U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Office Of Nuclear Energy Sensors and Instrumentation Annual Review Meeting

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

Jorge Carvajal
Westinghouse Electric Co.

DE-NE0008522

October 18-19, 2017

Project Overview

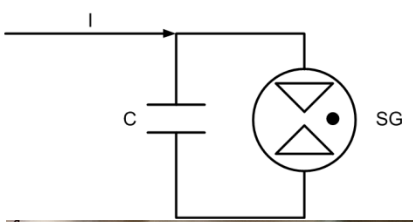
- **Goal, and Objectives**
  - Develop the technology necessary for a wireless reactor power distribution measurement system. This system utilizes highly radiation- and temperature-resistant vacuum micro-electronics (VME) technology that continuously broadcasts Self-Powered Detector (SPD) signals and 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.
  - Dr. James Turso, Co-PI, Pennsylvania State University.
- **Schedule**
  - October 1st, 2016 – September 30th, 2019.

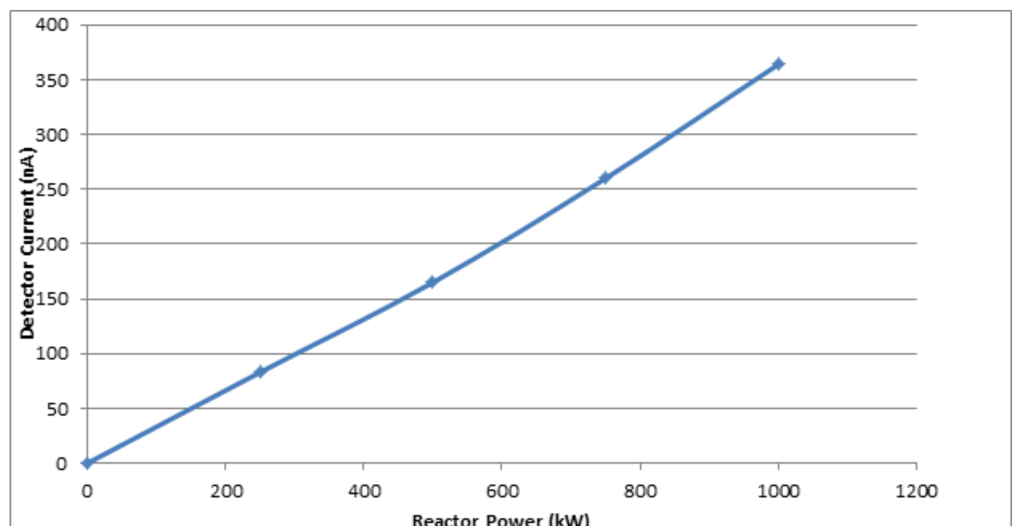
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Accomplishments

■ Year 1 Power Supply design and results

- Rhodium Self-Powered Detector (RSPD) Test Results at PSBR
  – Tested a RSPD in a 1” dry tube at 1x10^13 nv.
  – Detector produced 364nA and 500V at 1MW reactor power as measured by a Keithley Picoammeter.
  – Compared to the Vanadium detector 110nA and 40V.
  – Detector current output was the input into a capacitor/op-amp circuit.

