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# Wireless Reactor Power Distribution Measurement System Utilizing an In-Core Radiation and Temperature Tolerant Wireless Transmitter and a Gamma-Harvesting Power Supply

**Advanced Sensors and Instrumentation Annual Webinar**

**October 23, 2019**

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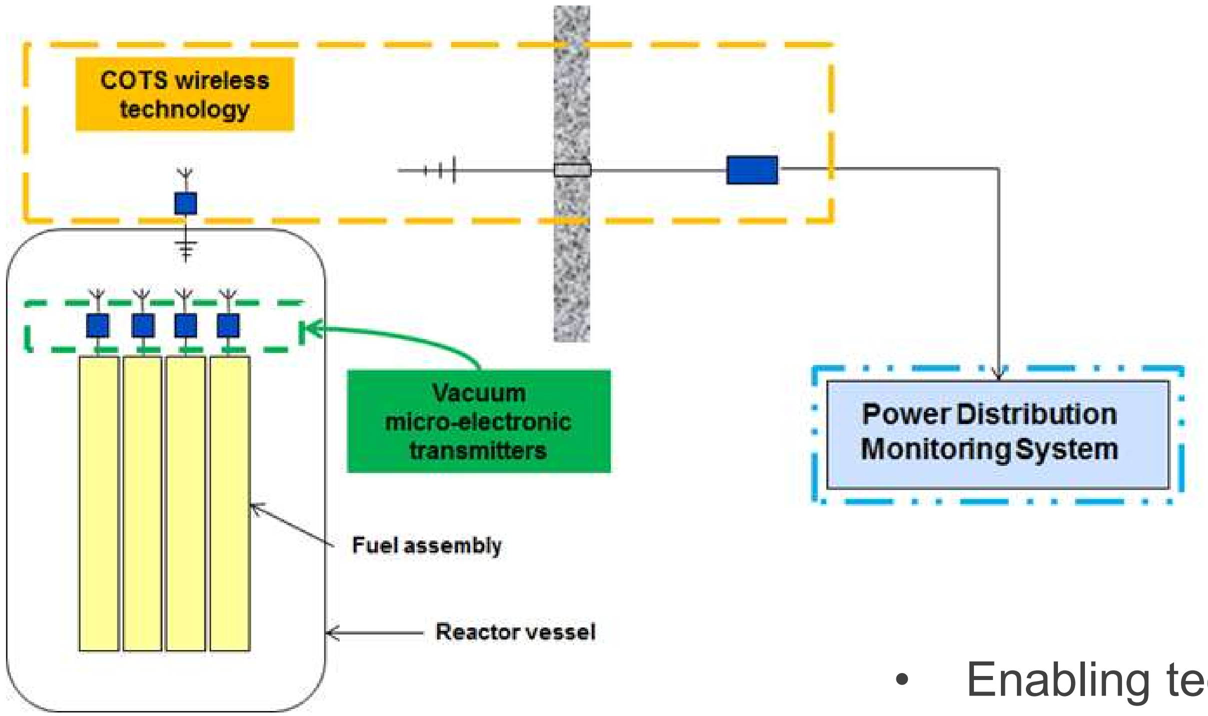
**Westinghouse Electric Company**

# Project Overview

- Goal and Objective
  - Develop the technology necessary for a wireless reactor power distribution measurement system. This system utilizes highly radiation- and temperature-resistant vacuum micro-electronics (VME) technology that continuously broadcasts Self-Powered Detector (SPD) signals and reactor coolant temperature sensor signal measurements to a receiving antenna. Other potential applications of the technology within a LWR containment environment will also be investigated.
- Participants
  - Jorge Carvajal, PI, Westinghouse Electric Co.
  - Michael Heibel, Co-PI, Westinghouse Electric Co.
  - Dr. Kenan Unlu, Co-PI, Pennsylvania State University.
- Schedule
  - October 1st, 2016 – July 31$^{st}$, 2020.

