Development and Demonstration of monitoring strategies and technologies for geological disposal

safe solutions for radioactive waste

Modern2020

Current state of the art of wireless data transmission systems for repository monitoring

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General background

Wireless technology in repository monitoring

Why applying wireless data transmission technologies?

- Many sensor are located behind safety relevant barriers, and wireless technologies allow data transmission without impairment of the barrier function

Why is RT&D on data transmission necessary?

- Wireless technologies are used in many applications, however, for the application in disposal monitoring, specific challenges need to be addressed:
  - In most present applications, high frequency radio waves are applied. These can easily be transmitted trough the air, but are strongly attenuated in solid media like host rocks or components of the engineered barrier system (cementitious materials, bentonite, etc.)
  - The long monitoring periods that are anticipated, together with the inability to access sensor nodes, require energy efficient solutions

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Overview Modern2020 Task 3.2

Task 3.2: Wireless data transmission systems

Contributors: *Amberg, Andra, Arquimea, ENRESA, EURIDICE, IRSN, NRG*, RWMC, VTT*

Subtasks:

1. Improve existing **short range** (tens of meters) wireless systems based on high or medium frequencies (*Arquimea, ENRESA, IRSN & VTT*)
2. Improve existing **long range** (hundreds of meters) wireless systems based on low frequencies (*Andra & RWMC*)
3. Evaluate the use of a **combination of** different range wireless **systems** to provide a complete data transmission solution (*Amberg, Andra, Arquimea, ENRESA, EURIDICE, IRSN, NRG, RWMC & VTT*)

Public Deliverable D3.2:

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)

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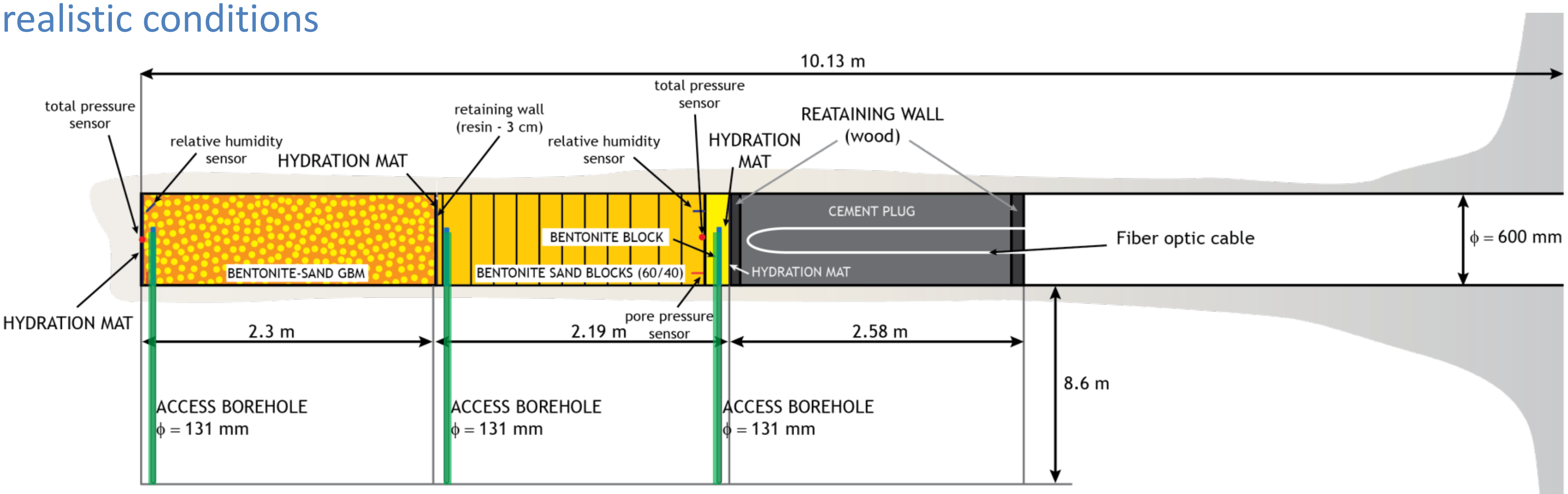
* *task leader*

