U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

ASI Advanced Sensors and Instrumentation

Irradiation Testing of Sensors

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

October 24 – 27, 2022

Reactor Experiment Designer: Joe Palmer

Idaho National Laboratory

Project Scope

- In the broad sense this program encompasses testing any type of developmental in-core sensor in relevant environments. Currently the main focus is on neutron flux sensors
- The flux sensors under investigation are:
  - Fission chambers – thermal
  - Fission chambers – fast
  - Self Powered Neutron Detectors (currently Rh based and later moving to other elements to detect fast neutrons or achieve rapid response)
- For the last two years this program has also included efforts to develop a retractable sensor mechanism

Project Schedule

FY22

Irradiated neutron sensors in high-temperature test rig at MITR (NSUF collaboration)

Performed high-temperature OSURR irradiation incl CEA sensors

Performed high-temperature NRAD irradiation

Developed retractable sensor mechanism and tested on bench top

Irradiated three sensor types in TREAT

During FY-22 this project irradiated sensors in four research reactors

FY23

Evaluate additional university research reactors for sensor testing

Perform high-temperature OSURR irradiation incl CEA sensors

Develop improved retractable sensor mechanism and test

Participants

- Joe Palmer – Project lead and test rig designer
- Kevin Tsai – PI for Self Powered Neutron Detectors (SPNDs), miniature fission chambers and concurrent testing in TREAT
- Loic Barbot – PI from CEA for miniature fission chambers and SPNDs
- Randel Paulsen – Lead technician for retractable sensor development and NRAD test rig assembly
- Logan Robinson – Mechanical Engineering intern from University of Texas at San Antonio
- Dr. David Carpenter (MIT) – Project lead at MIT for irradiation of neutron sensors in MITR (NSUF collaboration)
- Dr. Ge Yang (NCSU) – Project lead at North Carolina State University for retractable sensor development

Technology Impact

- Advanced instrumentation enables testing of nuclear fuels and materials in support of the US advanced nuclear technology industry
- A number of promising sensor technologies are in the pipeline. The early part of sensor development can be done outside of the reactor environment, but full technical readiness requires experience gained from in-core performance testing.
- Customers usually have only one shot to conduct their irradiation experiments. Because of the high costs test sponsors are frequently reluctant to incorporate unproven technologies in reactor experiments.
- Therefore, it is vital to demonstrate newly-developed sensors in operational conditions, prior to incorporating them into long-term high-value experiments
- Successful completion of these activities will create new monitoring capabilities in high-power test reactors (such as ATR) as well as specialty reactors such as TREAT

Accomplishments – TREAT concurrent testing

Developmental sensors are placed in cooling channels around fuel assemblies, rather than in experiments themselves. This approach lowers costs and does not interfere with high-value customer experiments.

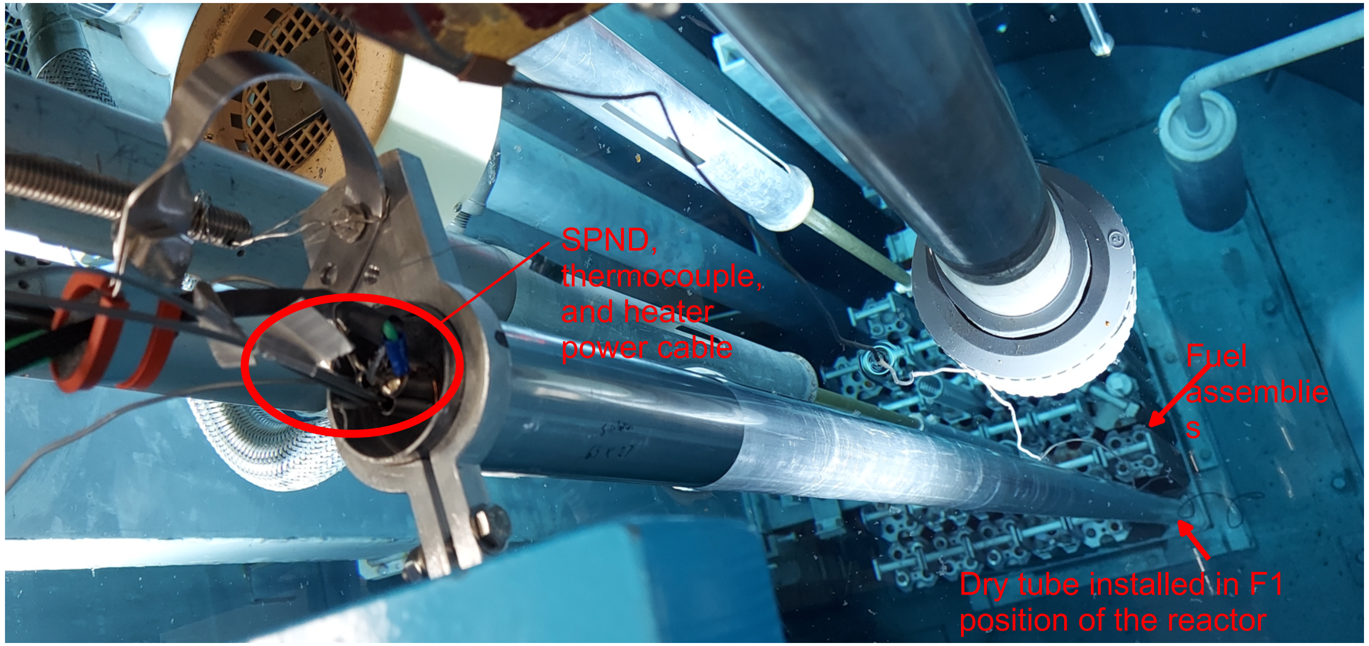
- During FY22 three sensors were tested in TREAT
  - •CEA SPNDs
  - •Temperature transducer assembly #3
  - •KAERI MPFD electronics

- Changes in configuration control requirements during FY2022 resulted in reduced utilization of TREAT. This is expected to continue through FY2023.

Accomplishments – NRAD heated sensor test

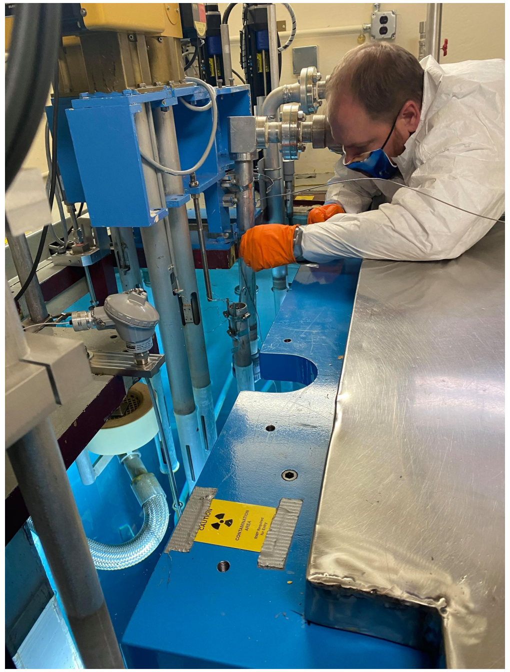
A low-cost test rig which could reach a temperature of 850°C was designed and fabricated in FY-2021 and used early in FY-2022

