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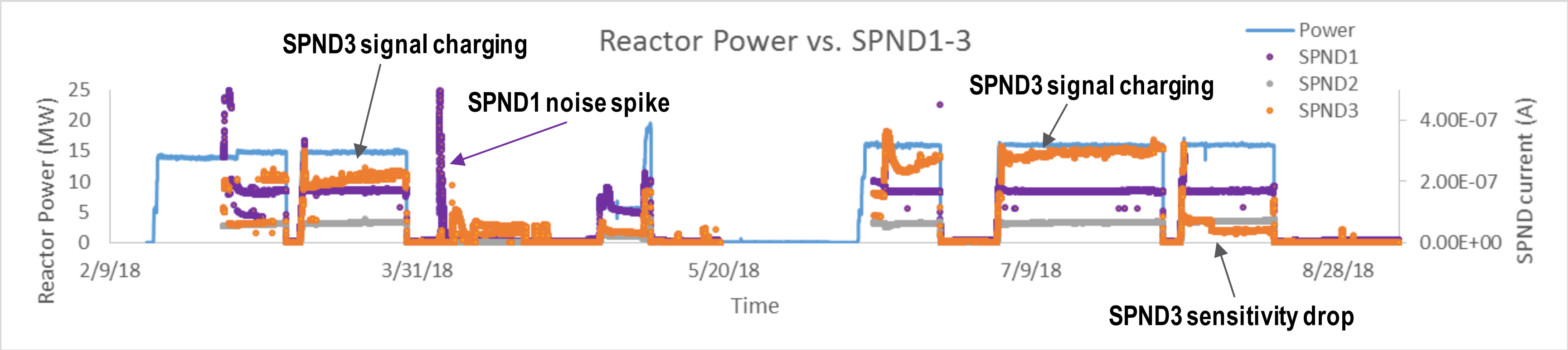
Demonstration of Self Powered Neutron Detectors Performance and Reliability

Background

- **Motivation:**
  - The unique fuel arrangement of the Advanced Test Reactor (ATR) provides great flexibility in operating the reactor – power may be "tilted" to one of four lobes resulting in:
    - Increased uncertainty in the neutron flux at any one experiment location.
    - Researchers forced to rely upon model-based estimates of neutron flux
- **Goal:**
  - Demonstrate Self Powered Neutron Detectors (SPNDs) in prototypical temperature and flux conditions in preparation for deployment in ATR and other high power reactor experiments.

Background

- **Technology gaps**
  - Sensor demonstration/qualification is needed to effectively deploy SPNDs to support experiments in ATR
    - Demonstration of SPND performance in ATR conditions
      - Sensor applicability and reliability
      - Signal/noise error assessment of SPND and electronic systems
    - Analytical/validation experiments targeting ATR conditions
      - SPND performance response to burnup, temperature, and neutron spectrum