Short range wireless data transmission

Implementation of a Wireless Testing Bench (WTB) facility at the Tournemire URL

Objective: Providing a test facility at Tournemire that allows to test wireless solutions under realistic conditions



Main outcomes:

- WTB is operational since July 2017.
- WTB hydration started in November 2017.
- Arquimea, Amberg, and Andra have performed several tests in the WTB.

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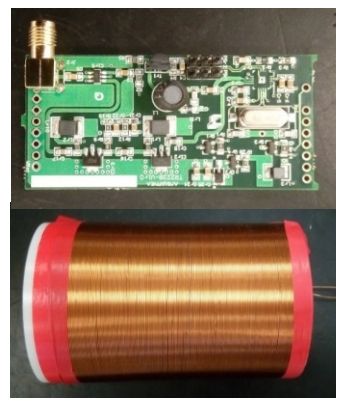
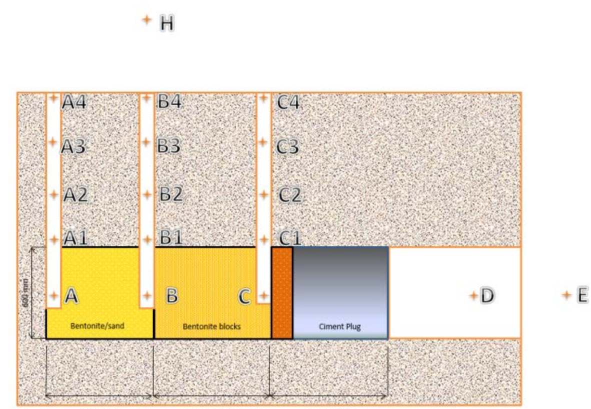
Short range wireless data transmission

Development, testing, and improvement of three short range systems

- Transmission distance: 4 - 23 m
- Transmission frequency: 4 kHz (Amberg), 125 kHz (VTT) or 2.2 MHz (Arquimea)

Main outcomes:

- Amberg and Arquimea performed successful tests in the WTB (Tournemire) over different distances, allowing to select best antenna and amplifier configuration, and to assess minimal signal strength for radio link under (partially) saturated condition.
- VTT performed successful tests in Onkalo & Espoo underground laboratory (granite).

From left to right: Testing inside the WTB access boreholes (left) and at the access gallery (right) at Tournemire(Amberg); Arquimea's receiver and antenna; receiver & transmitter positions in the WTB tested by Arquimea

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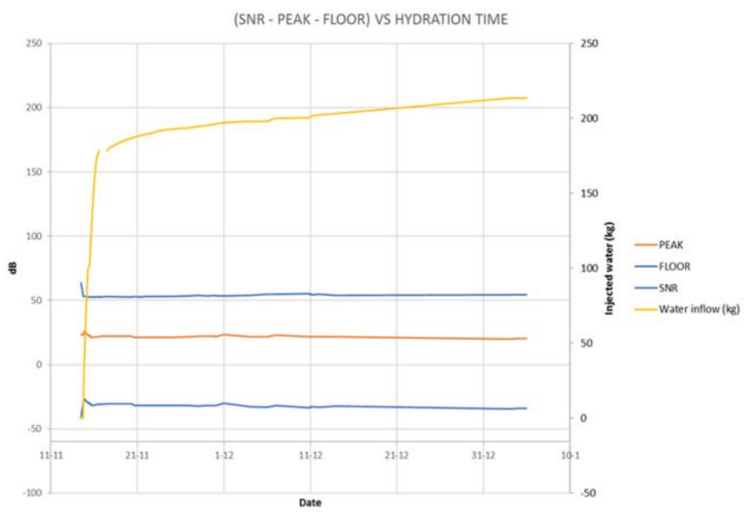
Short range wireless data transmission

Development, testing, and improvement of three short range systems

Main conclusions:

- Wireless data transmission over distances of 4 - 23 m through granite and (partially) saturated bentonite and clay rock has been demonstrated.
- The solutions cover a wide frequency range from 4 kHz to 2.2 MHz, each having its own benefits.
- Two of the three solutions were integrated in a wireless sensor unit (WSU) with versatile features that can be adapted to different cases of use.