Insulated Core Section of Test Rig for NRAD



Accomplishments – NRAD heated sensor test Oct 27, 2021

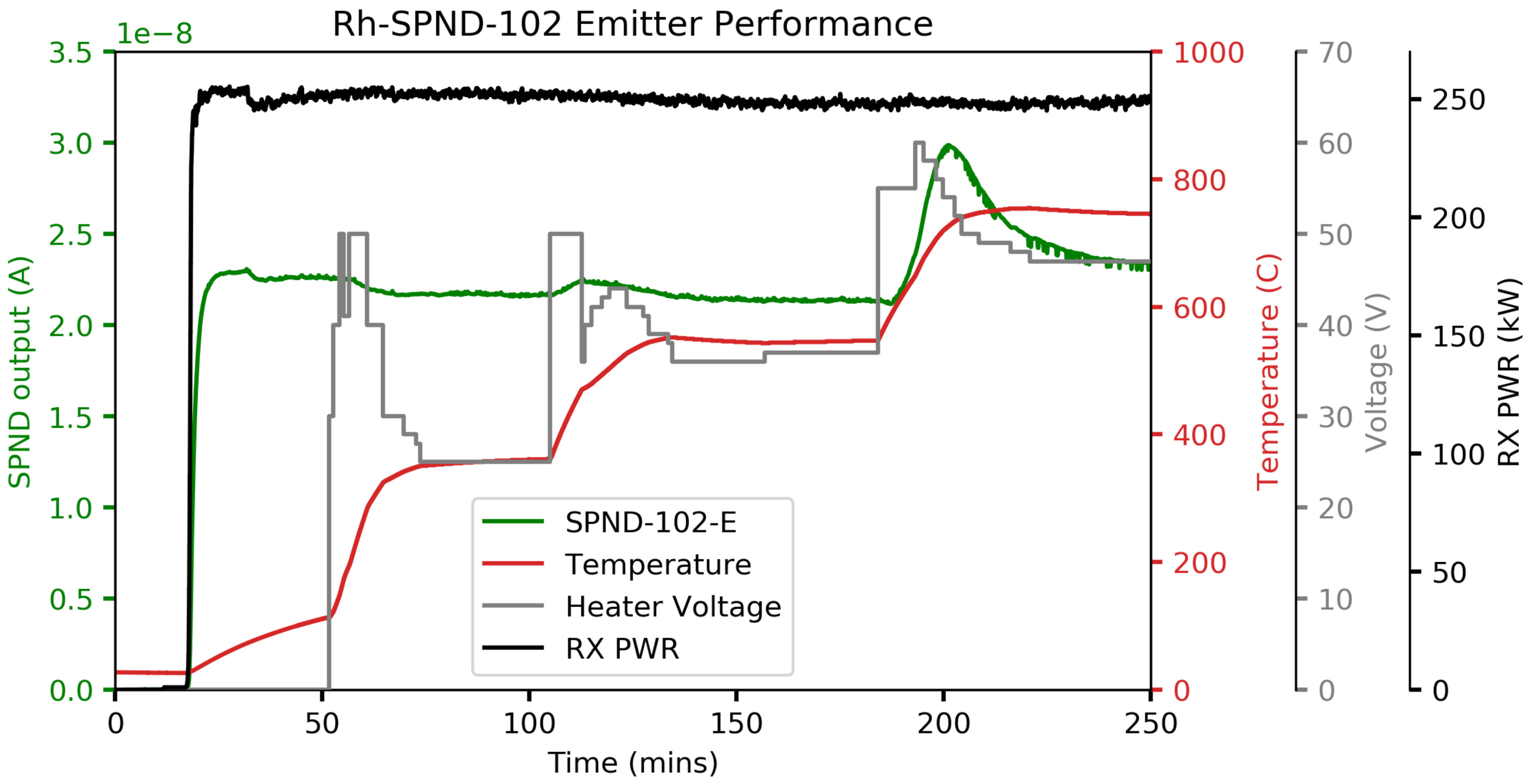
- Five-hour test run with temperatures varying between 100°C and 850°C
- Good signal to noise ratio for SPND even at moderate neutron flux available in NRAD
- An apparent temperature dependence in the SPND response was traced to interference from the electric heater (primarily)



Installing sensors

Gathering data in cask tunnel

Accomplishments – NRAD heated sensor test Oct 27, 2021



Data from Rh SPND (2.5 mm diameter) during Oct 27, 2021 NRAD sensor test

Accomplishments – NSUF/ASI Collaboration to Irradiate Neutron Sensors in the MITR Reactor

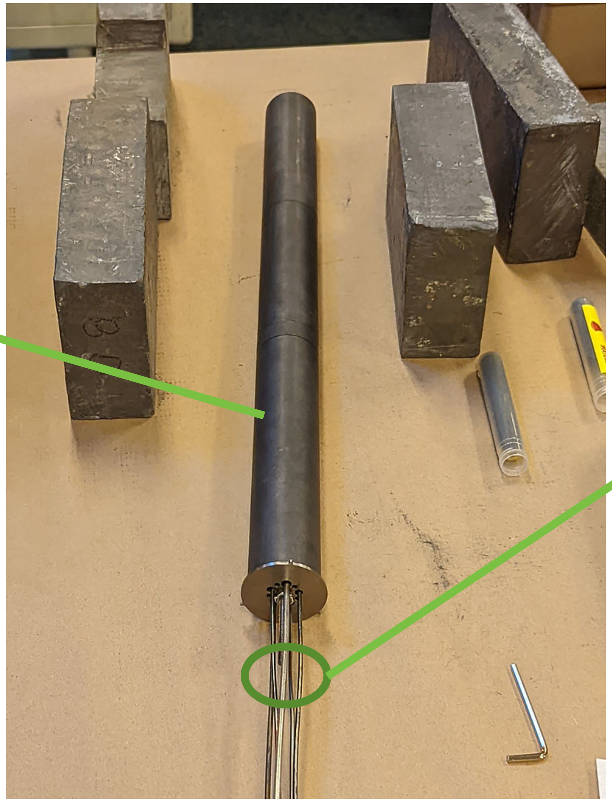
- In this collaboration, NSUF paid for irradiation at MITR, while ASI paid for the sensors and PI support
- This allowed ASI to obtain valuable performance data on newly developed sensors from a high-power material test reactor
- Because of the high nuclear heating rate, elevated temperatures were achieved without the interference of an electric heater