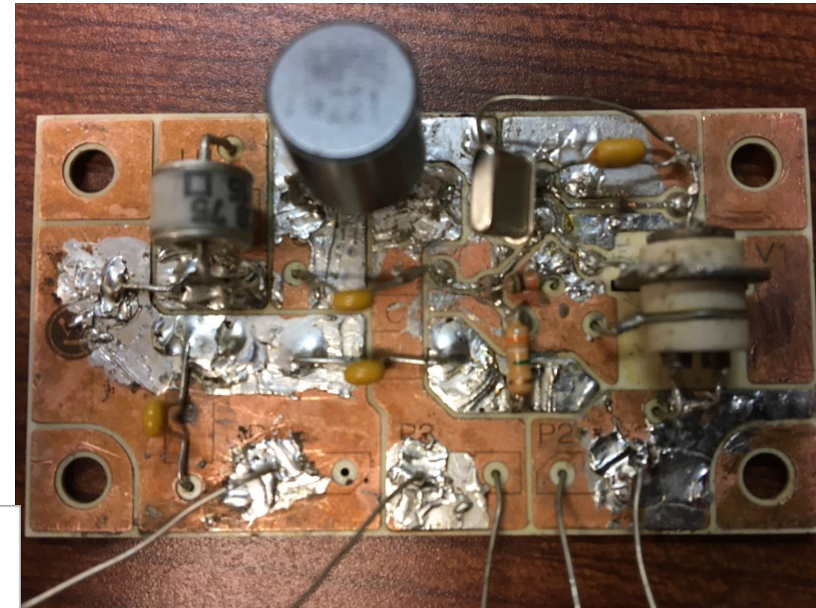


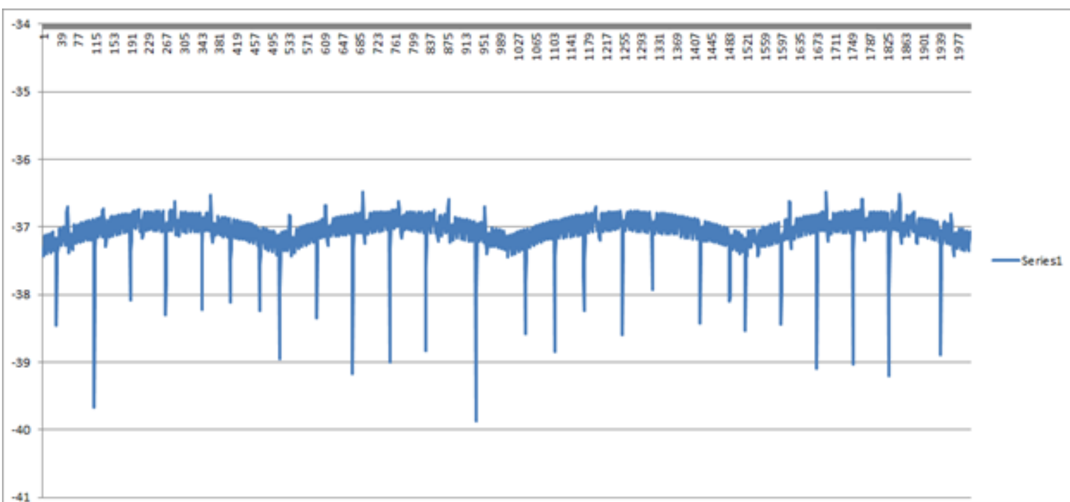


Accomplishments

Wireless Transmitter Design

- Amplitude modulated RF transmitter.
- Front end processes small detector current and turns oscillator ON/OFF.
- Very stable RF oscillator with a crystal resonator.