Measured signal strength after hydration of the WTB (Arquimea)

Transmission test at Posiva's ONKALO-facility (VTT)

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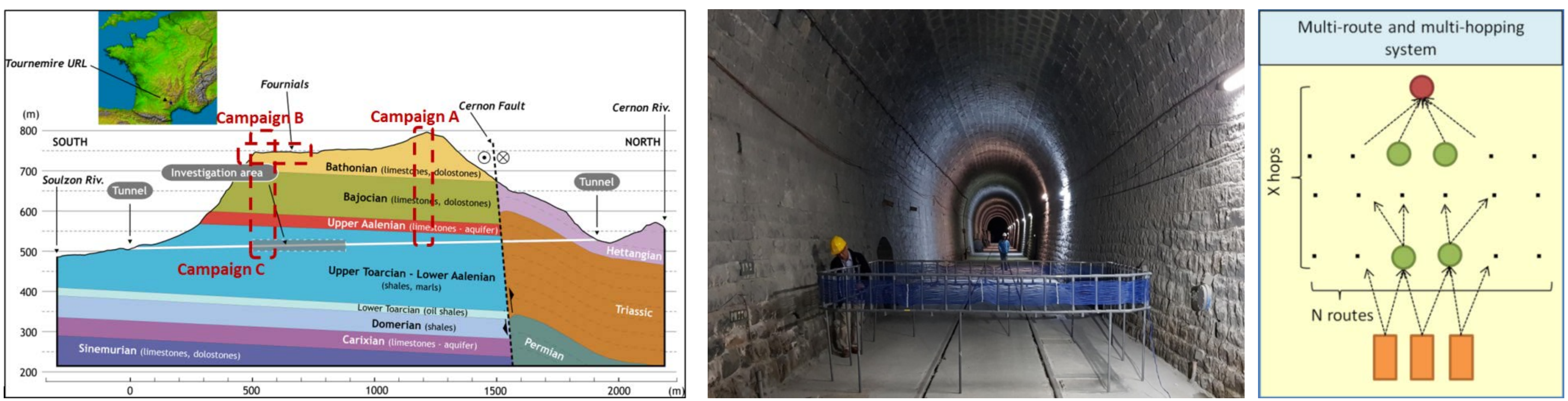
Long range wireless data transmission

Testing and improvement of three long range systems

- Transmission distance: 95 - 275 m, single (Andra, NRG) or multi-staged (RWMC)
- Transmission frequency: 8 - 9 kHz

Main outcome:

- Successful signal and data transmission experiments were performed by Andra & NRG in Touremire from the tunnel to the earth's surface (transmission distance 275 m).
- RWMC demonstrated a multi-staged **relay system** over 95 m at the surface; a 6-months endurance test with >4,000 transmissions including simulated failure of single nodes was performed without loss of data.



From left to right: Cross section of the Tournemire tunnel and indicated test locations (Andra); Andra's transmitter antenna in the Tournemire tunnel; Set-up of RWMC's multi-route and multi-hopping system

