Development and Demonstration of monitoring strategies and technologies for geological disposal

safe solutions for radioactive waste

Modern2020
Final Conference

Electric Power Sourcing of Wireless Repository Monitoring Sensors

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10th April 2019, PARIS

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

Introduction

- **Modern2020 Task 3.3 has investigated and developed long-term power sourcing solutions for sensor units inside nuclear repositories.**
- **Sensor units inside repository barriers should preferably be linked by wireless interconnections, which in addition to the communication concerns the necessary powering of the sensor units.**
  - ✓ Cables through engineered or natural barriers entail risks of nuclear material leakages
  - ✓ Chemical batteries have relatively short lifetime and can include problematic materials
- **The work has been focused to the following technologies:**
  - ✓ Long-term (at least 10 years) power sourcing technologies inside nuclear repositories:
    - Thermoelectric energy harvesting by exploiting thermal energy from the high-level nuclear waste (NRG),
    - Wireless energy transfer through engineered and natural repository barriers (VTT, NRG),
    - Long-term nuclear batteries (ORANO, ANDRA, RWMC)
  - ✓ Energy storage technologies for matching together the limited output power capacity of the power sources and variable power consumption of the sensor units (ARQUIMEA)

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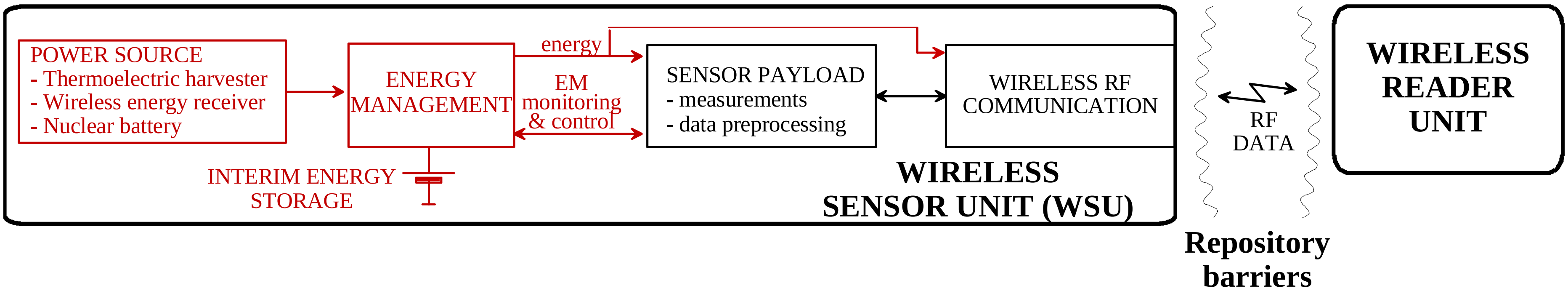
Exploiting Power Sources with Limited Output Power



- **Interim energy storage for buffering the sourced energy for further need**
- **Energy management for connecting the power source, interim energy storage and power consuming parts together**
- **Low duty-cycle operation of the wireless sensor unit (WSU)**
  - ✓ **Long energy accumulation periods into the interim energy storage (e.g. from one hour to even several days)**
    - **The WSU is kept sleeping with ultra-low power consumption**
  - ✓ **Short WSU activity cycles (e.g. from a few seconds to a few minutes)**
    - **Started by the activation of the WSU by an ultra-low power embedded circuit such as a timer, an interim energy storage supervisor or a wake-up radio receiver**

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Highlights of the Power Sourcing Technologies in Modern2020 Task 3.3

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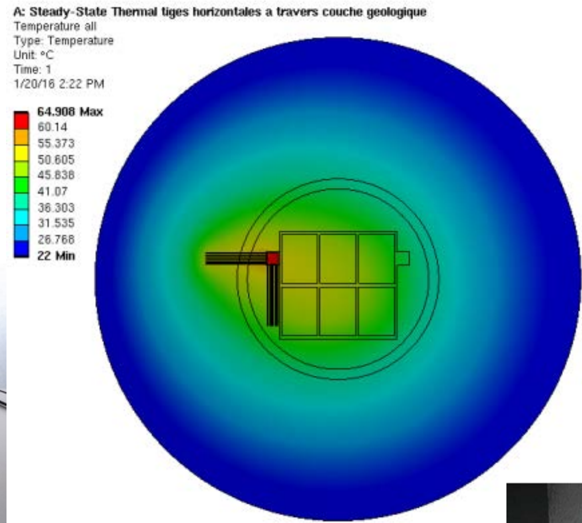
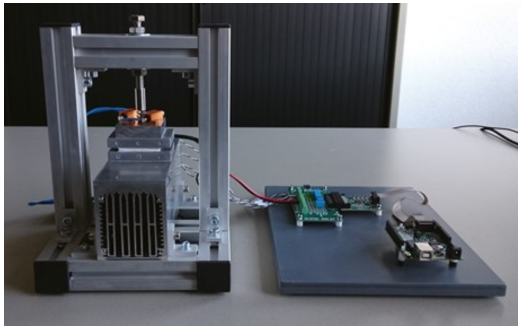
Simulated temperature field of a reference radioisotope thermoelectric generator (RTG) type nuclear battery by ORANO



