Wireless in nuclear applications

EU project Modern2020 – wireless technology for repository monitoring programme

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

Overview

- Introduction
  - Geological disposal in RWM and monitoring the repository, challenges.
  - Modern 2020 project
- Wireless for repository, state of the art
- HF techniques
- LF techniques
- Combined solutions
- Power supply alternatives
- Questions?

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Geological disposal in RWM

Currently, geological disposal is internationally assumed to be the only feasible option for the safe disposal of long-lived radioactive waste in the long term, in order to protect man and the environment. The long-term safety of geological disposal is currently demonstrated by the internationally used methodology of the "Safety Case".

Geological disposal aims to isolate and contain waste through appropriate design and operation of the facility (The repository), through sitting in a suitable geological environment, and by using an appropriate engineered barrier system (EBS). The EBS consists of man-made components of the multi-barrier system including, as appropriate, the waste form, the waste containers, the buffer, the backfill, the repository seals and other engineered features. Besides the EBS, geological barrier(s) as the host rock that enclosed the facility, isolates the waste from the biosphere, contains and retards radionuclides and maintain the protective function of the EBS. Any disposal concept and its engineered barriers must be tailored to the specific geological environment in which it is to function.

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Monitoring the repository

Monitoring during the implementation of geological disposal can be used to support the scientific and technical programme, and can be used to build societal acceptability. Identified monitoring objectives/roles in support of the scientific and technical programme include:

- To build confidence in the long-term safety case, including demonstration that the facility is evolving as expected.
- To build confidence in construction and operation.
- To demonstrate appropriate environmental performance.
- To maintain nuclear safeguards.
- To support stakeholder acceptability.
- To provide information for making management decisions (e.g. retrievability).

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Challenges for monitoring the repository

- Can in situ monitoring systems provide several decades of maintenance-free, reliable monitoring without intervention?
- Can information be collected on slow processes when the timescale for monitoring is limited, compared with the expected evolution of the disposal system?
- Can monitoring technologies withstand environmental conditions within the repository, which may include high mechanical and/or hydraulic pressure, chemically corrosive groundwater, elevated temperatures, and irradiation levels of several Gy/hr near waste packages?
- Can monitoring systems be successfully implemented without undermining the integrity of engineered and natural barriers (for example, through the use of non-intrusive techniques and/or wireless data transmission)?

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Wireless technology for repository monitoring programme

REQUIREMENTS :

- ✓ Buried operation with no access
- ✓ Avoid cables and minimize intrusion
- ✓ Power supply and data collect from more than one parameter (standard sensors)
- ✓ Lifetime >10 years and 100 years desirable
- ✓ Minimize power consumption (low reading frequencies)
- ✓ Move from batteries to other alternatives
- ✓ Withstand the expected conditions (T+H+M) + Radiation
- ✓ Transmission distance 300 - 500 m (deposition galleries – surface)
- ✓ Host rock: Clay, crystalline rock or salt

KEY FACTORS:

- ✓ Available room is limited at the deposition galleries, THM conditions are worse too.
- ✓ Bigger room at access galleries.

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Wireless technology for repository monitoring programme

The MODERN2020 Project

- Project full title: Development and Demonstration of monitoring strategies and technologies for geological disposal
- 28 partners from 12 countries (FR, ES, CZ, DE, IT, CH, BE, UK, NL, FI, JP & SE)
- 6 WPs
- 4 years
- 8.678 M€ budget and 6 M€ EU support.
- Started 01/06/2015 to be finished by end of May 2019

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Wireless technology for repository monitoring programme

WP3: R&D on monitoring Technologies

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Deputy: ***M. Rey***

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IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

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Development and Demonstration of monitoring strategies and technologies for geological disposal

Wireless technology for repository monitoring programme

State of the art

Mine communication: low-frequencies for in-mine and through the earth up to the surface. Example: 1-3 kHz with 8,7m loop diameter antenna, distance 180m.

Military communications: submarines ELF transmitters 20-200 Hz, rock-phones 5 kHz with 3,8m loop diameter antenna, distance 200m, 30 bits/s.

Organization /country	host rock /overlying rock	purpose of installation /experiments	experimental conditions	max. distance	results
MISL (Canada) at HADES URL	Boom Clay (45 m) sandy aquifer (180 m)	test of battery-supplied military communication equipment	9.1 m loop antenna, coaxial constellation, top-down constellation (receiver in HADES)	225 m	signal transmission was realized; signal attenuation* was about 10 dB**
MISL/ Nagra at Grimsel Test Site	crystalline rock (80 m) main access tunnel (100-250 m)	test of battery-supplied military communication equipment	9.1 m loop antenna, top-down constellation (transmitter at surface, receiver in access tunnel)	300 m	signal transmission was realized; signal attenuation estimates were near the error bounds (1.8 ±1.8 dB) **