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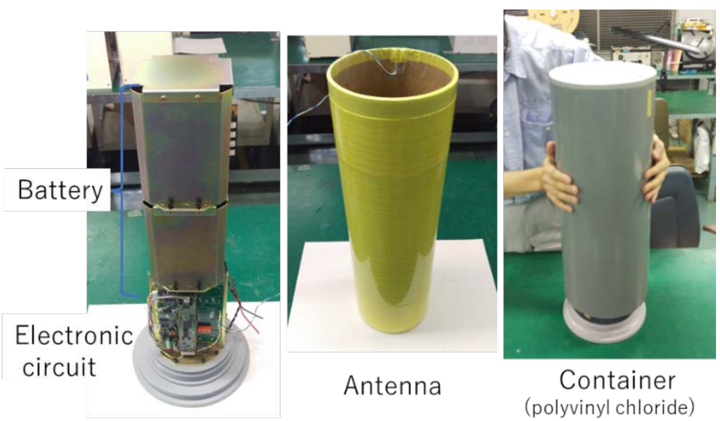
Long range wireless data transmission

Testing and improvement of three long range systems

Main conclusions:

- Long range data transmission was successfully demonstrated
- Good understanding of basic principles allow to custom-tailor energy efficient long range solutions that requires only 5 mWs/bit to bridge 275 m.
- A robust **multi-staged relay system** was demonstrated providing an significant alternative to single staged systems, were applicable.
- The reliability of the relay system was improved by developing a **multi-routing system** that allows to change the transmission route in case a device fails.



Left: RWMC's relay system; right: NRG's transmitter antenna in the Tournemire tunnel (bottom) and receiver antenna on top of the Tournemire plateau (top)

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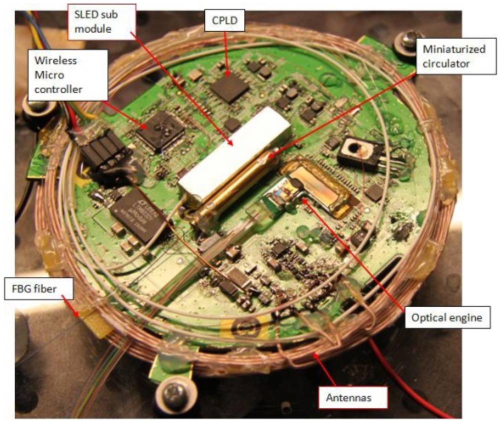
Combined wireless systems

Testing and evaluation of five combined systems

- Two **wireless sensor units** (WSUs) (Amberg, Arquimea).
- A fiber optic system (***mINT* fiber interogator**) in the Belgian supercontainer's concrete buffer: 2.4 GHz/0.1 m (EURIDICE).
- A vibrating wire sensor unit (**VSU**) for borehole monitoring: 5-10 m/8.5 kHz (Andra).
- A **combination** of a **short- and long range** wireless transmission system (Amberg, Arquimea, IRSN, NRG): 2.2 MHz/4 m + 8.7 kHz/275 m.



From left to right: Andra's wireless vibrating sensor node; Andra's receiver node at the WTB borehole in Tournemire; First prototype of the mINT fiber interogator, to be placed inside a supercontainer's buffer (EURIDICE)

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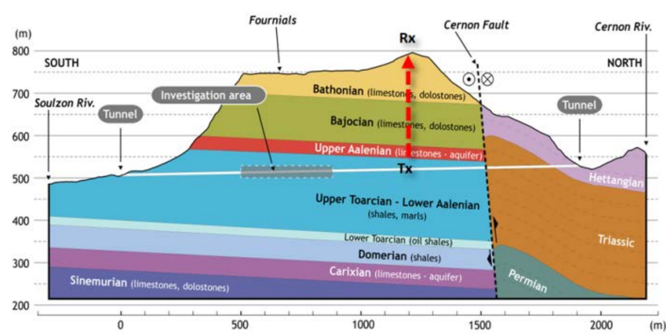
Combined wireless systems

Testing and evaluation of five combined systems

Main results:

- The ***mINT* fiber interogator** was successfully linked with a commerical IEEE 802.11 solution, allowing to transmit >600 kB/s through a concrete wall of >0.1 m.
- After testing in the WTB, two wireless **VSUs** were placed in the LTRBM borehole (WP4.3), transmitting data every six hours since July 2018 without errors.
- For the combined demonstrator, the technical options to link the short- and long range wireless transmission systems were outlined, and field characterization measurements were performed that allows to custom-tailor the long-range system to the specific conditions as present in Tournemire (demonstration part of WP4.3).



