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Performance of the supplemental instrumentation in the ATR AGR 5/6/7 irradiation

Advanced Sensors and Instrumentation Annual Webinar

October 31 – November 1, 2018

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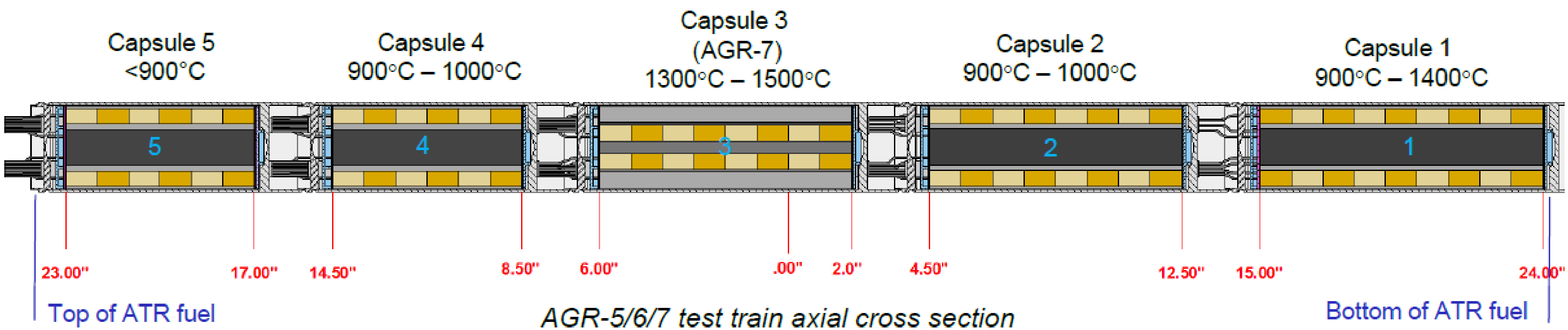
Idaho National Laboratory

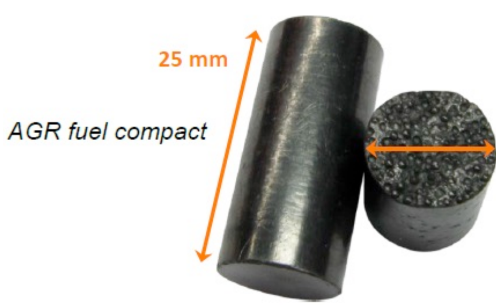
Advanced Gas Reactor (AGR) Fuel Development and Qualification Program

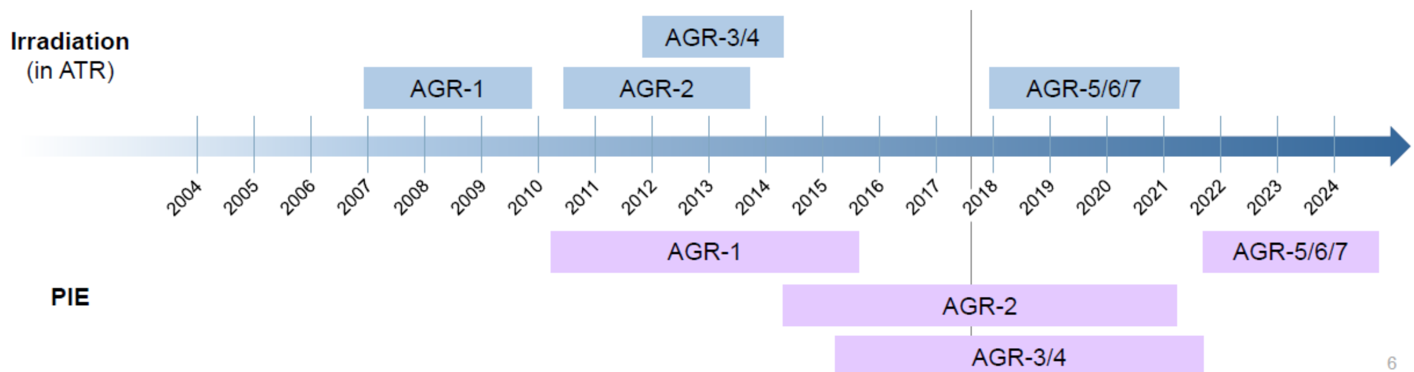
AGR Program: Provide data for fuel qualification in support of reactor licensing

- AGR fuel compact irradiation in ATR monitored by thermocouples
- Supplemental instrumentation added to test instrumentation performance
  - High Temperature Irradiation Resistant Thermocouple
  - Ultrasonic Thermometer
  - Optical Fiber Temperature Sensor
  - Self Powered Neutron Detectors and Micro-Pocket Fission Detectors



