INL/MIS-21-65026-Revision-0

Irradiation Testing of Nuclear Flux Sensors - Presentation for 2021 ASI Annual Webinar

November 2021

Changing the World's Energy Future

Joe Palmer, Kevin Tsai

Idaho National Laboratory

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ASI Advanced Sensors and Instrumentation

Irradiation Testing of Neutron Flux Sensors

CT-22IN070208

Advanced Sensors and Instrumentation (ASI)
Annual Program Webinar

November 15 – 18, 2021

Reactor Experiment Designer: Joe palmer

Idaho National Laboratory

Project Overview

- Objective

  Test and demonstrate in-pile instrumentation in conditions similar to those expected to be seen in service (i.e., the conditions they would see in either in irradiation experiments supporting advanced reactors, or ultimately, in advanced reactors themselves)

- Participants
  - Joe Palmer – Project lead and test rig designer
  - Kevin Tsai – PI for Self Powered Neutron Detectors (SPNDs) and concurrent testing in TREAT
  - Dr. Michael Reichenberger – PI for miniature fission chambers
  - Calvin Downey – ATRC test rig designer
  - Kory Manning – Lead technician for retractable sensor development
  - Dr. David Carpenter (MIT) – Project lead at MIT for irradiation of neutron sensors in MITR (NSUF collaboration)
  - Dr. Ge Yang (NCSU) – Project lead at NCSU for retractable sensor development team

Project Overview

Timelines of project activities FY-21 and FY-22

During FY-21 this project irradiated sensors in all four INL reactors plus the ISU Rx

FY21

Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep

- Nov: Initial irradiation of SPNDs in NRAD to work out bugs prior to ATRC irradiation
- Oct/Nov: Irradiation of optical fibers in ATR as part of HDG-1 experiment
- Feb: ATRC irradiation of SPNDs and fission chambers – verified %flux increase due to booster fuel
- Mar: Irradiation of Rh and Hf SPNDs in Idaho State's AGN-201 Rx (collaborative effort)
- Aug: High temperature (800^{o}C) sensor irradiation in NRAD
- Irradiated sensors in TREAT via "concurrent testing". This was done for every operating cycle in TREAT during FY-21

FY22

Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep

- Oct: Perform high-temperature NRAD irradiation
- Feb: Irradiate neutron sensors in high-temperature test rig at MITR (NSUF collaboration)
- Jul: Perform high-temperature NRAD irradiation incl CEA sensors
- Develop retractable sensor mechanism and test on bench top

FY-21 & FY-22 Milestones

Milestone	Due Date	Status
Test neutron flux sensors in ATRC	3/31/2021	Completed on time
Perform high-temperature neutron irradiation test on neutron flux sensors	9/30/2021	Completed on time
Complete high-temperature test of neutron flux sensors in NRAD	9/30/2022	On schedule
Develop retractable system for in-core instrumentation	10/31/2022	On schedule

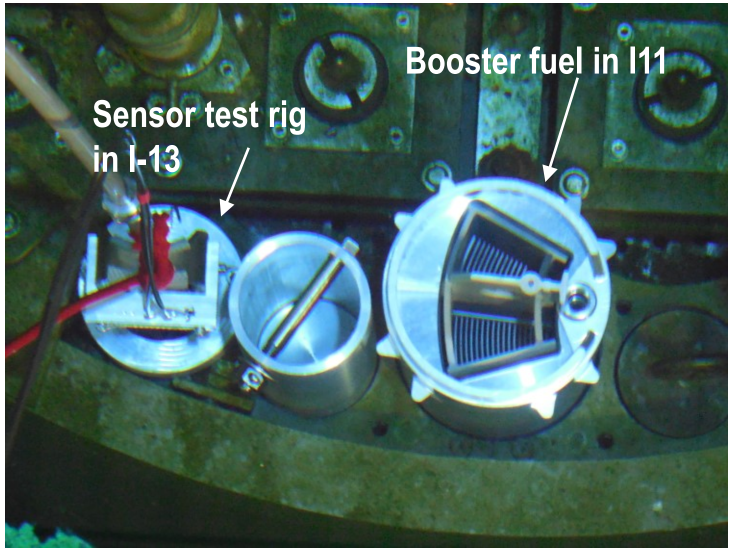
Technology Impact

- Advanced instrumentation enables testing of nuclear fuels and materials in support of the US advanced nuclear technology industry
- 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
- Successful completion of these activities will create new capabilities at the INL ATR and TREAT facilities that are crucial to acquiring data during irradiation testing
- Customers usually have only one shot to conduct their irradiation experiments
- Therefore, it is vital to demonstrate newly-developed sensors in operational conditions, prior to incorporating them into long-term high-value experiments