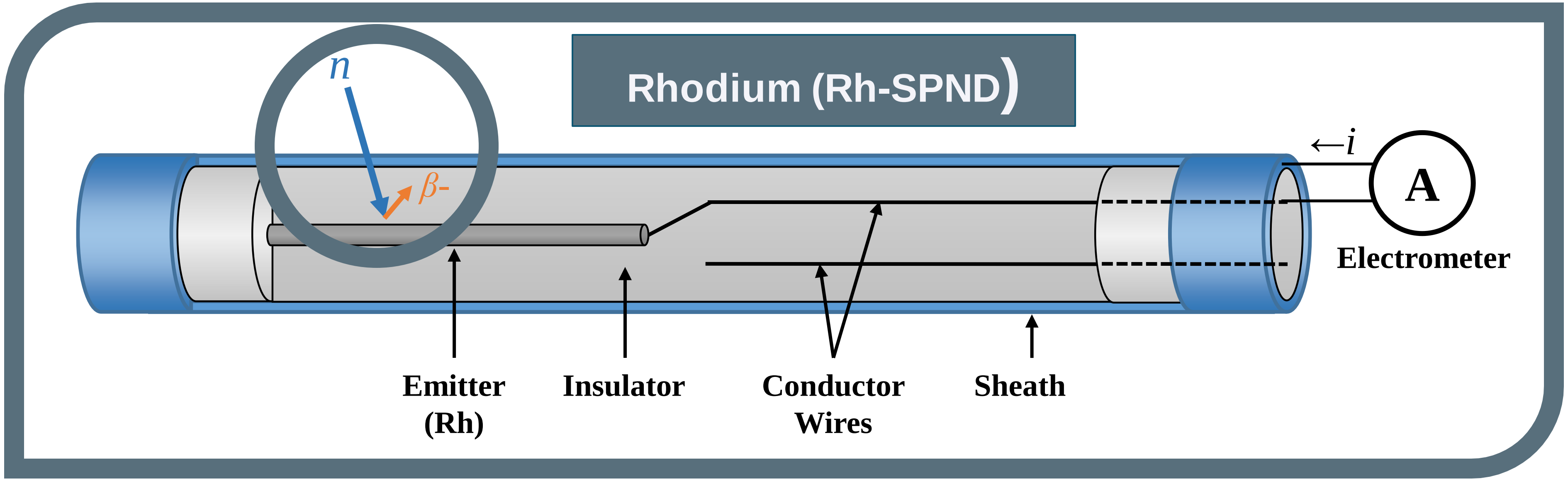


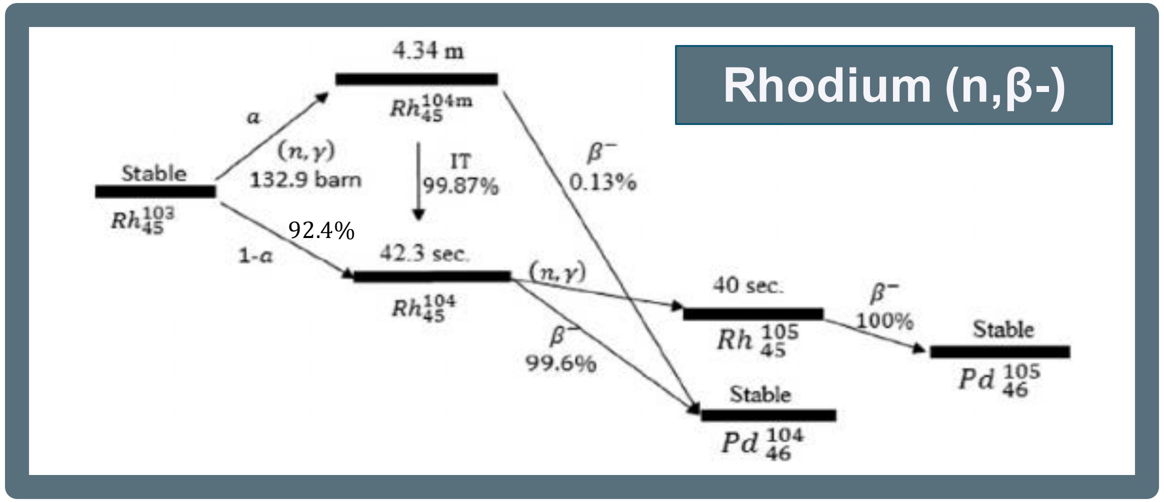
Vanadium SPND performance in past ATR Experiment.

MITR Irradiation Test Objectives

- Measure burnup of SPNDs at thermal fluence equivalent to one cycle in the ATR center flux trap
- Measure integral temperature-radiation effects in SPND outputs
  - Changes in reactor power with fixed temperature
  - Changes in temperature with fixed reactor power
- Evaluate self-shielding effects in SPNDs
  - 2 SPND designs—validate analytical models for adapting designs for specific ATR applications

Background – SPNDs

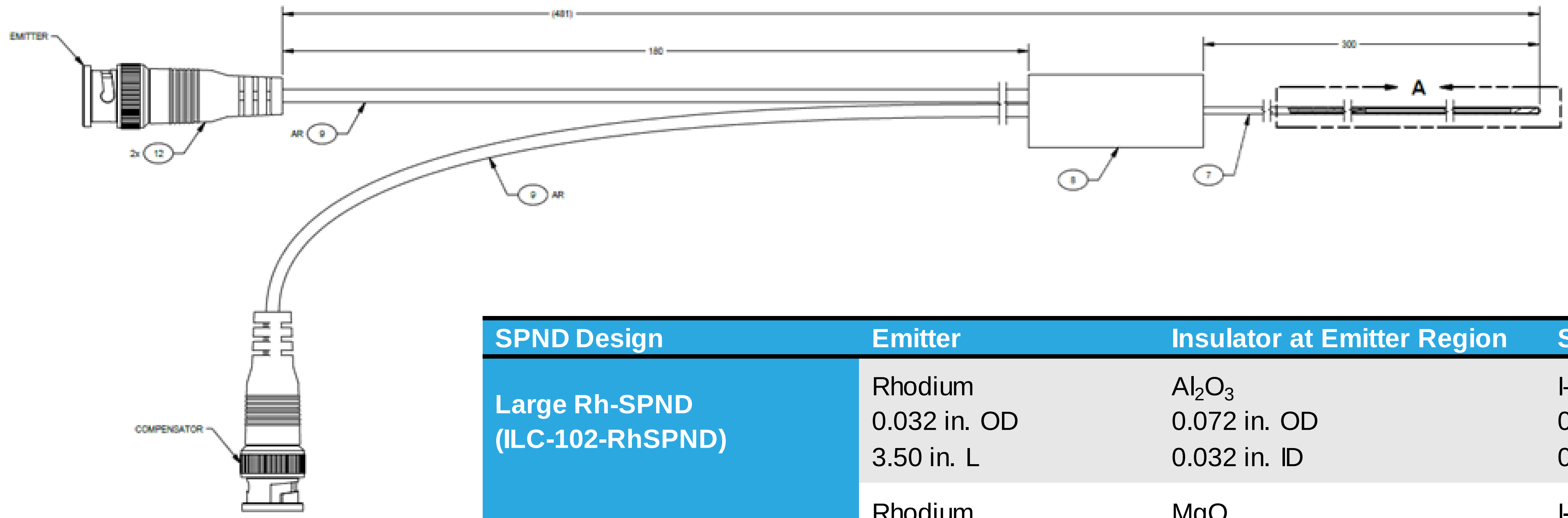




- Small physical footprint (<1/8” OD)
- Robust design
- Wide range of signal sensitivity
- Medium response time (92.3% 42s delay)

Idaho Laboratories Corp. SPND

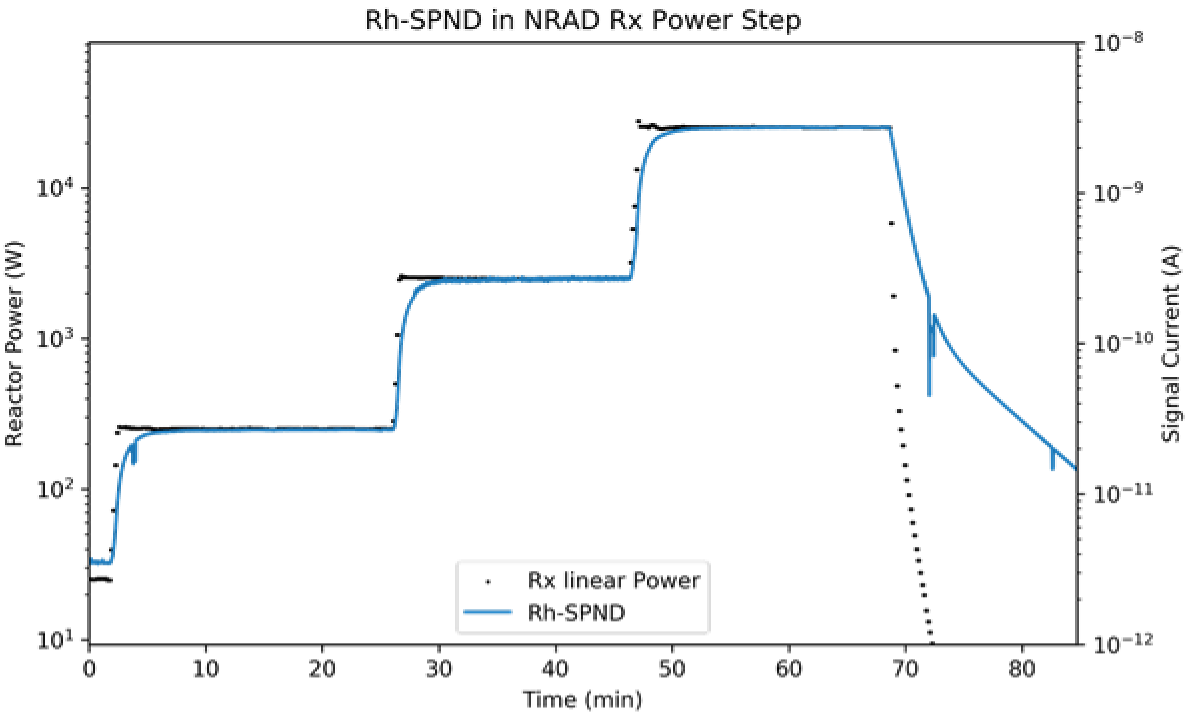
- 2 SPND prototype designs were procured from ILC.
  - 0.102-inch and 0.080-inch outer diameter (2mm and 2.6mm)
  - 2-wire design for emitter and cable compensation.

