# A Highly Instrumented Underground Research Gallery as a Monitoring Concept for Radioactive Waste Cells - Data Measurement Qualification

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7th European Workshop on Structural Health Monitoring
July 8-11, 2014. La Cité, Nantes, France

# A HIGHLY INSTRUMENTED UNDERGROUND RESEARCH GALLERY AS A MONITORING CONCEPT FOR RADIOACTIVE WASTE CELLS - DATA MEASUREMENT QUALIFICATION

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## ABSTRACT

This document presents a dedicated work performed in Andra's underground research laboratory (URL) in order to prepare, to test and to qualify the future monitoring system of underground disposal for the French long-lived, intermediate and high level radioactive wastes. Part of the monitoring system qualification process relies on testing sensors on full-scale demonstrators and ensuring that we carefully observe the desired parameters. One of these demonstrators is a concrete liner in a tunnel aiming at support the mechanical pressure of the host rock. A 3.6 meter long section of this gallery has been highly instrumented by various technologies of sensors. This paper describes the monitoring system installed and demonstrates how a numerical model of the demonstrator has been utilized to comfort and validate sensors' measurements.

***KEYWORDS :*** *radiocative waste, monitoring, sensors, underground, tunnel.*

## INTRODUCTION

The French National Radioactive Waste Management Agency (Andra) is in charge of the long-term management of the radioactive wastes produced in France. The industrial deep geological disposal facility called Cigéo[1] (in project), for high-level and intermediate-level long-lived radioactive wastes, should be built progressively and operated over a century. In addition to safety activities during operational period up to post closure, Andra has developed a monitoring strategy that includes instruments and decision support tools developments. This system must be able to operate over such a long period and has to be reliable and equipped with in situ reference points in order to evaluate measurement drift over time.

In order to experiment and qualify components of this strategy, a demonstrator of a potential monitoring system, implemented in a segment of 3.6m of an excavated gallery, has been performed in 2011 in the Andra's Underground Research Laboratory (URL) sited at Bure in the Meuse/ Hate Marne district (France). This segment consists of a concrete liner that supports the rock convergences at -490 m under the surface. A major goal of this demonstrator is to verify the mechanical phenomenology (e.g. foreseen rock strain or displacement surrounding the support) but also the pertinence of the association of sensors used for the thermo-hydro-mechanical monitoring.

The planned underground installations of Cigéo, will be stepwise constructed and operated for approximately a century. Subject to authorizations, Cigéo will be located close to the Andra

[1] Cigéo : the planned French Industrial Centre for Geological Disposal - see. http://www.cigeo.com for details

 

Underground Research Laboratory situated at Bure. The URL aims at studying the feasibility of the reversible geological disposal for high-level and intermediate-level long-lived radioactive wastes in the Callovo-Oxfordian clay formation. This facility was licensed on August 1999 and its construction (access shafts, basic drift network etc.) has been achieved in 2006. Nevertheless, more drifts are excavated for the on-going geological surveys, experimental programs or the engineering technological demonstrations.

The French “planning act” imposes that Cigéo repository must be reversible for several decades. The monitoring of the environment and the repository installations will provide the required information for safe operation of the facility during repository operation and after closure, its reversible management, and input for future decision-making and for improving the design procedures for future waste disposal cells.

Andra has developed a monitoring strategy and identified specific technical objectives in order to inform on process evolutions relevant to long term safety as well as those relevant to pre-closure management, and reversibility process. Long-term monitoring in geological repository requires maintenance-free systems that provide reliable and continued deployment over several decades without intervention. The Sensors’ reliability is the key issue to match a long term requirement where interpretation of measurement results may involve significant uncertainties.

Andra’s monitoring strategy to ensure a centennial reliability consists of (i) improving the components that affect reliability, drift or lifetime,(ii) combine different sensors technology in order to insure the measurement of the target parameters. Consequently, Andra has specified a multi-stage qualification procedure from controlled conditions in laboratory to real condition on field. Advancing towards final tests, radiation evaluation is performed and radiation hardening is designed.

This paper highlights a possible monitoring approach for the high-level and intermediate-level long-lived radioactive wastes disposal cells with cast-in-place concrete liner and provides detailed consideration of thermo-hydro-mechanical sensing technologies.

## MONITORING REQUIREMENT OF INTERMEDIATE-LEVEL LONG-LIVED WASTE DISPOSAL CELLS

In the underground repository, the harsh environmental conditions have consequences for all types of devices and systems. The main component of the monitoring system will be installed during the construction phase, run during the operational period and could be used for decades and/ or centuries for post-closure observation.