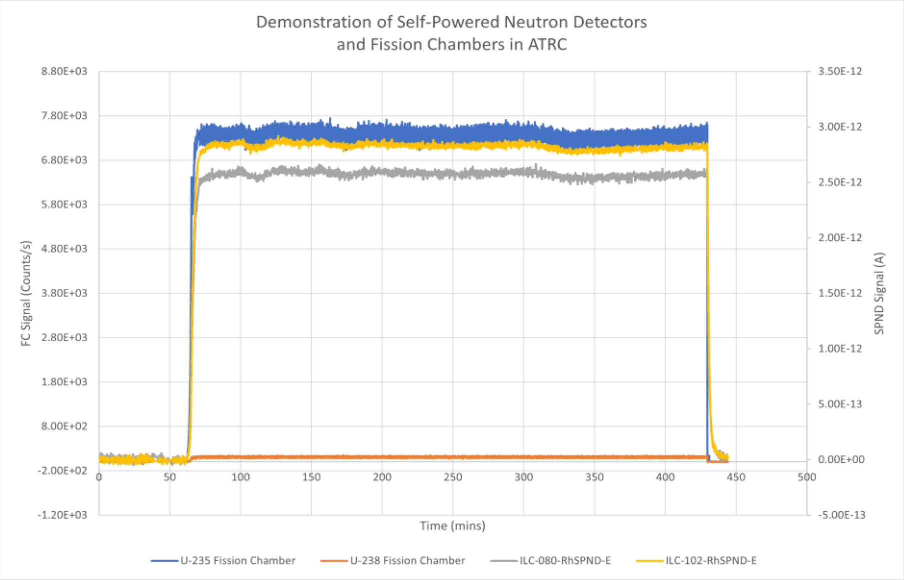
Technology Impact

- Much of the neutron sensor testing work in FY21 and FY22 is focused on testing at high temperatures
- Self Powered Neutron Detectors (SPNDs) and miniature fission chambers have been deployed in commercial reactors operating at up to 300^{o}C, and in general, their performance is well understood up to about 350^{o}C
- Advanced reactor concepts envision operating temperatures of 500^{o}C – 1000^{o}C
- Early indications are that these traditional neutron sensors may experience temperature effects at temperatures >500^{o}C
- A major effort in FY22 will be to better understand and mitigate these temperature effects (if they do indeed exist)

ATRC Test using Fission Chambers and SPNDs



Neutron experiment test rig and booster fuel installed in ATRC reactor



SPND and fission chamber data traces from 6-hour run in ATRC conducted Feb 11, 2021.

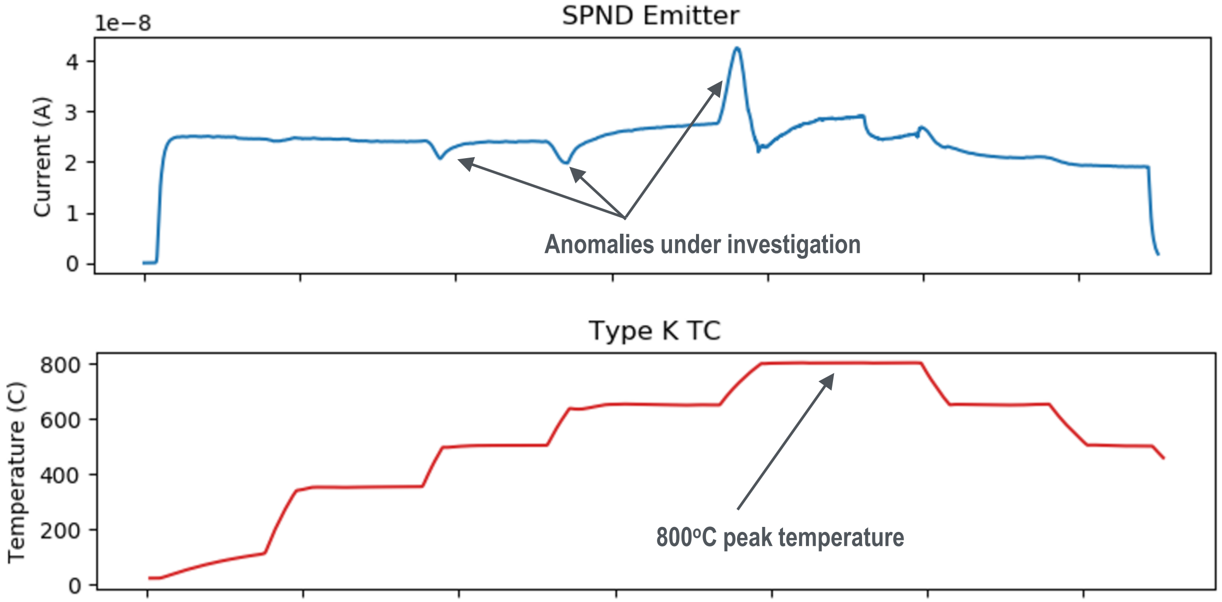
The Medium I-loop Project would like to increase thermal flux in the I-13 position of ATR by placing booster fuel in I-11. This ATRC sensor test confirmed their calculated increase.