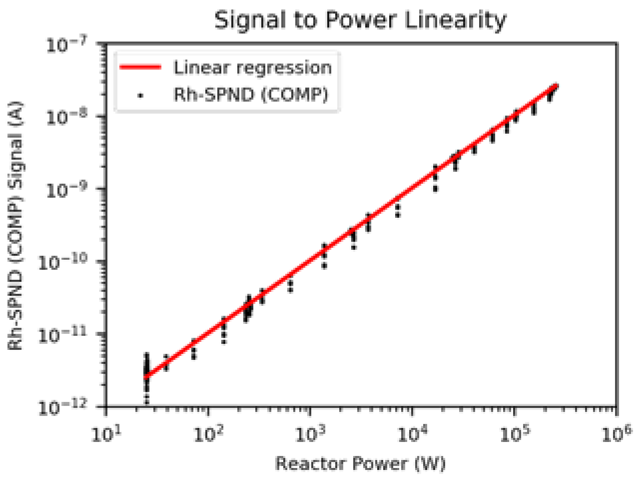


SPND Design	Emitter	Insulator at Emitter Region	Sheath
Large Rh-SPND (ILC-102-RhSPND)	Rhodium 0.032 in. OD 3.50 in. L	Al_2O_3 0.072 in. OD 0.032 in. ID	I-600 0.102 in. OD 0.072 in. ID
Small Rh-SPND (ILC-080-RhSPND)	Rhodium 0.020 in. OD 3.50 in. L	MgO 0.056 in. OD 0.020 in. ID	I-600 0.080 in. OD 0.056 in. ID

Preliminary Work

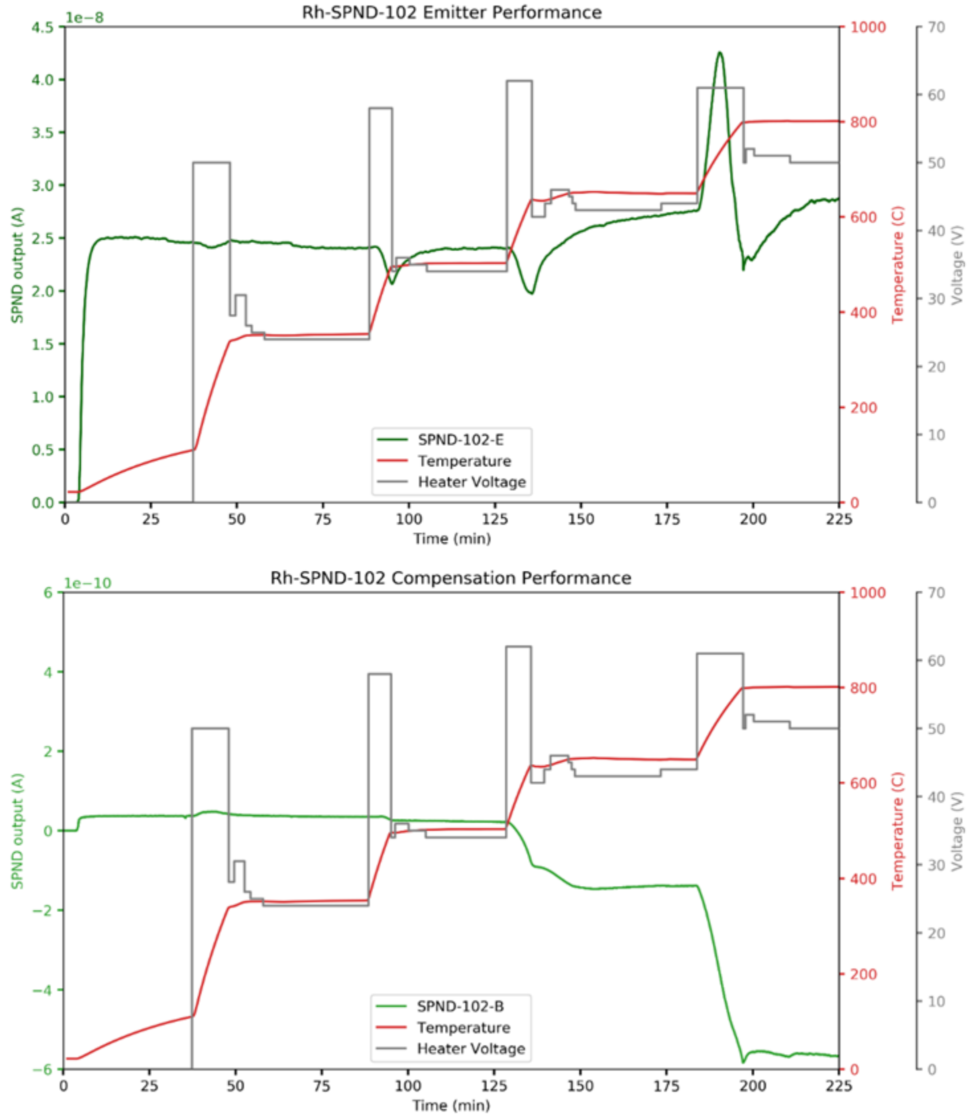
- **NRAD Irradiation Results**
  - Test performed over 5 decades of reactor power
    - Lowest power measured at 2.5W (2E7 n/cm·s²)
  - Demonstration showed good sensitivity and linearity