In addition to the harsh environment for sensors, the sensors lifetime is ensured selecting “basic” technologies (no on-board electronics). Sensing system must also be non-invasive. Sensor reliability is a key issue in meeting the requirements for long-term monitoring. The combination of instrumentation that provides redundancy would extend over the period of time which the instrumentation continues to provide usable data.

## ASSESSMENT OF THE MONITORING SYSTEM IN LARGE-SCALE EXPERIMENT

Andra URL gives the opportunity to evaluate monitoring section in real conditions. An experiment, named ORS (observation of concrete liners and structural support system) focused on the understanding of Thermal-Hydric-Mechanical behaviours, started in April 2011 in the GCR (Stiff conception gallery).

The gallery GCR had been excavated by a MAP tool (punctual attack machine) and has a diameter of 5.40 m. A shotcrete liner of 20 cm was put on the rock. Six months later, a concrete liner was built. More precisely, three different types of thick concrete liner, about 27 cm, were tested: (i) C60 (60 MPa at 28 days), (ii) C40 with compressible shims bolt, (iii) C60 without compressible shims. The goal is to evaluate the impact, in the medium and long term scales (for more detailed see [1]), on the hydro-mechanical behaviours and more particularly on the excavation damaged zone (EDZ).

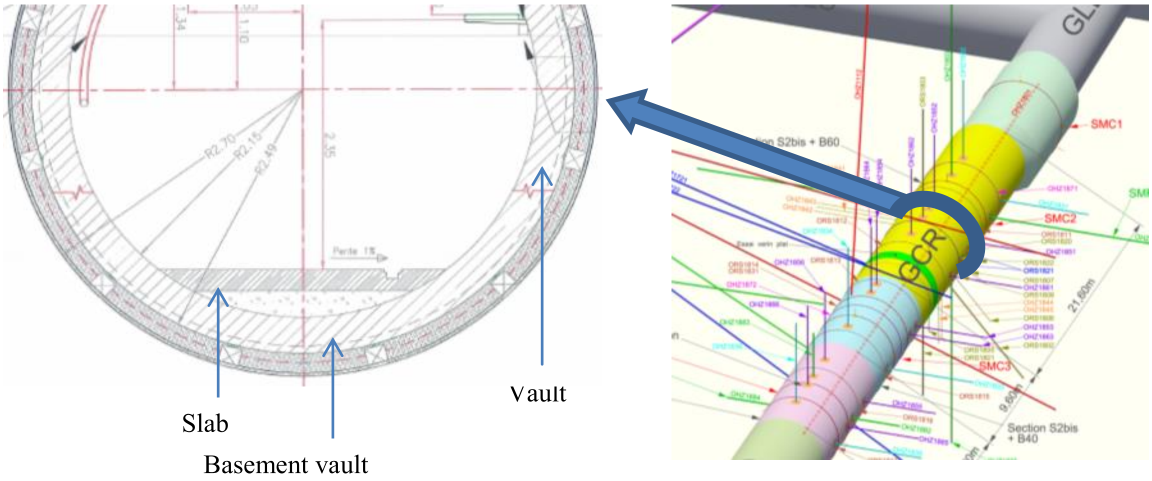


Figure 1: GCR gallery with 3 supporting types (right) and the construction parts and dimensions (left)

In the framework of the ORS experiment, a specific monitoring section was implemented inside a circular cross-section of 4.30 m in diameter. This instrumented section aims at being representative of the monitoring system for IL-LLW cells. The monitoring system has been implemented with the following objectives:

- Test implementation procedures for sensors, particularly for innovative technologies (ref. next chapter);
- In-situ test of different complementary sensor technologies for the THM characterization;
- Retrieve representative feedback on durability and robustness of sensors technologies;
- Test field calibration of temperature devices (for more detailed see [2]) in order to obtain traceable measurements.

## DESCRIPTION OF THE MONITORING SECTION TEST SYSTEM

In order to measure THM parameters in the section test, 129 localized sensors (Fig. 2) have been installed:

- 22 Vibrating Wire Extensometer (VWE) to monitor the strain in the concrete ring;
- 14 Time Domain Reflectometry (TDR) to follow the water content in the rock and the concrete ring ;
- 5 Pore Water Pressure (PWP) to measure the pore overpressure due to the impact of exothermal waste packages in the future repository
- 3 Total Pressure (TP) in order to follow the liners load by the host rock
- 3 Extensometer Multi-points Single-rod (EMS) for displacement measurements of the rock surrounding the waste cells
- 1 Temperature probe for each sensor above.

