Harsh Environment-Tolerant Flow Sensor for Nuclear Reactor Applications

Dept of Energy Small Business Innovation Research (SBIR) grant

Contract #: DE-SC0013858

Phase IIB Period of performance: 8/19/2019 – 8/18/2021

Sporian Microsystems, Inc.

PI: Jon Lubbers, Lead Mechanical Engineer (jlubbers@sporian.com, 303-516-9075 ext. 16)

Business Development Mgr: Laurel Frediani (lfrediani@sporian.com , 303-516-9075 ext. 25)

Outline

- About Sporian
- Motivation, Objective, and Requirements
- Technical Approach
- Review of Development
- Phase IIB Work Plan
- Schedule and expected availability

About Sporian Microsystems

- Sporian develops advanced sensor systems for a range of applications

Core Technical Competencies

- Novel Materials Science
- Leading Edge Signal Conditioning & Smart Electronics
- Advanced Electronics & Hardware Packaging

Advanced Sensor Technologies

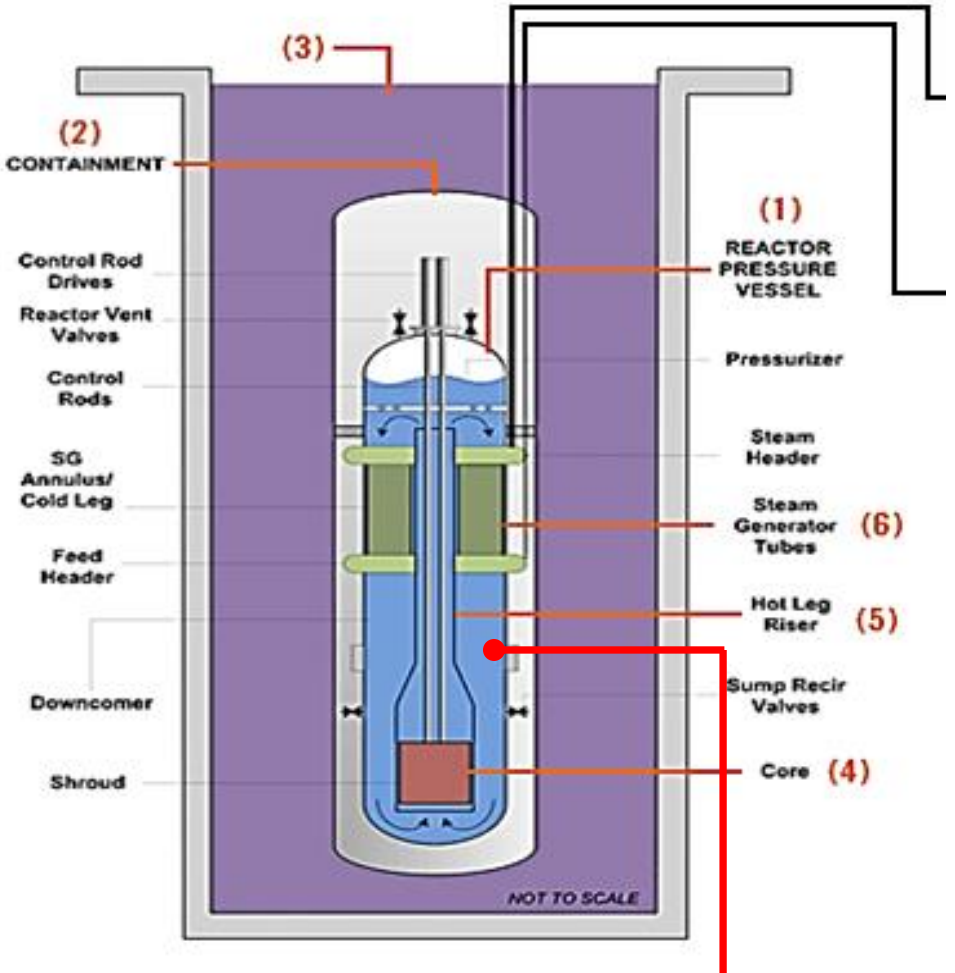
Biological & Chemical

- Fluid Composition
- Gas Composition
- Biomedical

Energy & Aerospace

- Very High Temperature
- Harsh Environments
- Asset Health Monitoring

Motivation & Objective



NuScale Nonproprietary Image

- Small Modular Reactors (SMR)
- Cooled by natural convection
  - Without pump, need to *measure* flow coolant flow
- **Objective**: Develop a liquid flow sensor to monitor reactor coolant flow