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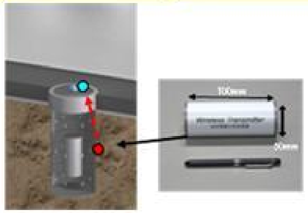
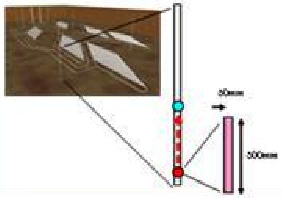
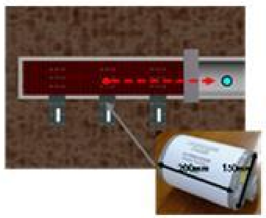
Wireless technology for repository monitoring programme

State of the art (Repository)

Since 2002 RWMC (JP) is working on wireless data transmission systems, using low frequency magnetic waves (1 kHz to 10kHz) for data-transmission on several scales (5 m to 30 m, 30 m to 100 m or around 300m) through crystalline rock or EBS components (e.g. bentonite).

Characteristics	Figure	Objectives
Size: L100mm × φ 50mm T. distance:20m Sensors: One inside +one outside Lithium batteries Data bit rate: 75bps		Repository based monitoring
Size: L 200mm × φ 50mm T. distance:20m Sensors: One-two outside Lithium batteries Data bit rate: 75bps		Repository based and borehole based monitoring
Size: L 200-350mm × φ 200mm T.distance:~30m Sensors: Up to 10 outside Lithium batteries Data bit rate: 75bps		Repository based and borehole based monitoring

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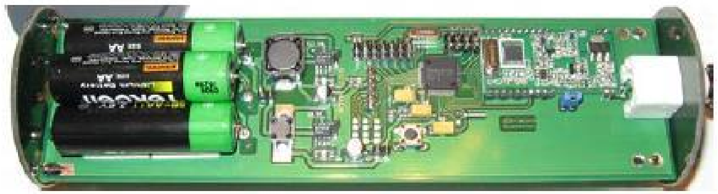
Wireless technology for repository monitoring programme

State of the art (Repository)

IBeWa: 433 MHz for in-mine using batteries as power supply and external aerial.

Lithology	Locality	Result
rock salt, Werra-Member (Na1)	Mine Merkers	distances up to 200 m
rock salt, Staßfurt-Member (Na2)	ERA Morsleben	distances up to 150 m
potash salt, Staßfurt-Member (K2)	Mine Teutschenthal	distances up to 100 m
argillaceous, detritus rich soil	City of Freiberg	distances up to 15 m
Freibergian gneiss (PR3F)	Mine Reiche Zeche, Freiberg	distances up to 3 m

Higher electrical conductivity



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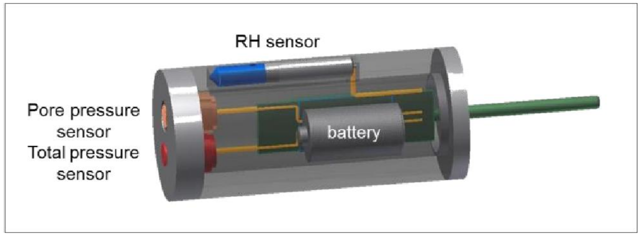
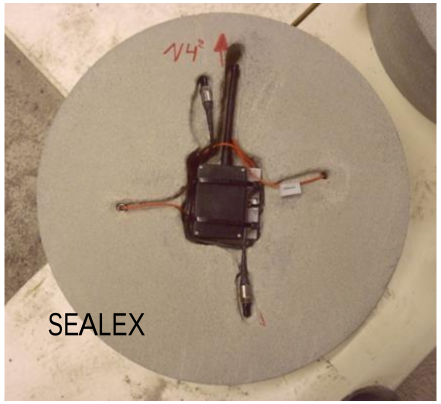
Wireless technology for repository monitoring programme

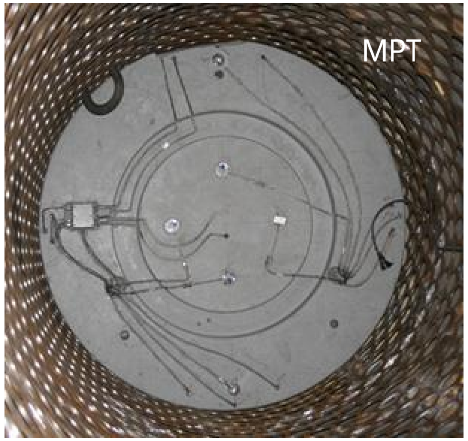
State of the art (MoDeRn project and after)