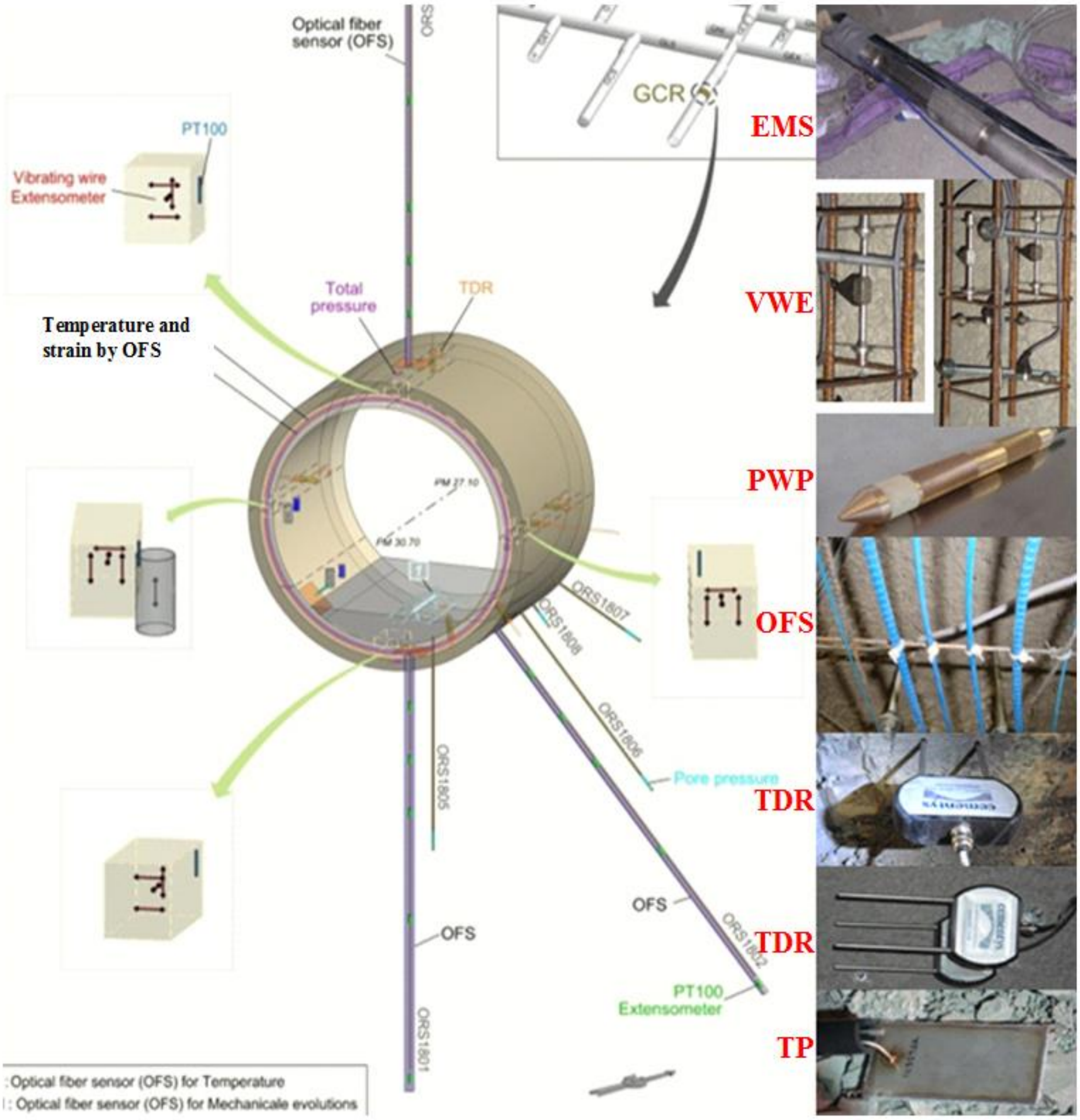


Figure 2: Schematic of the monitoring system designed for IL-LLW disposal cells & pictures of the sensors.

In addition, 11 optical fibre lines or optical fibre sensors (OFS) providing distributed strain and temperature measurements in the rock or concrete were implemented. Thanks to this type of sensors, the experiment provides more than two hundred points of measurements with a general sampling time of 30 minutes. In total, this experiment has now filled more than 10 millions of data in our database.

