBM)
- Sealing the LTRBM borehole with a cement plug



- Hydration of the bentonite buffer started on **September 21st 2018**

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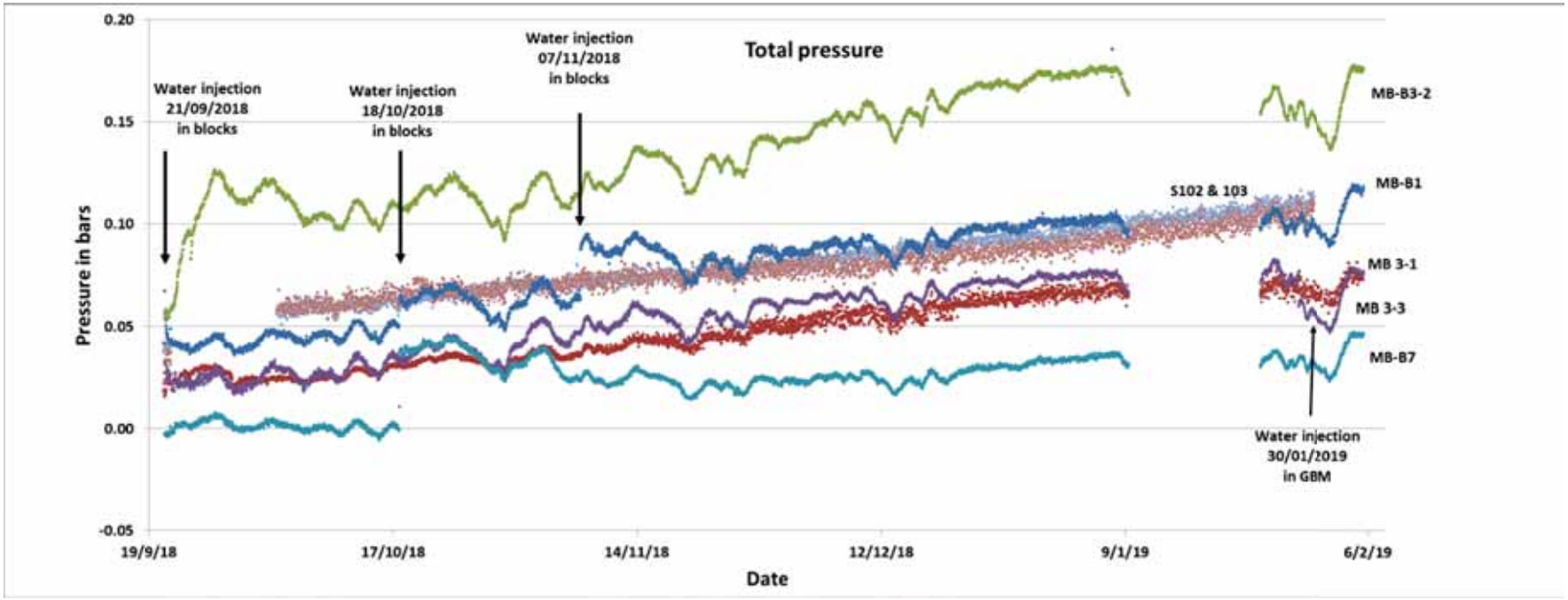
Performance assessment of new sensors (total pressure)



Time series plot showing the evolution of the standard wired sensors (MB-B1, MB 3-1, MB-B3-2, MB-B7) and wired transmitted total pressure sensors (S101, S102, S103, S104)