Organization /country	host rock /overlying rock	purpose of installation /experiments	experimental conditions	max. distance	results
NRG (Netherlands) at HADES URL (Belgium)	Boom Clay (45 m) sandy aquifer (180 m)	experimental measurement within MoDeRn	3.8 m loop antenna, coaxial constellation, 500 Hz to 5 kHz	225 m	under testing; signal transmission around 1 kHz was realized
AITEMIN (SP) at Grimsel Test Site (Switzerland)	Crystalline rock, concrete plug and bentonite buffer	experimental measurement within MoDeRn	Omnidirectional dipole antenna, 169 MHz	~5 m	signal transmission was realized;
AITEMIN (SP) at Tournemire Test Site (France)	Clayish rock, concrete plug and bentonite buffer	experimental measurement within SEALEX	Omnidirectional dipole antenna, 169 MHz	>3,5 m	signal transmission was realized; difficulties when buffer saturates
AITEMIN (SP) at Äspö URL (Sweden)	Crystalline rock, metal plug and bentonite buffer	experimental measurement within MPT	Omnidirectional dipole antenna, 169 MHz	2 - 5 m	signal transmission was realized only at the very beginning; difficulties when buffer saturates


GTS




SEALEX


MPT

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Wireless technology for repository monitoring programme

Wireless data transmission systems (Modern2020):

Subtasks:

1. Improve existing short range (tens of meters) wireless systems based on high or medium frequencies
2. Improve existing long range (hundreds of meters) wireless systems based on low frequencies
3. Evaluate the use of a combination of different range wireless systems to provide a complete data transmission solution

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High-frequency data transmission

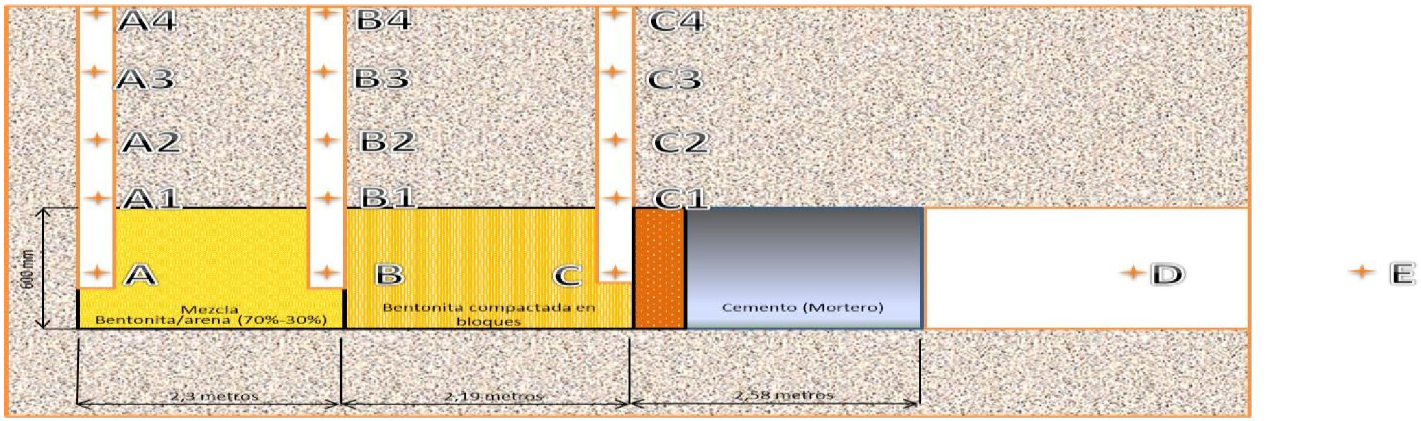
1.1 -Improve MoDeRn short range wireless systems (Aitemin-Arquimea):

Main objectives: Increase operating range when buried in the sealing material, lower sensitivity to the degree of hydration of sealing material, and increase energy efficiency. Integrate the antenna in the device body.

Results (before hydration):

- Signal strength tests over different positions
- Analysis and selection of best antenna and amplifier configuration
- Assessment on minimal signal for radio link

