



FEEDBACK FOR MORE THAN 20 YEARS OF MONITORING IN ANDRA UNDERGROUND RESEARCH LABORATORY

Modern2020 Final Conference, April 9-11 2019

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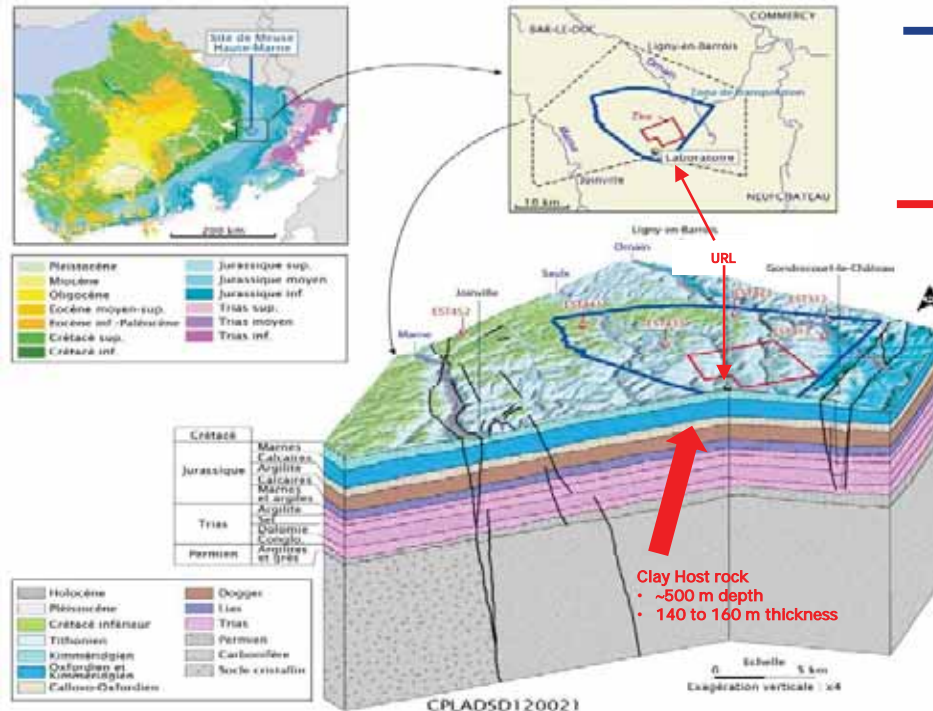


The cigéo Project

Its location and the Andra Underground Research Laboratory



Clay Host rock →



- ZT: 250 km²
 - Demonstration of feasibility principle of deep geological disposal (2005)
- ZIRA: 35 km²
 - Location of Cigéo underground facility (2009)