AGR-5/6/7 test train axial cross section





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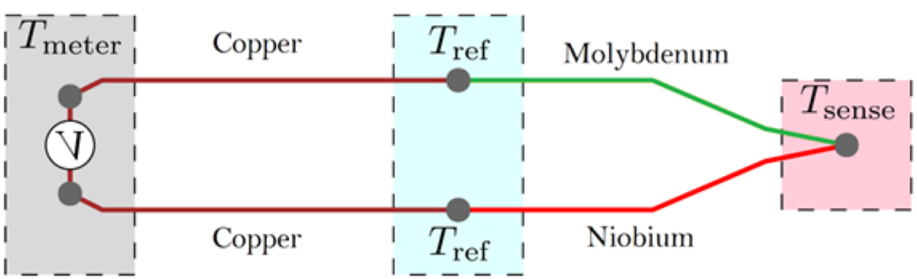
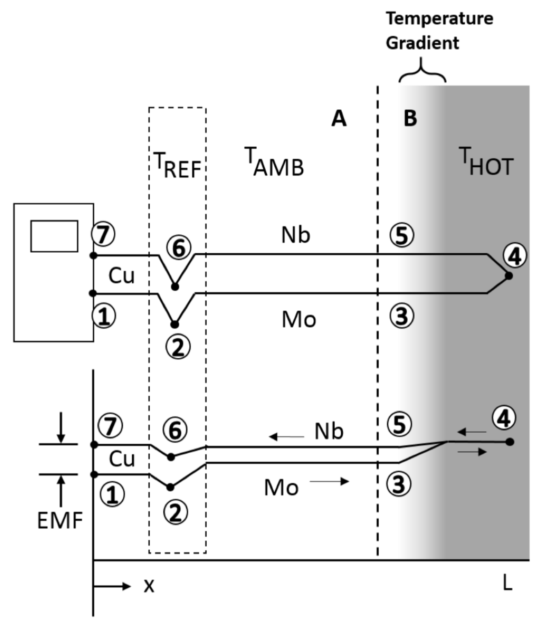
HTIR –Thermocouple: Background/Theory

R Skifton (INL)

- The High Temperature Irradiation Resistant Thermocouple (HTIR-TC) consists of a molybdenum niobium thermocouple junction.
- The use of dissimilar metals put through a temperature gradient generates electromotive force (EMF).
- The HTIR-TC is the first of it’s kind that has successfully shown to last for 1,000’s of hours at low signal de-calibration of ‘drift’.



$$EMF = \int_0^L \epsilon_1 \frac{dT}{dx} dx + \int_L^0 \epsilon_2 \frac{dT}{dx} dx$$

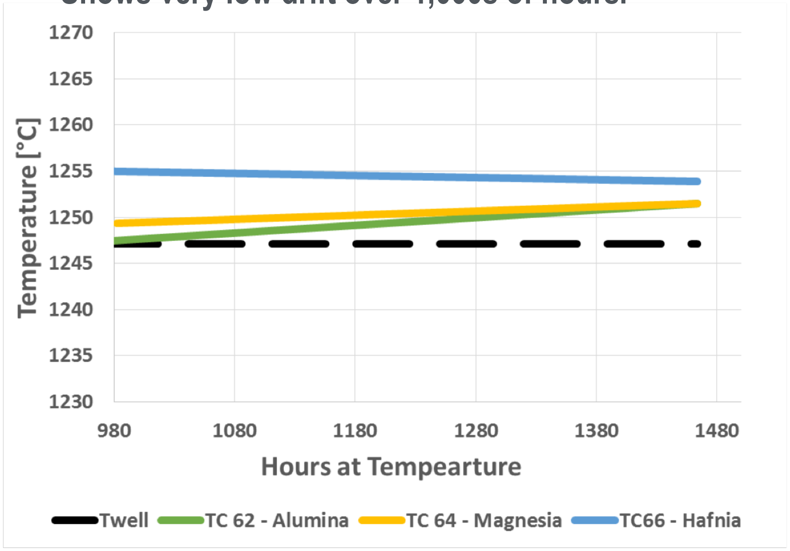


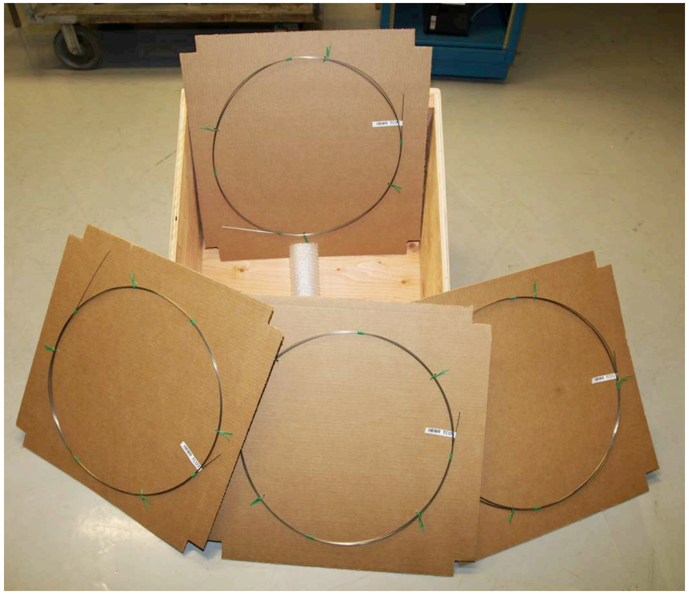
HTIR –Thermocouple: Fabrication / Installation

R Skifton (INL)

- **The HTIR-TC was fabricated and tested at High Temperature Test Laboratory (HTTL) before going into the AGR 5/6/7 test.**
- **20+ HTIR-TCs were able to be successfully installed (brazed) into the AGR 5/6/7 test trains.**

High Temperature Testing in Furnace (Out of Pile). Shows very low drift over 1,000s of hours.