Preliminary Work

- **Heated Irradiation**
  - (Emitter) At each temperature increase, SPND signal deviations occurred followed by a recovery.
  - (Compensation) The signal is inversely proportional to temperature.
  - From this irradiation it was theorized that the heater used in the experiment has an influence on the SPND output.
  - Further testing with other heating methods required.

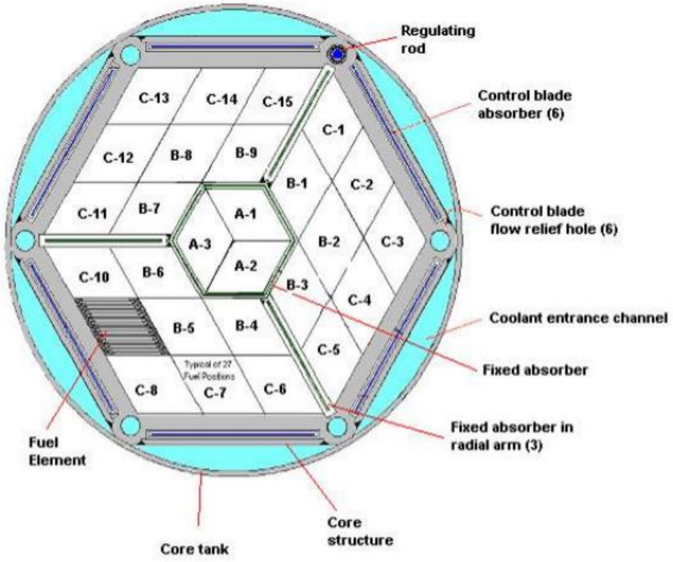


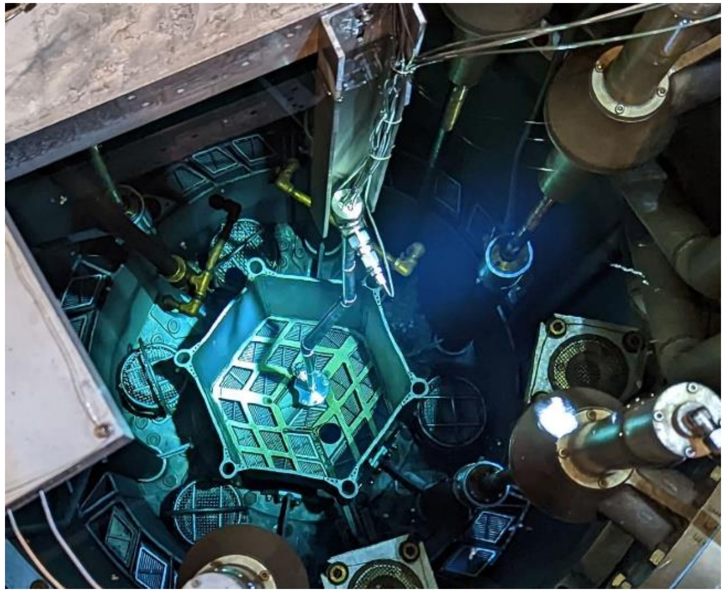
Rh-SPND response in NRAD heated experiment

Rh-SPND Testing at MITR

Facility Setup

- In-core A-1 position (10^{13} thermal neutron flux)
- Heater based on gamma heating
  - Central tungsten rod and varying gas (He/Ne) flow
- Temperature ranges from 600-800ºC at 6 MW.

