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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 31 – November 1, 2018

Jorge Carvajal
Westinghouse Electric Company

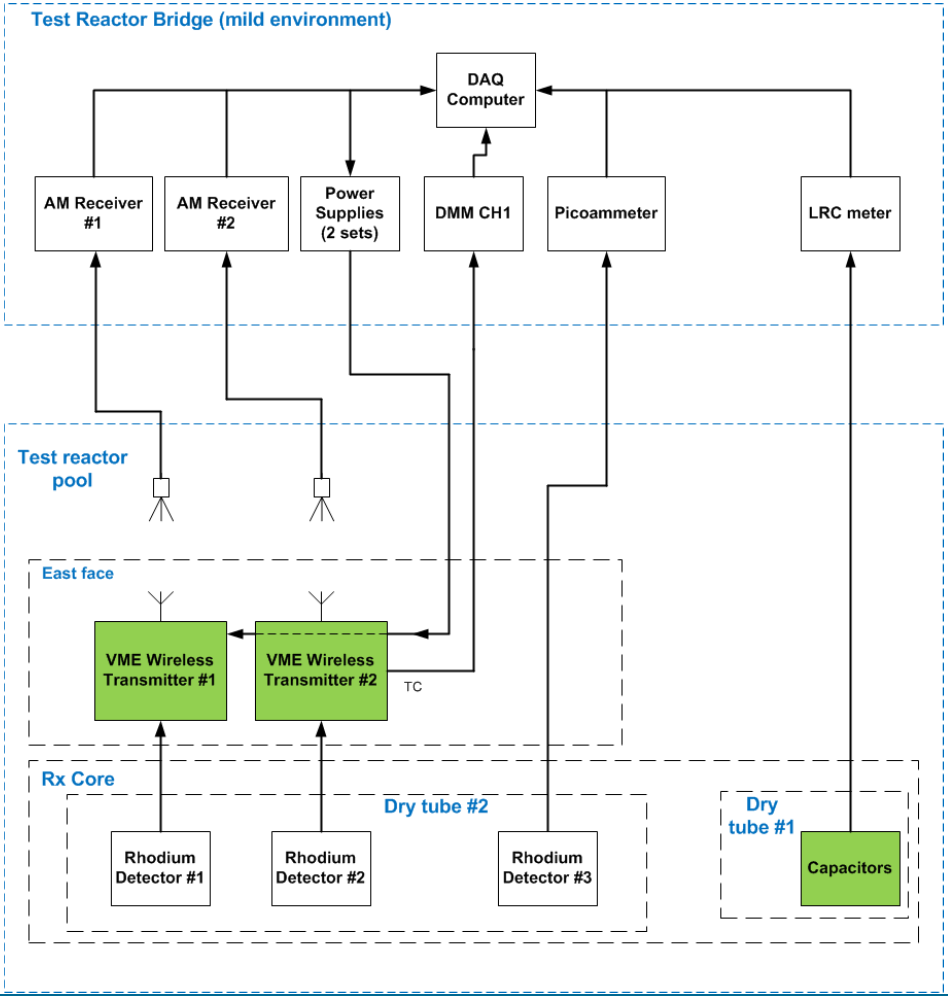
Project Overview

- 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 – September 30th, 2019.

Accomplishments

Penn State Breazeale Reactor Irradiation Test Results

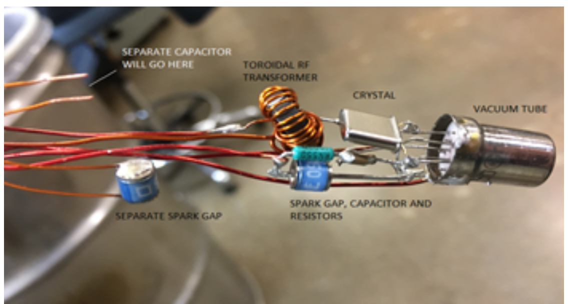
- New amplitude modulated Vacuum Micro-Electronic (VME) based transmitter noise issue resolved and data acquired.
- A combination of excessive receiver gain and vibration contributed to the noise on data from year 1.