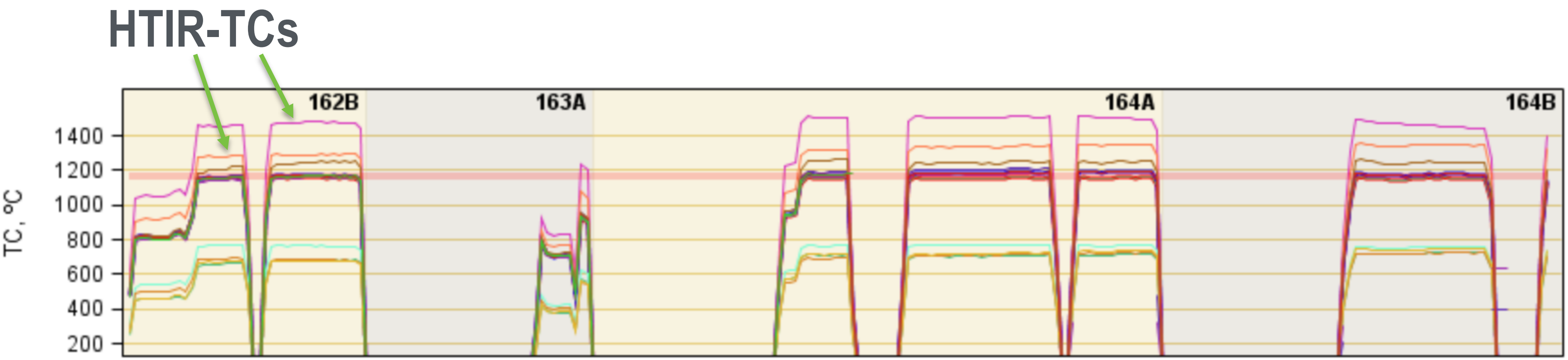


Packaging before going into the installation.

HTIR –Thermocouple: Performance Update

R Skifton (INL)

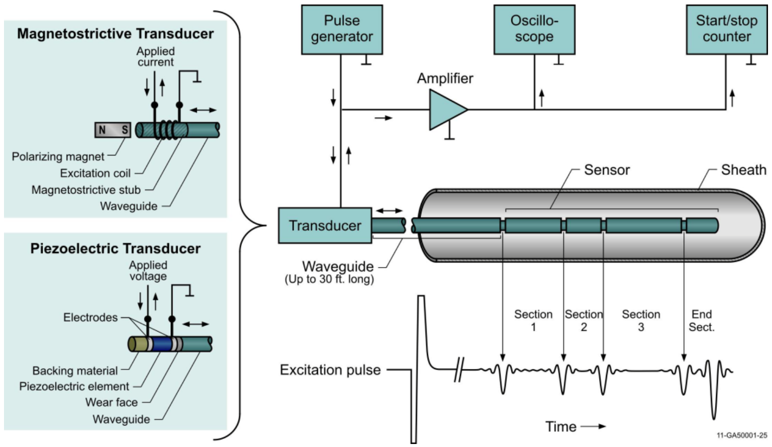
- **HTIR-TCs in the AGR 5/6/7 test have successfully and consistently read temperatures up to 1450°C for several reactor cycles.**
- **They return to these temperature levels after many reactor shut downs and startups**
- **The HTIR TC has a wide range as they match the reactor control TCs during a reactor shut down phase.**



Capsule 3 thermocouples in the AGR 5/6/7 experiment

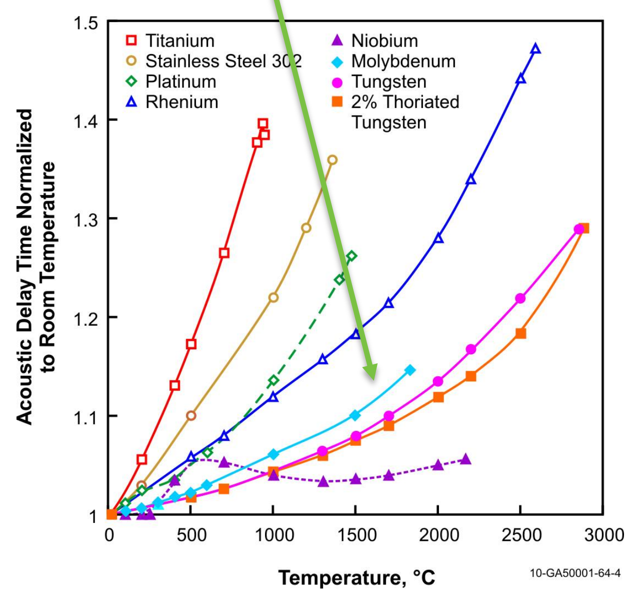
Ultrasonic Thermometer: Background/Theory

J Daw (INL)



AGR 5/6/7 UT sensor fabricated from Molybdenum

- Low Sensitivity
- High Melting Temperature
- Low thermal neutron capture cross section



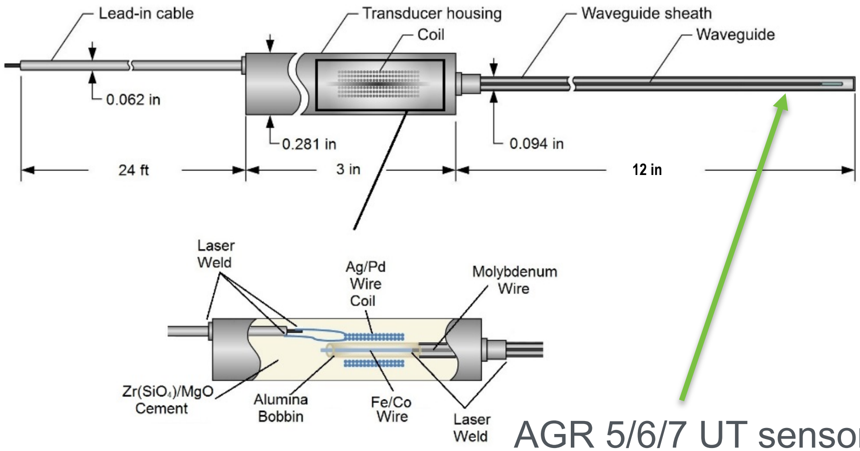
UTs work on the principle that the speed of sound in a material changes with respect to temperature. By sending sound pulses through a solid waveguide and measuring the time between reflections, temperature can be measured. Multiple reflectors along the length give a temperature profile. Sensor sensitivity is dependent on material and length of sensor.