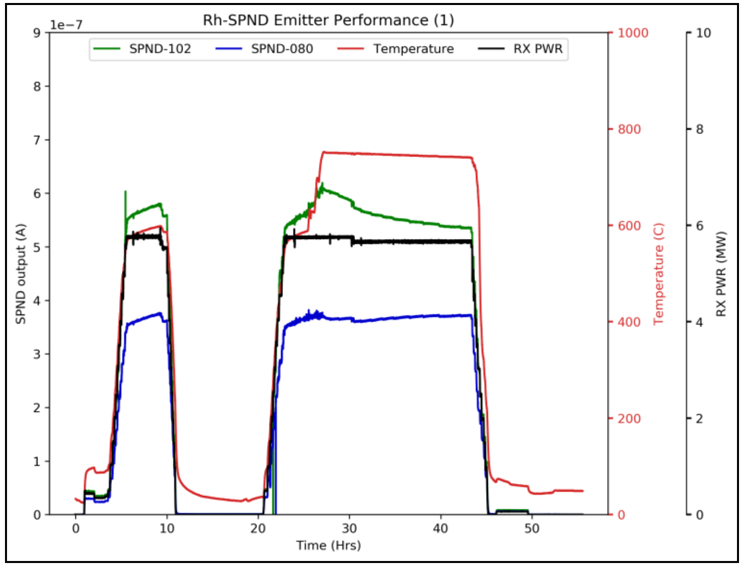


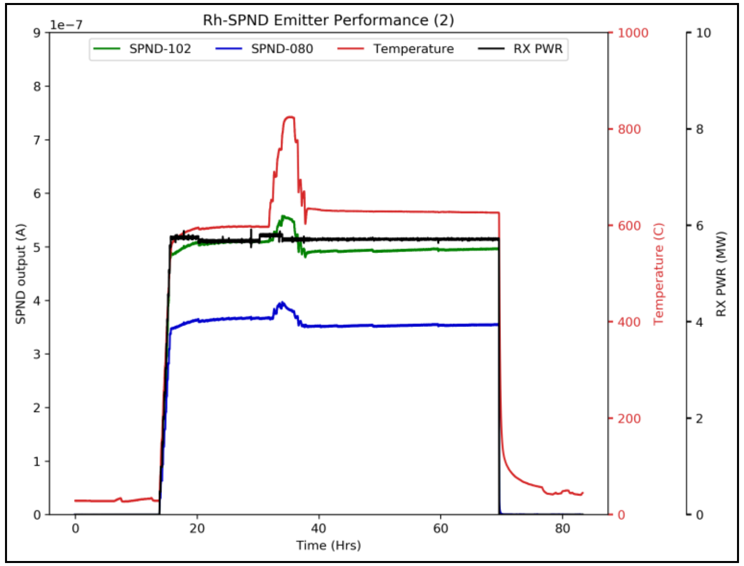


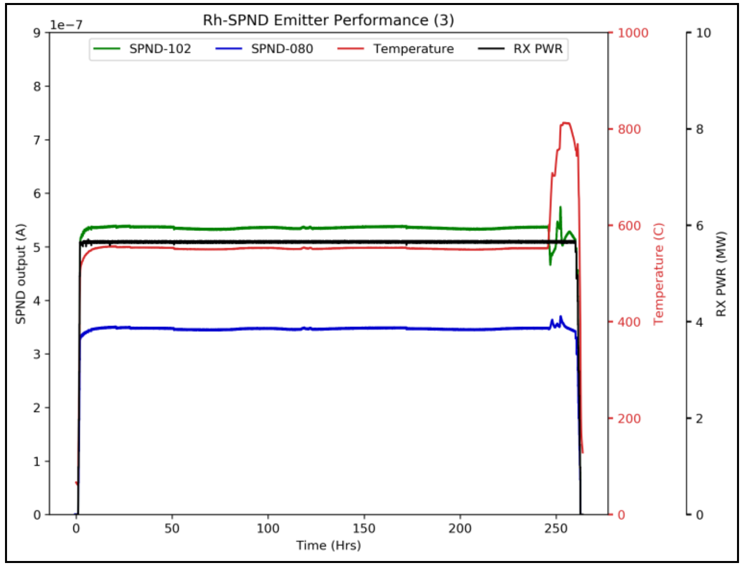
Results

MITR Irradiation Region of Interest

- Ramp temperature
  - Step-increase and maintain temperature
  - Increase and decrease temperature
- Steady-state temperature
  - Decrease power







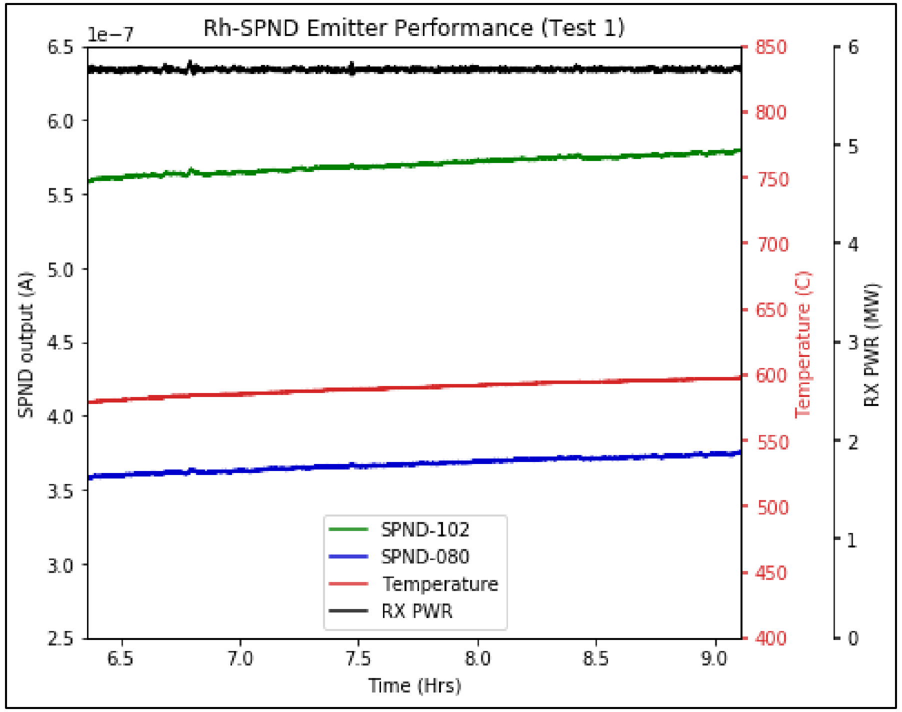
Results

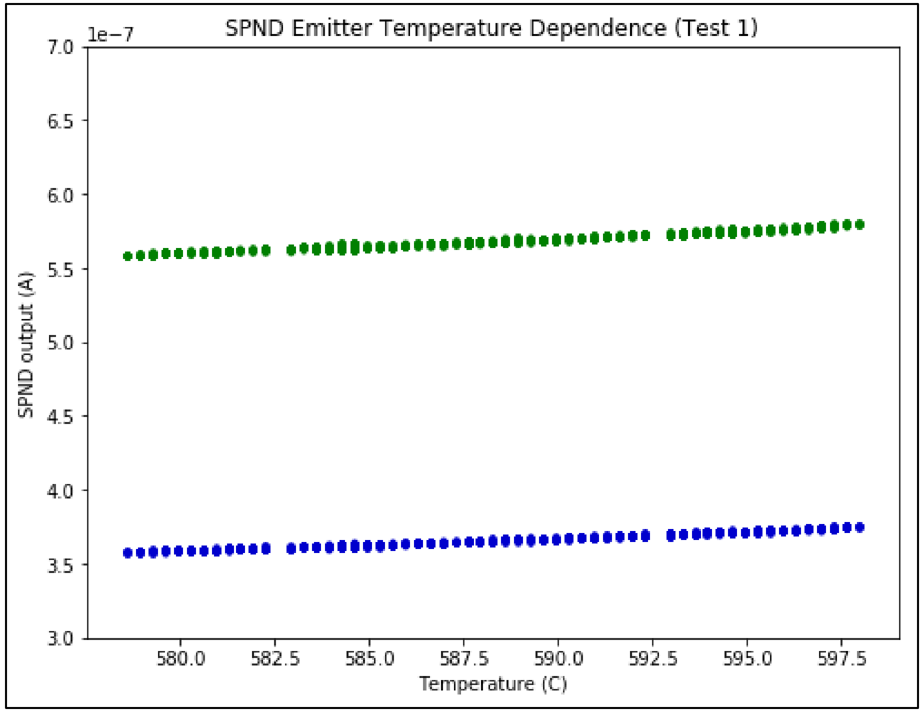
Steady-state power – ramp temperature

- Linear relationship for small temperature changes

$$SPND102(A) = (1.054 \times 10^{-9})T(°C) - 5.205 \times 10^{-8}$$
$$r^2 = 0.9838$$