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The Cigéo Project

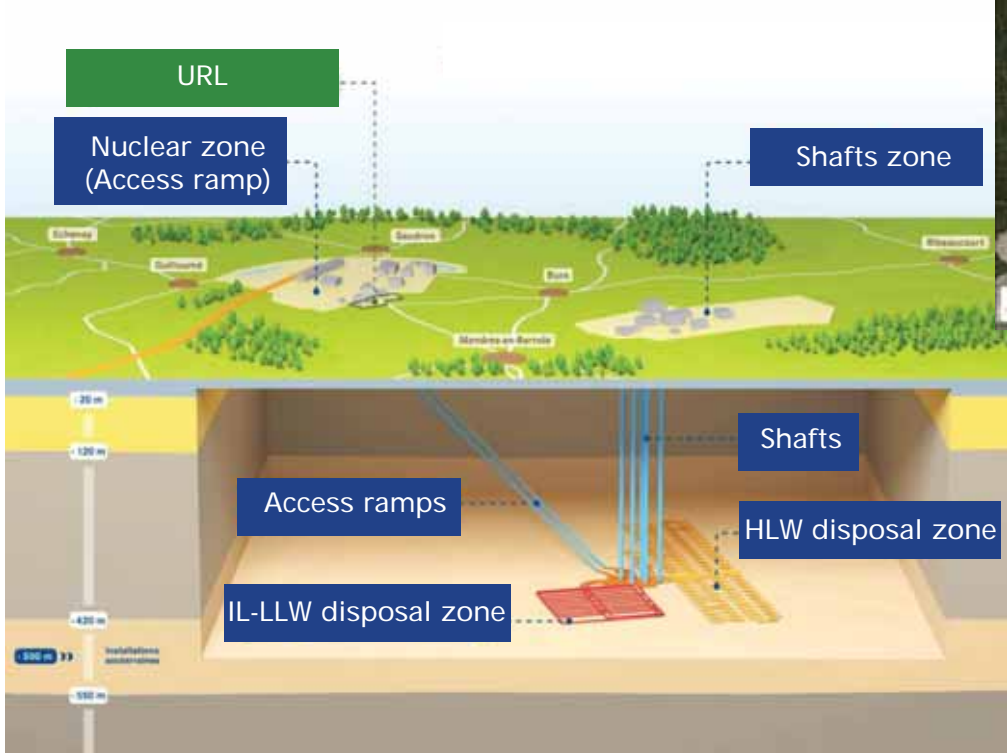
500 m depth

15 km² Underground facility

85000 m³ radwaste

120 Operating period

25 Mds Euros



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The Cigéo project

The monitoring program: application, requirements, "multi"

Application

- Construction and operational safety
- Retrievability
- Satisfaction of Post-closure safety functions during operating period
- Dialogue with stakeholders
- Knowledge management

Main requirements of monitoring devices/system

- Discretion (Non invasive)
- Durable as much as possible and reasonable
- Sensibility
- Resistant to disposal conditions (temperature, radiation, water...)
- Redundancy, complementarity
- Flexibility
- 3D vision of components



Multi-(macro)components

- Radwaste, disposal radwaste packages
- Disposal cells, drifts, access ramps, shafts, seals, disposal zones, overall underground architecture
- Geological and surface environments

Multi-materials

- Glass, metals, concrete, clay (backfill/seal)...
- Clay (host rock)...

Multi-scales

- Space: from several cm to several 10 km
- Time:

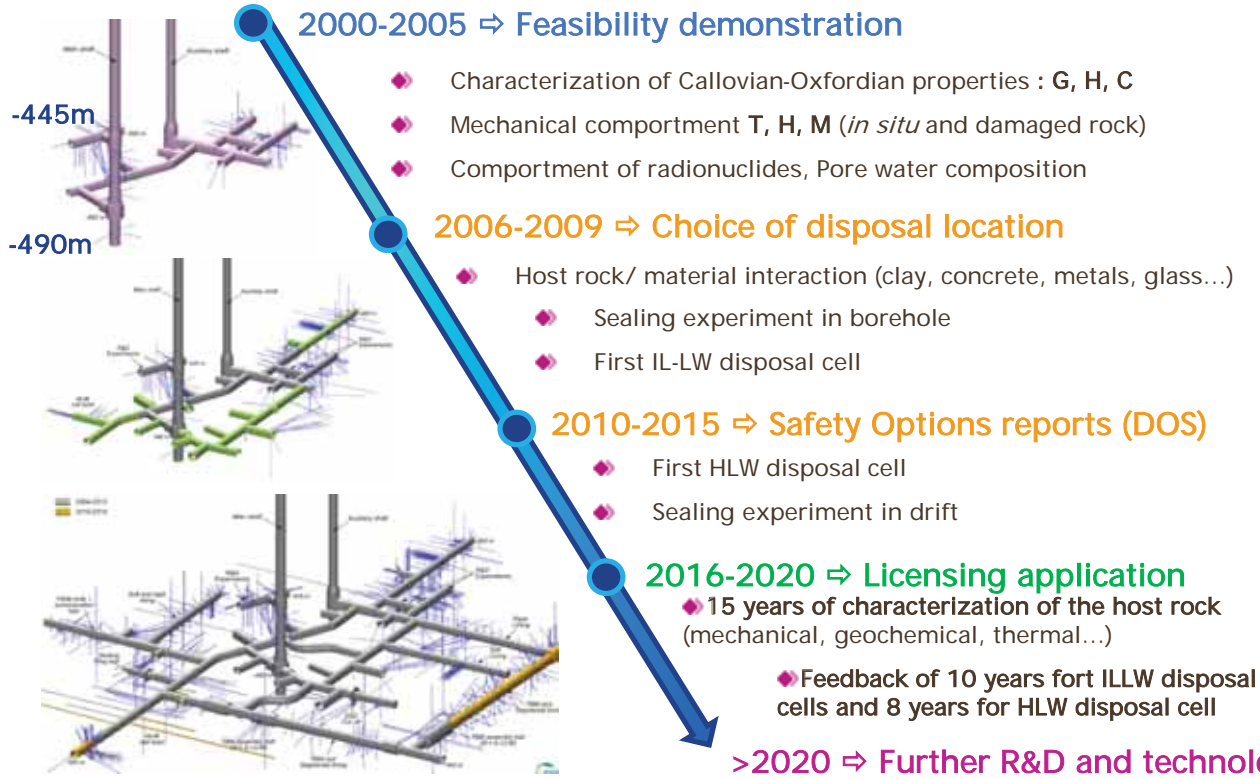


Multi-functions ⇒ Multi-processes ⇒ Multi-parameters

- Thermal, Hydraulic-Gas, Mechanical, Chemical, radiological

The Andra Underground Research Laboratory

A deployment, incl. Monitoring, with Cigéo milestones



CARACTERISATION
AND
FEASIBILITY

CONSOLIDATION

OPTIMIZATION

OPERABILITY

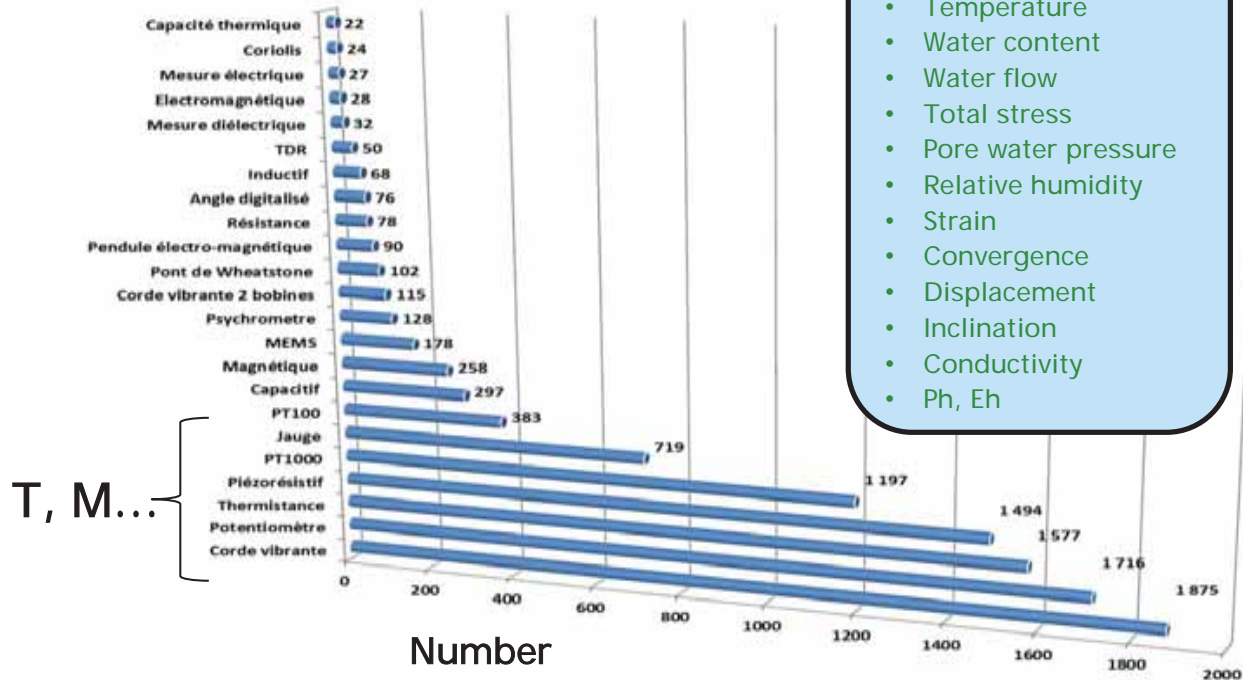
PILOT INDUSTRIAL
PHASE
PREPARATION

The Andra Underground Research Laboratory

The technologies of monitoring tested at 20219



Technology



Host rock and Engineered components

- Temperature
- Water content
- Water flow
- Total stress
- Pore water pressure
- Relative humidity
- Strain
- Convergence
- Displacement
- Inclination
- Conductivity
- Ph, Eh