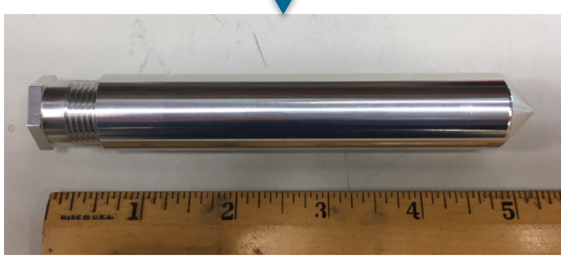


Accomplishments

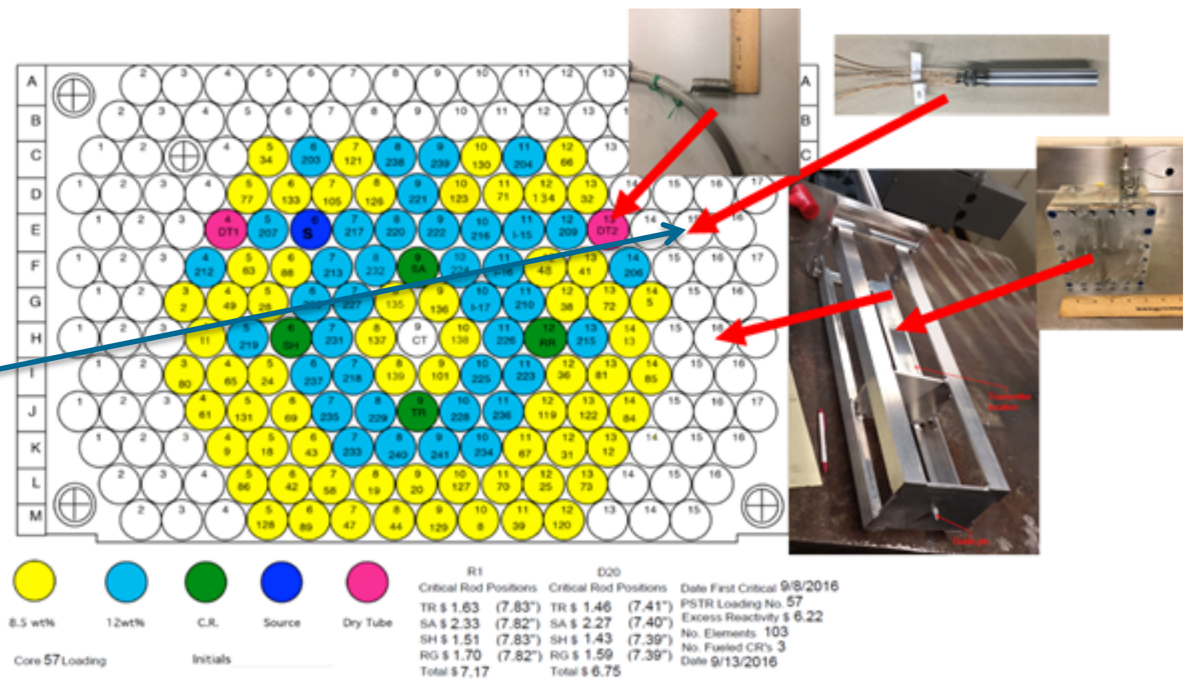
Penn State Breazeale Reactor Irradiation Test Results

- Total Neutron Fluence (n/cm^2)
  - DT2 (Rh detectors): 6.6E+18
  - E15 (Capacitors): 2.6E+18
  - H16 (Transmitters): 2.6E+18





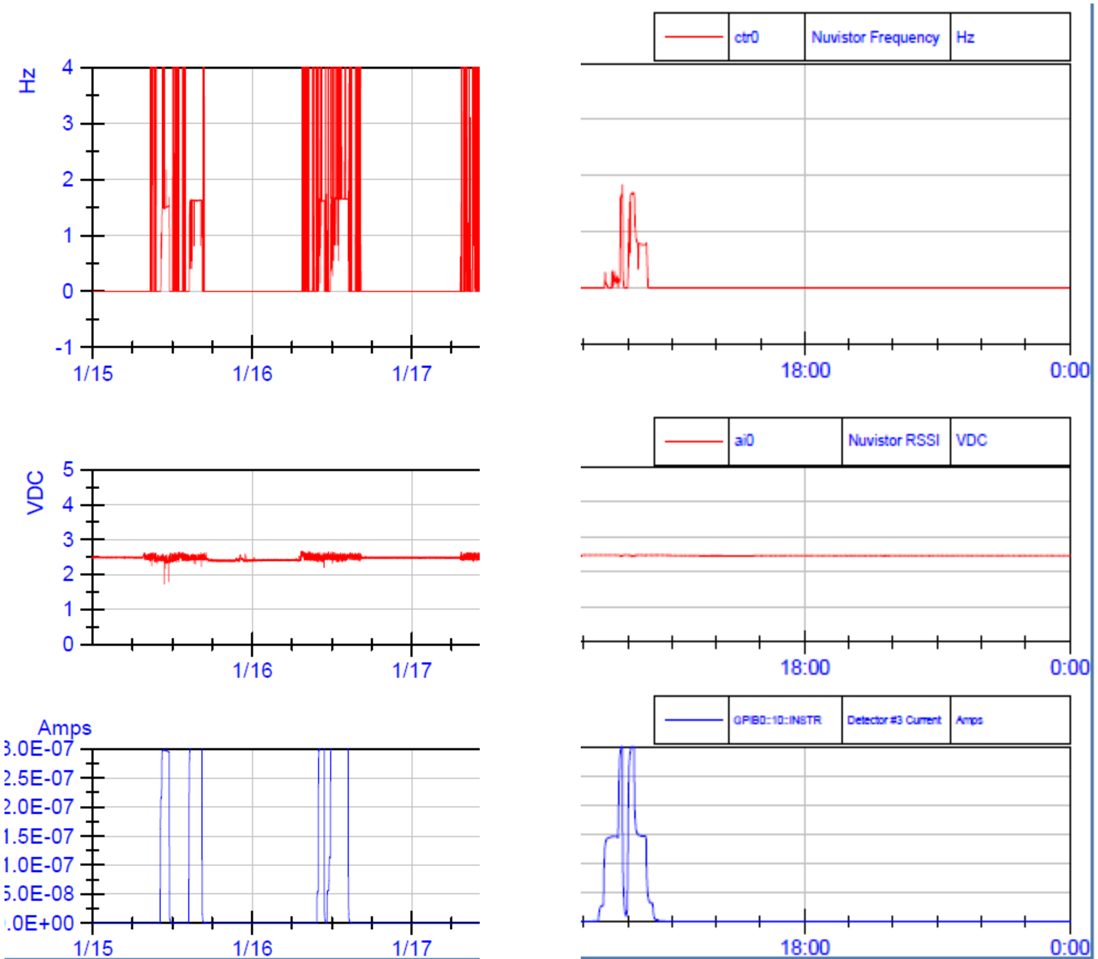
New AM transmitter with vacuum pulled inside enclosure