$$SPND080(A) = (8.876 \times 10^{-10})T(°C) - 1.564 \times 10^{-7}$$
$$r^2 = 0.9868$$





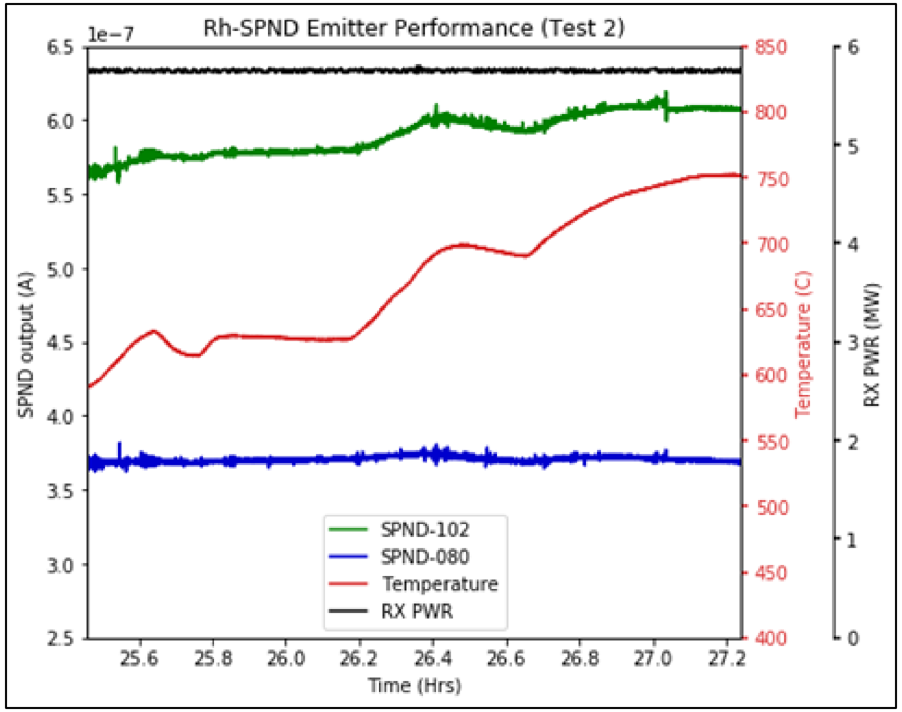
Results

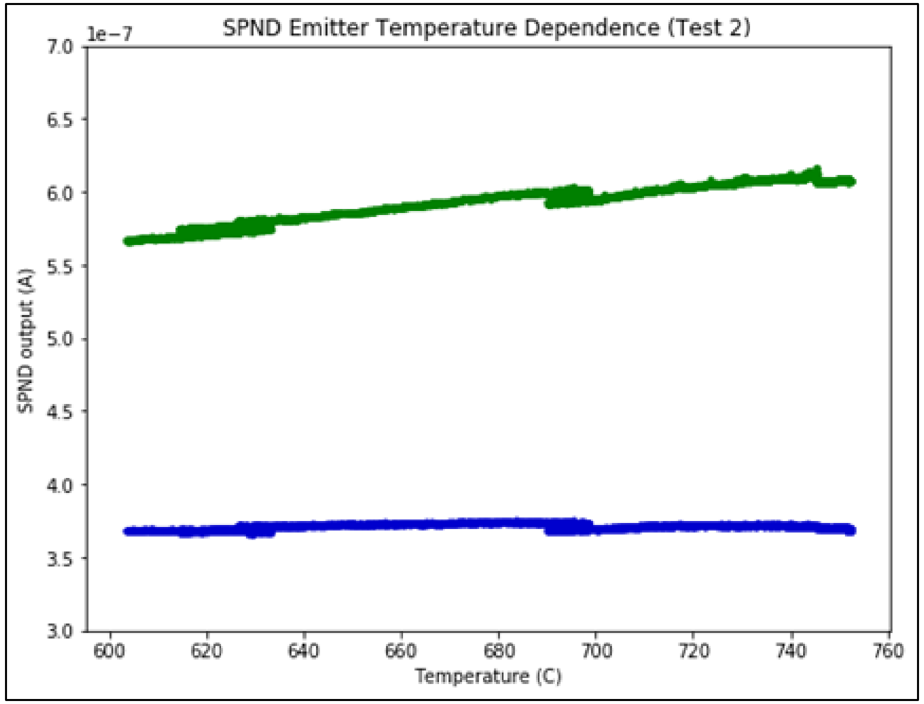
Steady-state power – step-increase temperature

- Linear response for larger SPND.
- No significant response change for small SPND.

$$SPND102(A) = (2.685 \times 10^{-10})T(°C) + 4.094 \times 10^{-7}$$
$$r^2 = 0.9643$$

$$SPND080(A) = (1.146 \times 10^{-11})T(°C) + 3.629 \times 10^{-7}$$
$$r^2 = 0.1256$$