# Project Overview

- Increase in reactor operating margin due to measurement density increase
- Improved reactor power distribution measurement accuracy will provide the capability to produce more electricity from the same amount of nuclear fuel, or produce the same amount of electricity from less nuclear fuel

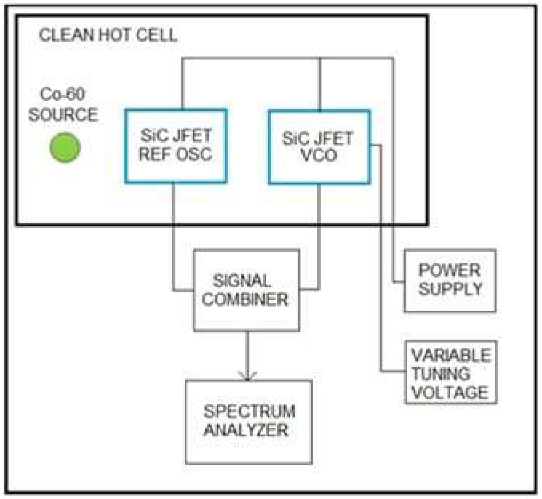


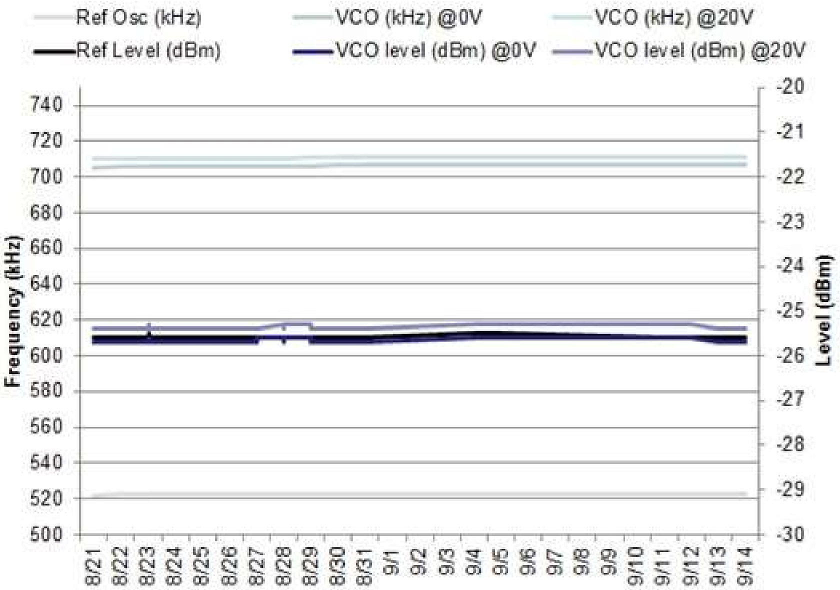

- Enabling technology for other applications such as In-pile sensors and in-containment applications

# Accomplishments

## Gamma Irradiation of SiC JFET Oscillator

- Minimal change after 6.8 Mrads.
- Applicable to Rx vessel head location for transmitting data within containment.