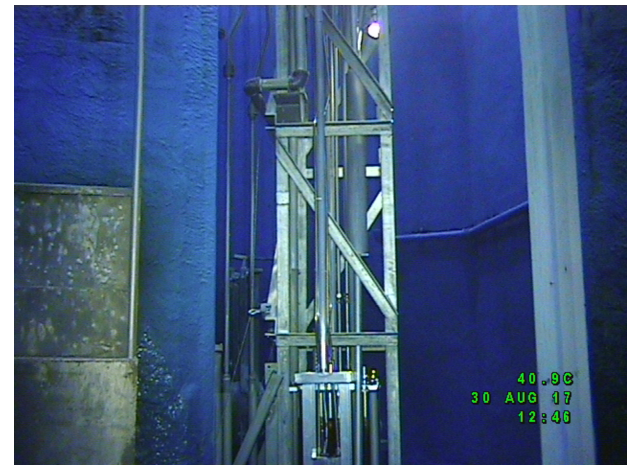


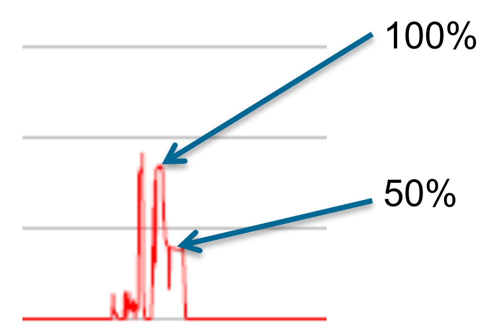
Accomplishments

Modulation Rate vs. Reactor Power measurements

- Noise reduction achieved.







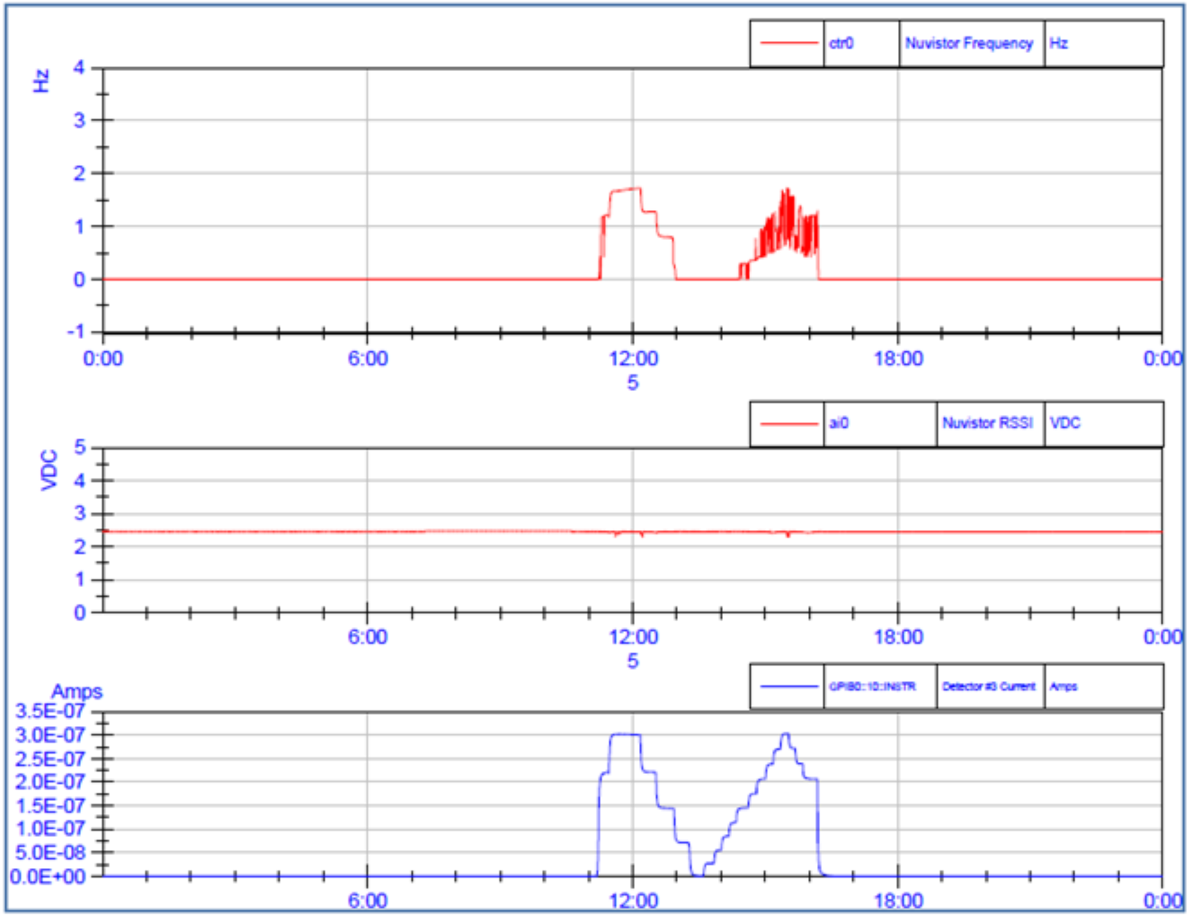
Original data

After adjusting discriminator

Modulation Rate vs. Reactor Power measurements

- Pulse responses (top) proportional to Rh SPD (bottom)
- Signal amplitude (middle) stable as Rx power varies
- 2 Rh SPD feeding the transmitter.
- 1 Rh SPD used as the detector