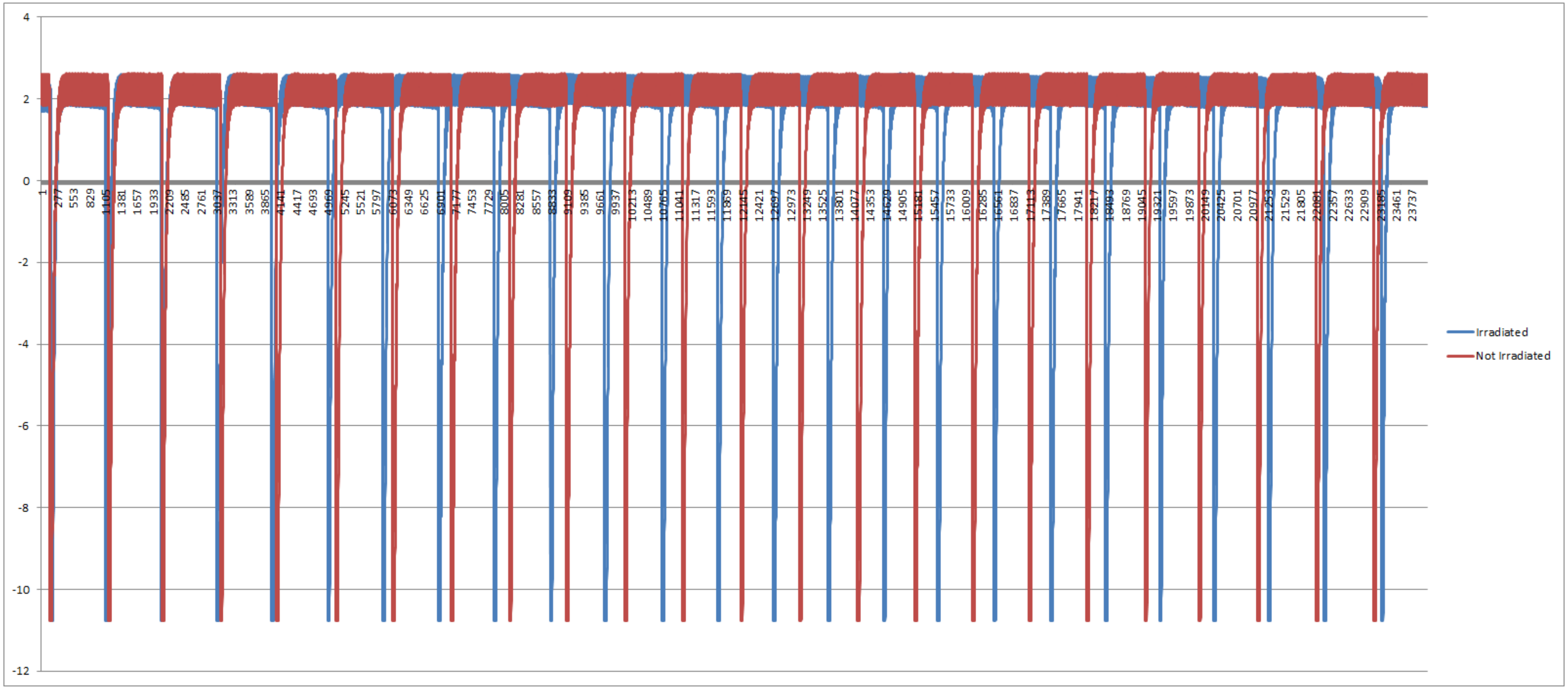


Current input (uA)	Pulse timing average (msec)	Pulse timing variance (msec)
3.0	214.5	1.2
3.2	210.8	1.2
3.4	162.3	0.3
3.6	157.0	0.4
3.8	154.5	0.1
4.0	148.8	0.4
4.2	142.1	0.3
4.4	131.9	0.3
4.6	113.4	0.1
4.8	113.1	0.1
5.0	97.7	0.05

Accomplishments

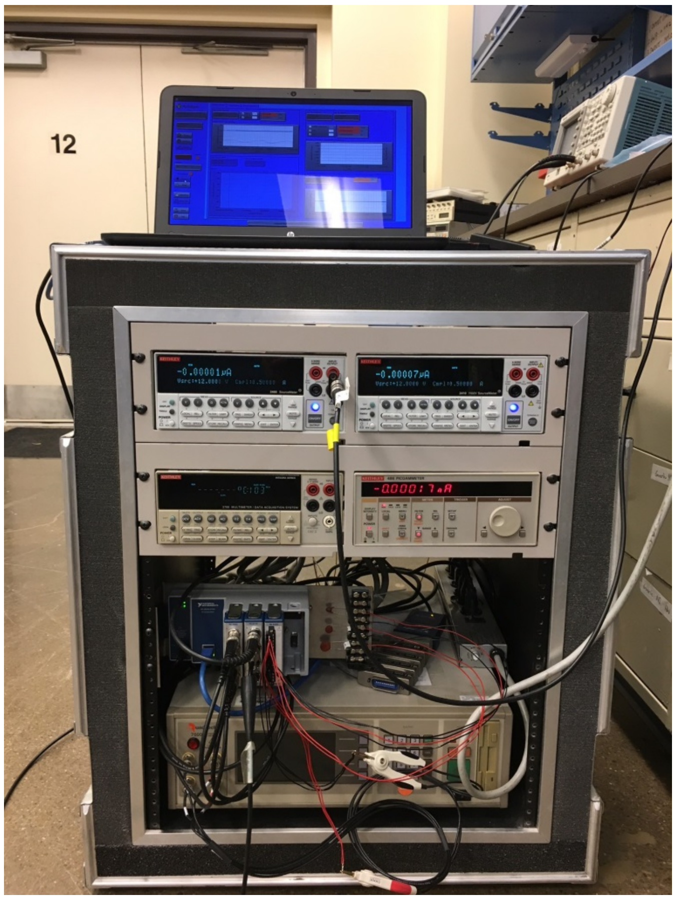
Wireless Transmitter Design cont..

