A Self-Powered, Wireless Sensor System for Remote and Long-Term Monitoring of Internal Conditions of Spent Nuclear Fuel Dry-Storage Casks
Goal and Objectives

The goal of this SBIR Phase IIB program is to develop a fully functional Self-Powered Wireless Sensor System (SPWSS) prototype for passive, long-term, and remote monitoring the internal conditions of nuclear waste casks.

Objective 1: Refine SPWSS prototype design and development to achieve TRL 7-8
- Refine sensor package design and prototype development to meet operation requirement, especially NUHOMS 32PTH
- Fine tune sensor sensitivity and resolution for dry-storage cask environment
- Refine microfabrication process and sensor integration technique
- Refine BAW transducer design to improve signal transfer
- Reduce overall dimension
- Refine interrogation unit and software for simultaneous measurement of temperature, pressure, relative humidity and hydrogen gas. Add fission gas sensing capabilities.
- Implement advanced signal processing algorithm to meet desired sensitivity and accuracy

Objective 2: Conduct irradiation test and performance evaluation in relevant environment.

Objective 3: Demonstrate abilities of the SPWSS system and commercialize the developed technology

Objective 4: Commercialization & Technical transitioning


Participants (scheduled): INL, ORNL, J Kessler and Associate, EPRI, Exelon
## Project Overview

### Schedule

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<td>1. Finalize project requirements</td>
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<td>4. Implement signal processing algorithm</td>
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<td>6. Conduct irradiation test</td>
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Overview of the SPWSS technology for remote, long-term monitoring of internal conditions of nuclear fuel storage casks

Pending patents

1. WIRELESS SENSOR SYSTEM FOR HASRSH ENVIRONMENT #16/285,579
2. HIGH TOLERANCE ULTRASONIC TRANSDUCER #16/749,667
3. POWERLESS ACOUSTIC SENSOR SYSTEM #16/528,577
Program overview

A Self-Powered, Wireless Sensor System (SPWSS)
for Remote and Long-Term Monitoring of Internal Conditions of Nuclear Waste Casks

**Phase I** - Completed
- Design a SPWSS prototype
- Build a SPWSS prototype
- Test SPWSS prototype performance
- Demonstrate feasibility of SPWSS approach

**Phase II - Completed**
- Complete SPWSS system design and development
- Test and evaluate the prototype performance
- Demonstrate abilities of the prototype system

**Phase IIB - Proposed**
- Refine SPWSS system
- Integrate with real DSC
- Conduct irradiation testing
- Build a showcase prototype for licensing and regulation
- Commercialize technology

**Phase III**
- Secure commercial partner
- Optimize system performance
- Comprehensive validation
- Transition technology

**KEY FEATURES:**
1. Passive, remote, long-term monitoring internal conditions
2. Multi-parameters
3. Expandable
4. High-accuracy
5. Cost-effective

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Summary of Phase IIB accomplishments

• Completed SPWSS overall system design and refinement
• Refined SAW sensor platform design, fabrication, packaging, and testing
• Refined BAW transducer design, fabrication and testing
• Designed and developed a high frequency EAMT transducer for noncontact ultrasonic detection
• Design and develop thermoelectric harvester and pulse generator for SPWSS
• Refining interrogation unit design and development
Technology Impact

- Develop high-temperature, radiation endurance ultrasonic BAW transducers for nuclear harsh environment applications
- Develop high-temperature SAW-based sensor platform for condition and gas species monitoring in nuclear environments
- Develop high-temperature TEG module for energy harvesting in nuclear harsh environment
- Support the DOE-NE research mission in nuclear waste management as well as nuclear power plants
- Enable smart spent nuclear fuel dry-storage canisters
- To be commercialized via collaboration with Orano, EPRI, etc.
SPWSS overall system design and refinement

In Phase II program:
- We have developed SAW sensor and its packaging
- We have performed sensor calibration and performance evaluation
- We have developed BAW transducers for wireless communication
- We have developed electronics prototype and complementing software
- We have performed Radiation test at UWM up to 1.8kGy gamma radiation level

Now we are refining our design for the NUMHOS 32 PTH

Conceptual designs of the SPWSS
SAW sensor development
- Corrosion test

Process
We followed the protocol provided by the ORANO for corrosion test

Results
Quantitative analysis suggests that there are changes in the temperature sensing capabilities

We recorded the time delay as function to temperature and extracted rate of change with temperature

SAW response before corrosion test.  
SAW response after corrosion test

Corrosion test setup

Visual inspection
SAW sensor development
- High temperature test

Results:
SAW sensors can survive temperature up to 300 °C, but show degradation when heated up to 350 °C in ambience.
The amplitude of SAW response decreases after heating to 350 °C.

For aging test sensor needs to survive ~450 °C for 30 days.
SAW sensor development
- Humidity sensing

Results:
Our testing suggests that the humidity sensing degrade with heating.

Humidity sensing calibration after high temperature test
BAW for wireless data transmission

Design and development
• We have developed BAW transducers for wireless acoustic communication.
• The BAW transducers is made of radiation safe materials.
• It can potentially survive for extended period of time in nuclear waste cask.

Photograph of nuclear waste cask and location for BAW transducer mounting

CAD image and photograph of developed transducer

Life expectancy:
• The simulation results are provided by ORANO
• Unshielded, 4500 rad/hr, time to failure = $200 \times 10^6 / 4500 = 5$ years
• 1” W shielding, 215 rad/hr, time to failure = $200 \times 10^6 / 215 = 100$ years

Configuration for radiation simulation. the “dots” are the Co-60 source, 1” tungsten is orange, wafer green.
Corrosion test

Results:
• No visible degradation was found
• No acoustic or electrical performance degradation was found.
EMAT for noncontact wireless receiving

EMAT Testing

Test setup

EMAT signal vs Gap

EMAT signal vs Gap

Signal amplitude (peak to peak mV) vs Gap (mm)

Map of EMAT signal

Captured waveform

Signal 1
Signal 2
Signal 3
Signal 4
Signal 5

Frequency (MHz)

Time delay (ns)
Thermoelectric Harvester development

Design and development

• We have developed Thermoelectric Harvester to fit in the NUHMOS 32PTH nuclear waste cask.
• We performed heat analysis simulation to estimate temperature difference across TEG module.
• Heat analysis suggest the choice of metal in harvester development is crucial.
• We have developed second harvester design to mechanically locking the module in the NUHMOS 32PTH nuclear waste cask.
Pulser development

Design and development

- We are developing a cantilever electrical pulse generator
- We have identified and tested electrical circuit to amplify electric pulse amplitude to improve signal to noise ratio
Interrogation unit

Development

Hardware system Refinement Rev 3

- Rev 2: ZYNG 7Z020 ZC702 EVM based 12” x 9” x 3”
- Rev 3: ZYNG 7Z010 MicroZed based 6.3” x 4.25” x 1.75”

ADC & Amp

Rev 2

ZYQ EVM

HV Trigger
Future development

- Refinement of SAW sensor and its calibration
- Fabrication and testing of thermoelectric harvester
- Refinement of pulser design
- Refinement in EMAT design
- Refinement electronic and software
- Sensor system testing
- Irradiation testing
- Commercialization/Transition
Questions and contact info

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