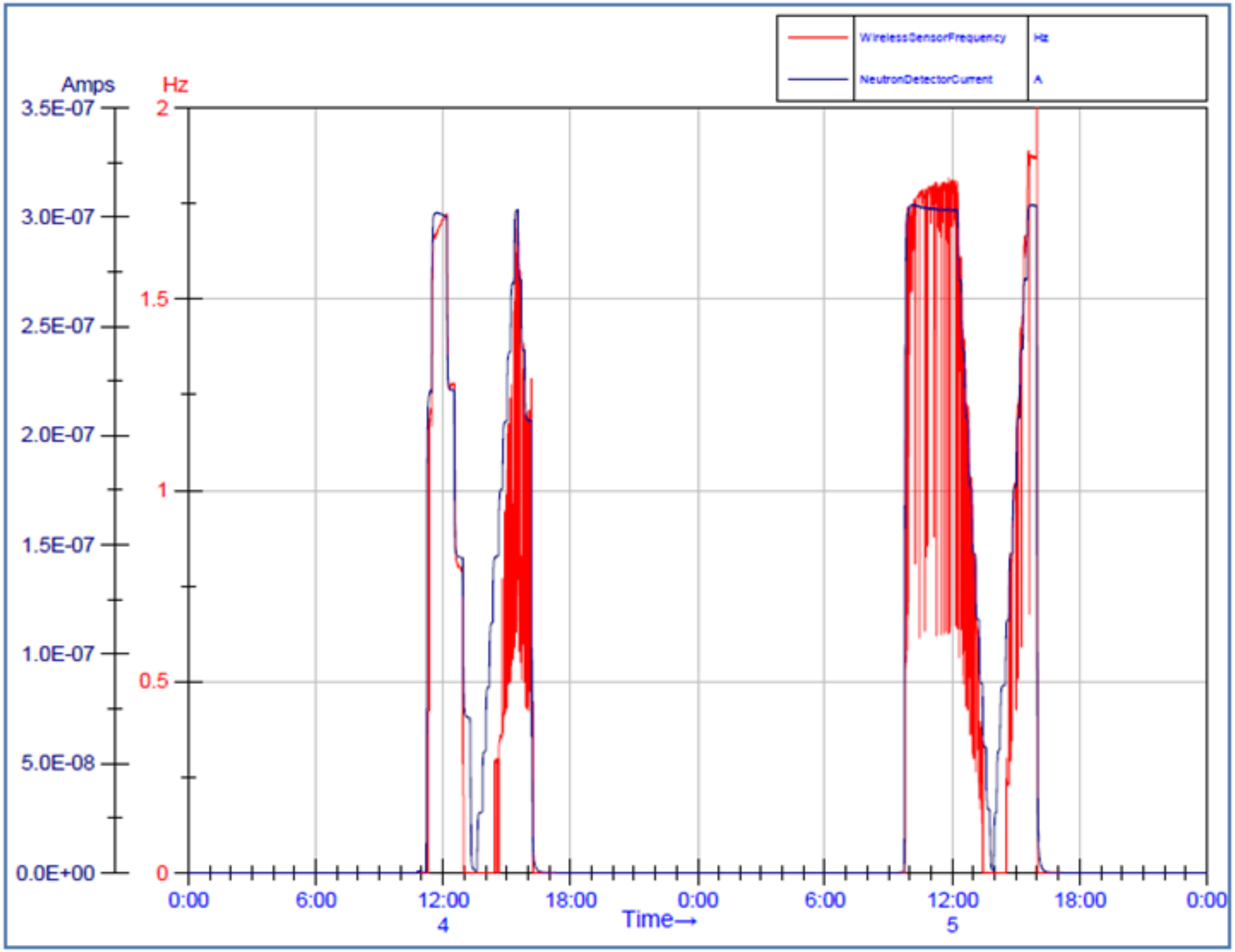
- Detector current below approximately 25% Rx power is not sufficient to trigger circuit.



