Development and Demonstration of monitoring strategies and technologies for geological disposal

safe solutions for radioactive waste

Modern2020

Monitoring Technologies (WP3) Approach and Key Messages

José Luis García-Siñeriz Martínez
& María Rey Mazón
AMBERG INFRAESTRUCTURAS S.A. (SPAIN)

9th April 2019

2nd International Conference on
Monitoring in Geological Disposal of Radioactive Waste

Cité Universitaire, Paris

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

Outline

- Starting point
- Methodology
- Work done
- Obtained results
- Conclusions

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

Development and Demonstration of monitoring strategies and technologies for geological disposal

Starting point

Monitoring Developments for Safe Repository Operation and Staged Closure

Outcomes from MoDeRn Project (2009-2013)

Monitoring: a tool capable of encompassing many different objectives and activities within a radioactive waste management programme.

Focus: **monitoring the near field of the repository**
Objectives: to *check the assumptions* in the long-term safety case
to *support the decision* making process.

Analysis of the capabilities of **monitoring technologies** for repository:

Measurement probes and methods / Data transmission / Energy supply

Results: Technologies exist but **with evident limitations**

Actions to carry out before repository monitoring starts:

1. Adaptation of the technologies to specific monitoring objectives, host rocks and repository concepts
2. Development of technologies for monitoring specific parameters
3. Improvement of the long-term performance.

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

AMBERG INFRAESTRUCTURAS

Starting point

Modern2020 Project (2016-2019)

Several problems identified as of **priority investigation** were addressed in MoDeRn

Overall objective in WP3: conduct research and technical developments on monitoring technologies. The specific objectives were:

- ✓ Improve and combine **Wireless Data Transmission** systems (WDT)
- ✓ Develop alternative **power supply sources** to batteries capable of extending the expected life time of the WDT
- ✓ Research on **new sensors** to measure relevant parameters when suitable probes do not exist or develop new techniques and probes when the existing ones do not comply with the required performance
- ✓ Refine and improve the the most promising **geophysical methods**
- ✓ Establish a **methodology to qualify** the monitoring components of the monitoring system intended for repository use
- ✓ Update the **state-of-the-art on monitoring technology** (Technology Readiness Levels)

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

Methodology

Development and Demonstration of monitoring strategies and technologies for geological disposal

Organisation and flowchart for WP3

WP 3 Partners

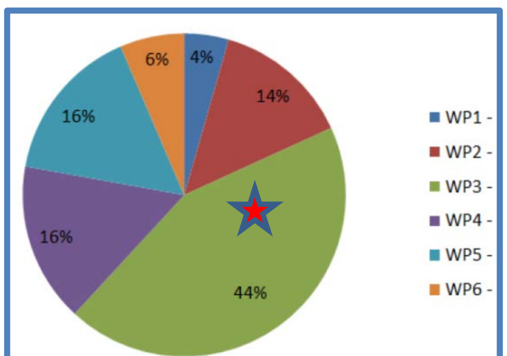
Work distribution

Task 3.1 (Coord.)	Task 3.2 (Wireless)	Task 3.3 (Energy)	Task 3.4 (Sensors)	Task 3.5 (Geophysis)	Task 3.6 (Methodology)
Main: **JL Gª-Siñeriz**	Main: **T. Schroder**	Main: **E. Strömmer**	Main: **J. Bertrand**	Main: **H. Maurer**	Main: **JM. Matray**
Deputy: ***M. Rey***	*Deputy:* ***J. Hart***	*Deputy:* ***J. Hakli***	*Deputy:* ***S. Lesoille***	*Deputy:* ***E. Manukyan***	*Deputy:* ***P. Dick***

Reporting

WP leader: **JL Gª-Siñeriz**
Deputy: ***M. Rey***

Coordinator: **J. Bertrand**
Deputy: ***M. Garcia***



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

Development and Demonstration of monitoring strategies and technologies for geological disposal

Work done

MAIN ACTIONS (Tasks)

- **Task 3.1**: Readiness level of monitoring technologies
  Coordination of research activities and link with the remaining WPs.
  Updating of the Readiness Level for the technologies developed in the project.
  Dissemination of the results.

- **Task 3.2**: Wireless data transmission systems
  Development of wireless data transmission systems (WDT):
  Short range systems based on high and low frequencies
  Combination of short and long range systems to provide a complete data transmission chain from underground to the surface.
  Research on FO combined with wireless data transmission

- **Task 3.3**: Alternative power supply sources
  Development of power supply sources for WDT, alternatives to “traditional” chemical batteries, capable of extending the expected life time.