Wireless Test Bench



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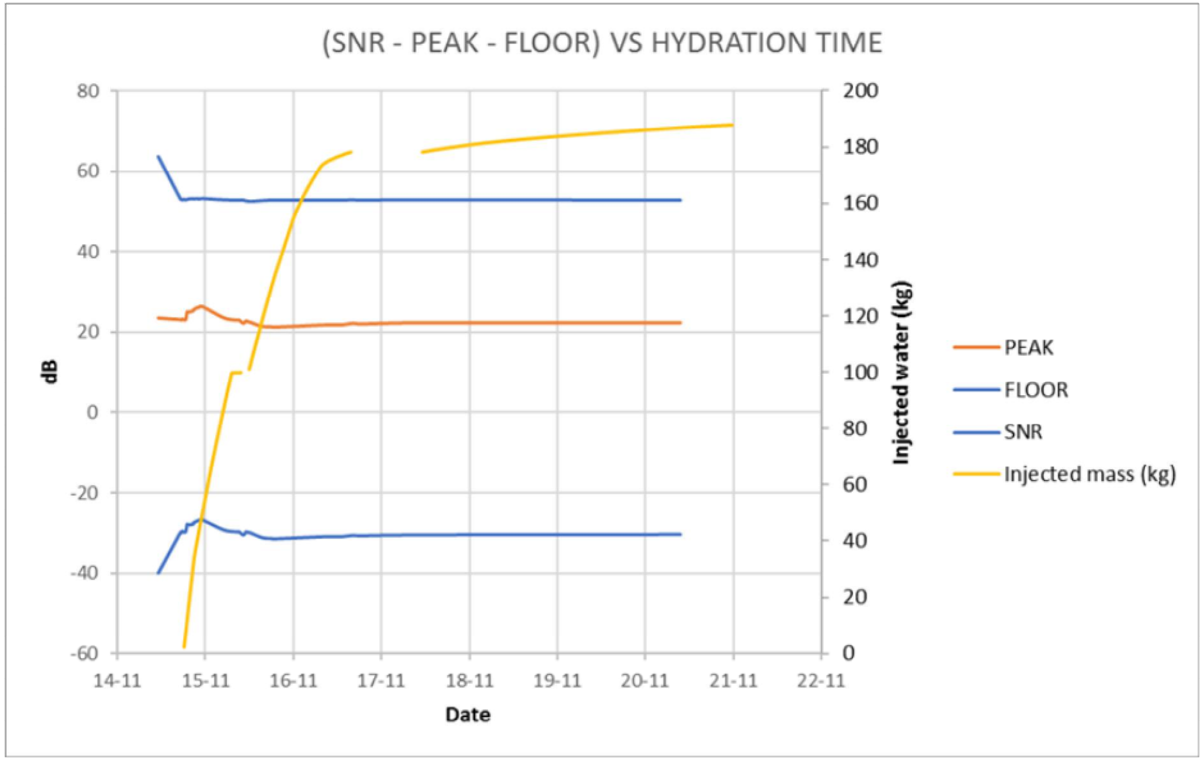
High-frequency data transmission

1.1 - Improve MoDeRn short range wireless systems (Aitemin-Arquimea):

Results (after hydration):

- 10 dB signal loss (SNR) during the first step of hydration (6 hours)
- Constant signal (SNR) since then (53 dB)



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High-frequency data transmission

1.2.- Wireless energy transmission with communication add-on, VTT:

- Objectives: to develop and demonstrate a 125 kHz wireless power transfer system with bidirectional data modem add-on through host rock with low electrical conductivity.
- Activities and results so far:
  - Feasibility analysis (finished) => 10 m wireless operation range is possible but reasonable power levels require rather big antennas (2 m diameter at the reader end, 0.1 – 0.2 m diameter at the sensor end). Even longer ranges are possible with bigger antenna diameters.
  - Laboratory pilot (finished) => The “All Wireless in One” concept is feasible in practice and the performance measurement results were sufficiently in line with the feasibility analysis.
  - Field pilot through the air (finished) => The results with a bigger sensor antenna (power receiver) were still in line with the feasibility analysis, besides the methods of which can be applied in future for estimating the effects of the design parameters modifications to the performance.
  - Field pilot through the host rock has been started and results are under evaluation and reporting.

Low-frequency data transmission

2.1.-Development of multi-hopping system (RWMC):

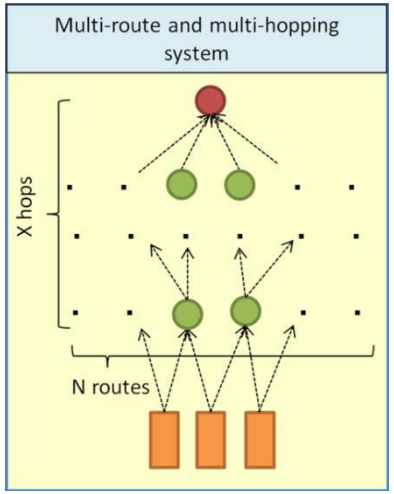
Main objectives: To improve energy efficency of long-distance monitoring system by network transmission using relay transmitters (hopping).