Wireless energy transfer pilot system in wet grassland in the Netherlands by NRG



Thermoelectric generator test bench by NRG

Design	TEH position	Length	Diameter	T_{min} [°C]	P_{out} [µW]		
					0 years	*50 years*	*100 years*
TEH-1S	Gallery lining	50 cm	5 cm	0.64	500	78	20
TEH-1L	Gallery lining	50 cm	10 cm	0.46	1020	170	54
TEH-2S	Backfill	15 cm	5 cm	0.46	370	52	8
TEH-2L	Backfill	15 cm	10 cm	0.40	490	72	14

Alternative thermoelectric energy harvester designs and their thermal model based output power estimations by NRG

Wireless energy transfer pilot system with integrated communication add-on through crystalline host rock in Finland by VTT

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VTT

Comparison between the Power Sourcing Technologies

Power sourcing option / Feature	Thermoelectric energy harvesting from the HLW containers	Wireless energy transfer through the repository barriers	RTG nuclear battery
Typical output power capacity	- Tens of µW to a few mW per unit	- Tens of µW to several mW (depends much on the wireless distance and the antenna size)	- Several W
Operation mode	- Continuous power output	- Continuous or discontinuous power output	- Continuous power output
Temporal variations in power output	- Slowly decreasing power output, depending on the decay of the HLW heat production	- Constant power output, can be adapted on demand by adjusting the power level of the power transmitter	- Slowly decreasing power output, depending on selected radionuclide(s)
Placement	- One or more units can be placed in a disposal cell; application limited to heat-generating waste	- Placement preferably close to the sealing plug; application in all waste sections possible	- Flexible unit placement possible; application in all waste sections possible as far as the heat transport is feasible
Expected impact on disposal concept	- Low impact, placement in single barrier is possible with minor alteration of the overall heat flow	- Low, due to placement close to the plug	- Safety assessment of the introduced radionuclides necessary - Interactions between heat pipes and the EBS need to be considered
Specific future research needs	- Energy storage options - Long-term reliability	- Energy storage options - Long-term reliability - Interactions with electrically conductive and magnetic permeable materials in the EBS - Adaptive antenna tuning	- Safety and long-term reliability - Heat transport in specific placements - Energy storage options in applications with high peak power consumption

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Energy Storages

- **Specific requirements for the interim energy storage**
  - ✓ Low enough self-discharge (remarkably lower than the energy source output power)
  - ✓ High enough power output capacity (higher than the peak power consumption of the WSU)
  - ✓ High enough energy capacity (higher than the energy consumption of one activity cycle of the WSU)
  - ✓ Long enough lifetime
- **Potential technologies (bottlenecks)**
  - ✓ Rechargeable batteries (limited output power capacity, aging)
  - ✓ Double-layer supercapacitors (relatively high self-discharge, aging)
  - ✓ Novel supercapacitors with improved features (lack of long-term reliability data):
    - Electrochemical pseudocapacitors
    - Hybrid (electrostatic + electrochemical) capacitors, e.g. lithium-ion capacitors
  - ✓ Nanocapacitors (under research)
  - ✓ Combinations of the previous

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Relevance of the Results from Modern2020 Task 3.3

- **Conclusions**
  - ✓ The investigated three power sourcing technologies are relevant and feasible for powering repository monitoring sensors but have also clear differences in how they can cover different application cases.
  - ✓ The results can be exploited as improved readiness for the design of complete repository monitoring systems.
    - The research has resulted in relevant input for the adaptation and fundamental limitations of the investigated power sourcing technologies in different repository environments.
    - The work has improved the understanding about the scaling of the powering subsystem to the powering needs of specific sensor applications.
    - The pilot designs can serve as reference material in the development of the powering subsystem for the forthcoming repository monitoring sensors.
- **Further activities**
  - ✓ In general, the further activities should be connected more closely to the development of more complete repository monitoring systems combining the powering subsystem with the sensor payload, wireless communication, encapsulation and the wireless reader unit.
  - ✓ Closer evaluation of the novel supercapacitor and other potential energy storage technologies for the long-term operation in the repository environment is also essential.
  - ✓ Other specific R&D needs can be found in the material listed on the next slide.

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Modern2020 Task 3.3 – More information

- **Modern2020 deliverable D3.3:**
  - ✓ Esko Strömmer (ed., VTT), Héctor Luis Abós Gracia (ARQUIMEA), Francisco Alvarez (ARQUIMEA), Pierre Forbes (ORANO), Ecaterina Rosca-Bocancea (NRG), Thomas Schröder (NRG): Long-term power supply sources for repository monitoring
- **Extended abstract in the Modern2020 final conference: "Electric Power Sourcing of Wireless Repository Monitoring Sensors"**
- **Technology specific posters in the Modern2020 final conference:**
  - ✓ T.J. Schröder, E. Rosca-Bocancea, J. Hart: Thermal Energy Harvesting From High-Level Waste
  - ✓ T.J. Schröder, E. Rosca-Bocancea, C.N.J. Stam: Wireless Energy Transfer Through Electrical Conductive Media
  - ✓ E. Strömmer, E. Bohner: Wireless energy transfer with data transfer add-on through low-conductivity host rocks

Thank You

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