$$c(T) = \sqrt{\frac{E(T)}{\rho(T)}}$$

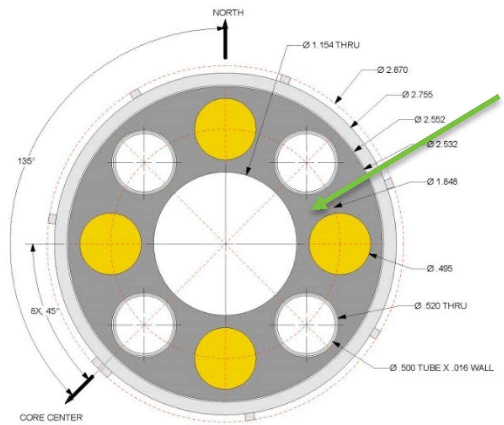
For waveguide diameter << acoustic wavelength, sound velocity is dependent only on changes to elastic modulus and density (assuming no stress)

Ultrasonic Thermometer : Fabrication / Installation

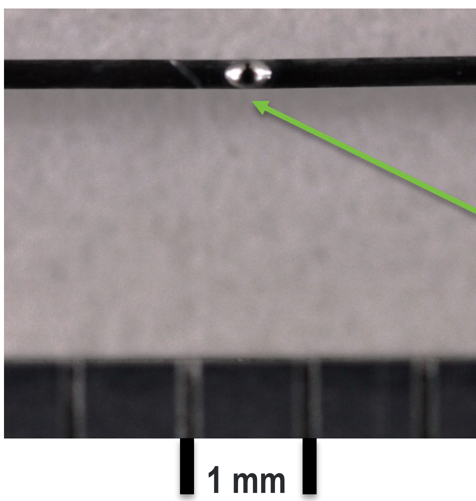
J Daw (INL)



AGR 5/6/7 UT sensor has single ~35 mm segment



UT installed in capsule 5 graphite: expected temperatures of ~700 °C



Sensor section created by welding small bump of molybdenum to 0.25 mm diameter molybdenum wire waveguide

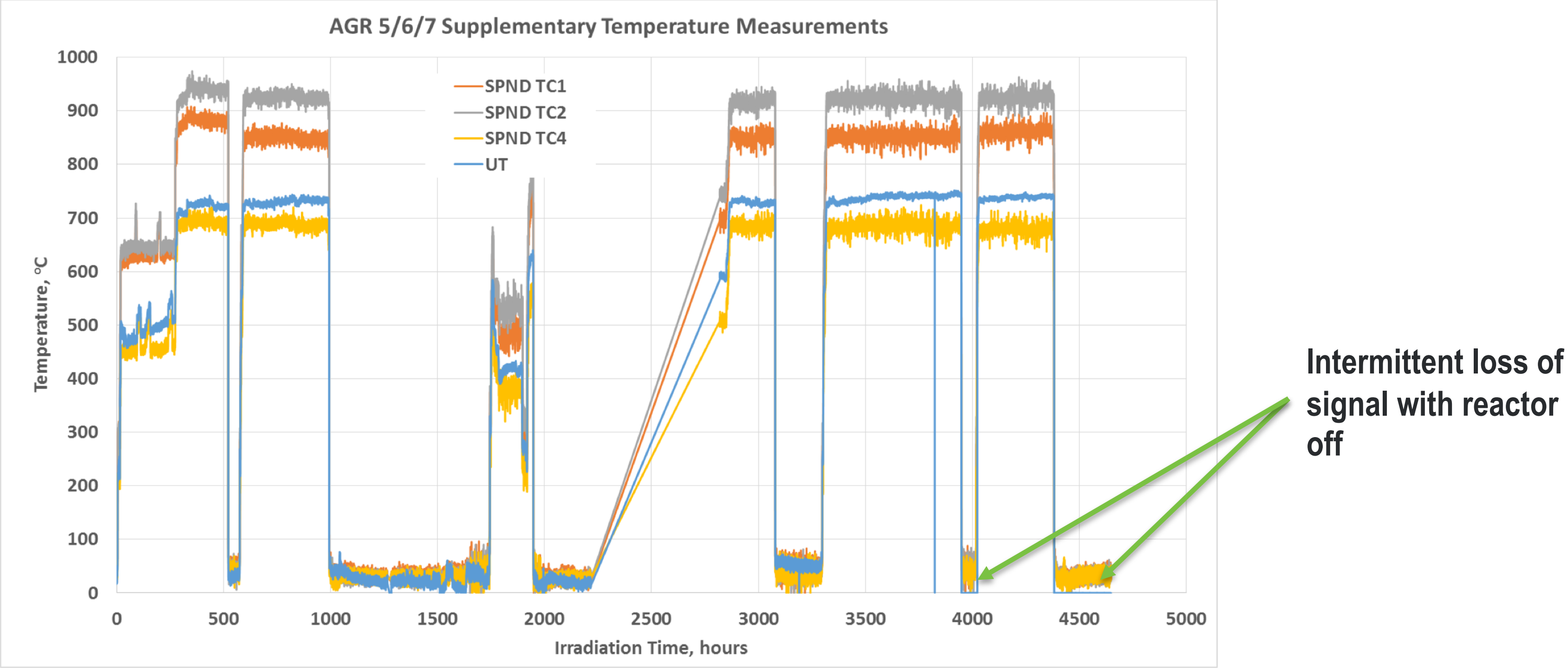
UT calibration in HTTL vacuum furnace

Ultrasonic Thermometer : Performance Update

J Daw (INL)

To date the AGR 5/6/7 has followed the same temperature trends as nearby thermocouples, but with reduced noise

- **Improved signal processing method using up-sampling and spline interpolation accounts for reduced noise levels compared to previous UT tests**
  - **Surprising result considering low temperature sensitivity of molybdenum and short length of sensor section**
- **Recent data shows intermittent loss of signal at low temperatures**
  - **Likely issue with mechanical robustness of coil materials**