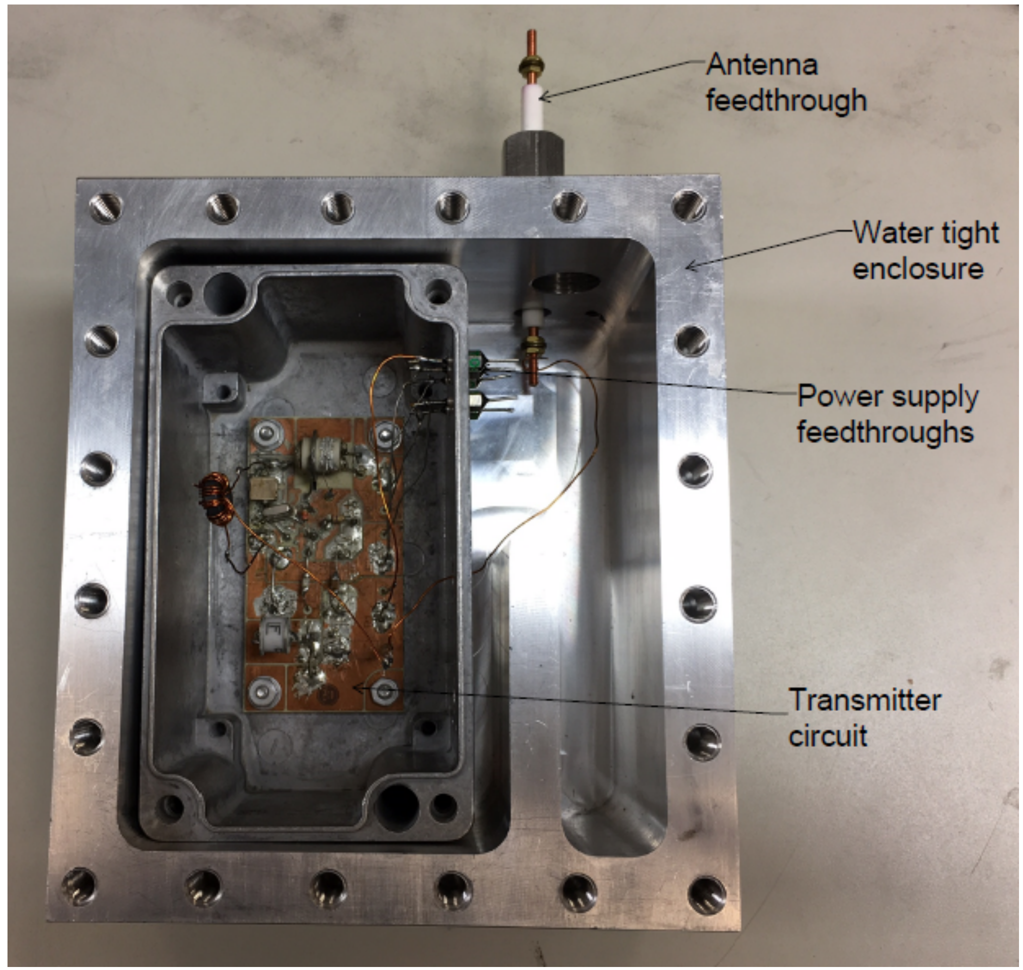
- Front end modulation test in Westinghouse Churchill Clean Hot Cell.



Accomplishments

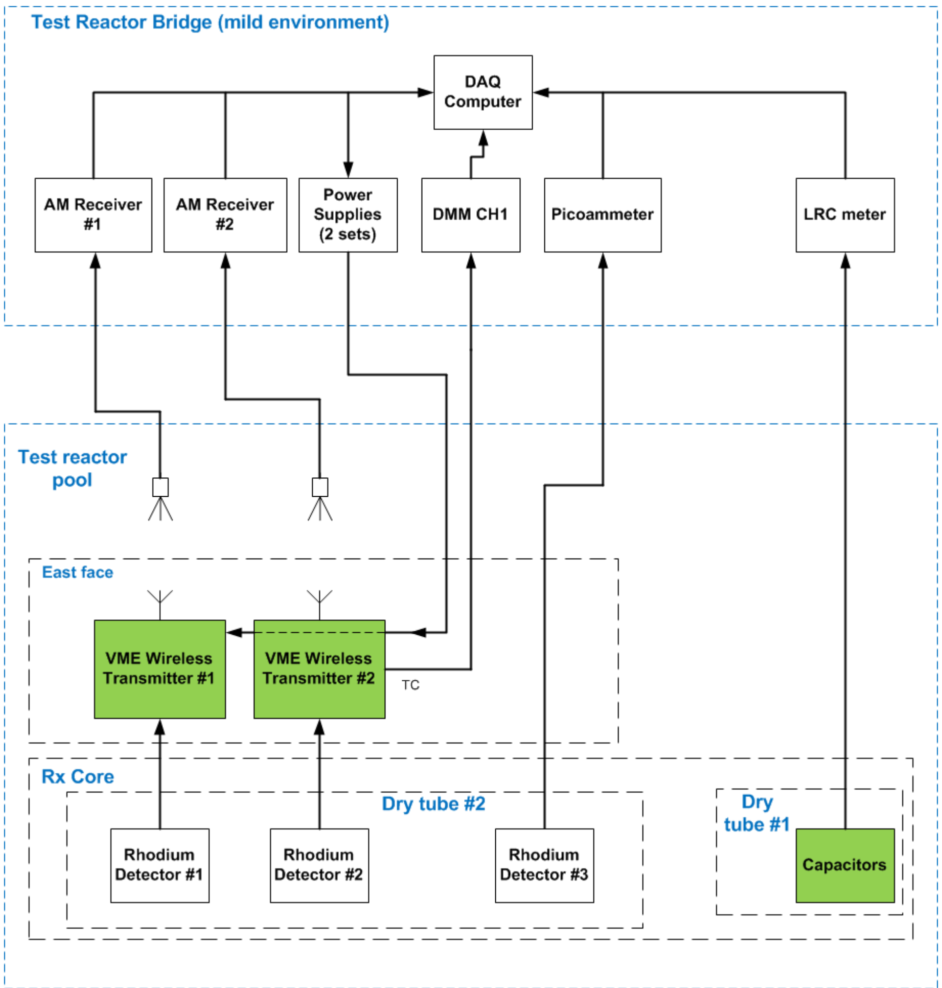
- **Wireless Transmitter and DAS final assembly**