Measured increase in thermal flux due to booster fuel (this ATRC test)	Calculated increase in thermal flux (via MCNP) due to booster fuel
23%	21%

High-Temperature Neutron Sensor Testing in NRAD

Installing neutron sensors (SPNDs) in NRAD

Gathering data in cask tunnel adjacent to NRAD

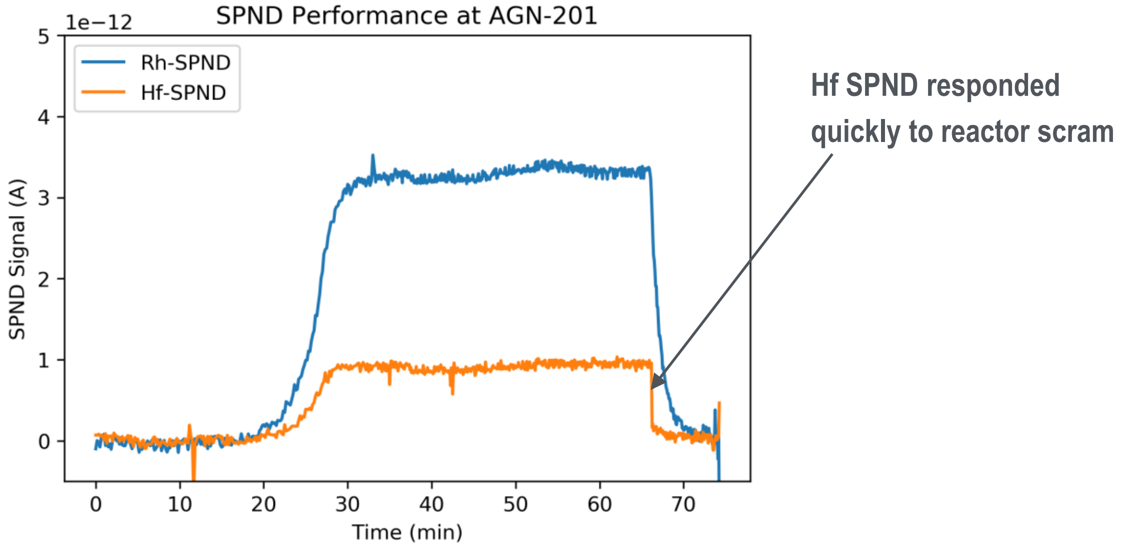


SPND signal compared to temperature profile

Accomplishments

SPND Sensors Irradiated in Idaho State University AGN-201 Reactor

Installing SPNDs in AGN-201 Rx



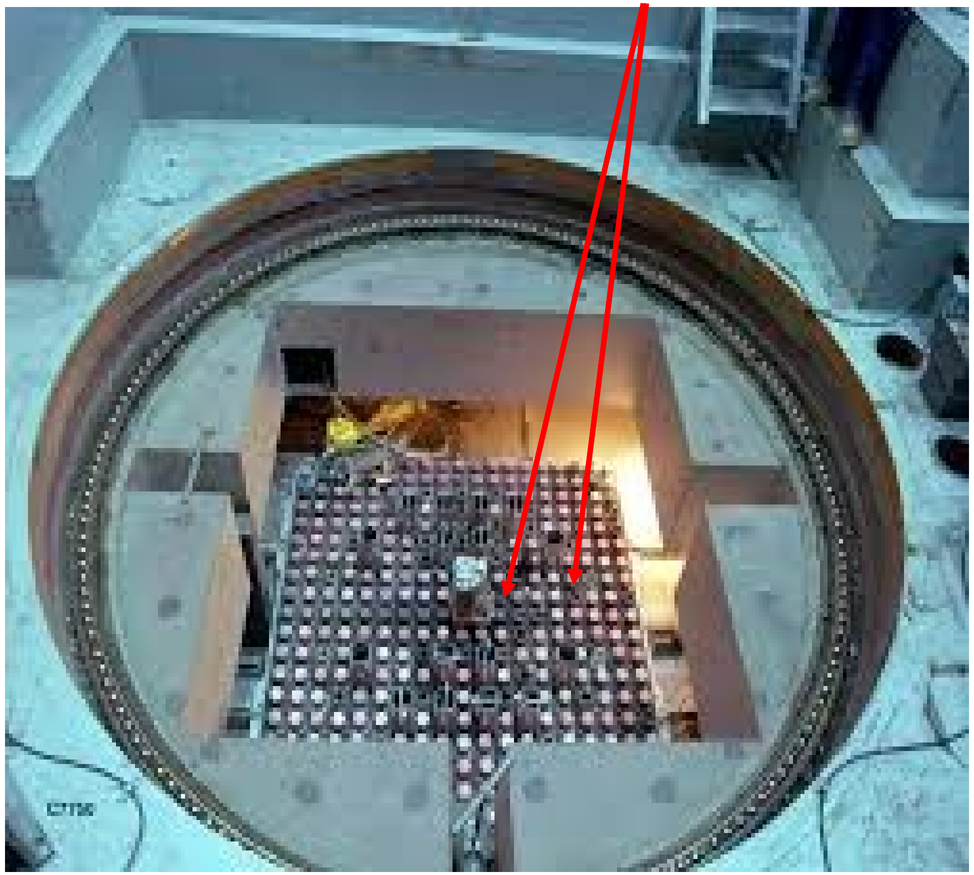