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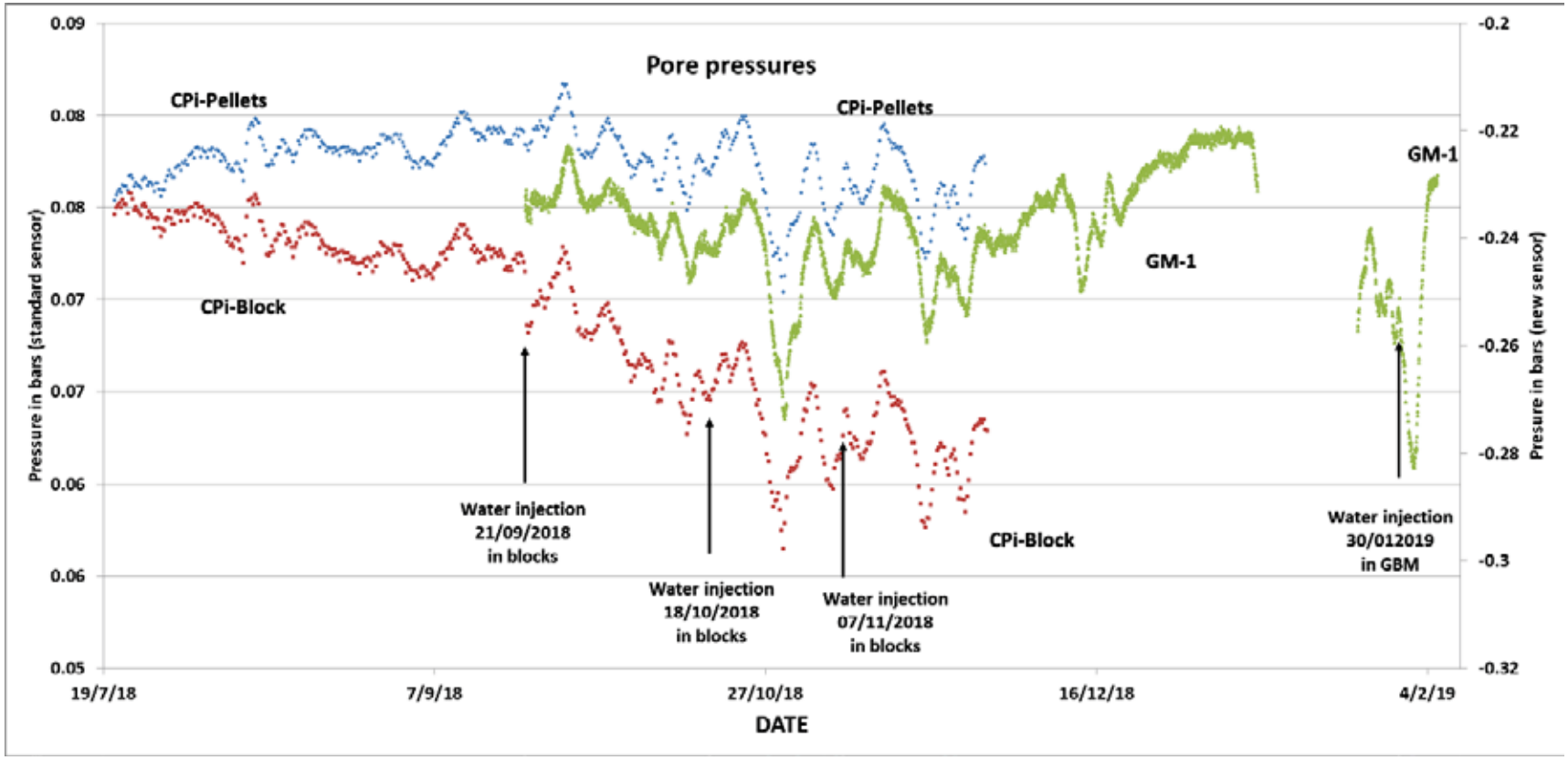
Performance assessment of new sensors (pore pressure)



Time series plot showing the evolution a wired standard pore pressure sensor (GM-1) and wireless transmitted pore pressure sensors (CPi-Block, CPi-Pellets)