From left to right: Andra's wireless vibrating sensor node; Cross-section of Tournemire tunnel and location of NRG's long range transmission system; Receiver antennas for site characterization measurements at the Tournemire plateau (NRG)

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Current state of the art

Overview on current experience on wireless data transmission in URLs

Distance	Transmission mode	Energy efficiency [mWs/bit]	Data rate [bit/s]	Transmission frequency	Host rock/barrier (location)	Organization	Reference
0.1 m	Resonant cavity antenna	<0.002	>600'000	2.4 GHz	Concrete buffer	EURIDICE	Modern2020
4 m	Electric dipole antenna	~0.5	1200	169 MHz	Bentonite/shotcrete (Grimsel URL)	AITEMIN	MoDeRn
4 m	λ/4 loop antenna	0.75	38'400	2.2 MHz	(Partially) saturated bentonite (Tournemire URL)	Arquimea	Modern2020
5 - 10 m	Magnetic loop antenna	~0.5	75	8.5 kHz	(Partially) saturated bentonite (Tournemire URL)	Andra	Modern2020
23 m	Magnetic loop antenna	1000	1	125 kHz	Granite + Air (Espoo research hall)	VTT	Modern2020
25 m	Magnetic loop antenna	7	75	8.5 kHz	Sedimentary rock (Meuse / Haute-Marne URL)	RWMC/Andra	[1]
30 m	Magnetic loop antenna	1	1600	4.0 kHz	(Partially) saturated bentonite (Tournemire URL)	Amberg	Modern2020
30 m	Magnetic loop antenna	500	20	0.6 kHz	Bentonite/shotcrete (Grimsel URL)	MISL	[2]
225 m	Magnetic loop antenna	1100	25 - 100	1.8 kHz	Boom Clay & saturated sandy aquifer (Hades URL)	NRG	MoDeRn
250 m	Magnetic loop antenna/relay system	3710	75	8.5 kHz	Sedimentary rock (Horonobe URL)	RWMC	[3]
275 m	Magnetic loop antenna	2880	75	8.5 kHz	Limestone & Shale (Tournemire URL)	Andra	Modern2020
275 m	Magnetic loop antenna	5	30	8.7 kHz	Limestone & Shale (Tournemire URL)	NRG	Modern2020

[1] Suzuki, K., et al,"*Development of Miniaturized Wireless Transmitter and Borehole type Receiver with Low Frequency Magnetic Waves*" Proc. of the International Conference and Workshop of MoDeRn Project, Luxembourg, 19 – 21 March 2013
[2] T. Spillmann, "*Application of wired, wireless and non-intrusive standard monitoiring techniques. The TEM Project at the Grimsel Test Site - ANNUAL REPORT*" Nagra Arbeitsbericht NAB 08-52, Wettlingen, Switzerland, 2008
[3] Tsubono, K., et al., "*Development of Wireless Monitoring Systems for Geological Disposal*" Proc. of the 6th East Asia Forum on Radwaste Management, Osaka, Japan, November, 2017

Conclusions

- Several data transmission technologies have been developed and tested, covering transmission distances from 0.1 m to more than 275 m.
- Experiments have been performed under relevant conditions, e.g. in the Tournemire WTB, from the Tournemire tunnel to the surface, and in VTT's underground testing facility.
- Where possible, the energy need was established, allowing to evaluate the applicability on the long term & necessary supply of power.
- On the short range, several options have been studied, with transmission frequencies ranging from several kHz to few MHz.
- Long range data transmission makes use of very low frequencies in the kHz-range, and data transmission has been achieved at very low power levels (5 mWs/bit).
- Five combined solutions were presented, showing that the research is successfully moving forward from development of individual technical components to integrated monitoring solutions (WSUs).