Hf-based SPND output compared to Rh-based SPND

Hf-based SPNDs have a rapid response (as illustrated above) and have been a research interest of Dr. George Imel of ISU for many years. Dr. Imel collaborated with ASI PI Kevin Tsai for this test.

Accomplishments

TREAT Concurrent Testing

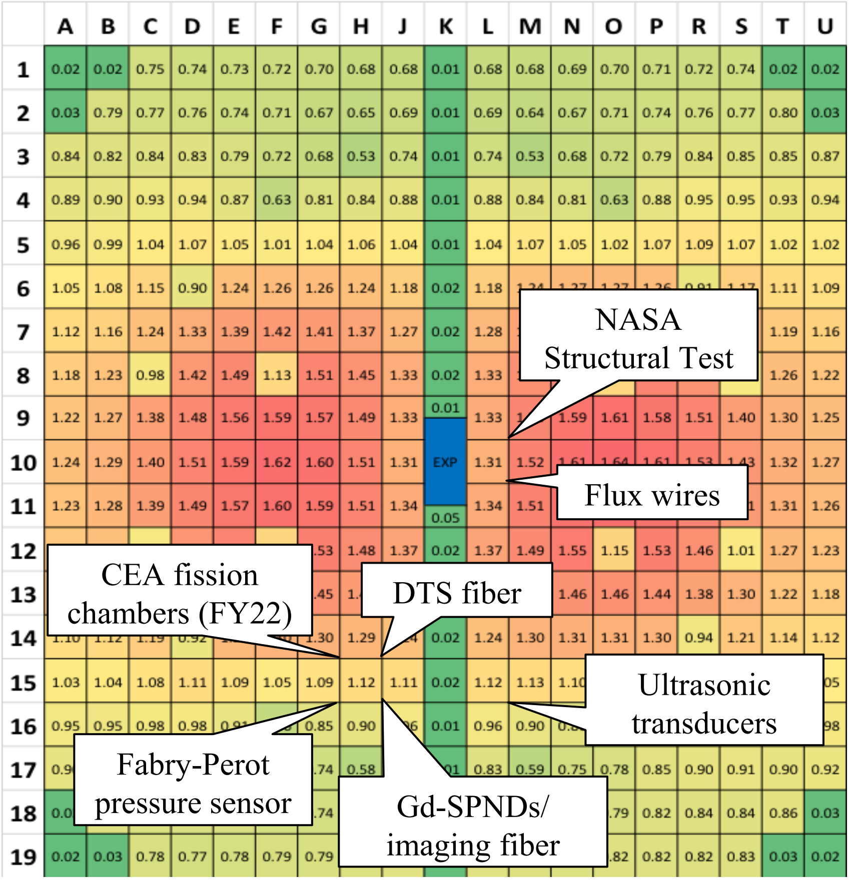
Developmental sensors are placed in cooling channels around fuel assemblies, rather than in experiments themselves. This approach lowers costs and does not interfere with high-value customer experiments.