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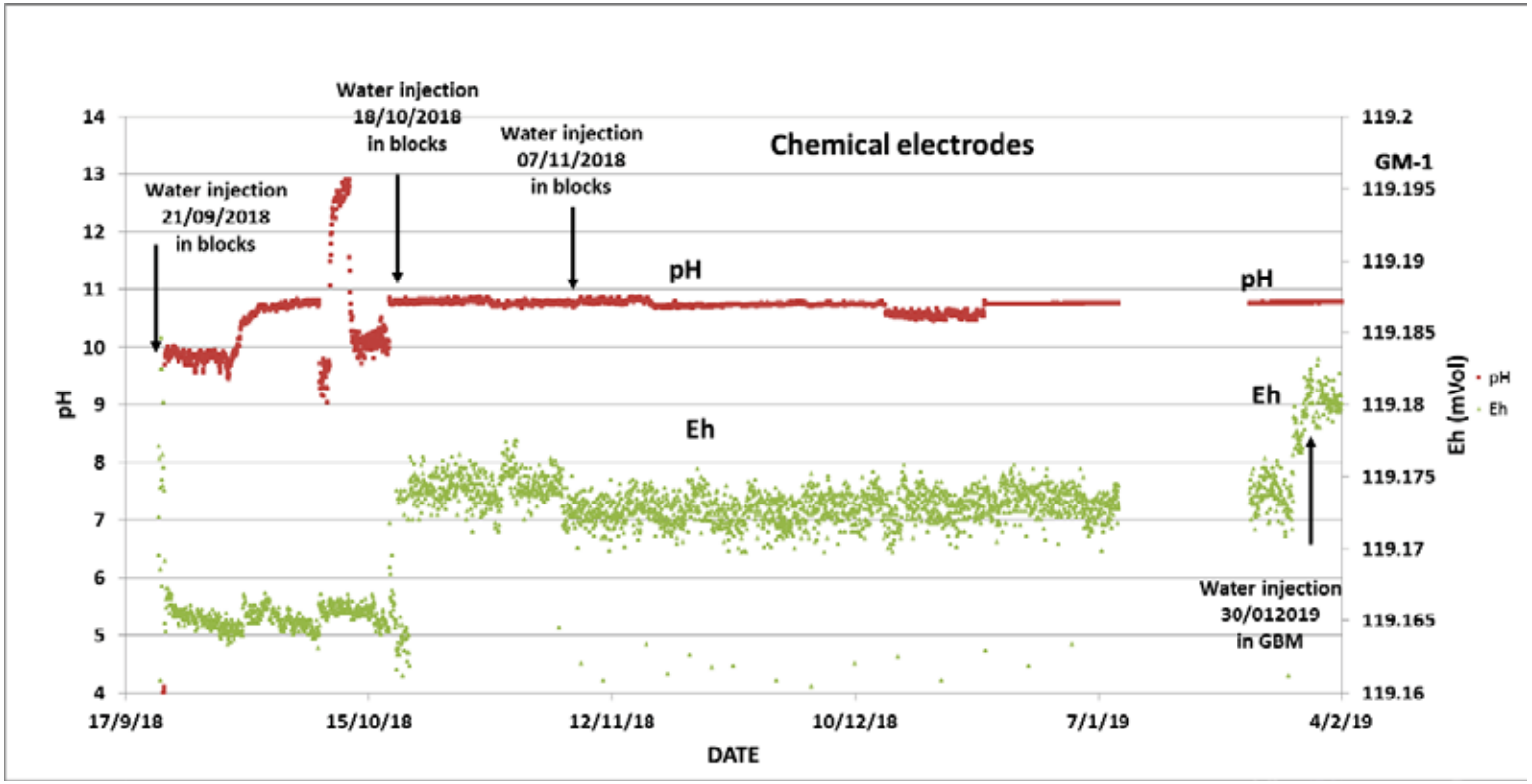
Performance assessment of new sensors (chemical electrodes)



Time series plot showing the evolution of chemical parameters: pH and conductivity (Eh)

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Performance assessment of new sensors

Data transfer

	Sensors	Buffer	Monitoring period	Data quality	Data transmission
New measuring instruments from WP3 to be tested:	pH	Precompacted blocks (60/40)	July 2018 – February 2019	2	Wired
	Eh	Precompacted blocks (60/40)	July 2018 – February 2019	2	Wired
	Cl-	Precompacted blocks (60/40)	July 2018 – February 2019	TBD	Wired
	Thermocouple Psychrometers	Precompacted blocks (60/40) and GBM	NW	---	Wireless
	THMC smart sensor	Precompacted blocks (100/0))	NW	---	Wired
Other new measuring instruments to be tested:	Pore water sensors (vibrating wire based)	Precompacted blocks (60/40)	July to November 2018	1	Wireless
	Pore water sensors (vibrating wire based)	GBM	July to November 2018	1	Wireless
	Total pressure S101 (fibre-optics based)	Precompacted block 1 (60/40)	July 2018 – January 2019	3	Wired
	Total pressure S102 (fibre-optics based)	Precompacted block 3 (60/40)	July 2018 – January 2019	1	Wired
	Total pressure S103 (fibre-optics based)	Precompacted block 3 (60/40)	July 2018 – January 2019	1	Wired
	Total pressure S104 (fibre-optics based)	Precompacted block 3 (60/40)	July 2018 – January 2019	3	Wired

1 – similar to standard sensors; 2- similar to those found in laboratory experiments; 3- significantly different from standard sensors; TBD: 4- to be determined; NW: Not working