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Conclusions

- Signal attenuation through different kind of solid media is sufficiently understood. For several frequency ranges, solutions are demonstrated and their performance are quantified. This allows to choose a suitable technology for each application case.
- A structured workflow has been developed and applied that allows to develop energy-efficient, location specific solutions for long range data transmission.
- Technologies are in different states of maturity, with the most advanced providing ‘all-in-one’ solutions, allowing to connect different types sensors to a wireless sensor unit (WSU).
- All technologies will benefit from further optimization, however, the maturity of the most systems is far enough to be applied in URL demonstrators. However, water-tight packaging, long-term reliability & power supply, interactions with metallic parts (other monitoring devices, components of the EBS), and testing under realistic conditions are critical aspects for a successful application.
- Further development of long-term solutions (>>10 years) need additional input with respect to requirements on measurement intervals, and data transfer.
- Evaluation of the two-staged combined solution shows that further efforts are necessary to plan and implement standardized interfaces for autonomous wireless monitoring solutions.

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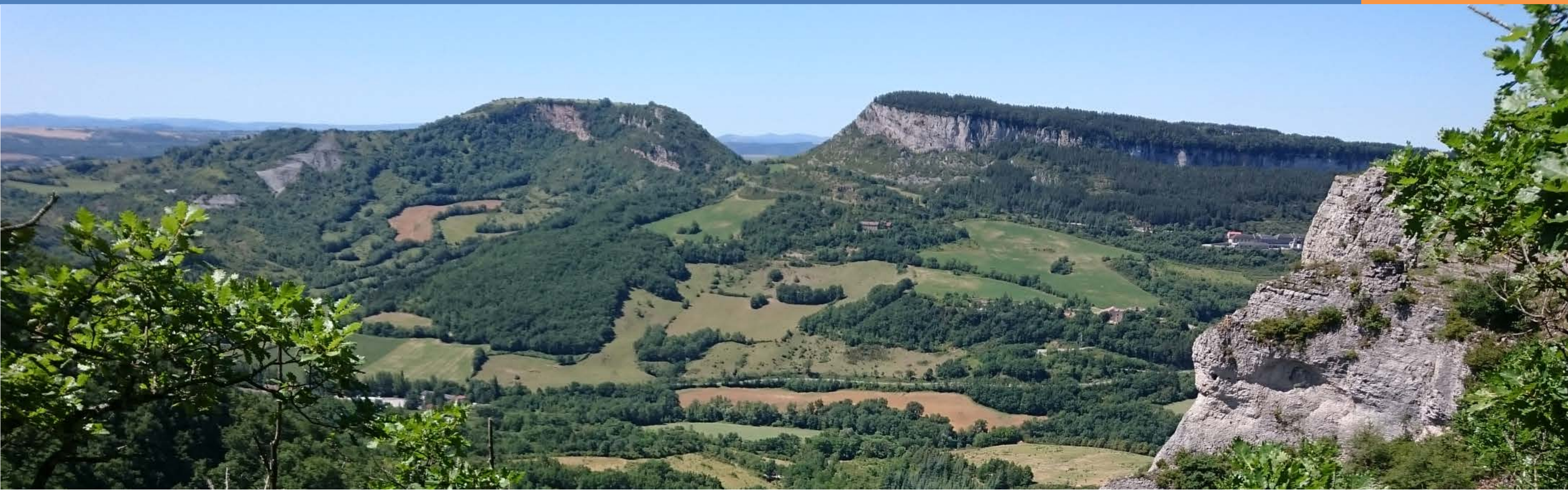
Thank you!



QUESTIONS?

Poster presentations related to Task 3.2:

- J. Eto, M. Kawakubo, Y. Suyama, N. Sugahara, *Development of a wireless relay system for monitoring of geological disposal using low- frequency electromagnetic waves*
- 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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NRG