TREAT Concurrent Testing

Concurrent Testing Sensors in FY-21

- NASA structural test
  - (non-ASI) Collaboration between NASA and TREAT to examine performance of carbon nanotube structural materials.
- DTS fiber
  - Dedicated position for FY22 fiber benchmark
- Fabry-Perot pressure sensor
  - FY-21 "Fiber Optic Fabry-Perot Pressure Sensor" activity
- Imaging fiber
  - FY-21 "In-pile Fiber Optic Based Imaging" activity
- Gd-SPNDs
  - Idaho Laboratories Corp. Gd-SPNDs follow-on testing.
- Ultrasonic transducers
  - Testing of ultrasonic transducer ceramic integrity.

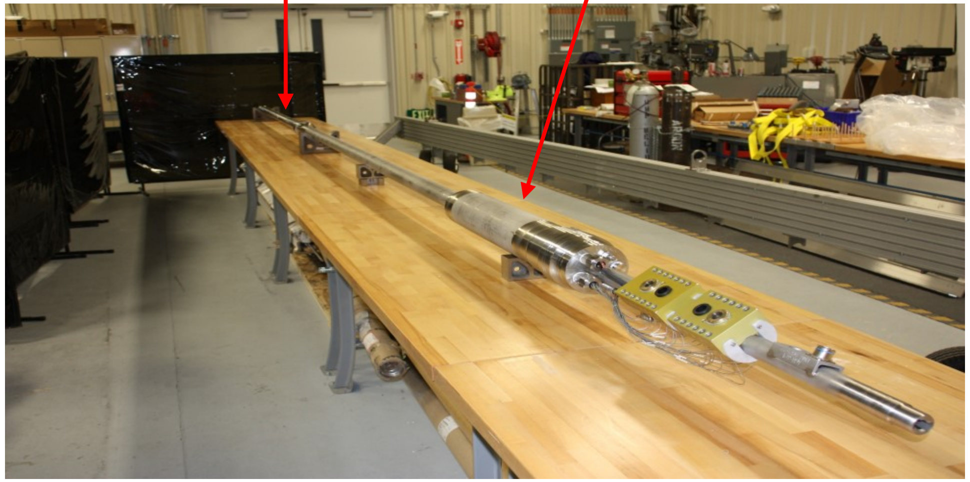


TREAT core map with relative flux ratios

Retractable Sensor Development – NCSU Capstone Team

Very high temperature in-core section of experiment where sensor is periodically inserted

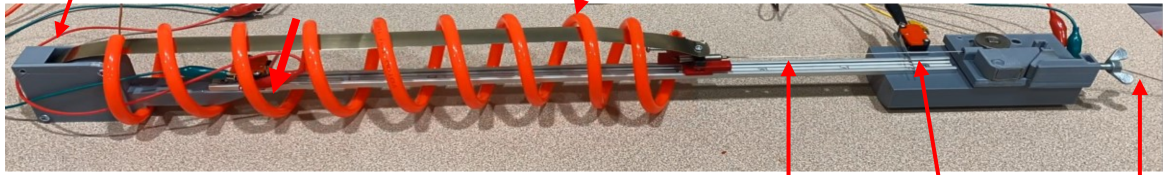
Upper part of experiment is larger (125 mm) and can accommodate drive mechanism. Temperature and radiation dose is low in this region



Complete ATR Instrumented Experiment

Constant force spring to keep tension on cable when sensor is retracted

Sensor leads are placed in this plastic coil, which prevents tangles as sensor is inserted and retracted