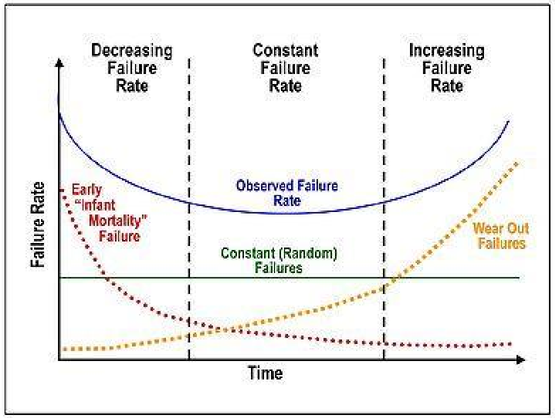
Activities and results so far:

- Development of the theory of multi-hopping system ✓
- Design and fabrication of electronic circuit ✓
- Fabrication and test (Endurance test is in progress)

Next steps:

- Result of the endurance test to find early "infant mortality" failures will be available in April 2018.
- Discussion to improve wireless monitoring systems





en.wikipedia.org/wiki/Bathtub_curve

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Low-frequency data transmission

2.2.- Long-distance data transmission (NRG), basic principles:

- ELF-VLF frequency range (few hundreds Hz to several tens of kHz)
- Magnetic field generation by loop antenna
- Small signal attenuation by interactions with components of the engineered barrier system or the host rock, mainly dependent on electrical conductivity
- Receiver in near-field or extended near-field: application on short (meters to 10s of meters), medium (several tens of meters) and long distance (hundreds of meters)

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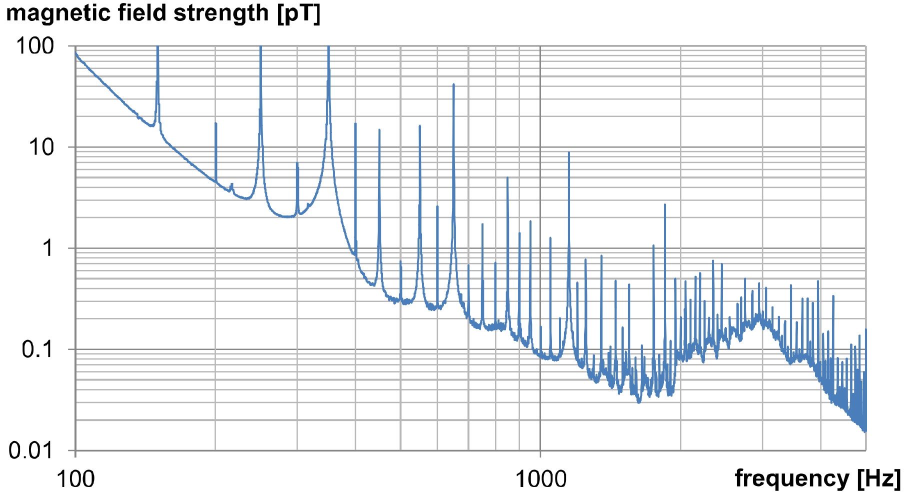
Low-frequency data transmission

2.2.- Long-distance data transmission (NRG), main challenges :

- Magnetic field strength decrease by $1/r^3$
- Low frequency results in low receiver antenna sensitivity
- 'Ideal' transmitter antenna requires large surface areas
- Energy-efficient data transmission requires receiver sensitivity in the fT-range
- Strong background interferences in the ELF-VLF frequency range
- No commercial hardware-platform available



Background noise measured on top of the HADES facility (Mol, B)

T.J. Schröder, E. Rosca-Bocancea, (NRG), *Wireless Data Transmission Demonstrator: from the HADES to the surface*, MoDeRn Deliverable D3.4.2, 2013

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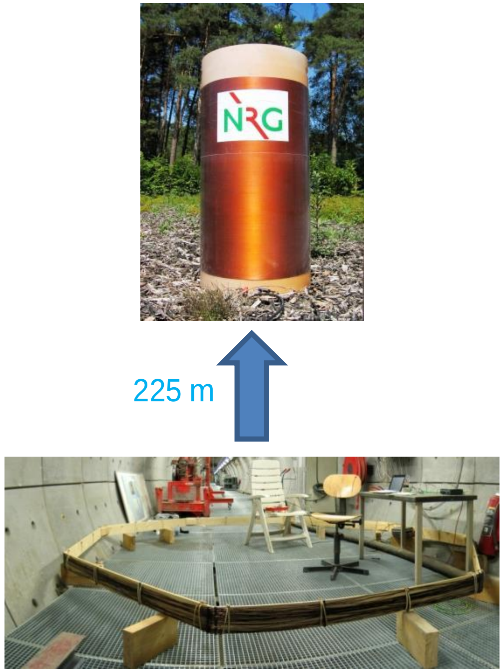
Low-frequency data transmission

2.2.- Long distance demonstrator at the HADES in Mol, Belgium (NRG)

- Demonstration of data transmission from the HADES URL to the surface (225 m)
- Transmission through high porous saturated clay and sandy aquifers (avg. electrical conductivity ±50 mS/m)
- Transmission frequency: ±1.8 kHz
- Data rates up to 100 sym/s were demonstrated
- Due to strong background interferences & limited space in the HADES, lowest demonstrated energy efficiency was 1 Ws/bit
- Data transmission under less unfavourable conditions (surface-surface experiments) was demonstrated with 0.02 Ws/bit



Transmitter and receiver antenna at the HADES facility (Mol, Belgium)