High-Level Requirements

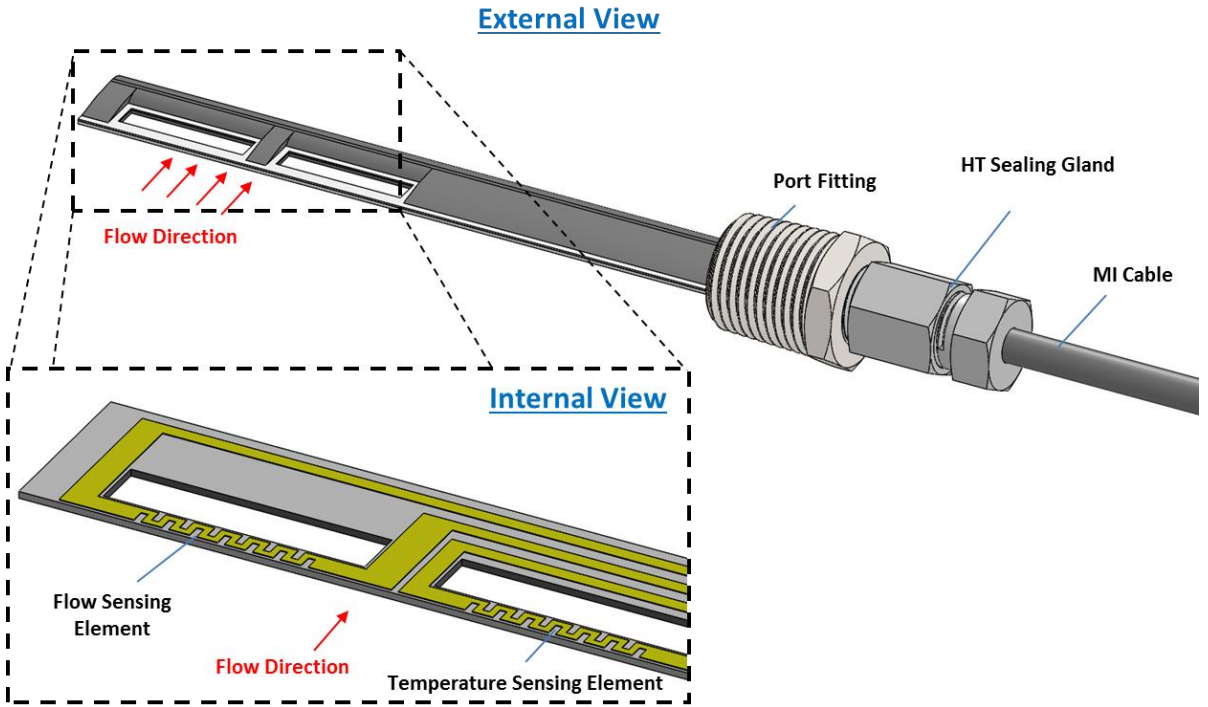
	Long-term Target Application: SMRs	Near-term Target Application: Industrial Processes
Fluid	Water (deionized + boric acid)	Molten metals or salts
Operating Temp	300°C	500-700°C
Operating Pressure	>1600 psi	<150 psi
Radiation	Up to 5E+20 n/cm^2	NA
Minimum Operating Life	2 years	6 months - 4 years
Potential Customers	NuScale, Westinghouse, Curtiss-Wright, Emerson	High-Temp Systems Design, Big Blue Technologies, various researchers
Commercialization Plan	Licensing, partnership, or acquisition	Direct sales

Technical Approach

- Thermal anemometry

- Build upon prior Sporian development of liquid and gas flow sensors
  - Leverage Sporian's previous experience in high temperature sensor materials, packaging, and design

- Focus on commercialization
  - Qualification-oriented testing
  - Quality controls
  - New markets



Related Work – Flow Sensors

- Turbine bleed air flow [i]
- Helium flow sensor for gas reactors [ii]
- Molten salt flow sensor for solar systems [iii] and molten salt reactor testbeds [iv]

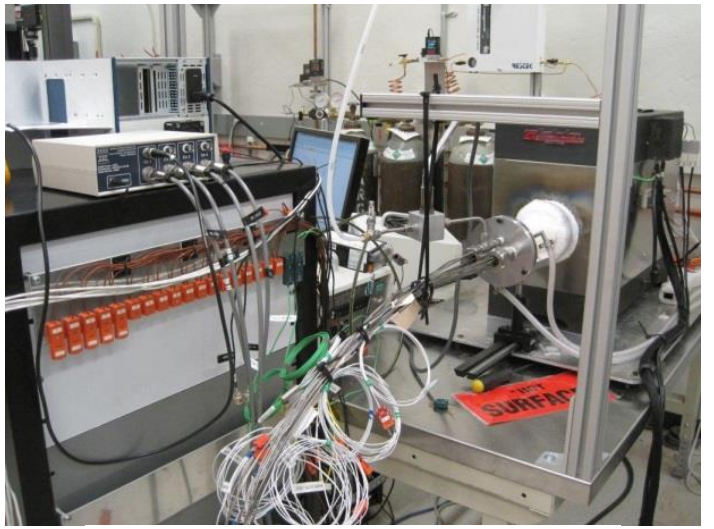
Gas Flow Sensor Prototype

Nitrate Salt Flow Sensor

1000°C He Flow Sensor Demo

Related Work – Nuclear Power Systems

- Reliable 1800°C temperature sensor [ii]
- Rod position indicator (RPI) [v]
- SiC-SiC composite joining [vi]
- Irradiation testing
  - >250 hours in TRIGA