Accomplishments

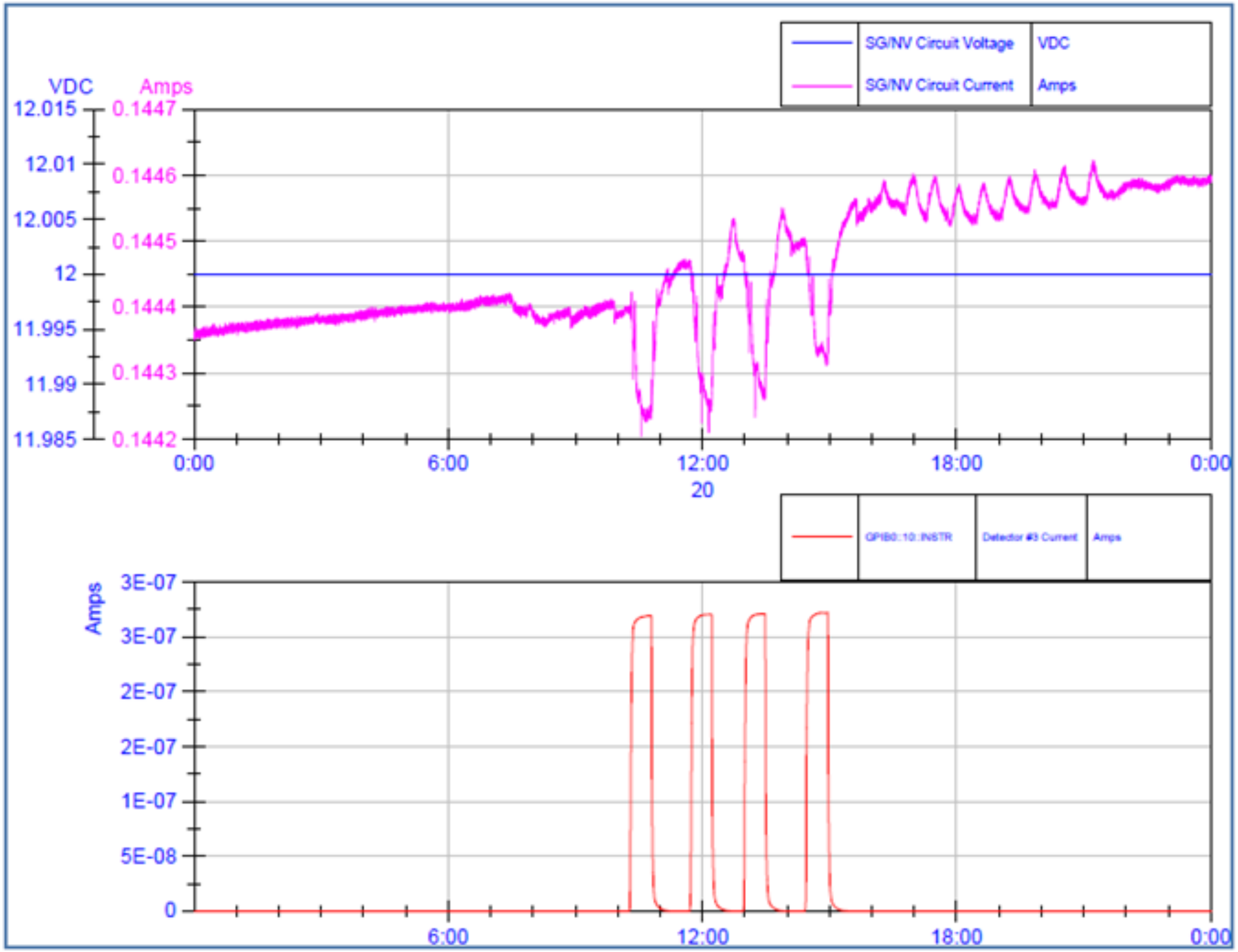
Modulation Rate vs. Reactor Power measurements

- Pulse responses in red
- Rh SPD in blue
- 2 Rh SPD feeding the transmitter.
- 1 Rh SPD used as the detector



Transmitter current draw variance

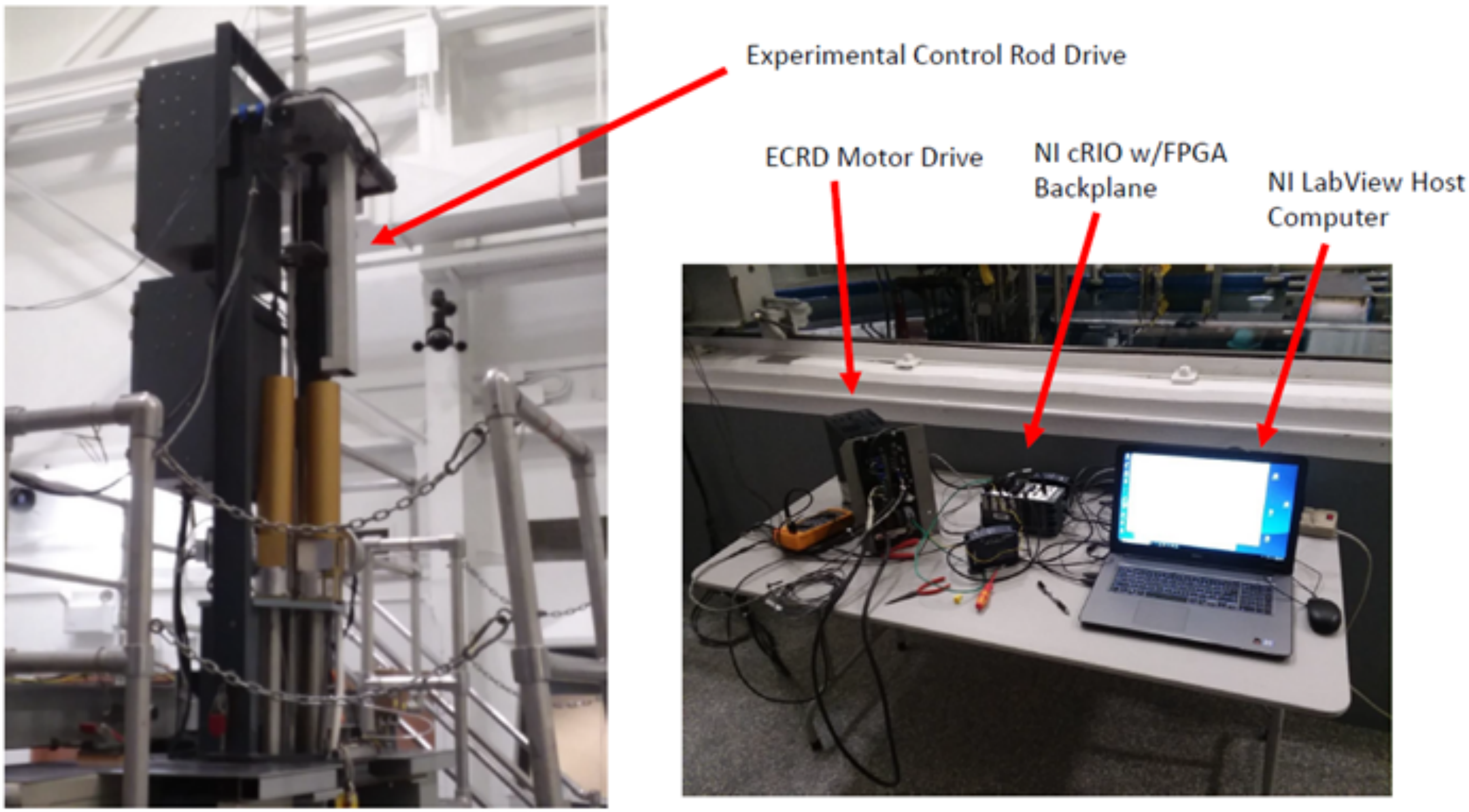
- Transmitter DC current variation vs. Rx power – minimal change



