Modern2020
Final Conference

Electric Power Sourcing of Wireless Repository Monitoring Sensors

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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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Highlights of the Power Sourcing Technologies in Modern2020 Task 3.3

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

Thermoelectric generator test bench by NRG

<table>
<thead>
<tr>
<th>Design</th>
<th>TEH position</th>
<th>Length</th>
<th>Diameter</th>
<th>$T_{\min}$ [°C]</th>
<th>$P_{\text{out}}$ [µW] 0 years</th>
<th>$P_{\text{out}}$ [µW] 50 years</th>
<th>$P_{\text{out}}$ [µW] 100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEH-1S</td>
<td>Gallery lining</td>
<td>50 cm</td>
<td>5 cm</td>
<td>0.64</td>
<td>500</td>
<td>78</td>
<td>20</td>
</tr>
<tr>
<td>TEH-1L</td>
<td>Gallery lining</td>
<td>50 cm</td>
<td>10 cm</td>
<td>0.46</td>
<td>1020</td>
<td>170</td>
<td>54</td>
</tr>
<tr>
<td>TEH-2S</td>
<td>Backfill</td>
<td>15 cm</td>
<td>5 cm</td>
<td>0.46</td>
<td>370</td>
<td>52</td>
<td>8</td>
</tr>
<tr>
<td>TEH-2L</td>
<td>Backfill</td>
<td>15 cm</td>
<td>10 cm</td>
<td>0.40</td>
<td>490</td>
<td>72</td>
<td>14</td>
</tr>
</tbody>
</table>

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

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

Wireless energy transfer pilot system with integrated communication add-on through crystalline host rock in Finland by VTT
## Comparison between the Power Sourcing Technologies

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


• Technology specific posters in the Modern2020 final conference:

✓ T.J. Schröder, E. Rosca-Bocancea, J. Hart: Thermal Energy Harvesting From High-Level Waste
✓ E. Strömmer, E. Bohner: Wireless energy transfer with data transfer add-on through low-conductivity host rocks

Thank You