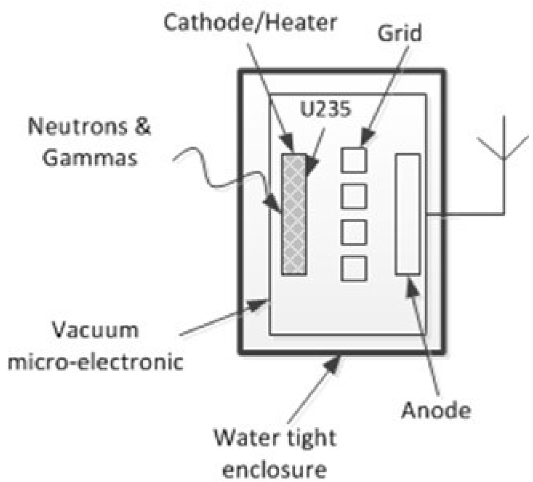


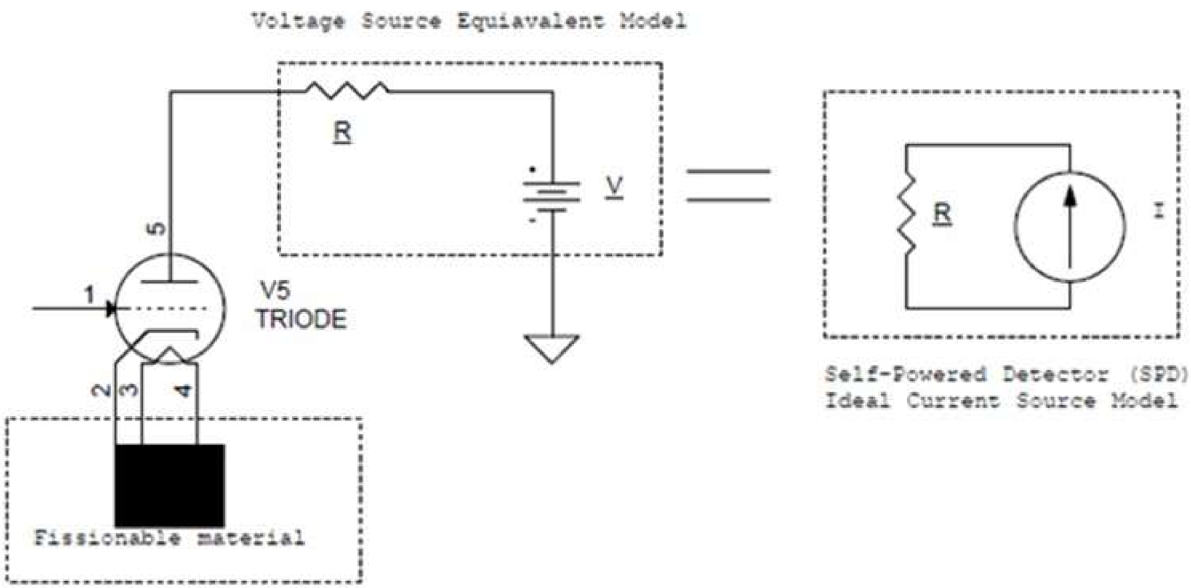




# Accomplishments

## Radiation assisted VME heater: Preliminary assessment of a fissionable heater element

- Thermionically emitted electrons
- 0.1 in height by 0.260 inch diameter heater element
- Temperature required between 500C and 900C