Many challenges were faced during the implementation phases for TDR in rock (adaptation to stiff rock) and OFS in concrete without rebars (for more detailed see [3]).

## FROM SIMULATIONS TO IN SITU MEASUREMENTS

The characterization of the clay rock, at -490 m, has been chosen to receive French radioactive wastes because of its very low permeability. In the Andra's URL, located in this clay rock, an experiment was lead in 2011 aiming to evaluate the rock behaviours when a concrete liner is belt in order to stop convergences of the host rock. This experiment consists of an instrumented tunnel section; about 3.6m length and 4.5m in diameter; heavily instrumented and already provided good measurements over more than two years.

After this period, the host rock parameters were introduced into models in order to evaluate the long term behaviours of the repository vicinity and therefore the safety of the repository. Before that, the elapsed time of excavation process, for each part of the gallery, was compared with those of the model as we can see in figure 3.

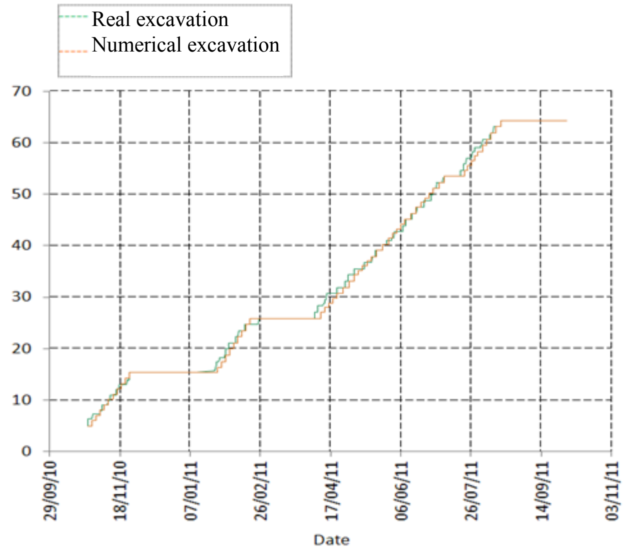


Figure 3: Elapsed time for the excavation of the gallery in the Model and in real

Indeed, we can see that the elapsed time spent for the excavation of the gallery was very similar with the model. This model included numerical sensors as virtual measurement points in order to compare it with real measurement points. Her, the mechanical behaviour of the gallery, due to its excavation, is presented with in order inform on excavating damaged zone around the gallery. Real and numerical sensor distribution in the gallery's liner is shown in Figure 4.