"Atmosphere"

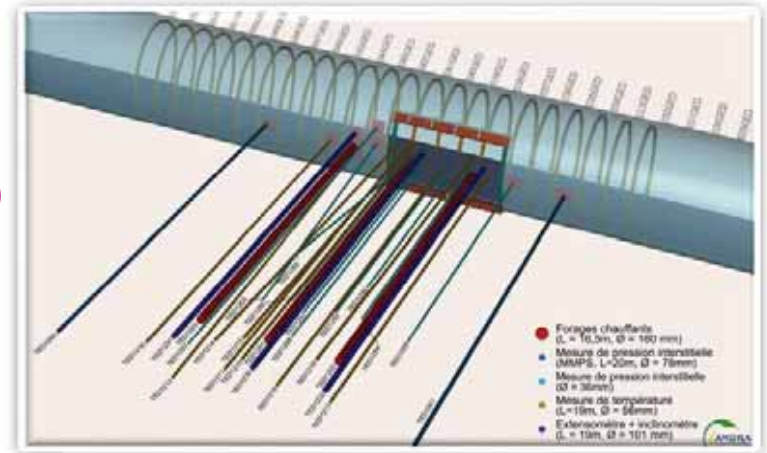
- Temperature
- Air flow
- Air velocity
- Hygrometry

Monitoring of thermal phenomena in Andra URL

Temperature measurement

Two technologies combined

- ◆ Point measurement by platinum probes
 - Sensibility : 0,01°C
- ◆ Distributed optical fiber sensor « Raman » (OF)
 - Sensibility : 0,1°C



Borehole measurements (≈1600 sensors in the URL)



OF measurements in concrete lining



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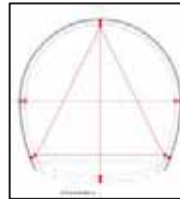
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Monitoring of Mechanical phenomena in Andra URL

Rock mechanical behaviour

Rock mechanical behaviour

- Convergence measurements
 - Invar alloy wire
 - Optical fibers
 - Convergence rods
- Strain measurements
 - Vibrating-wire extensometer (0.1 microstrains)
 - inclinometer (0.02 mm/m)
- Interstitial pressure measurements
 - MPS – Multi Packer System
 - Pore pressure cell
 - Interstitial pressure cell (vibrating-wire)



Inva alloy wire

Structure mechanical behaviour

- Vibrating-wire extensometers (one or double boils)
- Strain gauges
- Convergence rods
- Total pressure cells



Rock/structures stress changes

- Sensing plates measurements
 - Distributed measurements of othoradial stress in the concrete (5 mesures/cm²).

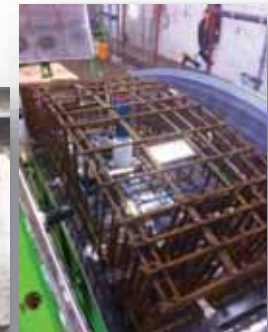


Example of application of vibrating wire extensometer



In the concrete structures

Prefabricated segments

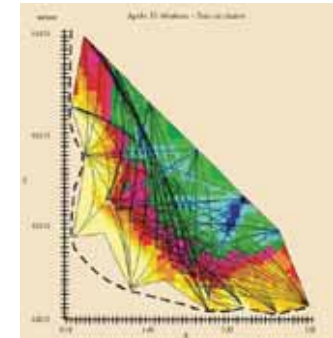


Monitoring of mechanical phenomena

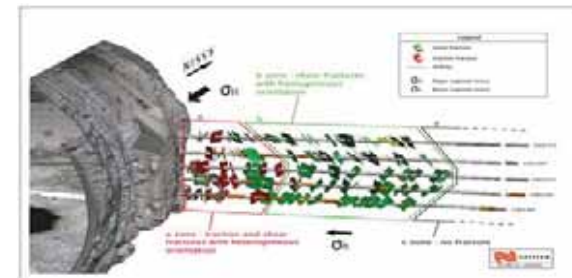
Evolution of the damaged zone

Proven and complementary methods

- 1. Geophysical methods** : Analysis of the P-wave travel time between transmitter and receiver to determine the speed of propagation of the wave in the medium traversed
 - Seismic frequency (important volume of rock)
 - Tomographic measurements at different scales (intersections shaft, drift, face of galleries, cells...)
 - Ultrasonic frequency (fine description of reduced volume of rock)
 - Well logging (« interval velocity measurements »)
 - « velocity survey »
- 2. Gas permeability measurements**
- 3. Geological observations** : Fracturing analysis on coring