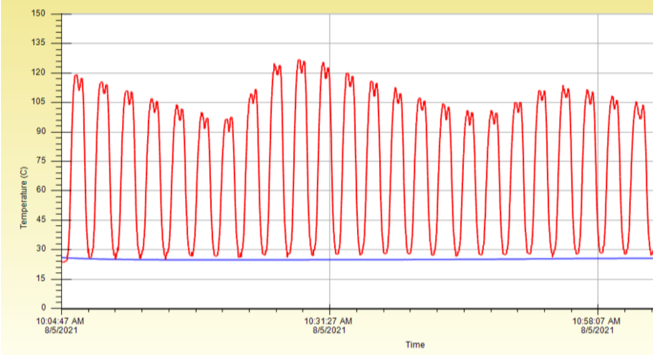


Sensor cable

Capillary tube

Limit switches at each end tell control system that sensor is either fully inserted or retracted

The life of in-core sensors may be greatly extended by inserting them only occasionally. This can still produce a very useful data set because MTRs normally run at constant power and the corresponding conditions within reactor experiments typically evolve relatively slowly.

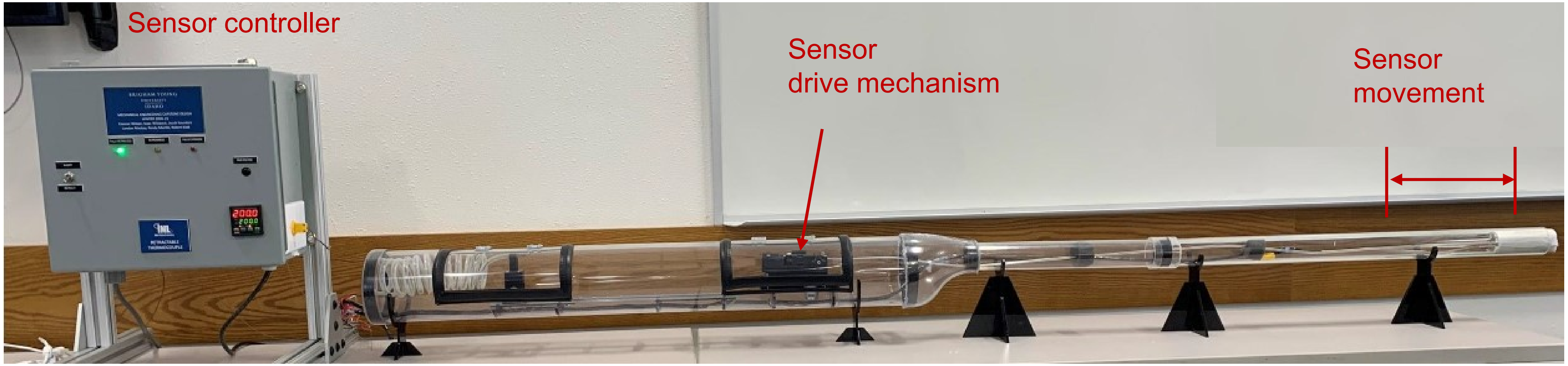


Thermocouple Response To Cycling in and Out of Furnace

Accomplishments

Retractable Sensor Development – BYUI Capstone Team

- Under the direction of INL reactor experiment designers, the BYUI capstone design team developed a system capable of inserting and retracting a thermocouple sensor, which is displayed here in a transparent mockup of a reactor experiment



Retractable Sensor Demonstration System

Award-winning demonstration system created by BYUI capstone team

Conferences and Publications

- J. Palmer (INL), G. Yang, N. Fikenscher, A. Chrystler, C. Jolley, H. Osborne (NCSU); "Retractable Sensors for In-Core Service in Material Test Reactors," 2021 Test, Research and Training Reactors (TRTR) Annual Conference, October 18-21, 2021; Raleigh, North Carolina.

Conclusion

- 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-21 this project irradiated neutron sensors in all four INL reactors plus the research reactor on the Idaho State University campus
- An important part of the FY-21 and FY-22 work scope is to gain experience with neutron sensors at temperatures relevant for advanced reactors i.e., 500 – 1000^{o}C
- Two university capstone design teams created functioning systems to demonstrate the retractable sensor concept during FY-21

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Questions?

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