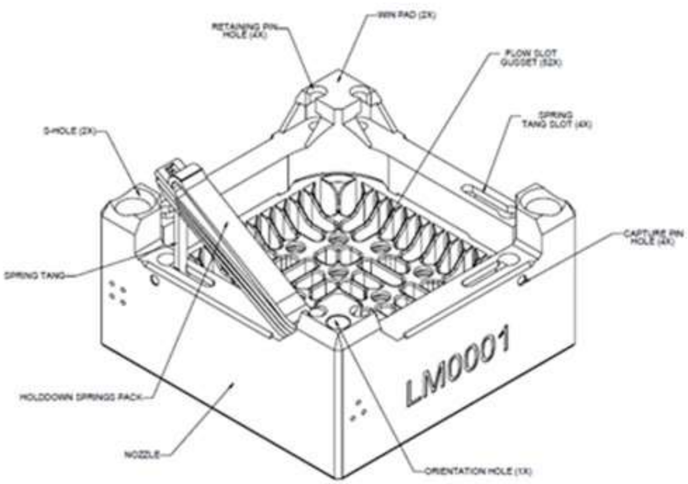


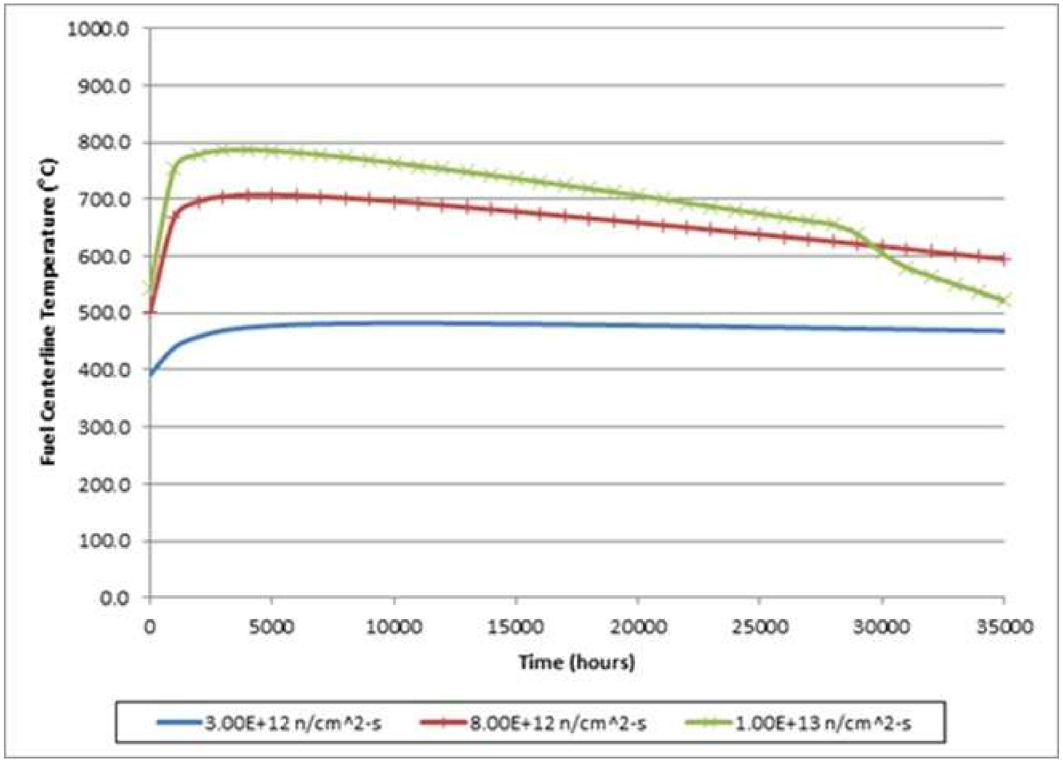



# Accomplishments

## Radiation assisted VME heater: Preliminary assessment of a fissionable heater element

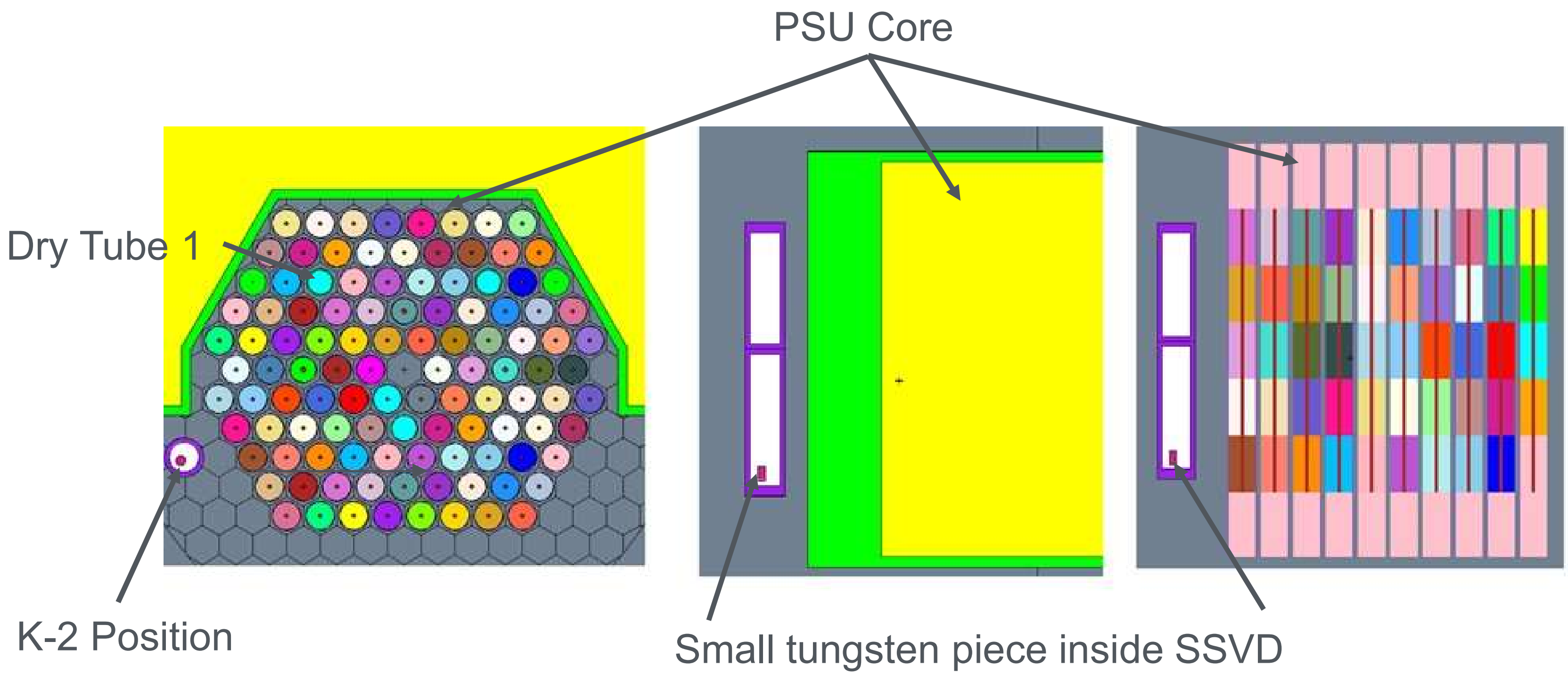
- Fuel performance code PAD
- VME located in fuel nozzle
- Fissile material is assumed to be a uranium dioxide (UO2) pellet with low enriched (ideally less than 5 w/o) U-235