Optical Fiber Temperature: Background/Theory

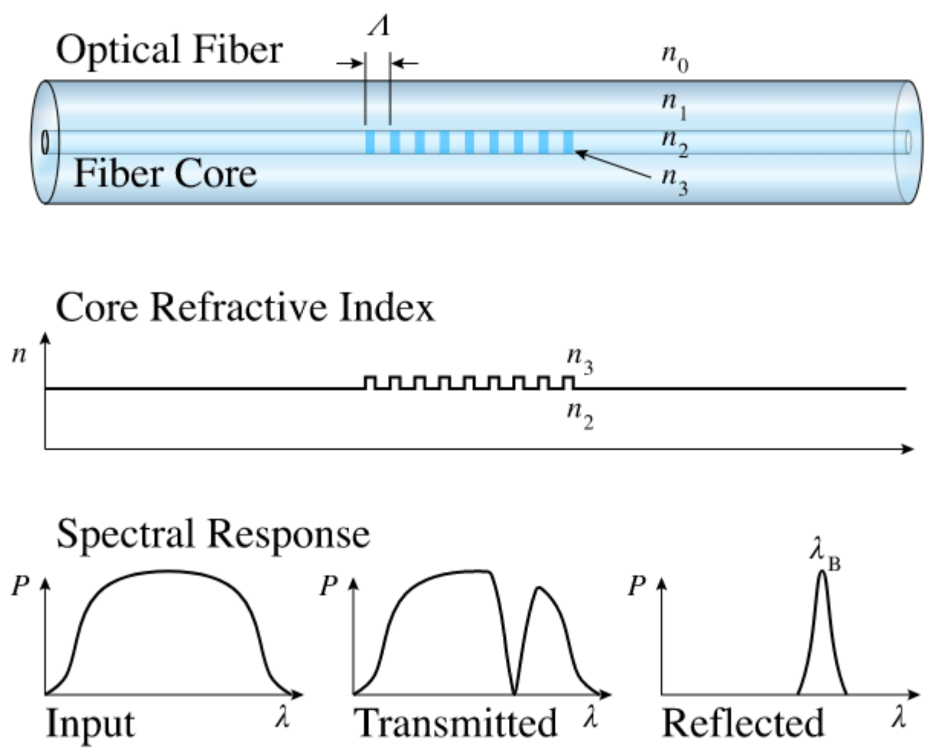
K McCary (INL)

- Fiber Bragg gratings are a periodic variation in the fiber core index of refraction that allow specific wavelengths of light to be reflected.
- The peak wavelength of a Bragg grating shifts with changes in temperature and strain. As an unconstrained fiber is heated the shift in the reflected wavelength of the grating can be correlated to temperature change.

Optical fiber sensors with fiber Bragg gratings fail in two main ways:

- The fiber Bragg grating can anneal out of the fiber due to high temperatures
- The fiber can darken from radiation induced attenuation.

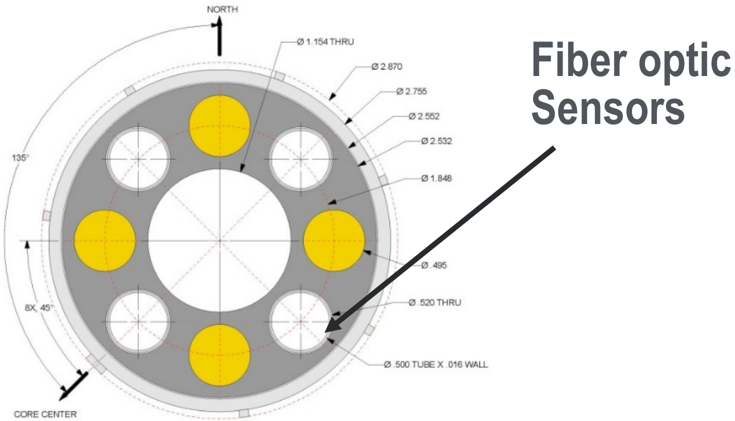
Both mechanisms prevent the sensor from producing a meaningful signal and temperature sensing fails.



Optical Fiber Temperature: Fabrication / Installation

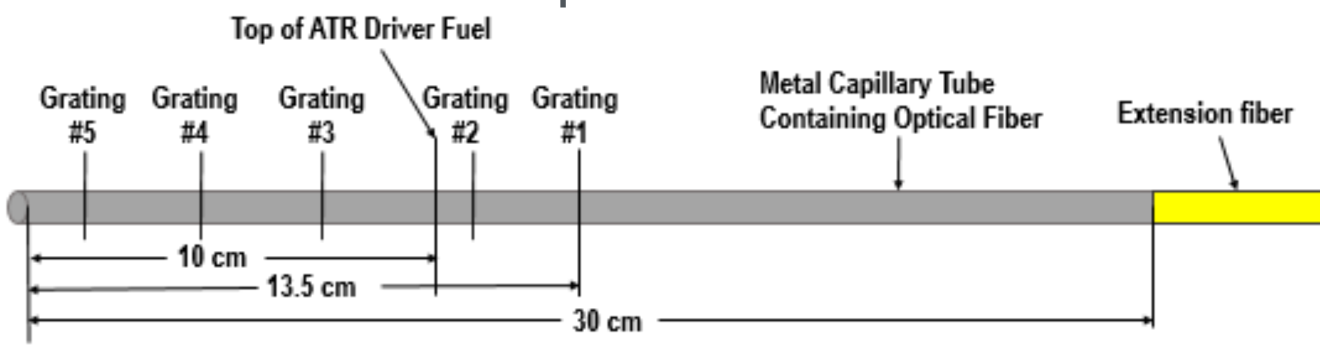
K McCary (INL)

There are two optical fiber sensors installed in capsule #5 at the top of the ATR fuel.