MITR Cambridge, MA

MITR core at full power

Accomplishments – MITR heated sensor test

Graphite sensor holder:
-High thermal conductivity
-Low neutron activation

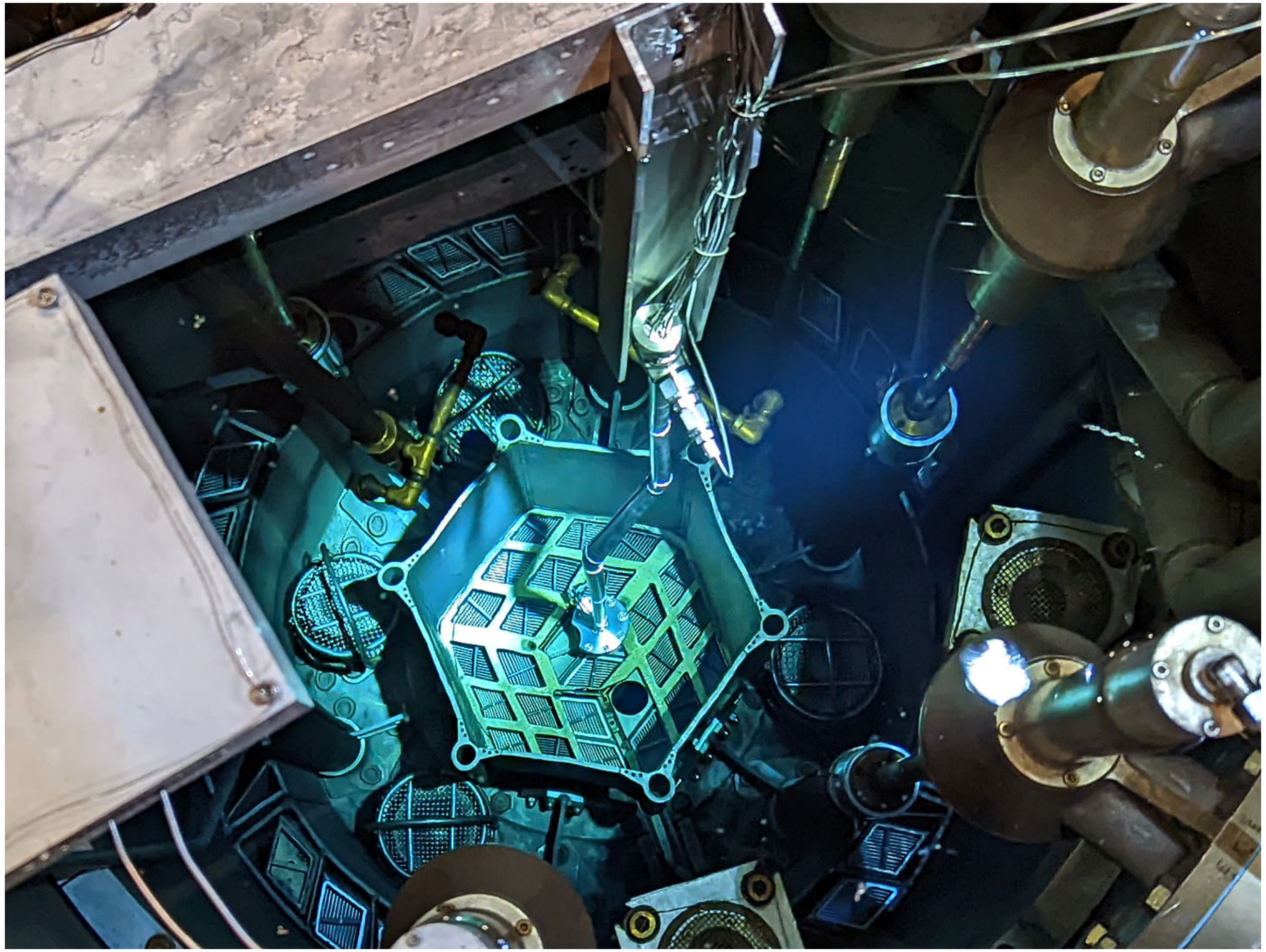


2 Rh based SPNDs
3 Mini fission chambers
5 Thermocouples

Accomplishments – MITR heated sensor test installation

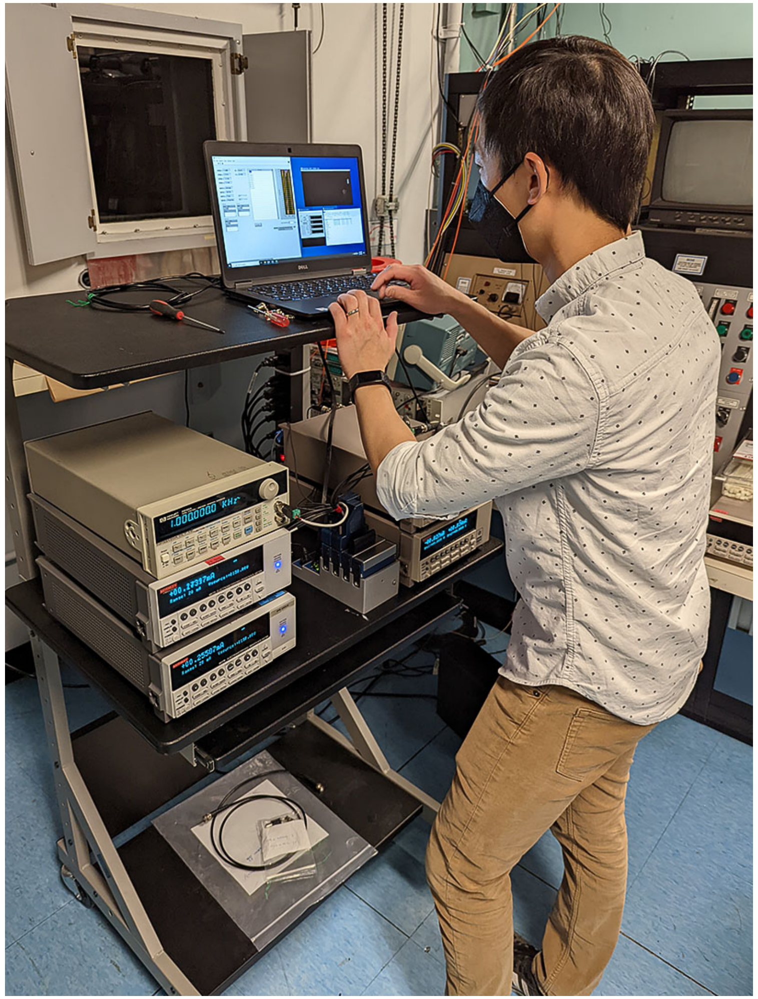
Installed in the high-flux A-1 position of the reactor

Uses nuclear heating and variable He/Ne gas mix to achieve controlled high temperature conditions