Accomplishments

Proportional-Integral (PI) controller to control PSBR TRIGA Rx with hardware and software compensation.

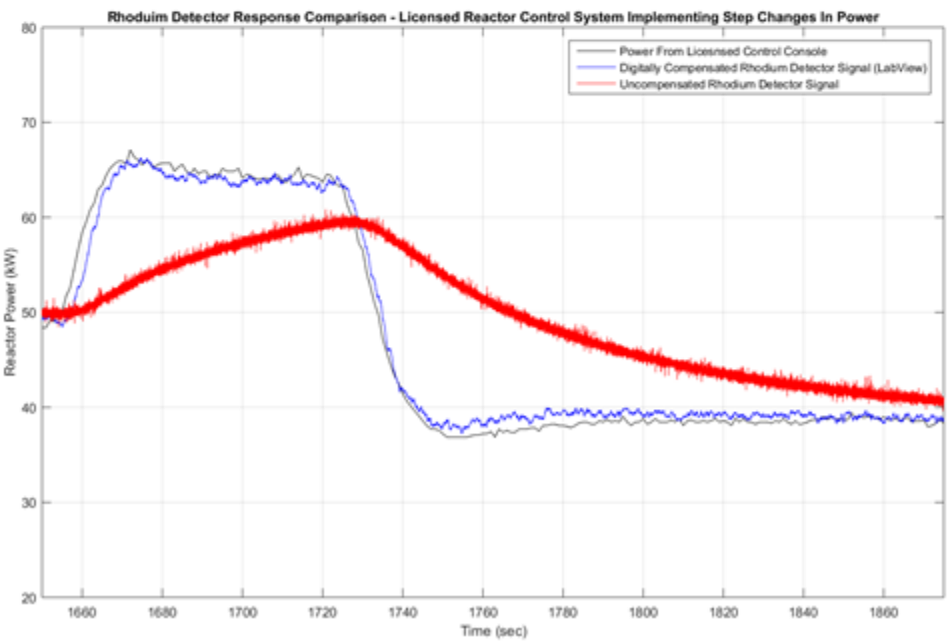
Rh detector → Picoammeter → Voltage output → PI controller → Experimental control rod

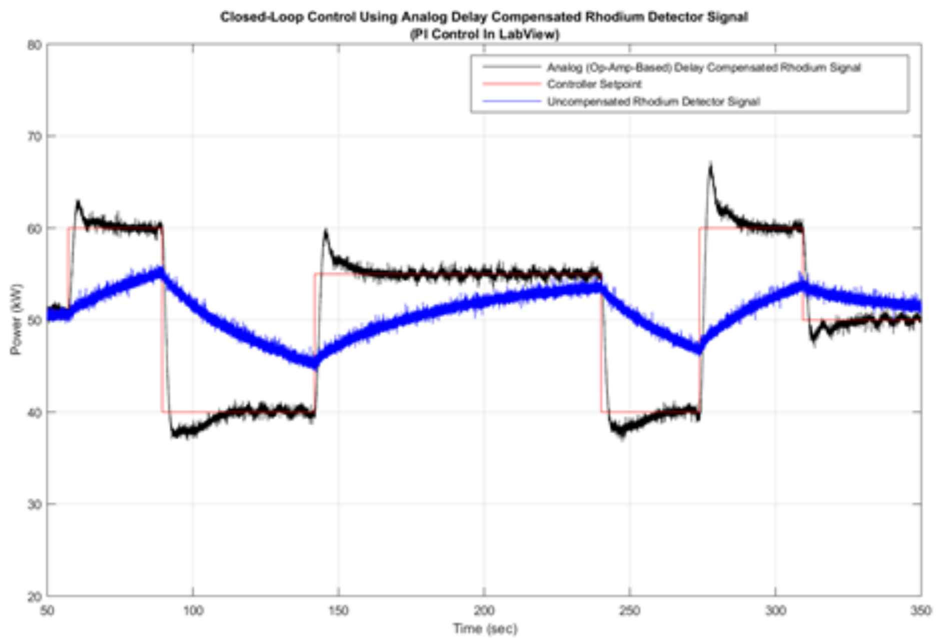


Accomplishments

Proportional-Integral (PI) controller to control PSBR TRIGA Rx with hardware and software compensation.