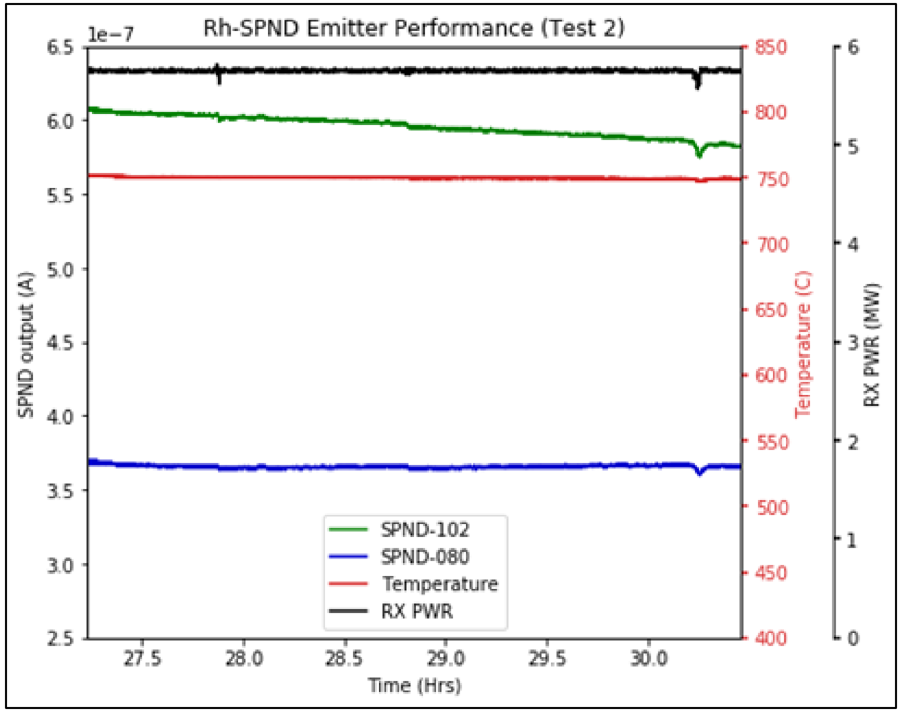
Results

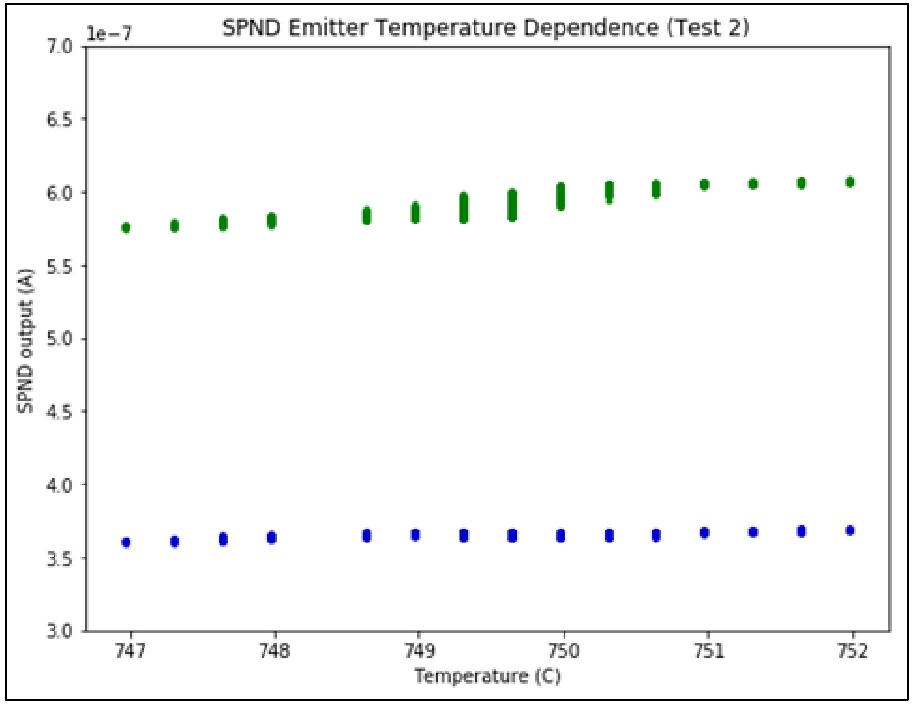
Steady-state power – post heating hold

- Decrease in signal in large SPND
- No significant response change for small SPND.

$$SPND102(A) = (9.668 \times 10^{-9})T(°C) - 6.654 \times 10^{-6}$$
$$r^2 = 0.8164$$

$$SPND080(A) = (5.357 \times 10^{-10})T(°C) - 3.605 \times 10^{-8}$$
$$r^2 = 0.1335$$