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

Work done

MAIN ACTIONS (Tasks)

- **Task 3.4**: New sensors

  Development/improvement of several new monitoring tech. tailored to geological disposal:

  FO distributed sensing chains (FBGs, Brillouin, Rayleigh and Raman Scatterings)

  Dew point thermocouple psychrometers

  Non-contact short-range displacement sensors

  Ion-selective electrodes

  THMC sensors

- **Task 3.5**: Geophysical methods

  Improve the most promising methods to promote non-invasive monitoring technique:

  Seismic full waveform inversion technologies

  Develop a monitoring method based on ERT and IPT.

- **Task 3.6**: Reliability & qualification of components

  Development of a qualification methodology applicable to each component of the repository monitoring system. Apply methods and tests to deliberately accelerate the degradation of monitoring equipment while checking its reliability.

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

Obtained results

Detailed results: Session 6, 10th April

- **T 3.2** Current State of the Art of Wireless Data Transmission Systems for Repository Monitoring (Thomas Schröder)
- **T 3.3** Electric Power Sourcing of Wireless Repository Monitoring Sensors (Esko Strömmer)
- **T 3.4** Overview of Optical Fiber Technologies for Radioactive Waste Disposal Site Monitoring (Patrice Mégret)*
- **T 3.5** Geophysical Monitoring of High-Level Radioactive Waste Repositories (Hansruedi Maurer)
- **T 3.6** Methodology for Qualifying the Monitoring Components (Jean-Michel Matray)

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

Obtained results

Posters with more detailed results on New sensors (TASK 3.4):

- ✓ **Development of thermocouple psychrometers for water content measurement**
- ✓ **SmartCell – Pressure and Humidity measurement for EBS**
- ✓ **Techniques for non-contact displacement measurement**
- ✓ Polymer Optical Fibre (POF) Bragg gratings for Nuclear Waste Repositories
- ✓ Toward long-term hydrogen monitoring with specialty optical fibers
- ✓ Qualifying distributed strain sensing systems based on optical fiber for the monitoring of radioactive waste repository
- ✓ Estimation of the initial dry density distribution of granulated bentonite mixtures in the Full-scale Emplacement experiment by means of active distributed temperature sensing
- ✓ Calibration of heated fiber-optic cable for monitoring dry density and water content in granulated bentonite mixture in the Full-scale Emplacement experiment
- ✓ Distributed pore pressure monitoring with a DOFS-system – Prototype test

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

Obtained results

Posters with more detailed results on other tasks:

- ✓ Development of a wireless relay system for monitoring of geological disposal using low- frequency electromagnetic waves
- ✓ Long distance data transmission through the underground: lessons learned from two demonstrators
- ✓ Wireless energy transfer through electrical conductive media
- ✓ Wireless energy transfer with data transfer add-on through low-conductivity host rocks
- ✓ Thermal energy harvesting from High-Level Waste
- ✓ Anomaly detection algorithms as a support for the geophysical monitoring of high-level radioactive waste repositories
- ✓ Demonstration of a two-staged wireless transmission chain out of the LTRBM borehole to the surface of the Tournemire plateau

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

Obtained results

Key messages:

✓ **Task 3.2 Wireless data transmission systems**

Understanding, design and demonstration of specific solutions that allow energy efficient transmitting data through components of the EBS or the host rock. Different technological solutions have been developed and tested under realistic conditions:

Frequencies: 4 kHz - 2.4 GHz

Transmission distances: 0.1 m - 275 m

✓ **Task 3.3 Alternative power sourcing technologies**

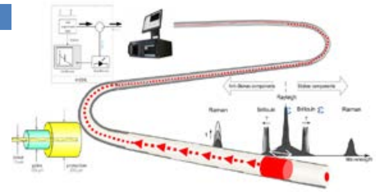
Understanding, design and demonstration of power sourcing technologies for wireless units inside repositories to substitute the chemical batteries: Thermoelectric energy harvesting around the high-level waste, wireless energy transfer through the natural and engineered repository barriers, and radioisotope thermoelectric generator type nuclear batteries.

In addition, potential technologies for an interim energy storage to enhance the applicability of these energy sourcing technologies were explored.

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

Obtained results

Key messages:



✓ Task 3.4 New sensors

Development of **custom-made fiber Bragg gratings** (FBGs) to adapt an irradiation sensor, improve a hydrogen sensor and develop new pH sensors.

Development of an **optoelectronic sensing chain**, using two or three scattering methods (Brillouin, Rayleigh and Raman) to provide distributed measurements of four parameters : temperature, strain, hydrogen and radiation.

Obtain a **fiber-optic distributed sensing solution of thermal conductivity**, density and water content in the EBS by means of heatable fiber-optic cables. Advancing on having fiber optic pressure cells for boreholes.

Production of **new sensors to measure suction based on thermocouple psychrometers** operating with the dew point method.

Study of more promising **non-contact** techniques for short-range **displacement sensors**.

Adaptation of **ion-selective electrodes** to measure Cl, Na and pH.