## Monte Carlo N-Particle Transport Code (MCNP) simulation for tungsten heater element

- Different radius and height used in calculation
- K-2 and Dry-tube 1 positions for PSBR
- Several methods used inside the MCNP to observe effect of gamma heating



# Accomplishments

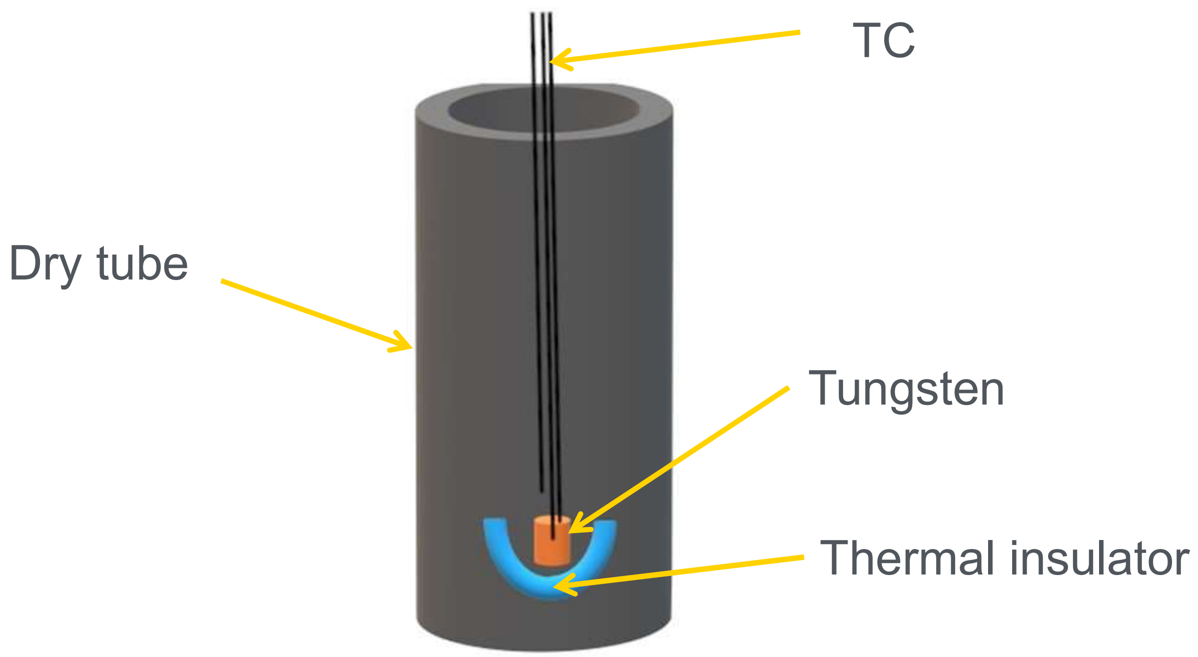
## MCNP simulation results for tungsten heater element