Evolution of P-wave travel



Damaged zone modelisation (σ_H)



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Monitoring programme of underground structure demonstrators

IL-LLW disposal cell

HLW disposal cell

IL-LLW disposal cell demonstrator in Andra URL GCR Drift: First monitored section (Rigid support)

Objective: To ensure the retrievability of packages during operating period

Rock (T,H,M)

- Platinum probes (T)
- Distributed optical fiber « Raman » (T)
- Time Domain Reflectometry TDR (H)
- Inductif extensometer (M)
- Pore water pressure (H)

Concrete lining/support (T,H,M)

- Platinum probes (T)
- Distributed optical fiber « Raman » (T)
- TDR (H)
- Vibrating wire extensometer (M)
- Distributed optical fiber « Brillouin » (M)
- Total pressure (M)

Concrete slab

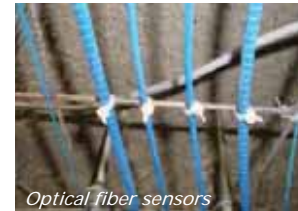
- Reference temperature device *Evertherm*[®]

Validation of *in situ* emplacement

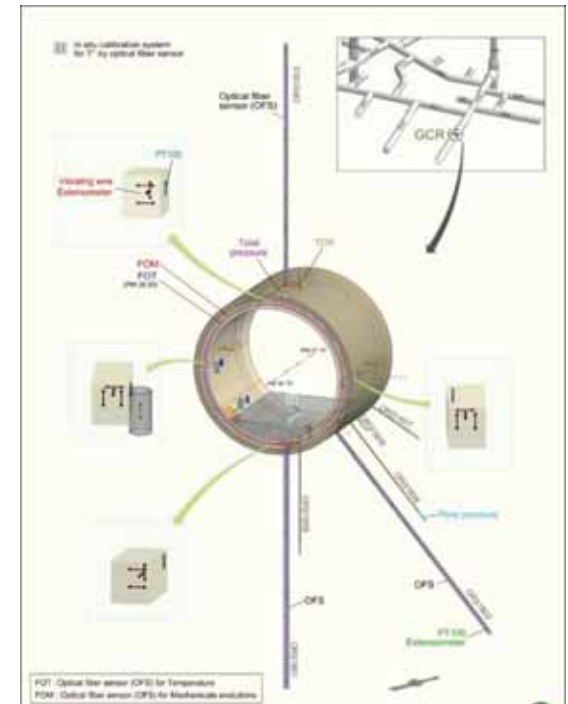
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Pore water pressure



Optical fiber sensors



≈ 130 sensors



IL-LLW disposal cell demonstrator in Andra URL

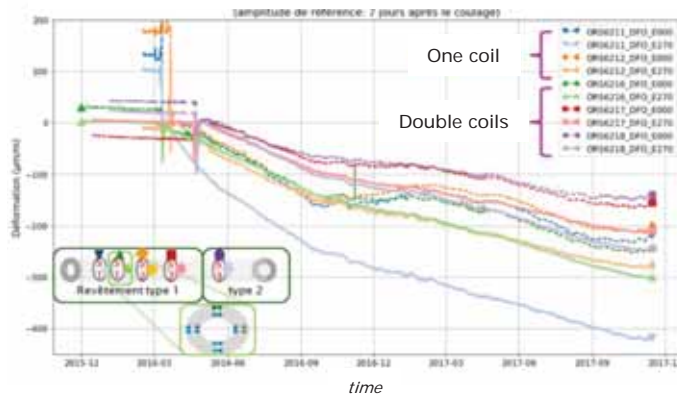
GER Drift : Second monitored section (Rigid support)