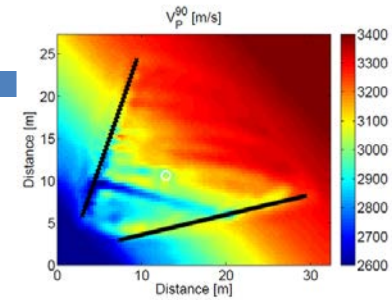
Development of a **smart cell by combining Thermal Humidity Mechanical Chemistry** (THMC) sensors.

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

AMBERG INFRAESTRUCTURAS

Development and Demonstration of monitoring strategies and technologies for geological disposal

Obtained results



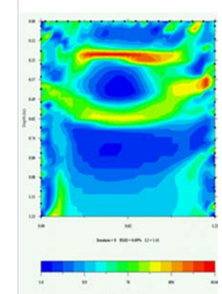
Key messages:

✓ **Task 3.5 Non-invasive monitoring based on geophysical techniques**

Seismic full waveform inversion (FWI) technology further developed, such that it can be applied to realistic repository monitoring problems

Differential tomography algorithms established that allow subtle changes of the physical properties in and around a repository to be monitored

First steps towards **anomaly detection algorithms** performed that allow quick detection of changing conditions



Geoelectrical and induced polarization tomography algorithms developed and tested that allow electrical properties to be determined

Constitutive relationships between electrical parameters and geotechnical parameters (e.g., temperature and moisture content) established.

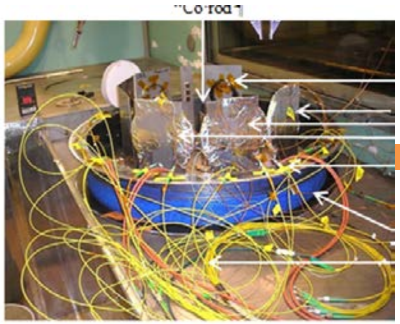
This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n° 662177

AMBERG INFRAESTRUCTURAS

MODERN 2020

Development and Demonstration of monitoring strategies and technologies for geological disposal

Obtained results



Key messages:

✓ **Task 3.6 Methodology for qualifying monitoring components**

Multi-stage analysis for the development of a qualification process for selecting and testing the monitoring components:

- Study of transferable experience from other industry fields
- Analysis of similar case studies operating in conditions similar to repositories

Proposal of a common multi-stage methodology for qualifying monitoring components of the measurement chain (sensor, connecting cable and/or wireless system/controller) at a Deep Geological Repository (DGR).

✓ **Task 3.1 Readiness Levels of technologies**

A practical way of asses the maturity of a technology is to assign a TRL (Technology Readiness Level). The proven NASA and DoD technology assessment model was used: 1 (basis principles) to 9 (successfully proved under operational conditions).

All the technologies started with TRL from 3 to 6 and progressed up to TRLs of at least 7 (prototype demonstrated under operational environment) or are being qualified in a specific demonstrator (TRL 8).

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

AMBERG INFRAESTRUCTURAS

Conclusions

There is margin to perfect and still challenges to face:

Long range wireless transmission systems:

- Energy efficiency, as it can present a limiting factor the amount of data that can be transmitted;
- Long-term power supply sources;
- Potential interactions of transmitter antennae with magnetic permeable materials and the effect of heterogeneities;
- Data transmission beyond 275 m of distance;
- Development of data processing methods to improve overall performance.

Short range wireless transmission systems:

- Tuning of the antennae;
- Increase of packaging and automation.

Follow-on activities:

- Integration and verification of the energy sourcing parts;
- Overall design of the monitoring systems with several wireless sensor nodes;
- Improvement of wireless energy transfer;
- Integration of the bi-directional data transfer:

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

Conclusions

There is margin to perfect and still challenges to face:

Fiber Optics: Raman scattering for temperature measurement needs to suppress dramatic radiation impact, further improvement is feasible for strain measured using Brillouin or Rayleigh scattering. A combination of Al and Ge doped fibers is needed to measure the radiation spatial distribution on the MGy range. Proof of concept for Hydrogen sensing has been obtained but there is still a lot of research to assess the lifetime of the sensitive element. pH sensing is feasible but should be tuned to the range 11-13. The FO cable to measure bentonite properties through distributed Raman temperature still require work to meet the readiness level.

New sensors: the dew point psychrometer, the THMC smart cell and the ion-selective electrodes to measure Cl, Na and pH need to be properly validated under conditions similar to those expected in the repository. The identified non-contact techniques for short-range displacement sensors should be implemented in practice in order to improve the readiness level.

Geophysical monitoring: further research is required for making these technologies more applicable and complementing the actual tools for repository monitoring.

Long-term reliability: reliability and radiation hardness should be extended at least to the wireless solutions. Several measures are applicable: redundancy, anticipating drift margins and component derating, or qualification and screening. Cost evaluation needs to be included for selection.