| Position | Radius/Height (cm) | Volume/Area ($cm^3/cm^2$) | Mass (g) | F6 Tally Result MCNP (MeV/s) | F6 Tally Error (%) | F4 Tally Result Neutron Flux ($n/cm^2s$) | W | W/g | Temperature (°C) |
|---|---|---|---|---|---|---|---|---|---|
| Dry Tube 1 | 0.35/0.254 | 0.098/1.33 | 1.89 | 1.97E+12 | 4.03 | 1.69E+13 | 0.316 | 0.167 | 738.44 |
| Dry Tube 1 | 0.35/0.395 | 0.15/1.64 | 2.93 | 5.59E+12 | 2.36 | 1.83E+13 | 0.895 | 0.305 | 972.26 |
| Dry Tube 1 | 0.43/0.254 | 0.15/1.85 | 2.85 | 5.42E+12 | 2.24 | 1.79E+13 | 0.867 | 0.305 | 926.12 |

# Accomplishments

## Monte Carlo N-Particle Transport Code (MCNP) simulation for tungsten heater element

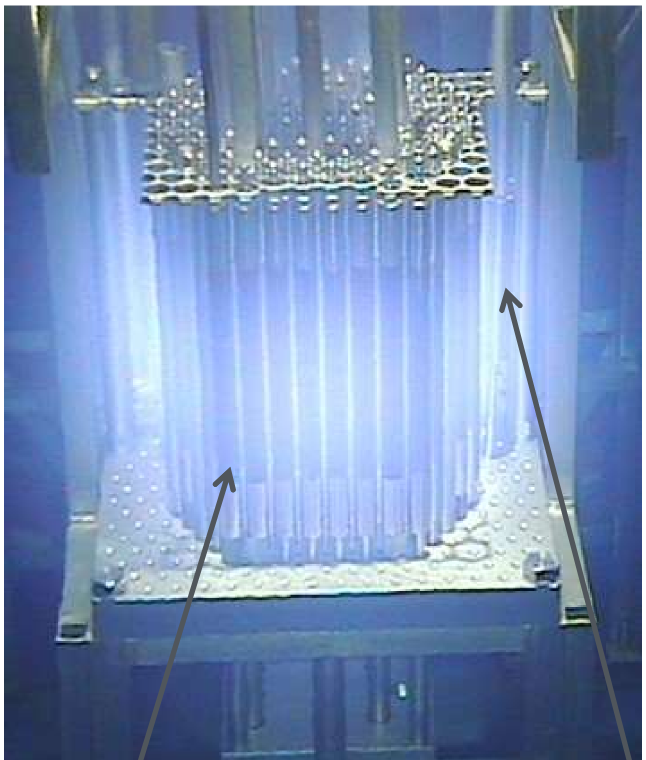
- Tungsten heater prototype



# Accomplishments

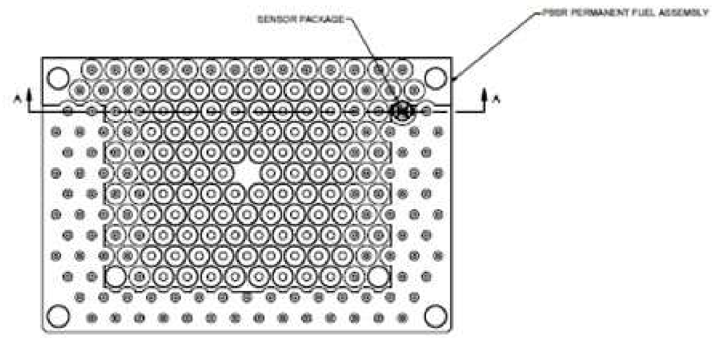
## Wireless transmission through metal obstacles