Feedback of GCR experiment \Rightarrow 2 monitored sections GER

- Improved sensor implementation in the rock/concrete support/cladding
 - \approx 230 sensors
 - 2 types of Optical Fiber connections (plug: fast/ splice: robust)
- Comparizon of technologies
 - Example of strain measurements
 - 2 types of Vibrating wire extensometers
 - 2 types of Optical fibers

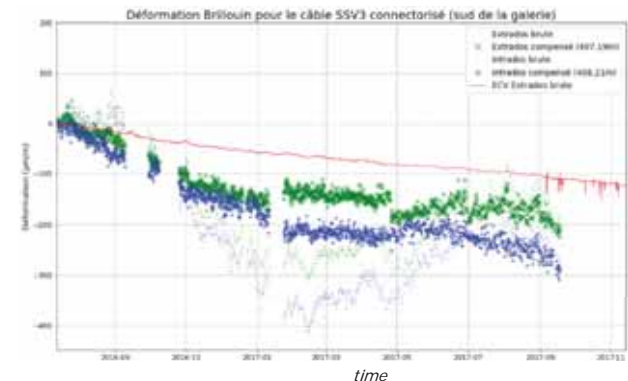


Strain measurements for different vibrating wire extensometers



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Strain measurements different OF vs vibrating wire extensometer

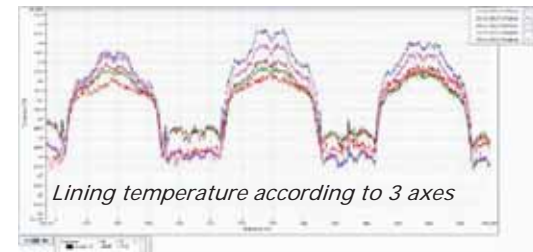
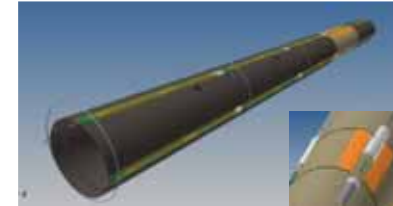


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HLW disposal cell demonstrator in Andra URL Incremental development of optical fiber (OF)

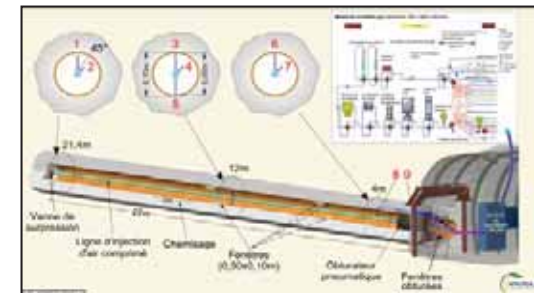
AHA1604 (2017) – 112 meters

- non-intrusive instrumentation by optical fiber on the liner for the monitoring of the thermomechanical behavior
- OF (longitudinally « extrado » on 10 m), 2 OF types
- 1 section for ovalization (distributed OF in spiral)
- Device performed on 15m without break of OF



ALC1605 (2018) – 28 meters

- Implementation test on a heating cell (28 m)
- OF (longitudinally « extrado » on 28 m), 2 OF and 2 fixing methods
- 2 sections for ovalization (distributed OF in spiral resistant to 90°C) + Vibrating wire extensometers
- One section for chemical measurement (gas and water)



HLW disposal cell demonstrator in Andra URL 2019 - Full scale demonstrator AHA1605

Objectives

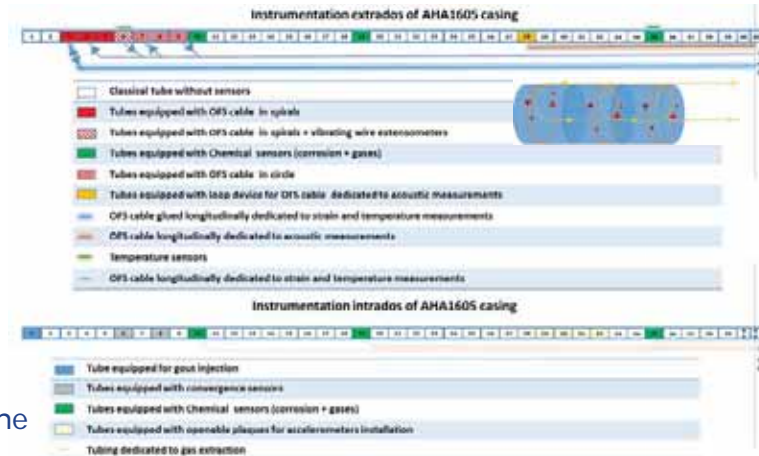
- Demonstrate Andra's ability to monitor THMC parameters of HLW disposal cell (80 m length) representative to HLW repository zone (industrial pilot phase)
- Test, improve and validate sensor's installation procedures
- Provide data to enhance data fusion methods