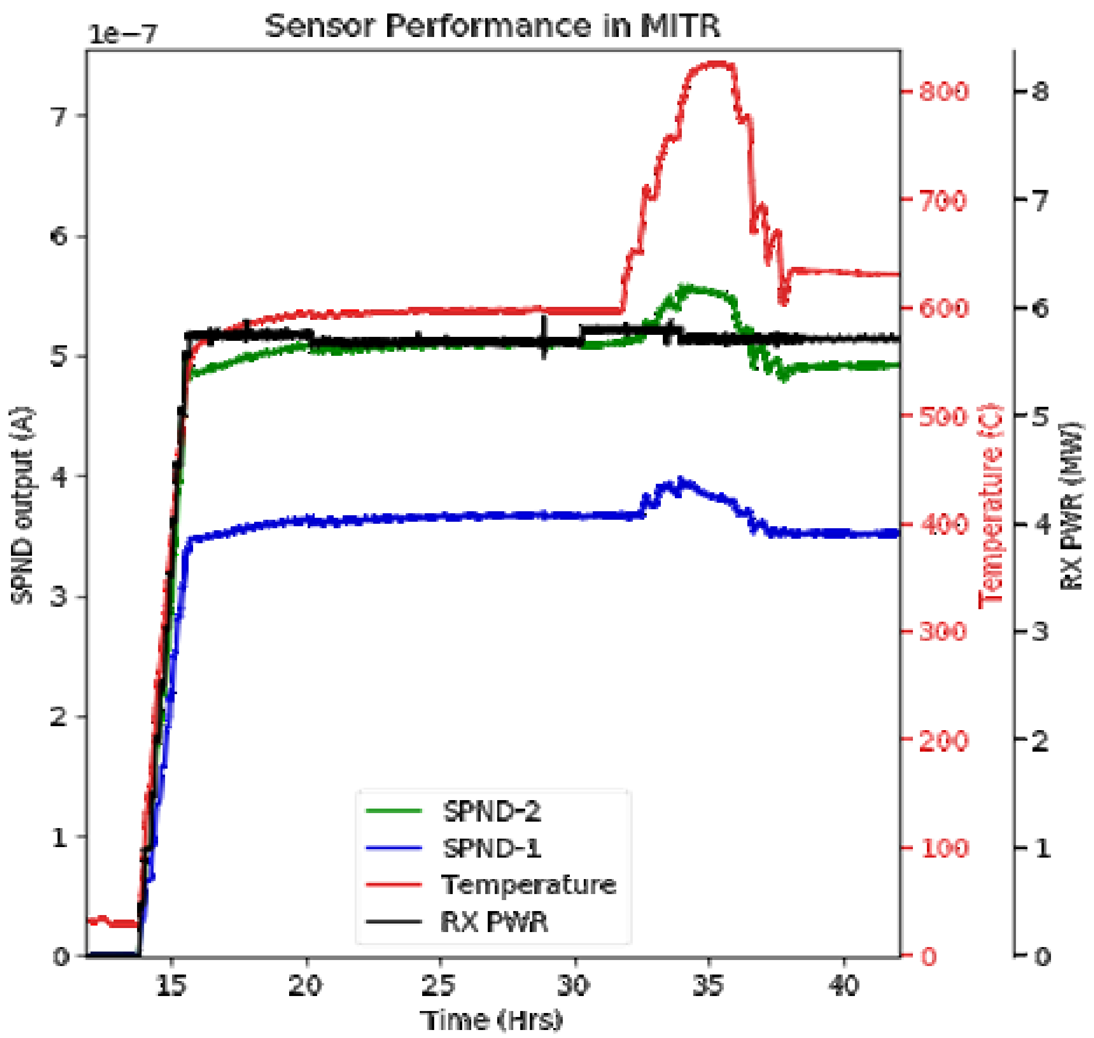


Accomplishments – MITR heated sensor test data acquisition

- Irradiation started Jan 26, 2022 – for a nominal 70-day irradiation cycle
- Peak temperature achieved: ~800^{o}C
- SPNDs functioned normally at peak temperature with some temperature dependence
- Fission chambers did not tolerate high temperature



Accomplishments – MITR heated sensor test data

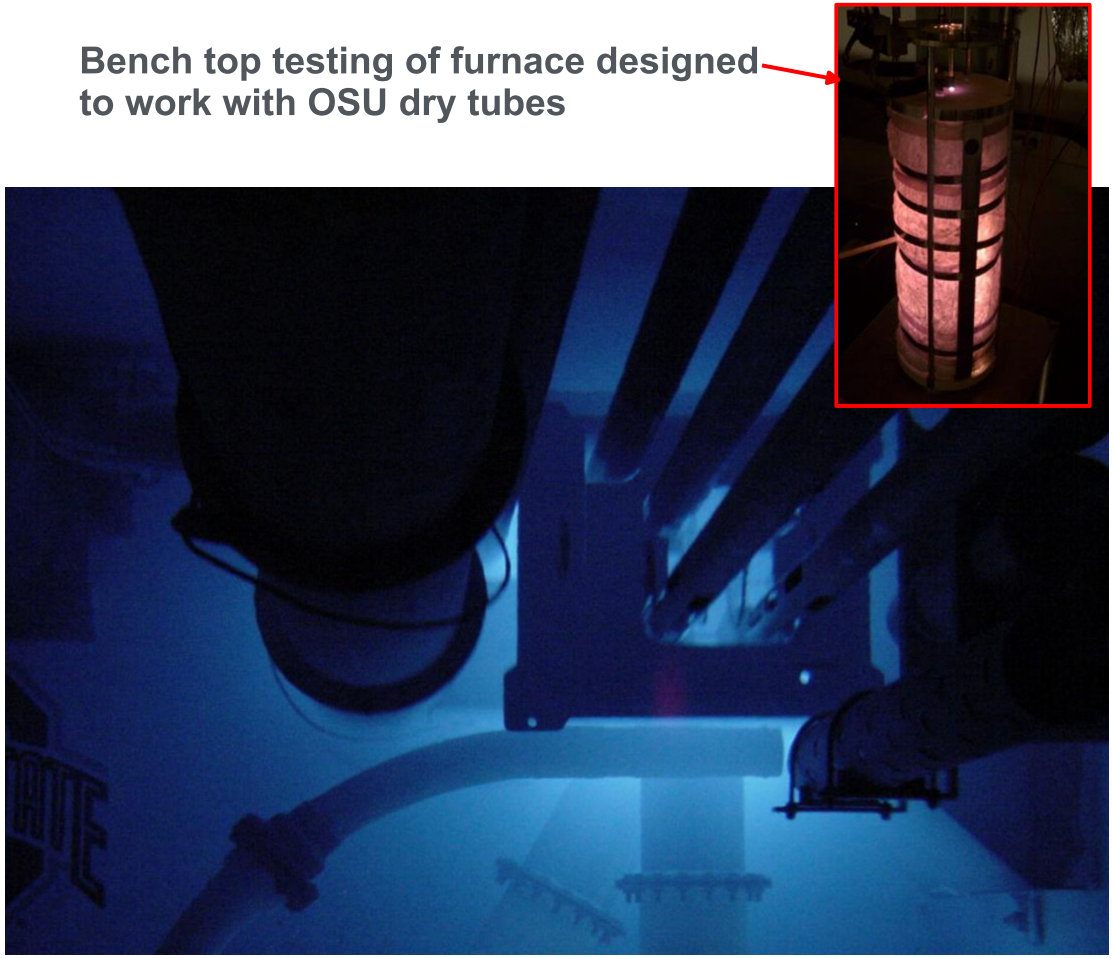


Data from SPNDs in MITR during early hours of the test

Final irradiation for FY22 switched from NRAD to OSURR

- Operation of INL's NRAD reactor was been curtailed since April 2022
- Based on previous experience with high temperature testing of optical fibers in the Ohio State University Research Reactor (OSURR), this program elected to move the final FY22 test to OSURR
- Testing took place on 9/2/2022 and included fission chambers from both INL and CEA (French atomic energy commission)