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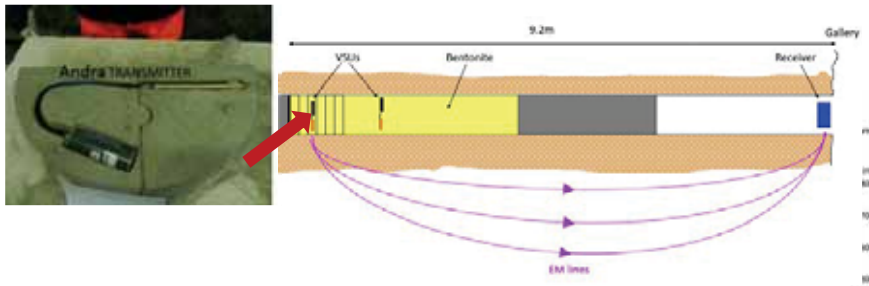
The Long Term Rock Buffer Monitoring (LTRBM)

General set-up:

- Data from two vibrating sensor units (VSUs) were transmitted in two stages:
  - out of the LTRBM borehole to the main gallery (8 - 10 m)
  - from the Tournemire tunnel to the earth's surface (275 m)
- Long range data transmission takes place at 8.6 kHz, a data rate of 30 bits/s, and a transmitter power of 110 mW. More than 35 kByte (~6000 data values) were transmitted. Several coding and modulation methods were compared.

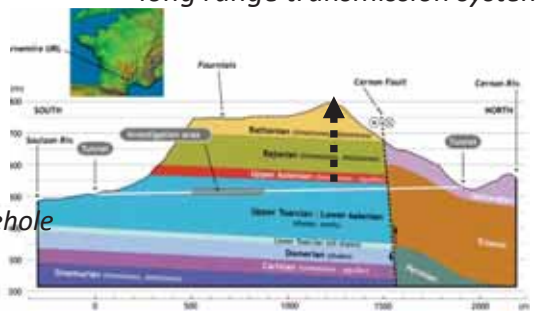
Results:

- Andra's two VSUs were successfully emplaced in the LTRBM borehole, and coherent pressure data from the VSUs have been transmitted without transmission errors since July 2018.
- Long range data transmission could be achieved with bit error rates of 0.002% and a power level that provides no limitation for the application case (5 mWs/bit).



Andra's vibration sensor node and its location in the LTRBM borehole

Cross section of the Tournemire tunnel and location of NRG's long range transmission system



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Project Deliverable:

T.J. Schröder (ed.), E. Rosca-Bocancea, J.L. García Siñeriz, G. Hermand, H.L. Abós Gracia, J.C. Mayor Zurdo, J. Verstricht, P. Dick, J. Eto, M. Sipilä, J.M. Saari, *Wireless data transmission systems for repository monitoring,* Modern2020 Deliverable D3.2, submitted

Poster presentations:

- T. J. Schröder, E. Rosca-Bocancea, C.N.J. Stam, G. Hermand, P. Dick, *Demonstration of a two-staged wireless transmission chain out of the LTRBM borehole to the surface of the Tournemire plateau*
- T. J. Schröder, E. Rosca-Bocancea, C.N.J. Stam, *Long Distance Data Transmission Through The Underground: Lessons Learned From Two Demonstrators*

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The Long Term Rock Buffer Monitoring (LTRBM)

Main conclusions

- LTRBM is the only demonstrator of Modern2020 that incorporates part of the new innovative sensors and wireless transmission units developed in the project. LTRBM is fully operational and working, the target dry density was achieved, saturation of the bentonite buffer is ongoing and swelling is recorded
- 7 months after the installation, all wired commercial sensors are working, nearly all the wired sensors are working , data quality is comparable to the standard sensors or to experimental studies. Data recorded from the new sensors may differ from expected results (recalibration ?)
- Two out 4 of the wireless transmitters are working . The two well-working wireless systems provide a realistic overall data link (from the tunnel to the surface ≈ 270 m) with very reasonable performance with respect to energy efficiency, bit error rate/data points missing, and data rates
- LTRBM illustrates the difficulties in testing new sensors under realistic conditions (embedded in the rock or buffer) as if they fail no solutions are currently available to remove them and repair the defect. The proposed qualification methodology developed in WP 3.6 should improve greatly the required development process.

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The Long Term Rock Buffer Monitoring (LTRBM)

Next steps

- **Continue monitoring for the next 3-5 years in collaboration with Modern2020 partners**
- The LTRBM sensors will be connected by May 2019 to a new data acquisition system
- A new web interface will be available to all Modern2020 partners by May 2019 to follow the evolution (performance) of the LTRBM sensors
- Demonstrate a fully automated wireless system in future
- Repair leaks
- Combine other geophysical tests (acoustic)

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