T.J. Schröder, E. Rosca-Bocancea, (NRG), *Wireless Data Transmission Demonstrator: from the HADES to the surface*, MoDeRn Deliverable D3.4.2, 2013

NRG

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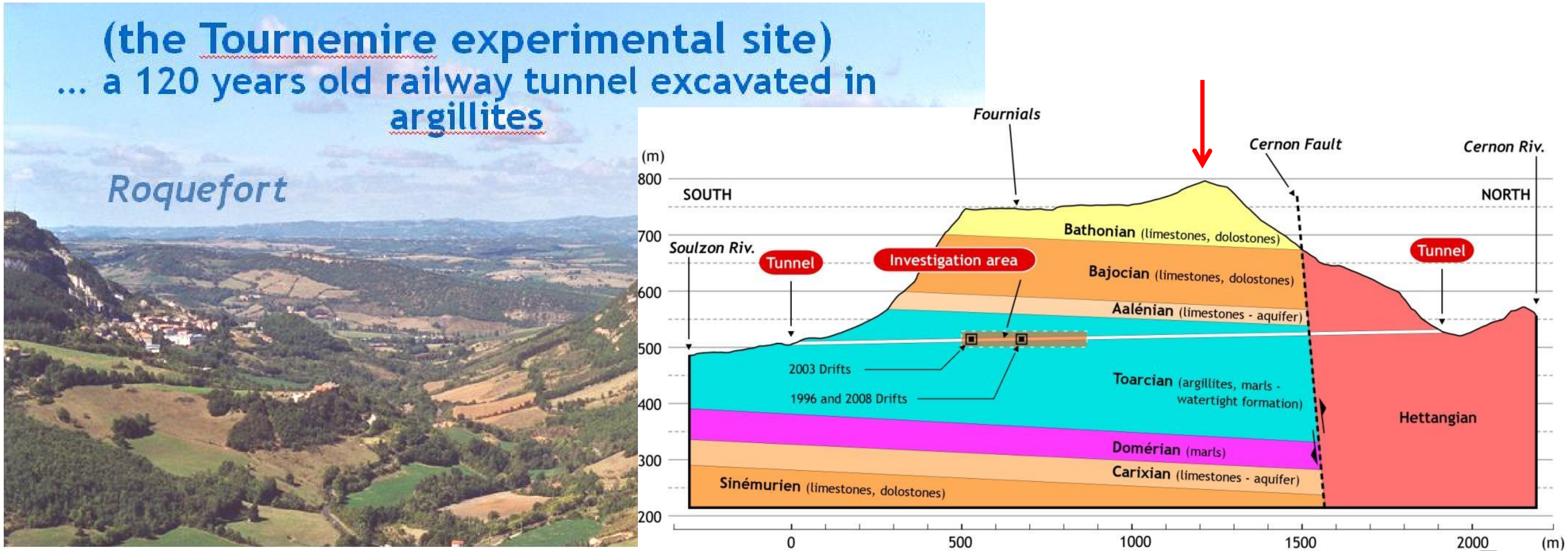
Combine short- and long-distance wireless technologies

3. 1.-Long distance demonstrator in Tournemire, France:

NRG

- Demonstration of data transmission from the Tournemire URL to the surface (275 m)
- Work performed is a part of a combined effort to demonstrate a combined data transmission chain out of disposal cell to the surface



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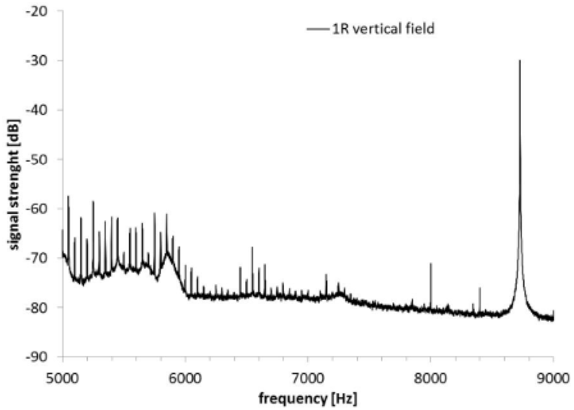
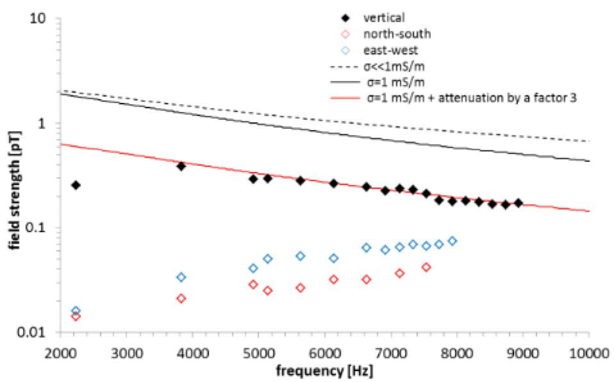
Combine short- and long-distance wireless technologies