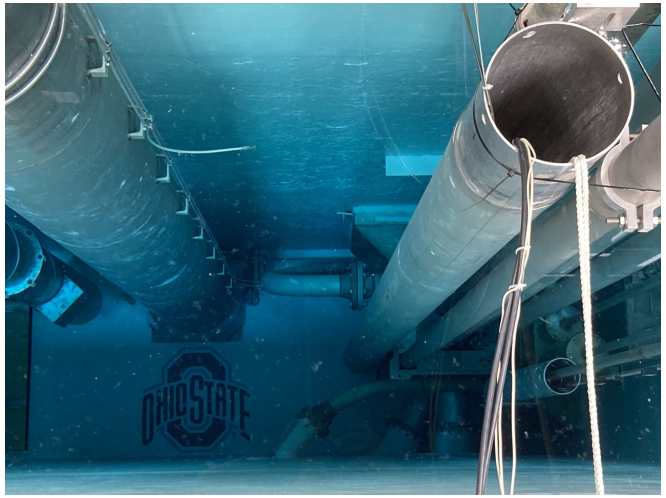
Bench top testing of furnace designed to work with OSU dry tubes



OSU reactor during operation with dry tube (on left) next to reactor core

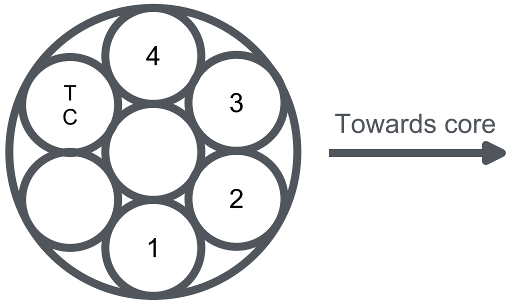
OSURR overview

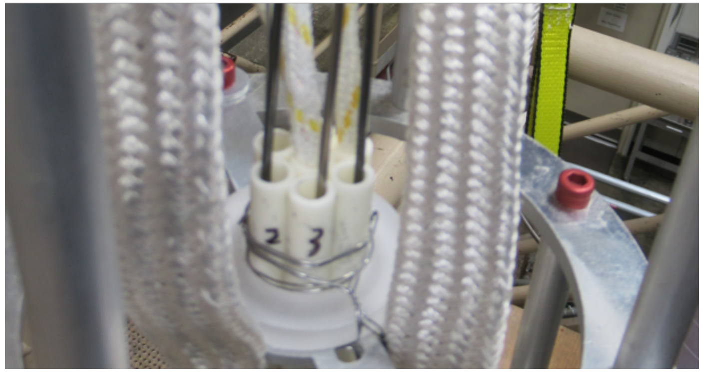
- Based on Bulk Shielding Reactor (BSR) at ORNL
- Supplied by Lockheed Nuclear Products
- First went critical in 1961 / Light water open pool / Plate-type fuel
- HEU to LEU conversion in 1988
- Multiple vertical dry-tubes for experiments
- 450 kW max. - ~10^{12} $n.cm^{-2}.s^{-1}$

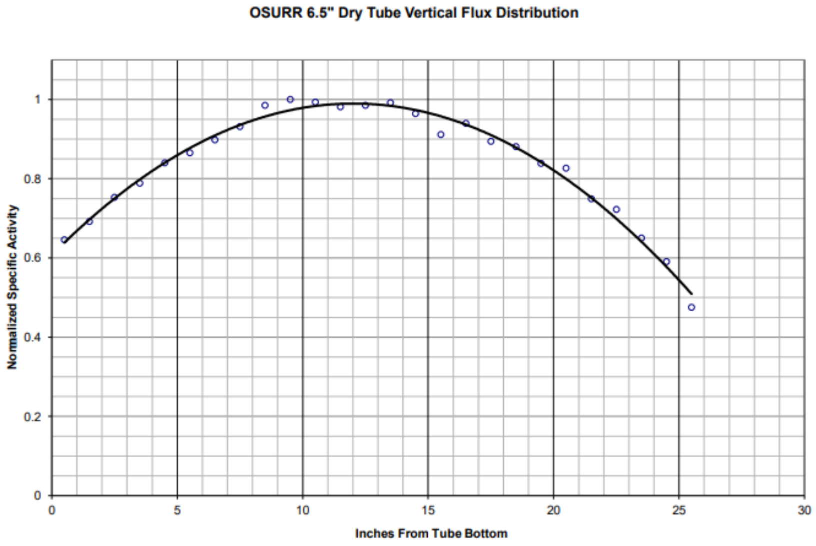


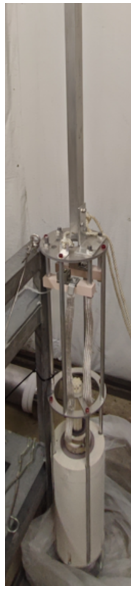
OSURR experimental setup

Sensor	Sensitive Region in tube height (in.)	Tube position
PH U5 FC	13 – 13.4	4
PH U8 FC	11.6 – 12	2
CEA U5 FC	12.4 – 12.6	3
CEA Rh-SPND	9.2 – 11.2	1