- Open-loop and Analog compensated signal

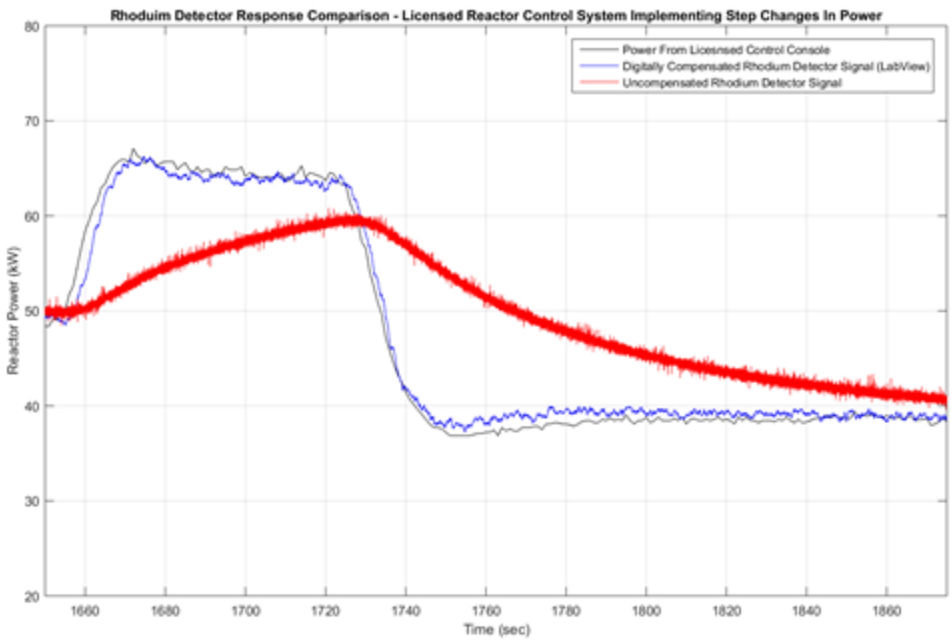


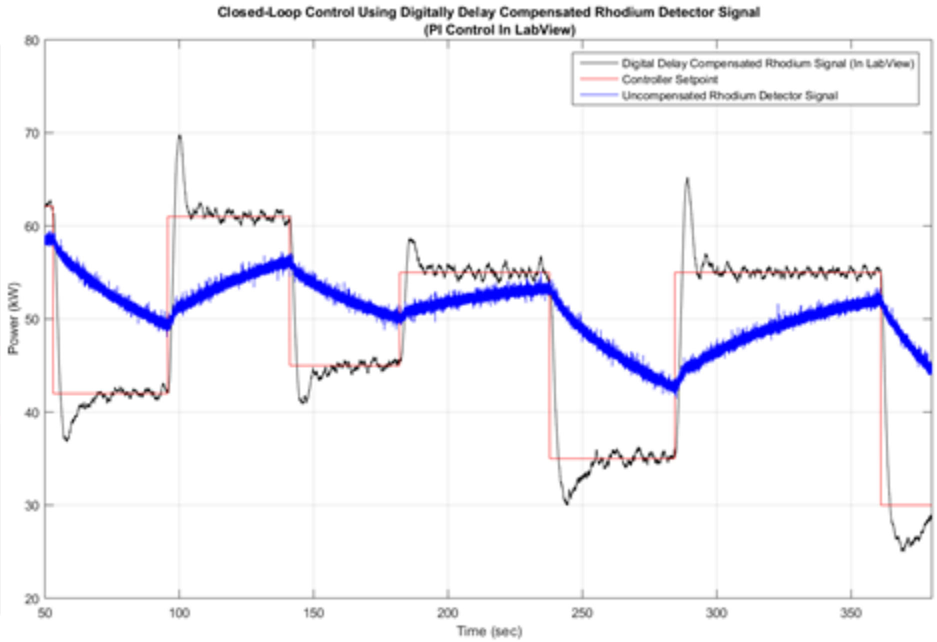


Accomplishments

Proportional-Integral (PI) controller to control PSBR TRIGA Rx with hardware and software compensation.