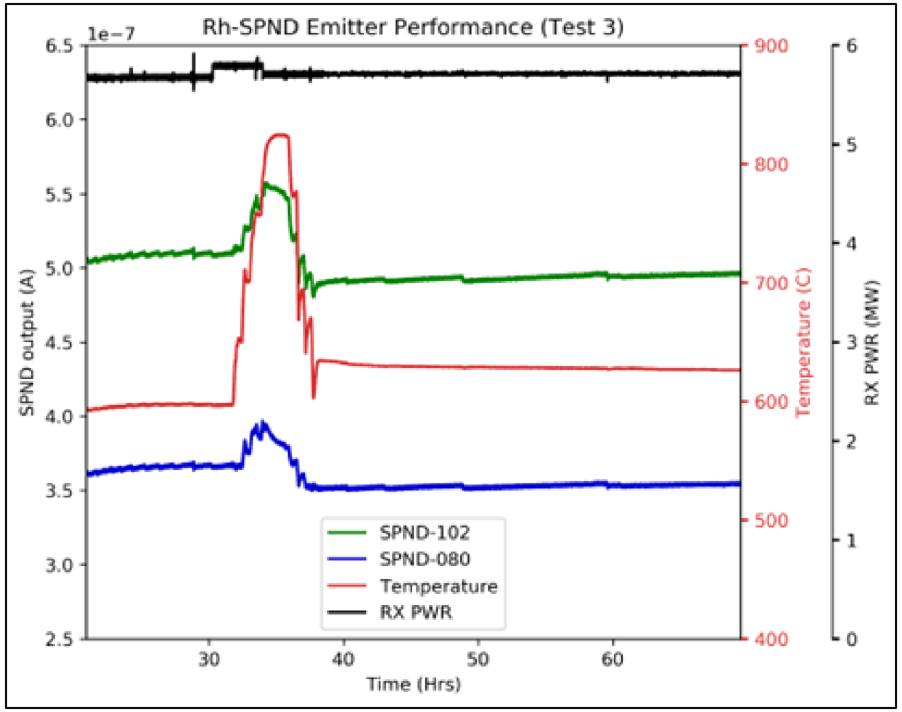


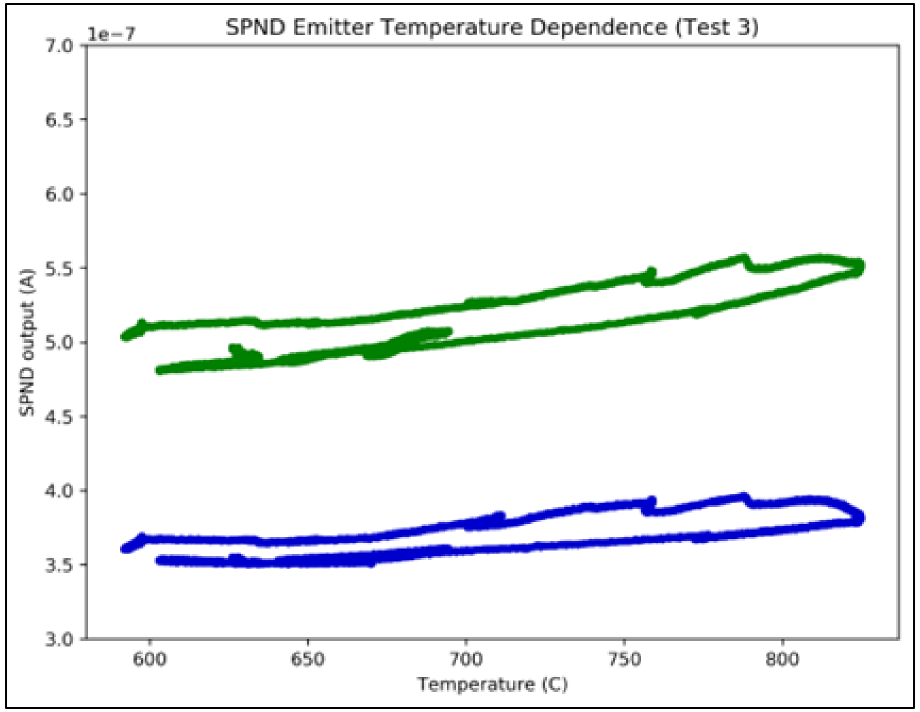


Results

Steady-state power—step increase and decrease temperature

- Non-invertible behavior identified in both SPND
  - Decay related to a long time constant

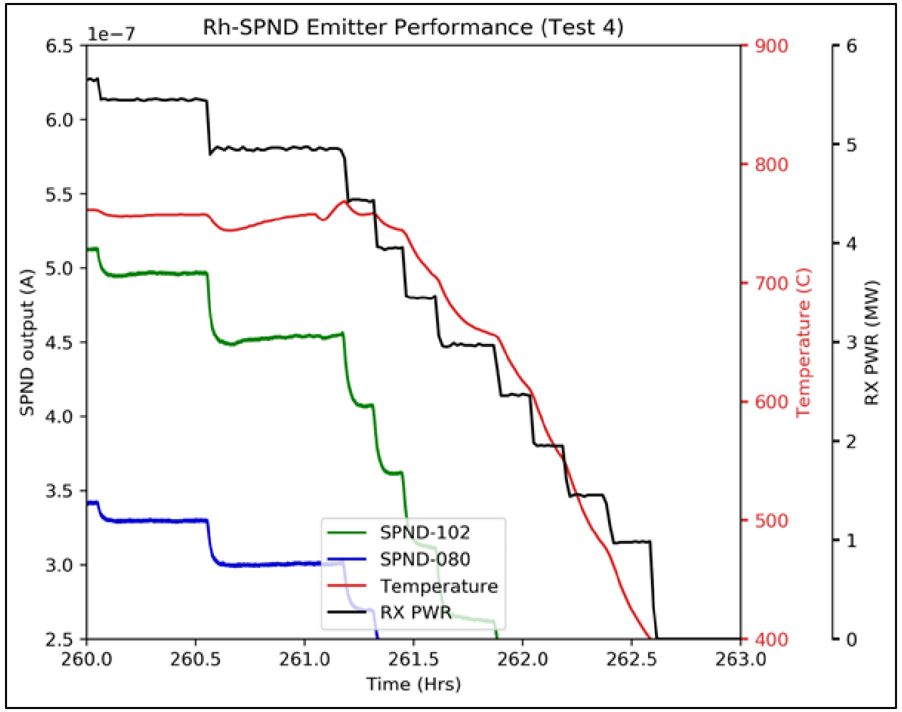




Results

Steady-state temperature – decrease power

- SPND was capable of tracking power changes in steady temperature.
- Survivability and no significant burnup after thermal fluence equivalent to one cycle in the ATR center flux trap



	RX Power (MW)	ILC-102-RhSPND (A)	ILC-080-RhSPND (A)
Power 1	5.65	5.13E-07	3.42E-07
Power 2	5.45	4.96E-07	3.30E-07
Power 3	4.95	4.53E-07	3.00E-07
Power 4	4.43	4.17E-07	2.76E-07

% Difference	RX Power	ILC-102-RhSPND	ILC-080-RhSPND
1 to 2	-0.036	-0.033	-0.035
1 to 3	-0.124	-0.117	-0.121
1 to 4	-0.216	-0.188	-0.193

Conclusion

Overview of results

- Demonstrated sensor survivability with acceptable response and signal/noise error.
- However, the ILC-Rh-SPNDs have a significant temperature dependence at the application range of 600-850°C.
  - Direct proportionality (approximated as linear) to temperature changes
  - Exponential decay at steady temperature
  - The signal response to temperature are more observable in the larger diameter SPND

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