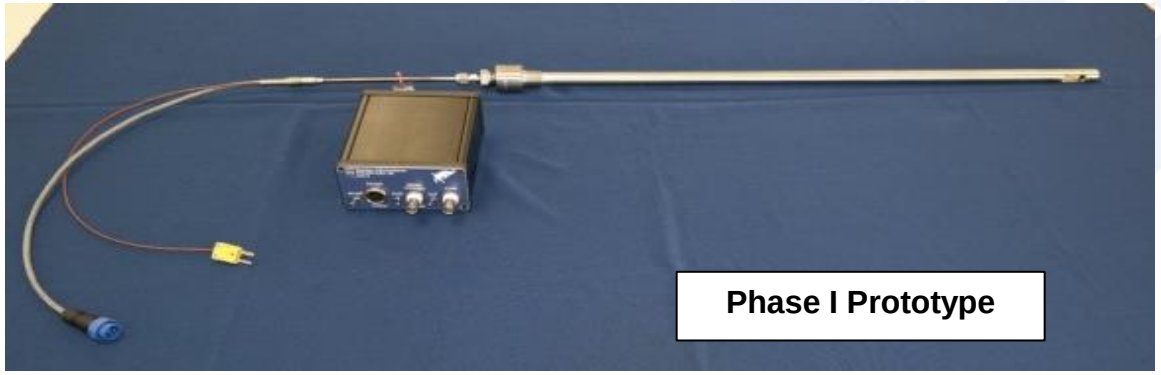


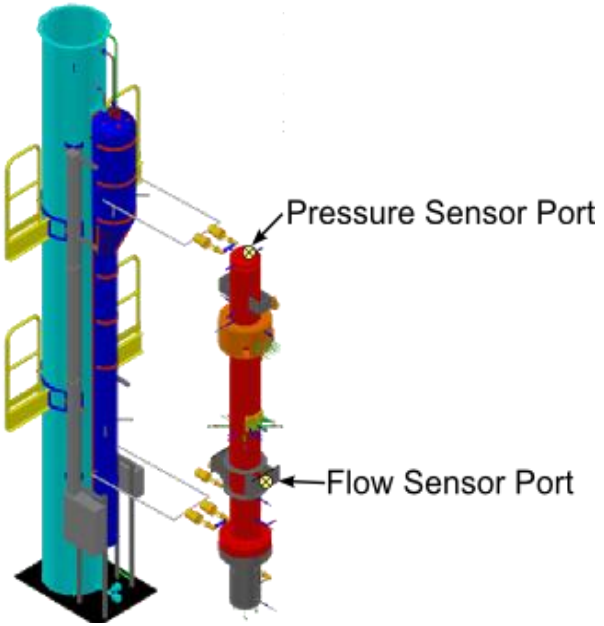
Sporian Temperature Sensors in ATR Mockup Test System

Sporian RPI on CRDM at UC-Davis McLellan Research Center

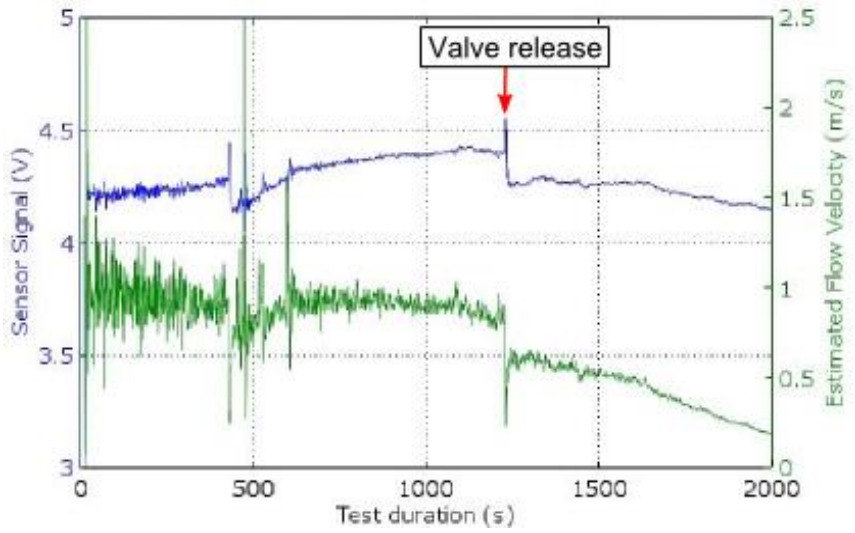
Phase I Summary

- SMR flow sensor developed
- Final device tested in NuScale Integrated System Test facility (NIST-1)