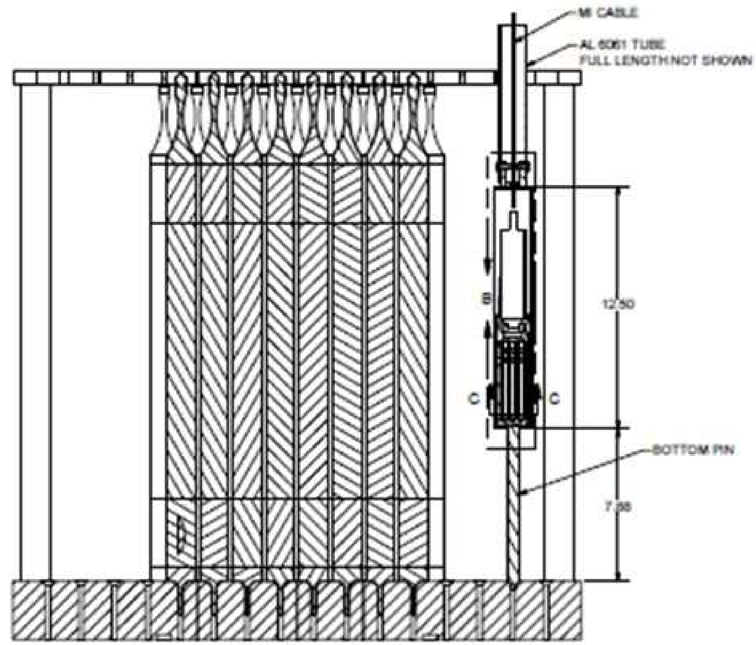
- Neutron flux approximately 4x10^12 n/cm^2/sec