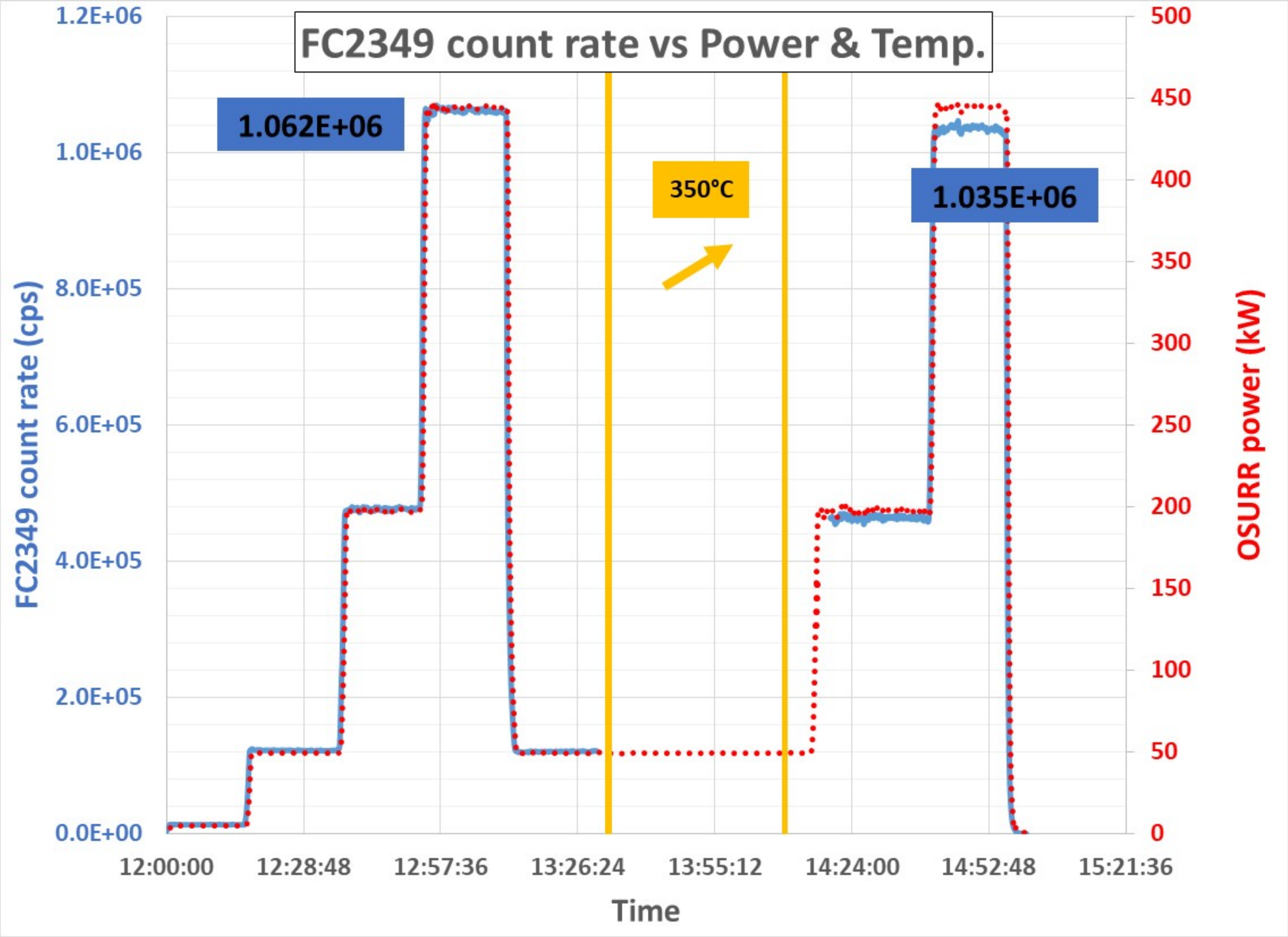








Fission chamber performance during OSURR irradiation



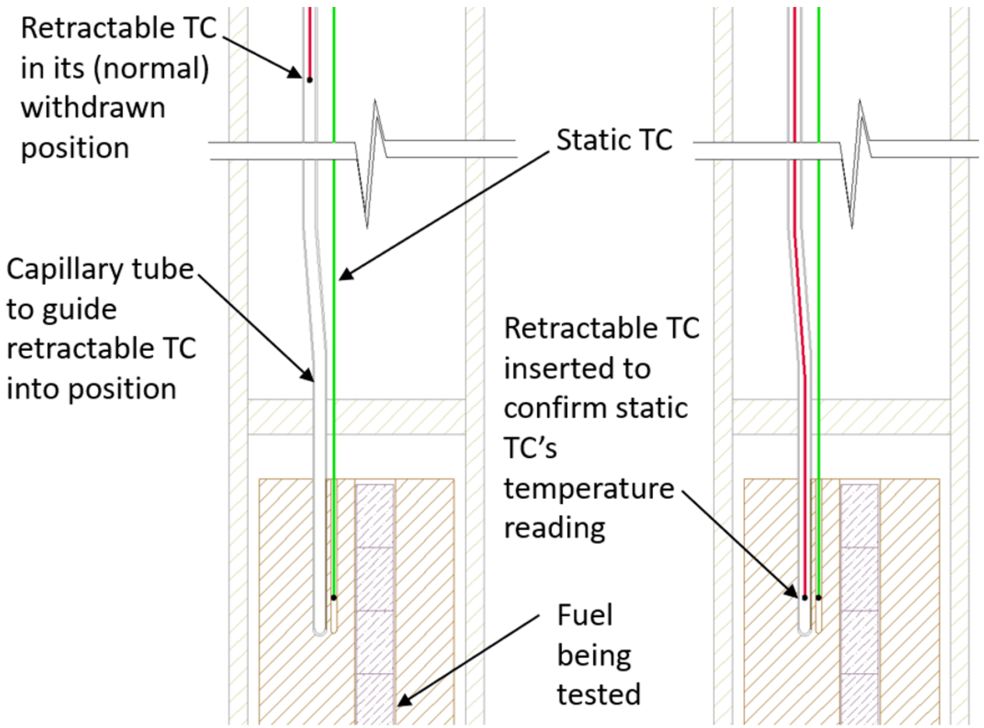
Data from CEA thermal (U235) fission chamber during OSURR irradiation

Motivation for retractable sensor development

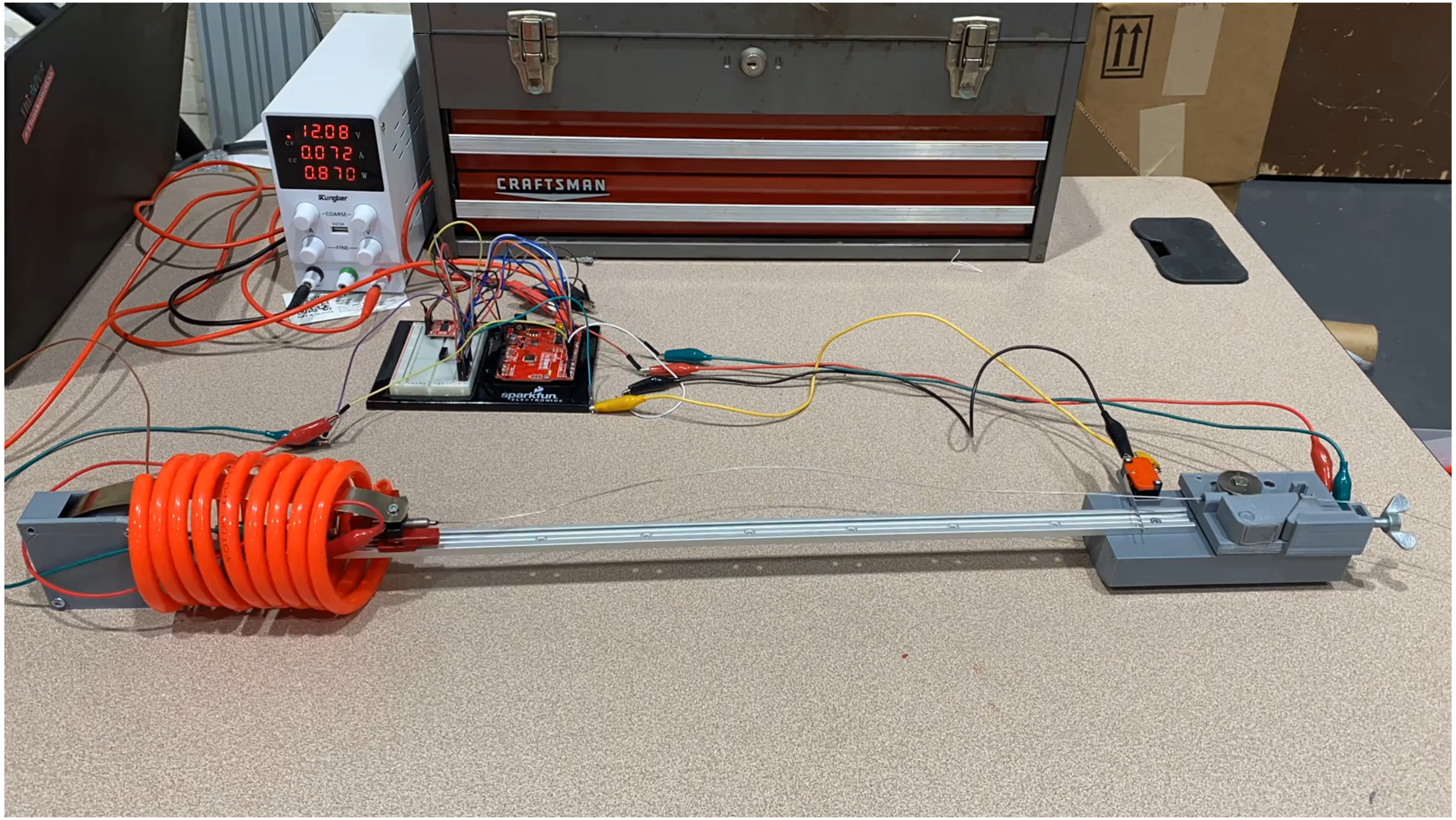
High power test reactors such as the Advanced Test Reactor (ATR) create an extremely harsh environment for in-core sensors. This environment causes sensor decalibration or failure. Since most long-term tests are nearly static in nature, even a single measurement per day is adequate for most experiments. Recognizing this, an idea for a “retractable sensor” was conceptualized.