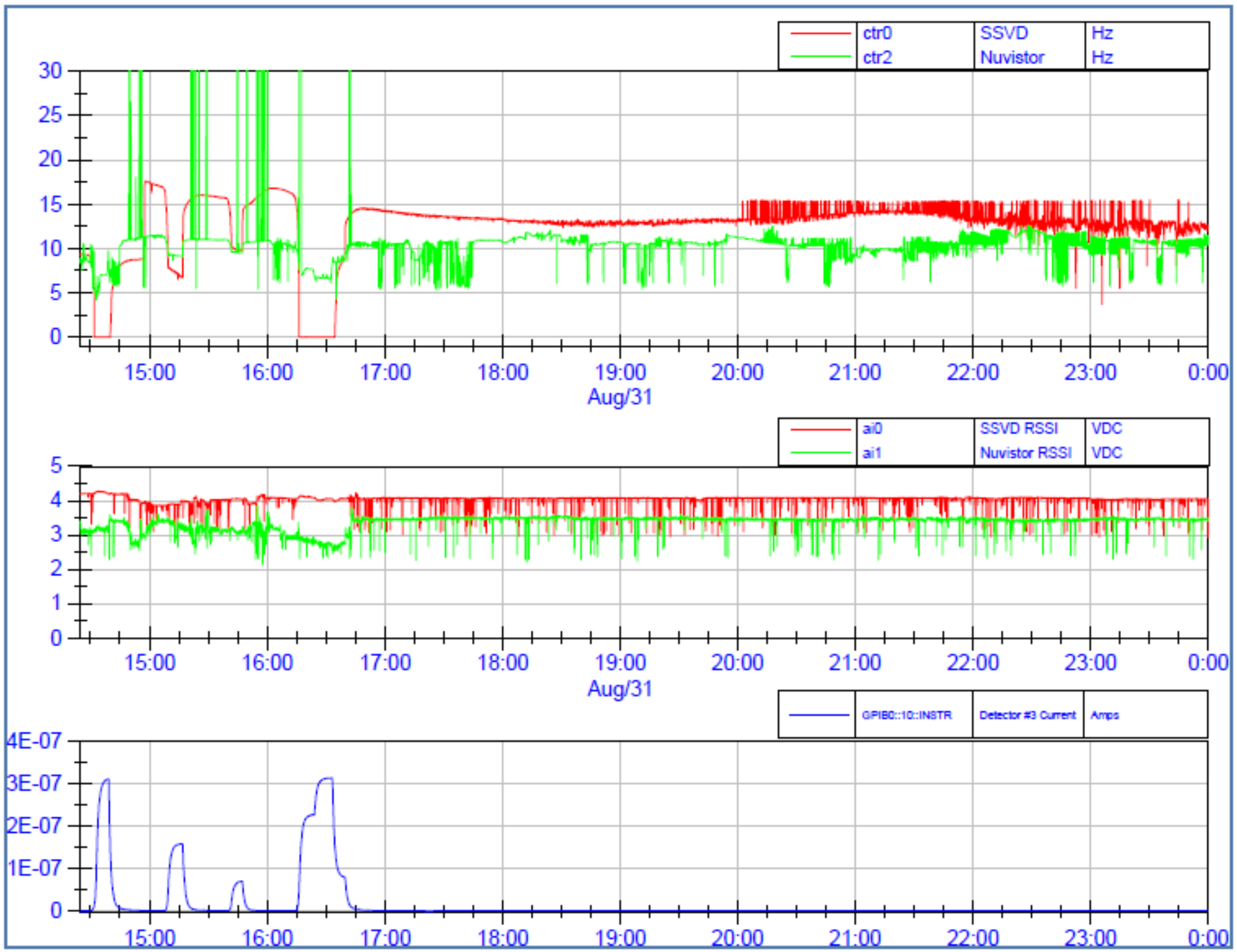
Accomplishments

■ Irradiation Test at PSBR



Accomplishments

- **Initial test results – Amplitude & AM vs. Rx power**