Sensors

- **Temperature**
 - Distributed OF (longitudinally)
- **Strain**
 - Distributed OF (longitudinally and in spirals)
 - Vibrating wire extensometer
- **Chemistry (extrados & intrados casing)**
 - Gaz (O₂, H₂), water properties (pH, EH),
 - Corrosion (new technologies)
- Evolution of the **damaged zone** (before and during the excavation)
 - Geophisic methods (acoustic, electric)

Additional methods

- **Robot equipped with sensors (T, H₂, ...)**



Data management of Andra URL

A complete and robust system since 2002

Basic data Acquisition

SITE WORK
Excavated galleries, drilled boreholes, scientific operations

ANALYSIS MEASUREMENTS OBSERVATIONS

SAMPLING
Soils, fluids, environmental conditions

MONITORING
Data acquired from sensors on several sites

- Matisa/Neuville Matisa Center
- Underground Research Laboratory
- Piezometric network
- environmental network of OPE
- Marc Trest project (Switzerland)

GEOSCIENCES
Web application to access information from GEO database

- Visualize information related to works, drill and scientific operations
- Visualize hydrological, hydrogeochemical, geological, geochemical and environmental data
- Plotting functionalities
- Search functionalities for samples, analysis files ... with specific criteria
- Display statistics

GEOSCOPE
Software to access information from SAGD database

- 2D/3D display with hyperlinks and sensors localizations
- Viewing time measurements on a graph for a secude or group of sensors
- Viewing the table of values
- Qualitative/disqualification
- Export data to various formats
- Links to documents (calibration, report, drilling file, installation reports...)
- Logbooks

Basic & Reference data storage

1 300 boreholes
9 700 scientific operations
4 300 daily reports
> 63 600 solid samples
> 14 140 fluid samples

Data acquisition and management system (SAGD)

20 000 measure points
2.7 billion of values

NOVA (GIS)
Software specialized in visualization of georeferenced data

- Filters: Entities can be requested with specific conditions (simple or/and spatial queries)
- Styling: Geographical data does not inherently have any visual component. It is therefore necessary to apply a style to data to visualize these data, i.e. to define the color, thickness and other visible attributes used to render data on a map.
- Processing: operation on the topology, aggregations, statistics...
- Data caching: The map server generates on the fly all the images needed for a map during a query by a user
- Security management: It is possible to define users and assign them read / write rules on the different data available on the server.

Management and data visualization

Monitoring in Andra URL Synthesis

A large feedback of 15 years of development to support licensing application of Cigéo

- A robust level of knowledge already acquired
 - THMC sensor: nature (redundancy, complementarity), number, location, resolution, sensibility, fiability, emplacement in different media...
 - Data management system
- To propose a panel of tools and means of monitoring
- To be implemented and optimized during the pilot industrial phase
 - Further development of monitoring in the URL with future technological demonstrator (disposal cells, seals...) 2019-2015
- Consistent with international feedback from other URLs: Mont-Terri, Aspo, Grimsel, HADES, Horonobe, Onkalo...
- Consistent and/or complementary with feedbacks from other domains: nuclear plants and nuclear facilities (incl. decommissioning), dams, railway and road tunnels....



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Monitoring in Andra URL to be continued...

To improve monitoring techniques

- Gas: Raman lidar, optical fibers...
- Kinetic of Corrosion: existing sensors to be qualified in situ
- water chemistry: continuous measurements
- Damage zone (extension...): geophysics
- Geometry: development of robots to perform 3D scans and integration of sensor...

To limit cables obtrusion

- Wireless transmission
- Optimization of sensor emplacement

To improve data management

- 4D visualization
- Automatic analysis
- Big data environment...

To innovate

- Muons
- Americium energy sources...

To prepare the link of data management system with BIM of Cigeo

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