3.1.- Long distance demonstrator in Tournemire, France (NRG):

- Site characterization has been performed in order to:
  - measure local interferences in vertical and radial directions;
  - measure the sensitivity of an updated receiver set-up;
  - quantify vertical and radial field propagation through the overburden of the Tournemire tunnel;
  - identify potential impact of the rails in (and outside) the tunnel on magnetic field propagation.
- Rails in the tunnel attenuates magnetic field propagation by a factor of three
- Low electrical conductivity allows higher transmission frequencies: 6-9 kHz
- Expected energy need is ±2 mW/bit (to be demonstrated)





Preliminary results: *Background noise at the surface (left) and measured and modelled signal strength (right).*

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Alternative Power Supply Sources

1. Energy harvesting based on low thermal gradients
2. Energy storage (Fundamental)
3. Wireless energy transmission
4. Miniaturized nuclear generators (Feasible but big volumes)

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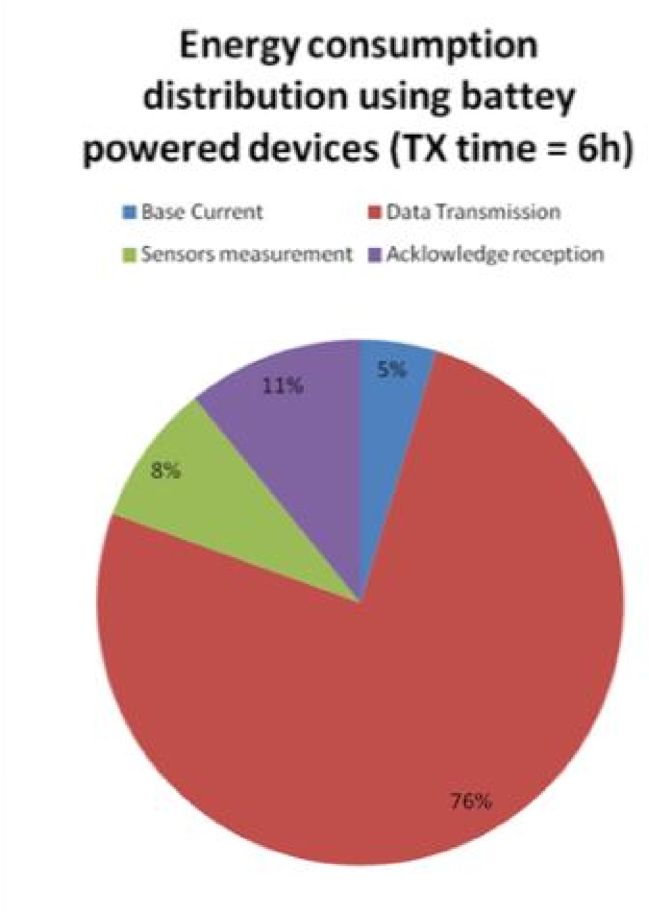
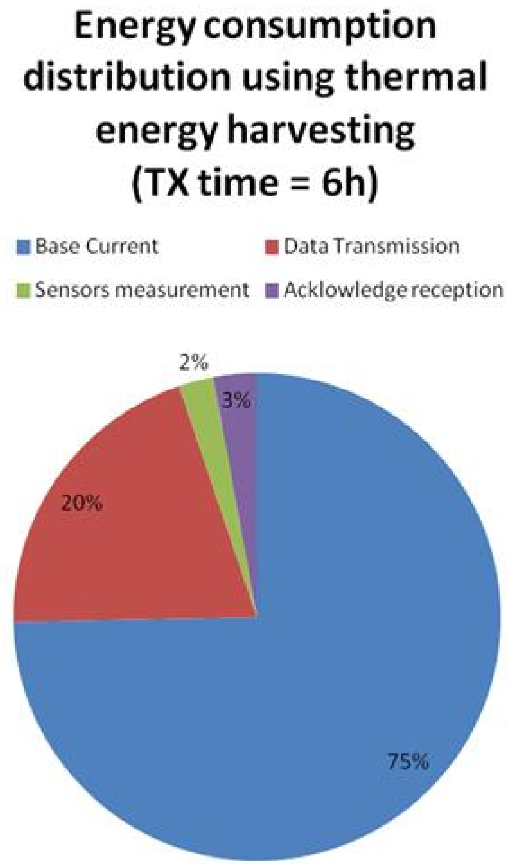
Energy requirements

Energy balance of a HF wireless device using batteries and getting energy using harvesting methods