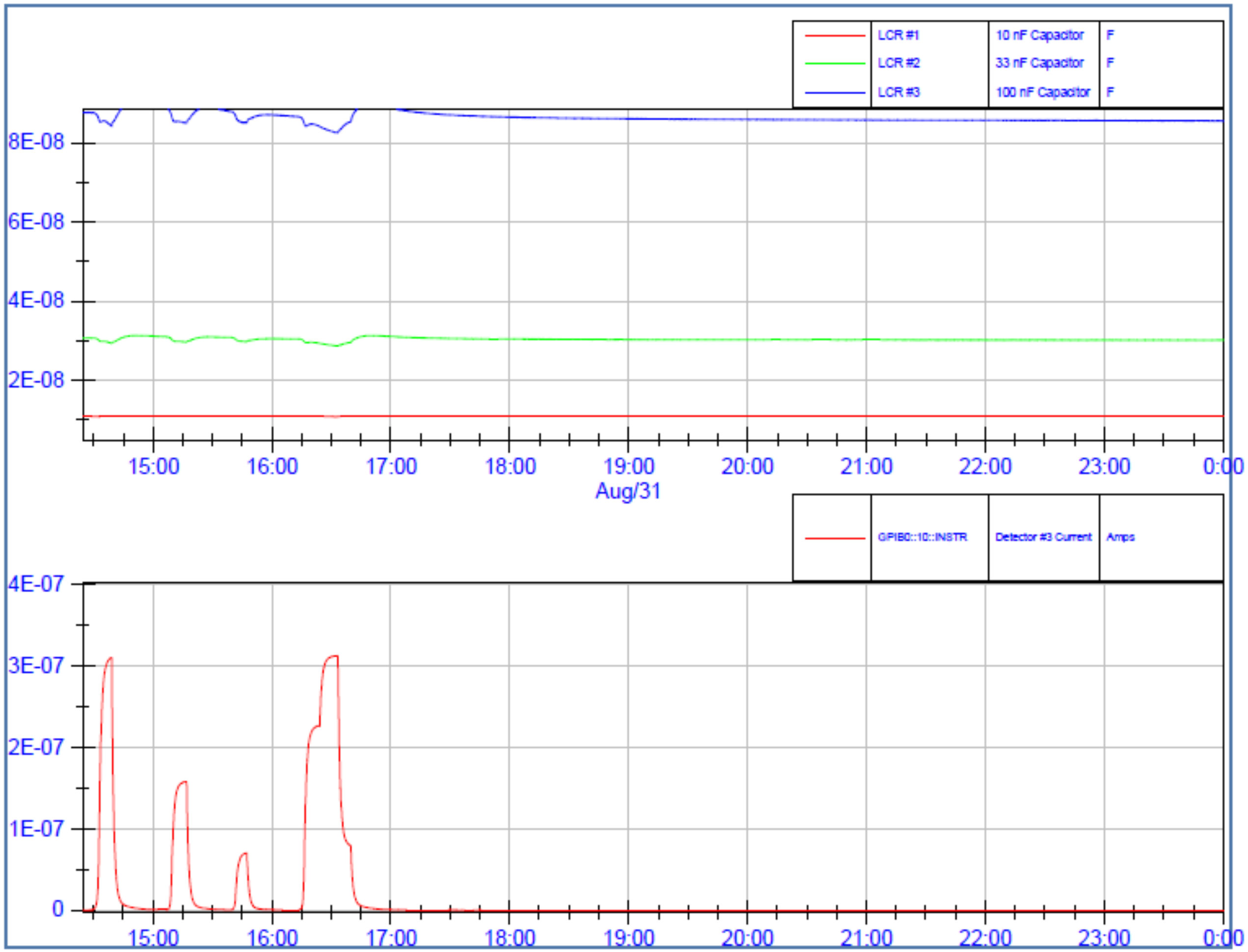
- Top graph, frequency output is the wireless transmitter amplitude modulated output.
- Red and green top trace dips represent reactor power fluctuations.