- Open-loop and Digitally compensated signal





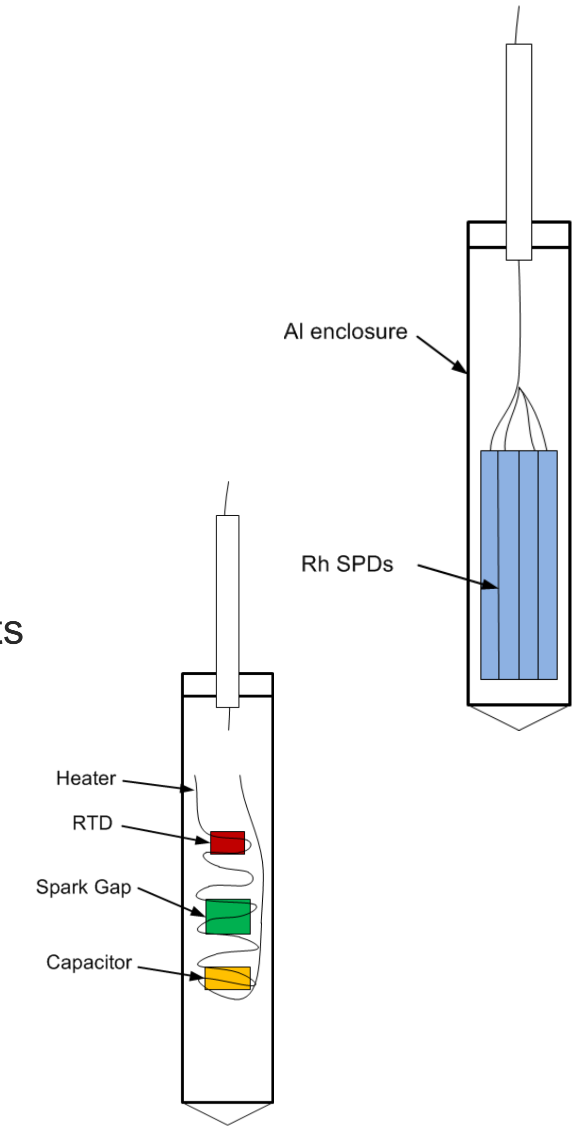
Accomplishments

Power supply configurations

- Several Rhodium detector arrangements have been tested at PSBR with mixed results. Shelf shielding has caused issues.
- Final year plan is to build a device from gamma harvesting material such as tungsten or platinum and investigate how to replace the VME heater element with a similar material.

Sub-circuit temperature test

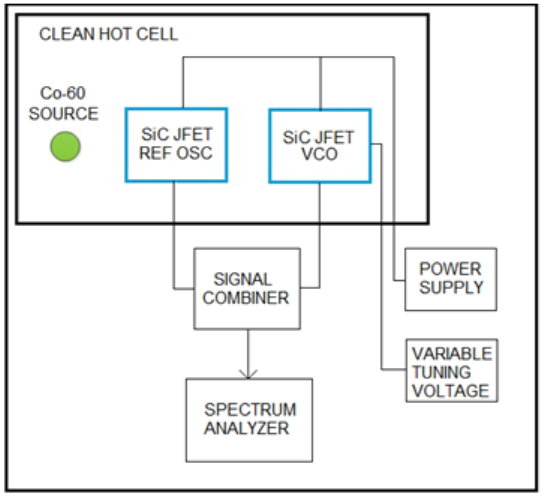
- Front end of transmitter circuit has been temperature tested while in the core.
- Decrease in insulation resistance at high temperatures presents a greater challenge than radiation induced damage.

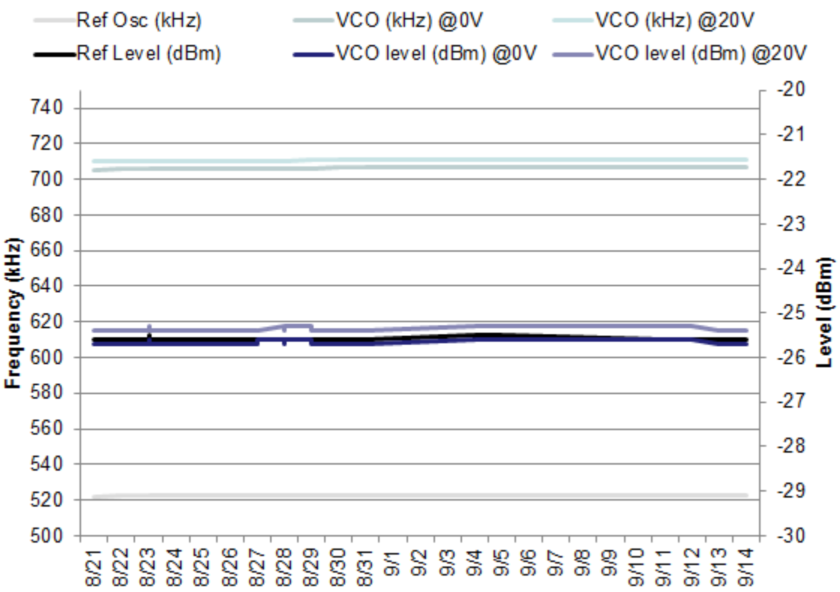


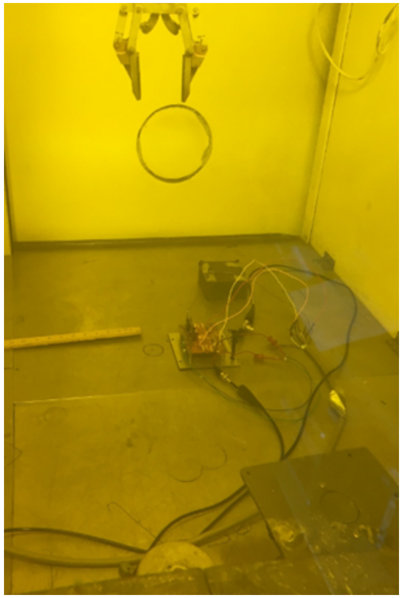
Accomplishments

Gamma Irradiation of SiC JFET Oscillator

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







Accomplishments

Publications

- Full paper submitted to the 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.”
- Paper submitted to “Annals of Nuclear Energy” journal titled “Toward the Implementation of Self-Powered, Wireless, Real-Time Reactor Power Sensing.”
- Poster presentation during early June at the Argonne National Laboratory “Digital Environment for Advanced Reactor Workshop.”

Technology Impact

- 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.

- 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.

Conclusion

Demonstrated that processing the small signal output (300nA to 600nA) generated by the Rh SPD can be wirelessly transmitted with an amplitude-modulating transmission scheme in the presence of neutron and gamma radiation.

Email: carvajjv@westinghouse.com

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