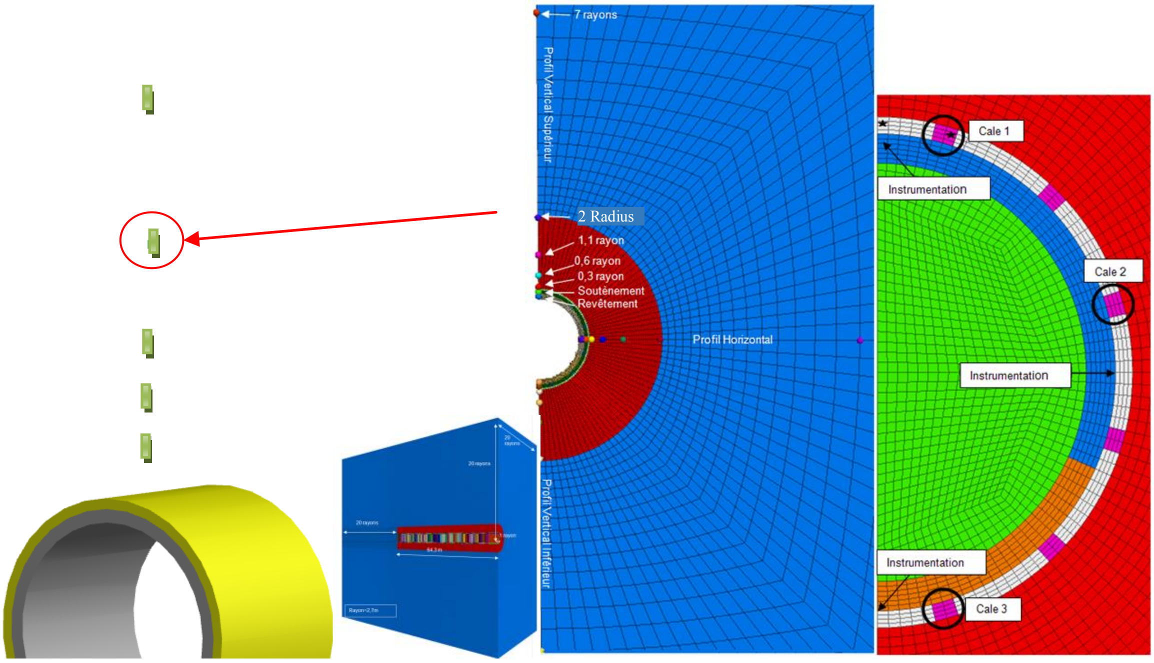


Figure 4: Model of the gallery (zoom in 3 steps) with displacement sensors (right), and sensors installed in the URL gallery (left).

The Figure 5 presents experimental and simulated displacements in the clay rock in the bottom borehole of the gallery (Figure 2: ORS1801 borehole). The period shown is about 10 days (1000 measurements with a recording sampling time of 15 minutes): it is the period where gallery convergences are significant.

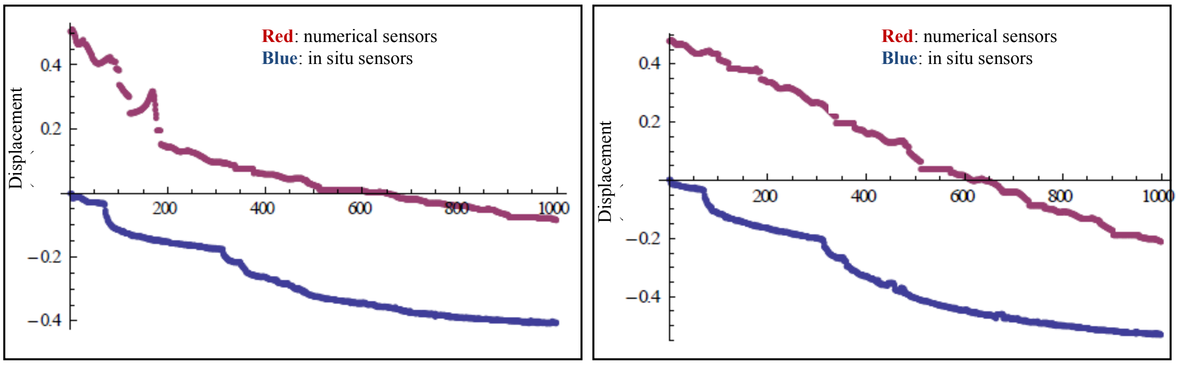


Figure 5: Comparison between experimental and numerical sensors for displacement measurements at 2 different depths in a borehole.

It is worth noted that these data are relative rock displacements between two points along the borehole. Actually the referential point is the edge of the sensor (at 8 meters depth in this experiment). On both comparisons presented above, we observe roughly the same evolution: a displacement of 0.5 mm for sensors at 5 m deep (left side) and 0.6 mm at 3.5 m deep (right side). The main differences between simulated and real displacements are due to operation schedule phases that were not integrated in the mathematical model.

Some first results come up immediately when we observe these two curves. Indeed, we can see that the model predicts a swelling of the rock around the gallery, due to the concreting heat and concrete water, which don't occurs.

Also, we can see that real measurements are relative to the first measurement after installation, when model measurements are relative to the initial position before excavation of the gallery.

## DATA MINING

In order to manage the very important number of data delivered by the monitoring system in the future repository, Andra started to study the data mining feasibility in order to make an automatic first step qualification of data. It starts with a comparison of data provided by different technologies of sensors to ensure that no failure or no divert on the sensor. In the second time, measurements are compared to the model in order to evaluate if the measurement values still in the predicted domain.

If the evolution of measurements is normal, and out of predicted domain, the model parameters are adjusted in order to take into account the new normal evolution domain.

The process is iterative and have to operate all the time where the system still operating.

## CONCLUSIONS

This monitoring experiment will continue for several years in order to gain information about aging, accuracy, possible drift and robustness of sensors. The survival rate of sensors after 2 years and half is about 95% , which proves the robustness of the selected technologies, even for the innovative and recent ones. The feedback obtained for implementation of sensors will guide future R&D programs and choices to increase sensor reliability and decrease failure during the construction phase.

First results of data – model inter-comparison have shown well correlated behaviour between different technologies and also between simulation and measurements. More measurement data will be compared in order to assess multi-parameter influences in models and develop correlation technics. Data mining and data process methods for underground SHM will be elaborated starting with sensors' failures, automatic detection and first level of data qualification.

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