- CEA supplied sensors
- One of the sensors was broken during installation.
- The second sensor was incorrectly connected initially
- Capsule #5 has seen temperatures around 700°C

- Standard telecommunication fiber with germanium doped cladding is contained within a metal capillary tube
- Type-I regenerated Bragg gratings are heat treated for high temperature resilience
- Each fiber has 5 fiber Bragg gratings 3 cm apart for 5 temperature measurements in 12cm
- Gratings #1 and #2 are at a lower temperature and flux above the ATR fuel.

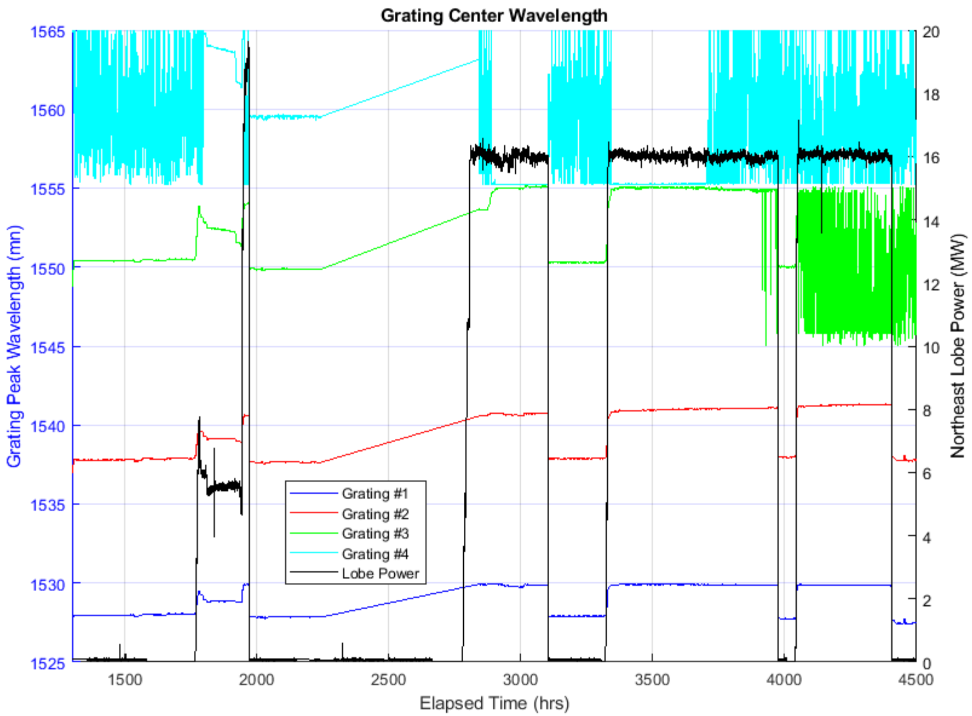


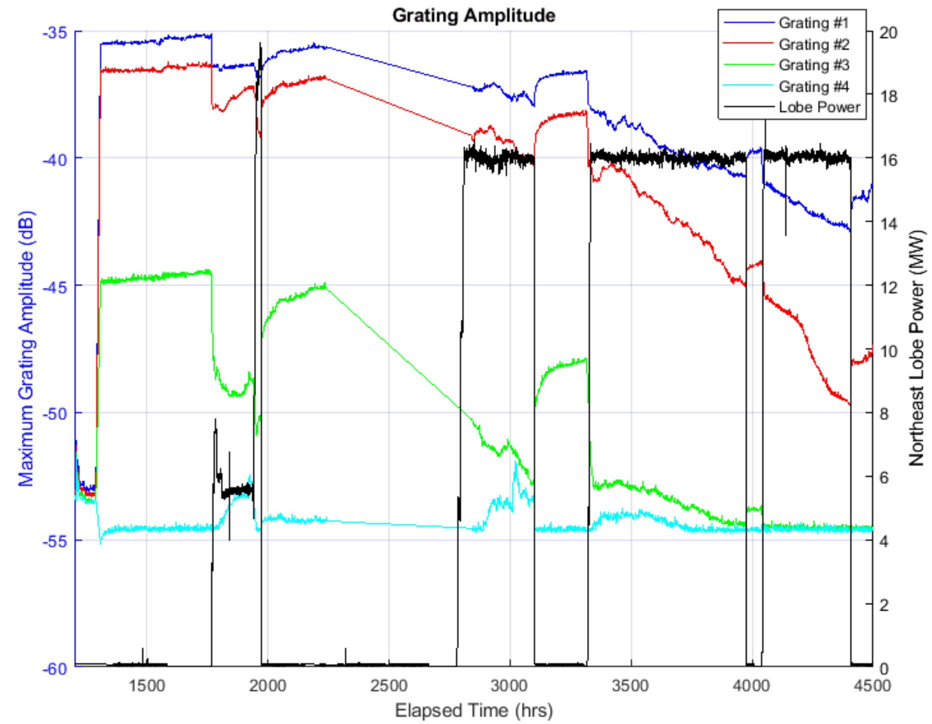
Optical Fiber Temperature: Performance Update

K McCary (INL)

Bragg gratings fail when the backscatter amplitude of the grating is reduced to the background noise

- Gratings #3, #4, and #5 – signal attenuated
- Gratings #1 and #2 -- continued operation after total accumulated fluence of:
  - Grating #1: 5.9×10^{20} n/cm^2
  - Grating #2: 7.5×10^{20} n/cm^2 (signal drifting)