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Accomplishments

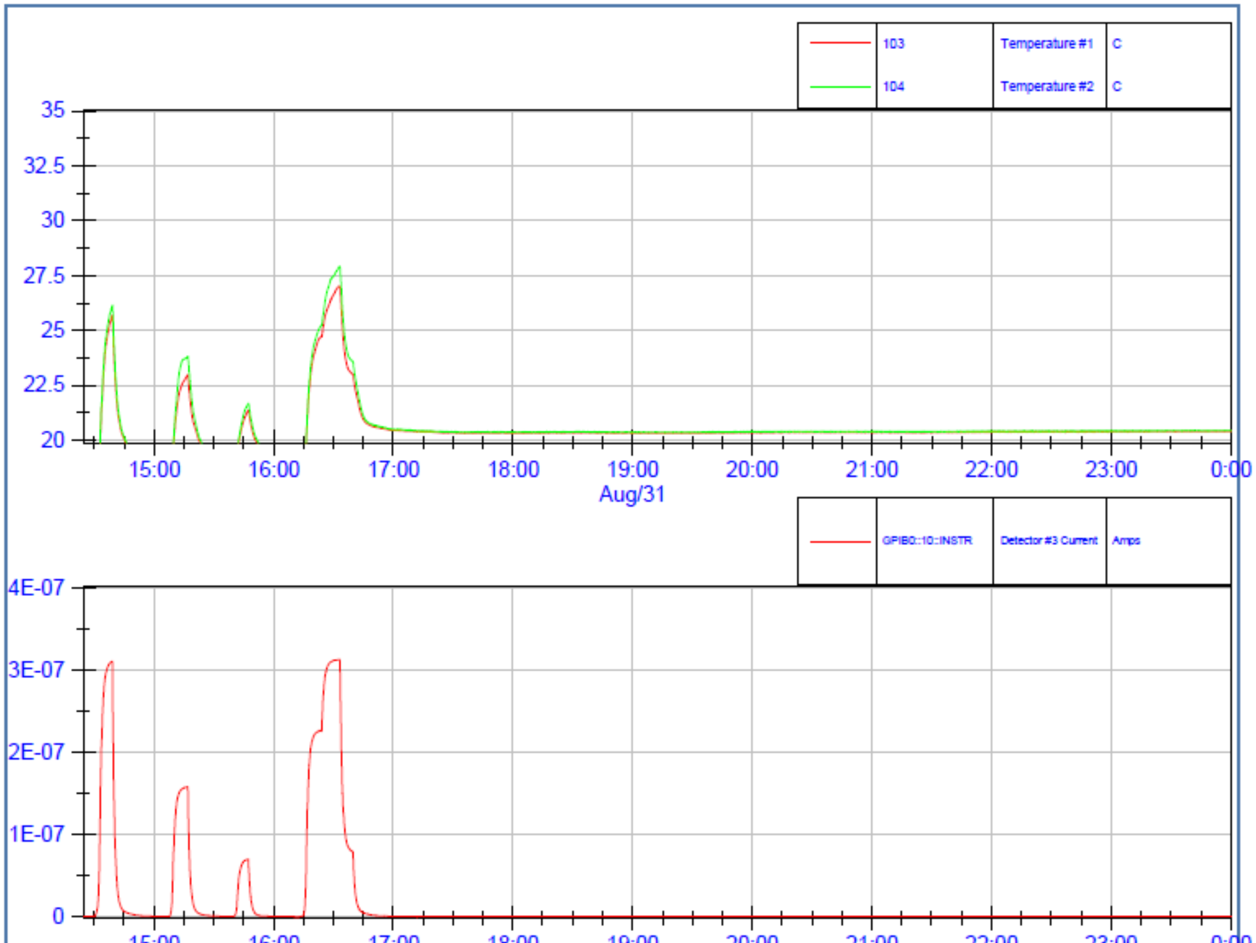
Capacitance vs. Rx power



- No change in capacitance to date.

Accomplishments

- **Temperature vs. Rx power**



- Thermocouples located in the interior of both wireless transmitter enclosures.