Retractable sensor in-core use

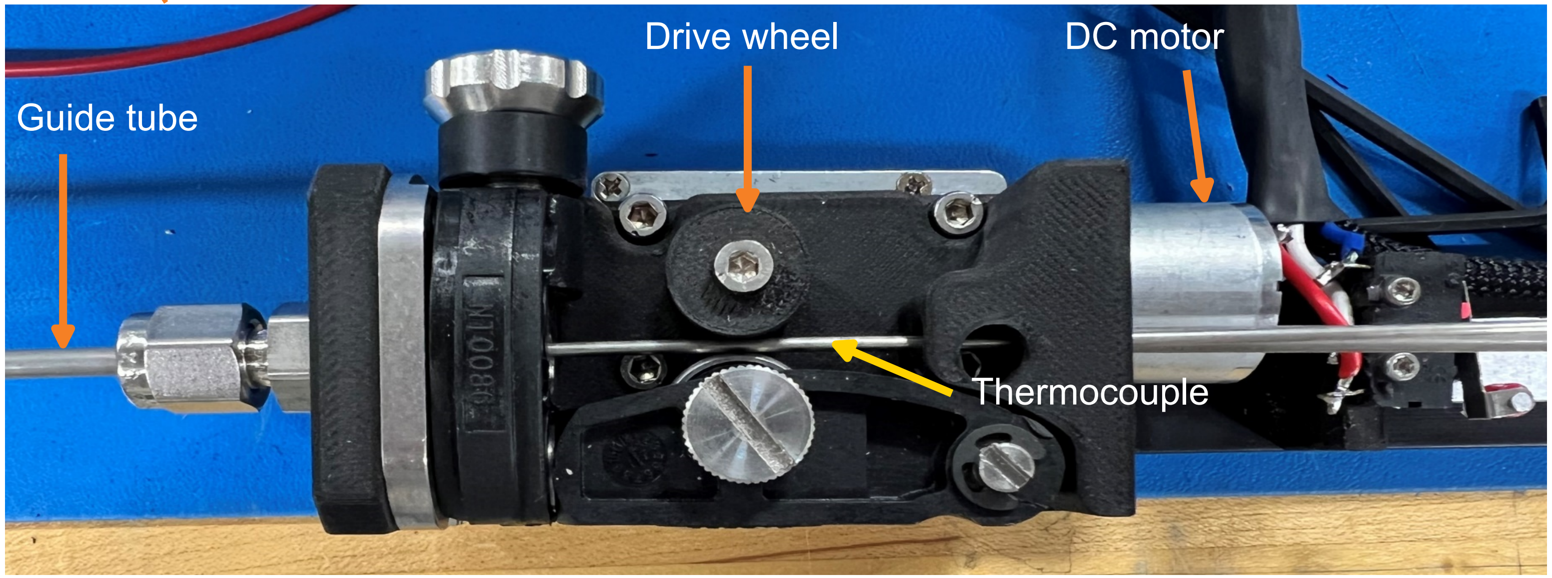
- The basic idea is to push the sensor (e.g., a thermocouple) into the in-core location to be measured, leave it for approximately 60 seconds to reach the equilibrium, transmit the signal, then pull it up and away from the high-neutron-flux and high-temperature region.
- The sensor would be guided to the appropriate location by a small-diameter capillary tube (essentially a very deep thermowell).
- The distance the sensor would need to traverse during each daily cycle is around 40–90 cm. By adopting such a scheme, the sensor would spend only a few hours in the high-flux/high-temperature environment over the life of even the longest irradiation experiment, thus maintaining calibration.