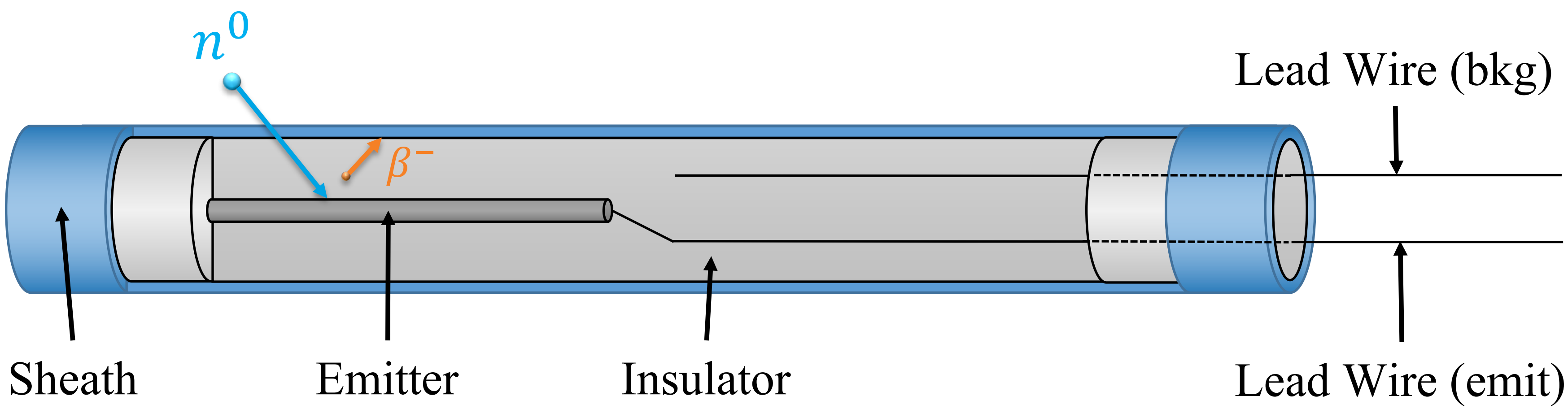




- Current state-of-the-art radiation hard fibers in development expected to withstand higher fluences than standard telecommunication fiber
- Radiation hardened optical fiber based- sensors for MTRs are under development

- **Self-Powered Neutron Detectors (SPND) provides real-time, localized, neutron flux.**
- **Considered the workhorse for in-core flux sensor for nuclear industry.**
- **Vanadium emitter SPND.**
- **Neutrons interact with the emitter generating electrical current proportional to the neutron flux.**

$$n^0 + {}^{51}_{23}V \rightarrow {}^{52}_{24}Cr + \beta^-$$

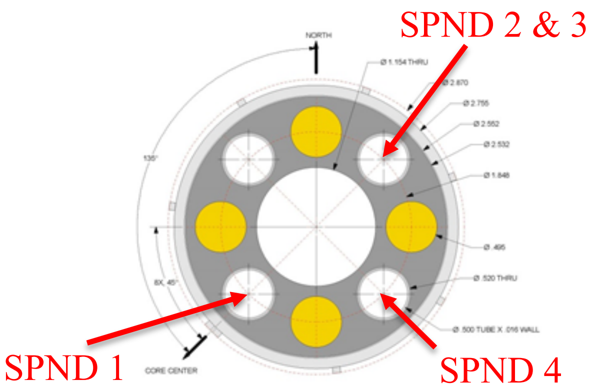


Schematic overview of an SPND

SPNDs : Installation

K Tsai(INL)

- Four SPNDs are placed in the thru-tube of capsules 2 through 5
- Electrical current signals from both lead wires of each SPND are measured by an electrometer and recorded by a DAS



Cross-sectional view of capsule 2, 3, 5 and SPND insertion location

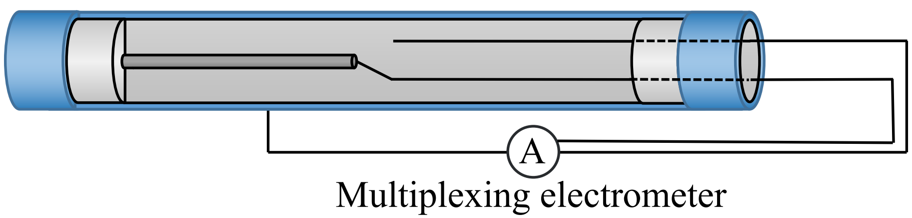
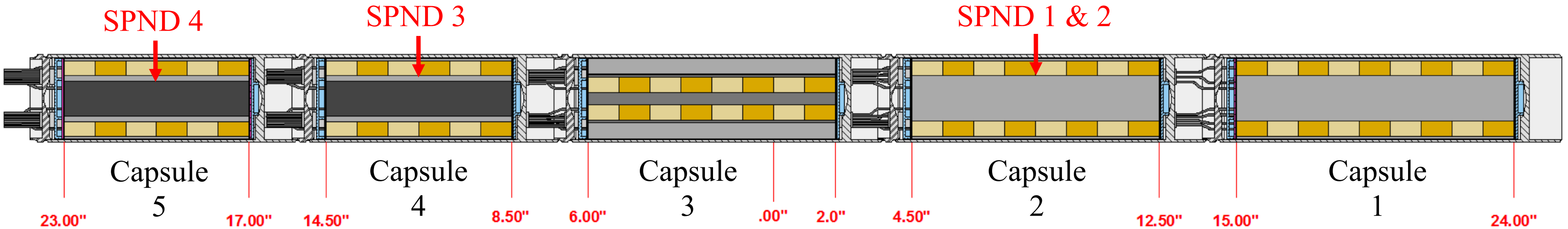