U.S. DEPARTMENT OF ENERGY

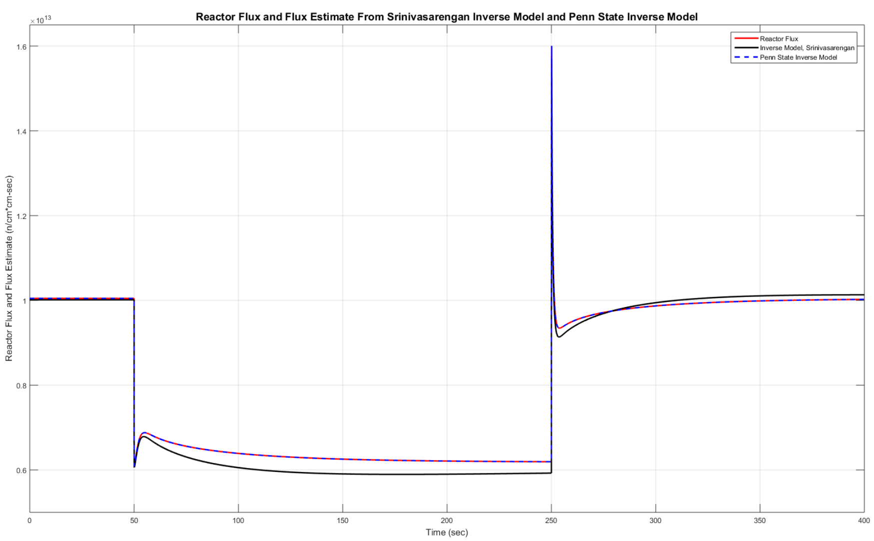
Nuclear Energy

Accomplishments

- PSU Researchers modeled PSU TRIGA Reactor in Matlab/SIMULINK
- Modeled Vanadium Detectors, and applied dynamic inverse model to convert current from detector to reactor power.
- Good results (albeit sensitive to measurement noise)
- Currently applying the inverse model to TVA plant operating data

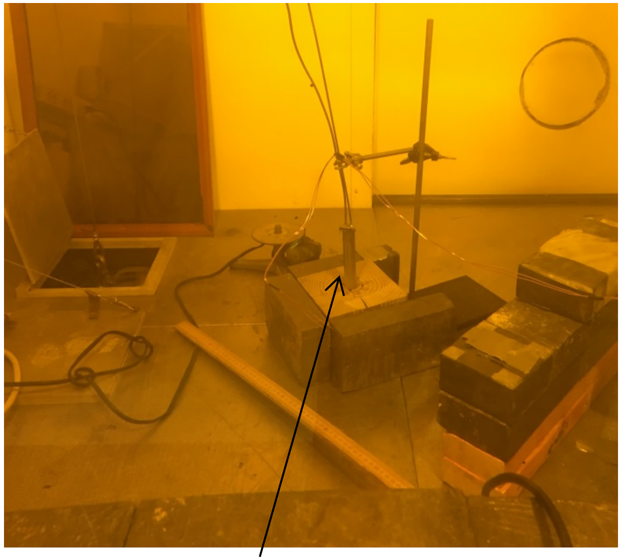
$$\frac{dN_{52}(t)}{dt} = \frac{-(k_{pv} + k_{gv})\lambda_{52} N_{52}(t)}{k_{pv}} + \frac{i(t)}{k_{pv}}$$

$$\phi(t) = \frac{k_{gv}\lambda_{52} N_{52}(t)}{k_{pv}\sigma_{51} N_{51}(0)} + \frac{i(t)}{k_{pv}\sigma_{51} N_{52}(0)}$$



Accomplishments

- **Irradiation Test initial conclusions**
  - Two wireless transmitters, individual capacitors and self-powered detectors are being irradiated at the PSBR.
  - Receiver is capable of receiving a low amplitude (-65dBm) at 20MHz and 25MHz.
  - Leakage current issue:
    - In the presence of a gamma field, the air ionizes and creates a path for enough current to "leak" from the circuit.
    - Initially surprising given the low voltage (~80V).
    - Several tests performed in the Westinghouse CHC to prove that non-insulated wires exposed to air and gamma radiation "rob" the circuit of its current.
    - Test enclosure on the right included various wire insulations, bare wire with air and under vacuum.



Test enclosure

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.***

Conclusion

- **Year 2 test plans:**
  - Test a wireless transmitter configuration that is under vacuum or completely encapsulated with a ceramic insulator.
  - Long term test of new configuration demonstrating accurate reactor power vs. transmitter modulated output.
  - Rev B of the power supply: Higher power density.

- Developing radiation and temperature tolerant devices that can operate within the core without the addition of new penetrations and cabling are critical to minimizing maintenance cost for plants and increasing their operating margins.