Gen I retractable sensor developed by NCSU undergraduate Design Team



GEN II retractable sensor developed by INL summer 2022

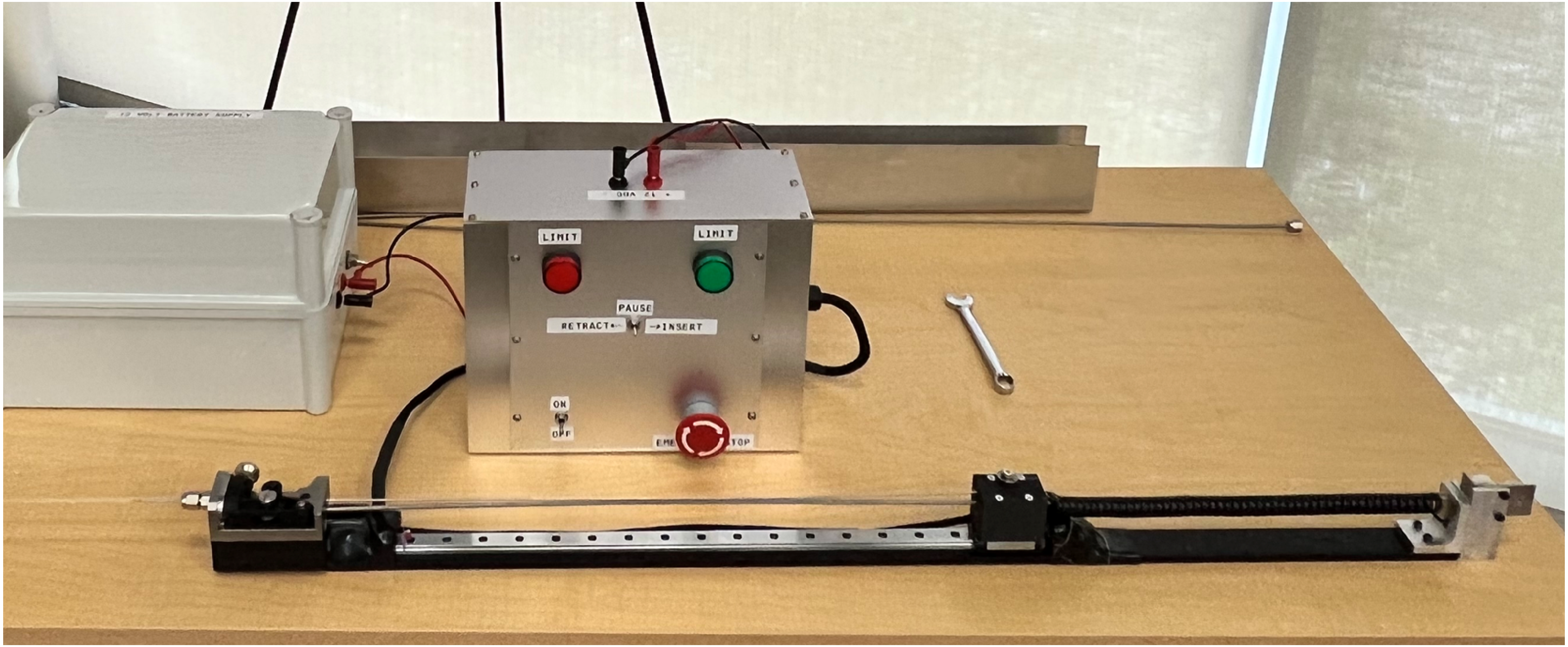


Retractable Sensor Mechanism

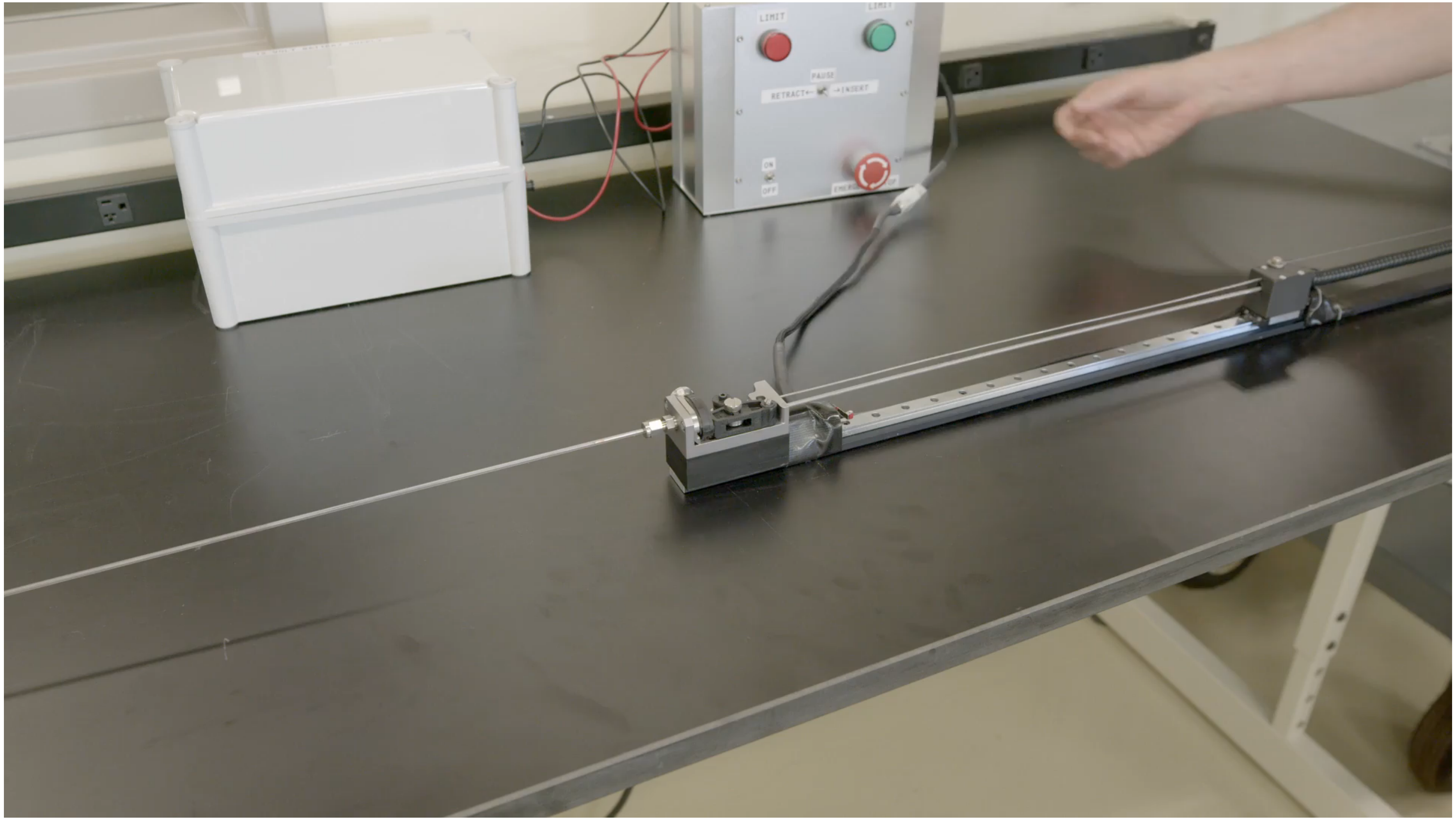
System built by:

Randel Paulsen – INL technician
Logan Robinson – Intern from University of Texas at San Antonio

GEN II retractable sensor developed by INL summer 2022



GEN II retractable sensor developed by INL summer 2022



Publications

INL/XXX-XX-XXXXX
Revision X [only after initial release]

Development of Temperature Compensation Tools for SPNDs Operating in High Temperature Environments

October 2022

Milestone Report—M3CT-22IN0702014

Kevin Tsai
Idaho National Laboratory

Concluding remarks

- Advanced instrumentation enables testing of nuclear fuels and materials in support of the U.S. advanced nuclear technology industry
- It is important to demonstrate newly-developed sensors in operational conditions, prior to incorporating them into long-term high-value experiments
- In FY-22 this project irradiated neutron sensors in four reactors
- An important part of the FY-22 work scope was to characterize neutron sensors at temperatures relevant for advanced reactors i.e., 500 – 900^{o}C
- Considerable progress was made in refining the retractable sensor drive mechanism into a system with a small footprint

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Thank You