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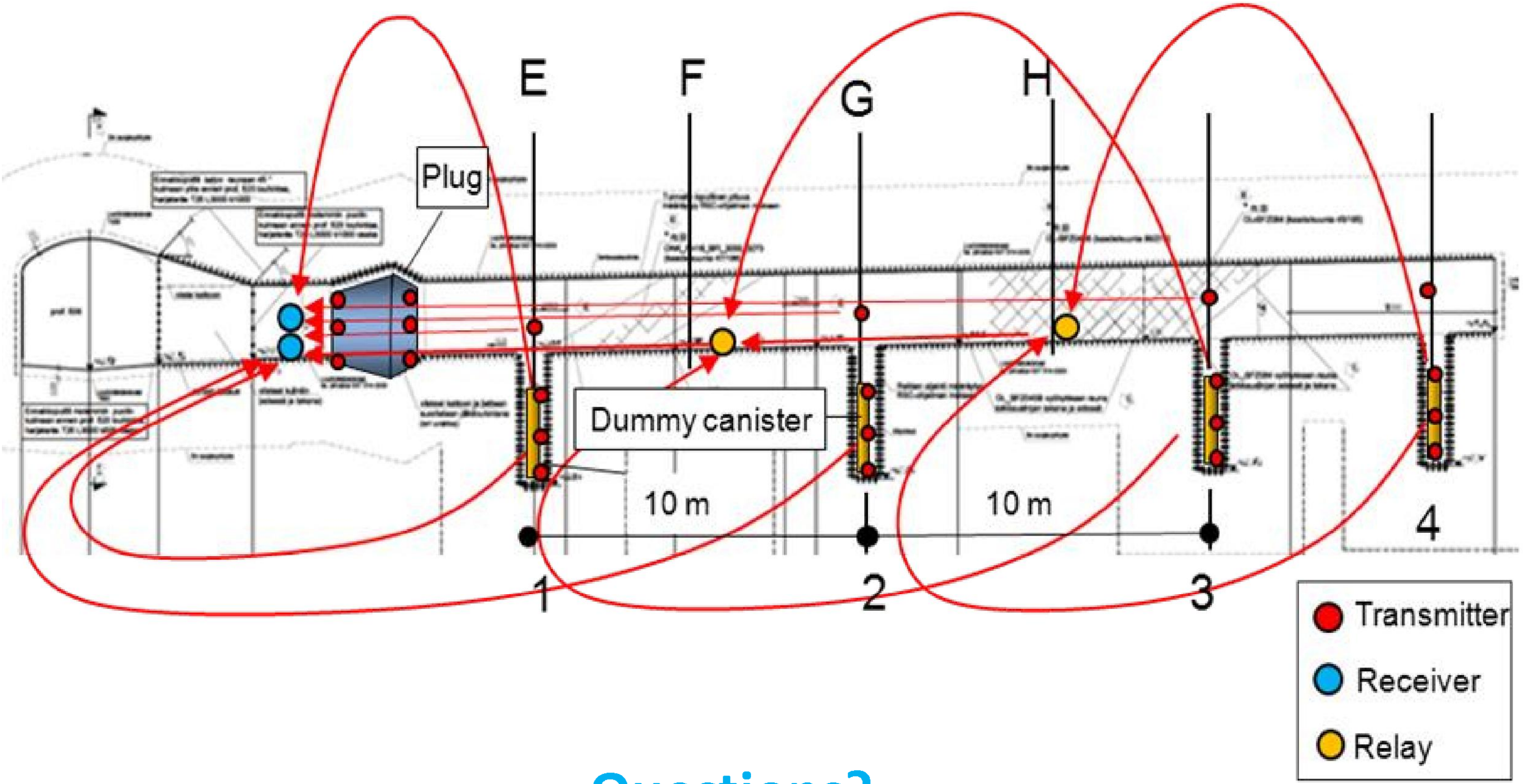
Wireless technology for repository monitoring programme



Questions?

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Service Portfolio Overview for Underground Engineering

PROJECT MANAGEMENT

- Project & Cost Management
- Tender & Contract Management
- Overall Risk Management
- Public Relation
- Quality Management
- Commissioning & Training

DESIGN

- Geological Studies
- Feasibility Studies
- Preliminary- & Tender Design
- Geotechnical & Structural Analysis
- Time & Cost-benefit Analysis
- Value Engineering

REALISATION

- Detailed Design
- Construction Supervision
- Project & contract Management
- Control Survey
- Geotechnical & Vibration Monitoring
- Material testing

OPERATION

- Maintenance Concepts
- Facility Inspections
- State Assessments

RENEWAL

- Structural Assessments
- Inspections
- Renewal Design
- Refurbishment
- Tunnel Electrification / Modification

Thank You!

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EXPERT SERVICES

- Expertise
- Risk & Safety management
- Aerodynamics & Ventilation
- Site Safety
- Seismic Prediction
- Concrete Optimisation
- TBM Site Logistics consulting
- Tunnel & Shaft Surveying
- Process Optimisation

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