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

Conclusions

There is margin to perfect and still challenges to face:

- The developed **guidelines for multi-stage qualification** methodology applicable to each component of the monitoring system needs to be applied systematically in order to ascertain its validity and improve it if required.

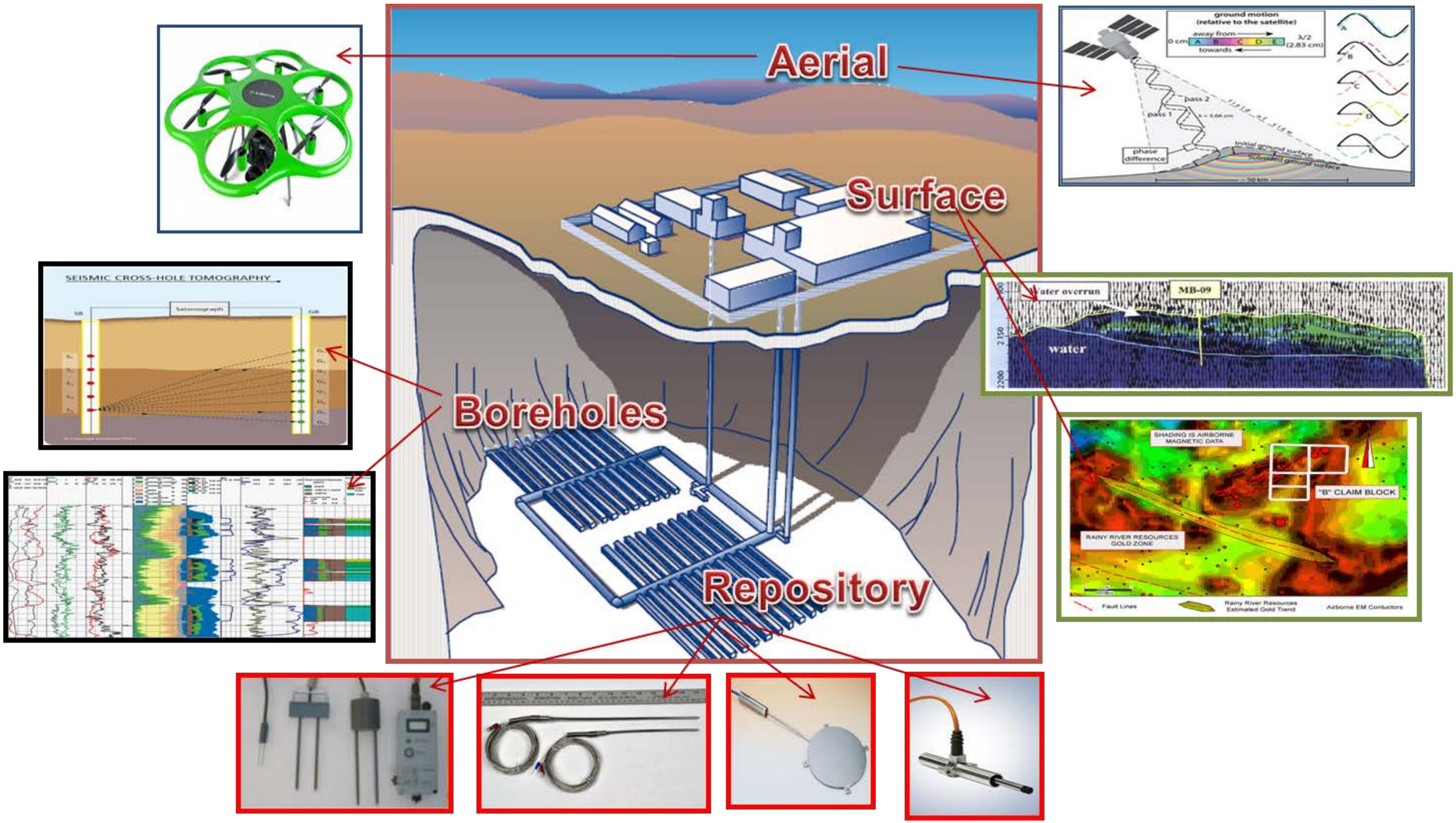
- Other topics: the new monitoring techniques provide much more information (huge amounts of digital or analog data) that the standard **data acquisition systems** can not properly handle. Furthermore, the fast spreading of the BIM (Building Information Modelling) technologies to all kind of civil works will demand to integrate the monitoring data as part of the **digital model** of the future repository.

- Although the list of potential improvements is large it does not mean that the work done was unsatisfactory, quite the contrary. The R&D teams founded thanks to Modern2020 are currently capable of developing the required activities, but they **need additional funds and time**, being a shame not taking advantage of the created resources.

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

Development and Demonstration of monitoring strategies and technologies for geological disposal

Questions?



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