Fuel

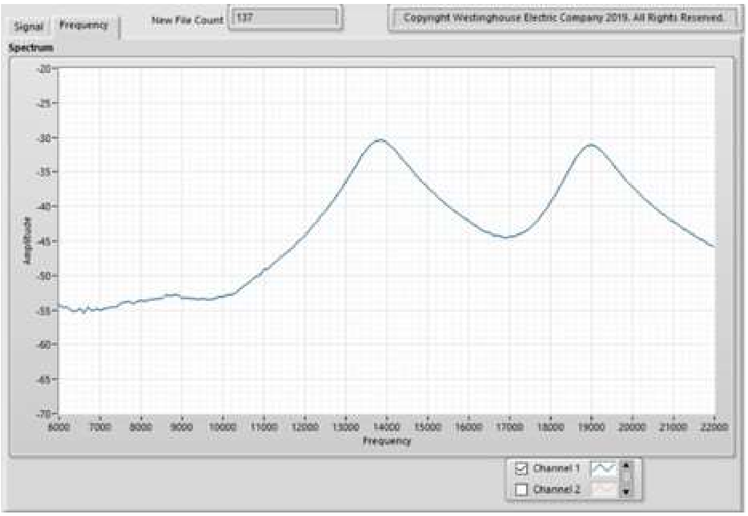
Transmitter enclosure

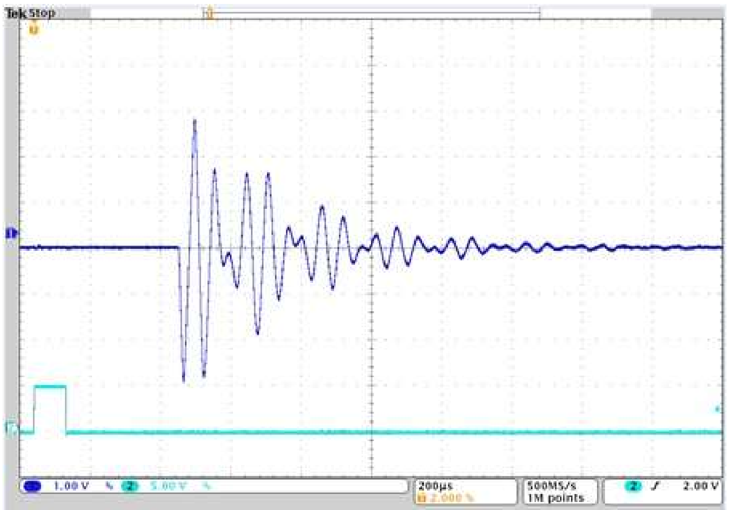


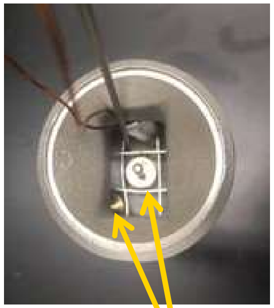



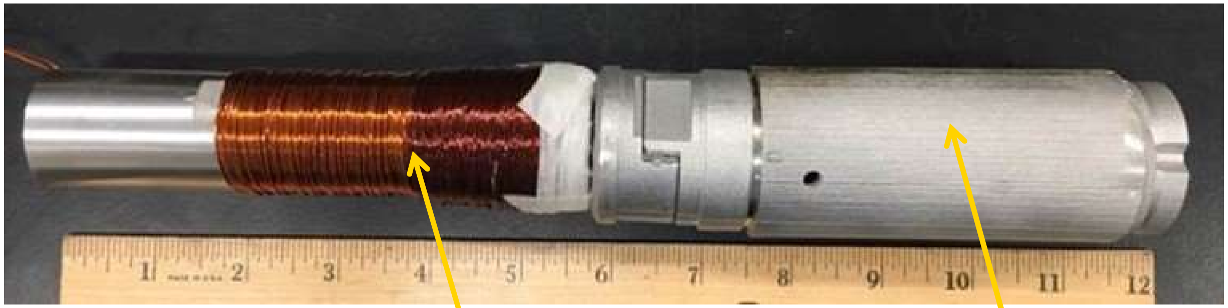
# Accomplishments

## Frequency domain signal separation





Multiple transmitters

Transceiver

Transmitter holder

# Accomplishments

## Publications

- 2019 NPIC&HMIT conference titled "Wireless Reactor Power Distribution Measurement System Utilizing an In-Core Radiation and Temperature Tolerant Wireless Transmitter and a Gamma-Harvesting Power Supply."
- "Toward the Implementation of Self-Powered, Wireless, Real-Time Reactor Power Sensing," Annals of Nuclear Energy.

# Technology Impact

- Advances to the State of the Art: Demonstrate that it is possible for smart sensors to be used for an extensive period of time in a high radiation and elevated temperature environment. The benefits associated with this technology include the ability to gather more data without the need for additional cables or vessel penetrations.

- Impact: Power distribution measurements currently utilize SPND axially located within approximately one-third of the fuel assemblies. The proposed project would enable 100% of fuel assemblies to be instrumented by placing a VME wireless transmitter in the top nozzle of each fuel assembly. It is expected that this technology would enable the plant to increase reactor operating margin due to improved fuel usage knowledge.

- Commercialization Plan:
  - Current plan is to make these sensors/transmitters integral to future fuel assemblies.
  - Technology results in significant Margin Uncertainty Recovery (MUR), which enables better fuel cycle management, power uprates and lower fuel enrichment.
  - Evaluating other applications such as in-rod sensors and dry-cask monitoring.

# Conclusion

- Simulations have shown that fissile material or high density material (e.g. tungsten) can generate enough heat to power a VME. Material depletion must be considered.
- Demonstrated that a passive sensor signal can operate at high temperatures and be resolved in the frequency domain, which can enable the deployment of numerous sensors within a single fuel assembly.

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