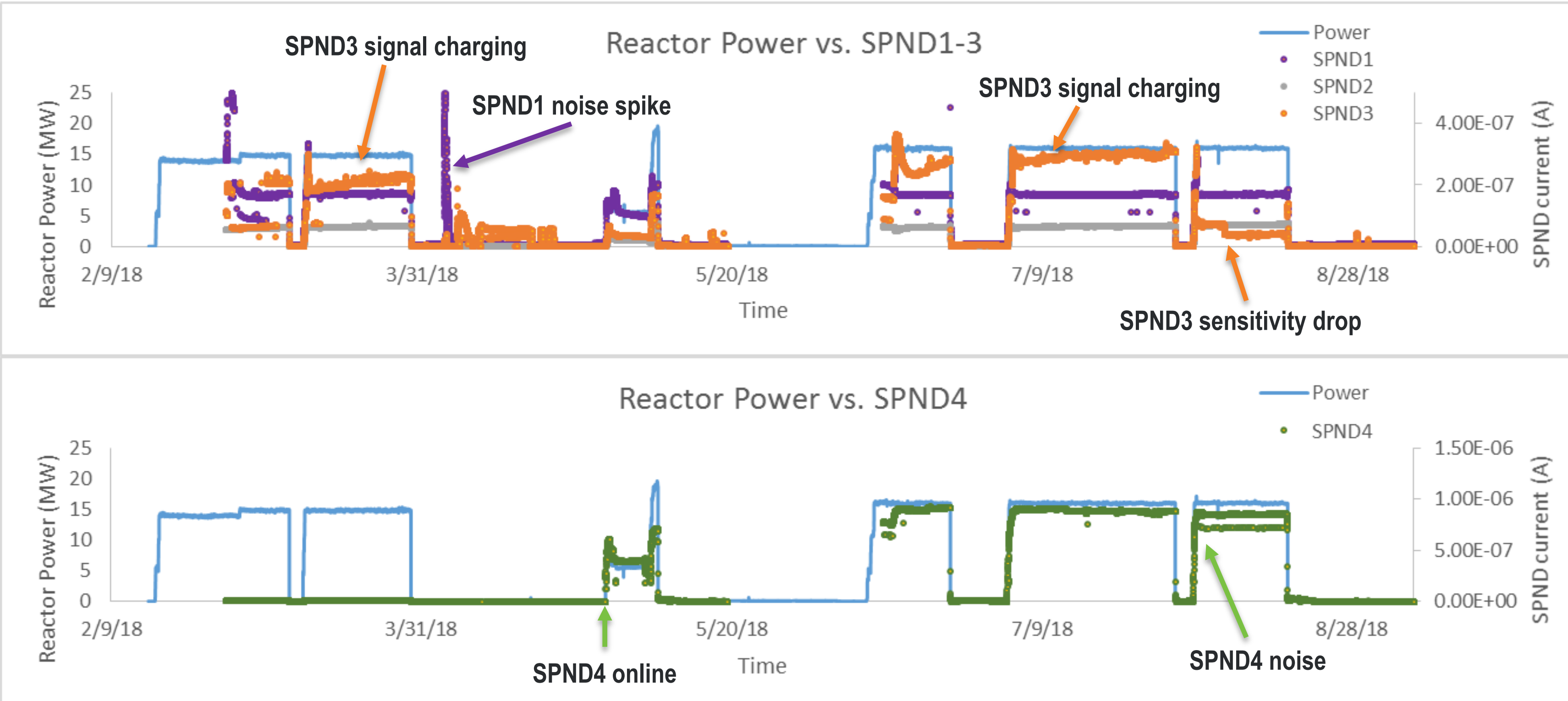
Diagram of SPND readout



SPND depth location inside AGR5/6/7 test capsules

SPNDs: Performance Update

K Tsai(INL)



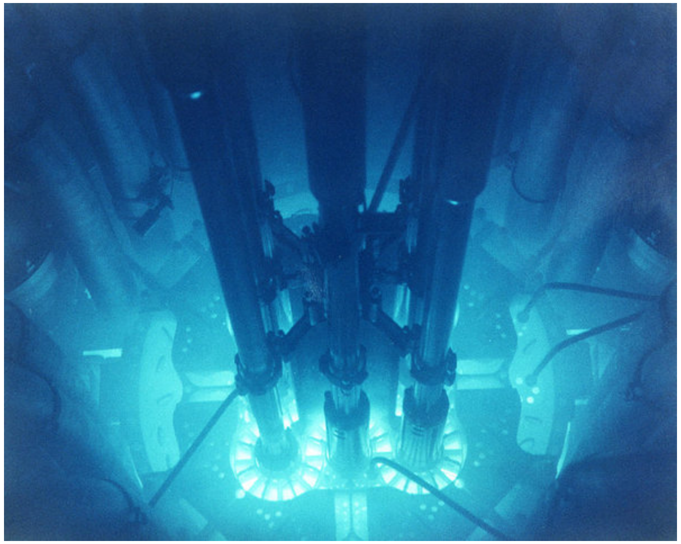
- SPNDs 1 and 2 are tracking reactor power well with few noise spikes
  - Noise suspected from current transfer between sheath and environmental surroundings
- SPND 3 displaying a noisy, charging characteristic and a drop in sensitivity
  - Signal degradation under investigation
- SPND 4 signal inconsistent, displaying oscillatory noise
  - Oscillatory noise potentially due to circuit short between emitter lead wire and sheath

Conclusion

Material test reactor instrumentation development and deployment strategy leverages long-duration irradiation experiments

- Instrumentation performance validated through multiple reactor cycles
- Lessons learned from aggressive simultaneous instrumentation deployments in AGR 5/6/7 and ATF-2

Development of a dedicated ATR instrumented irradiation vehicle will allow for ongoing instrumentation qualification tests



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