NuScale Nonproprietary Image



Sporian sensor data in NIST-1

Phase II Summary

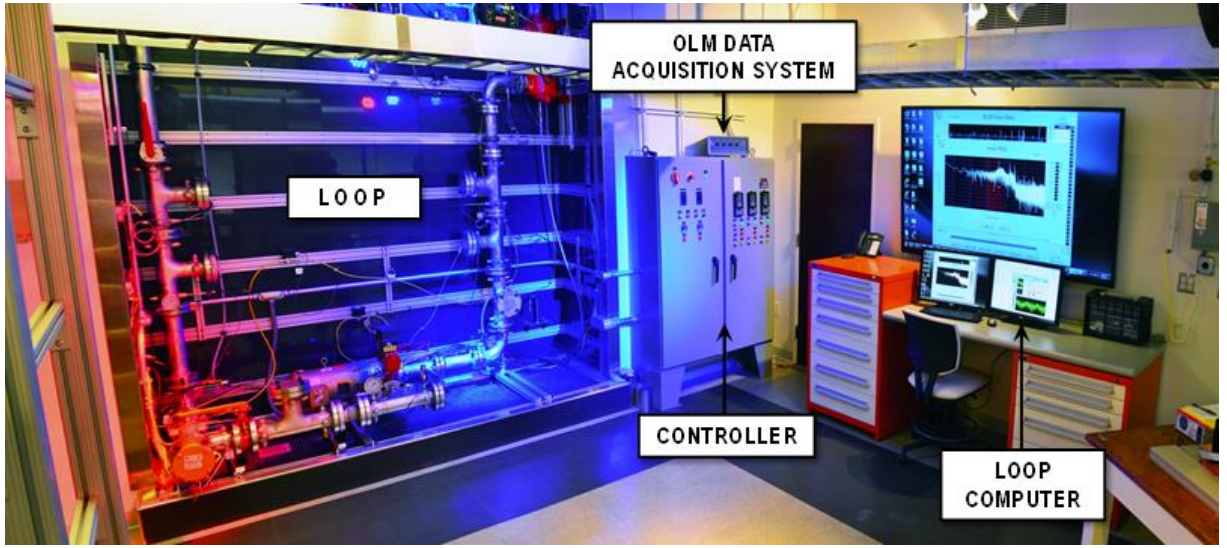
- Design & Process Improvements
  - Focus on reliability
  - Custom excitation mode developed and implemented
    - Improves utility in diverse environment

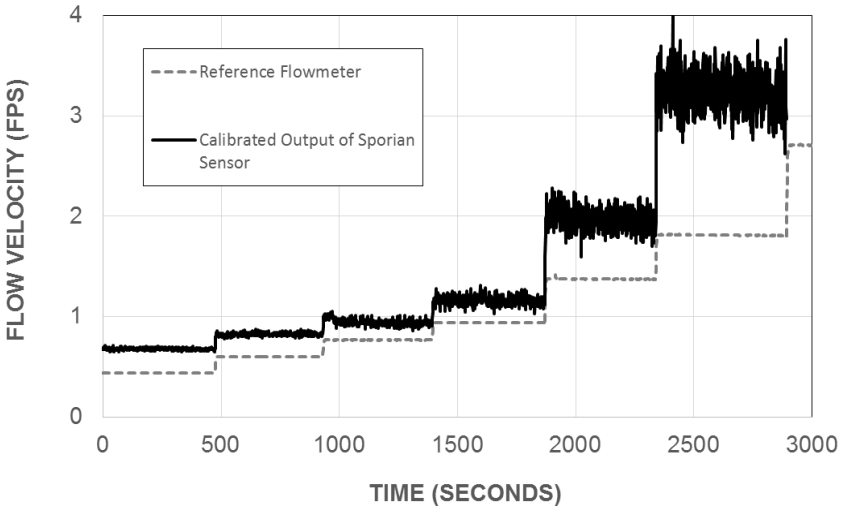
- Internal Testing (typically to MIL-STD-810G)
  - Vibration, leak, thermal shock, thermal cycling, accelerated aging

- External Testing & Demonstration

Phase II External Demonstrations

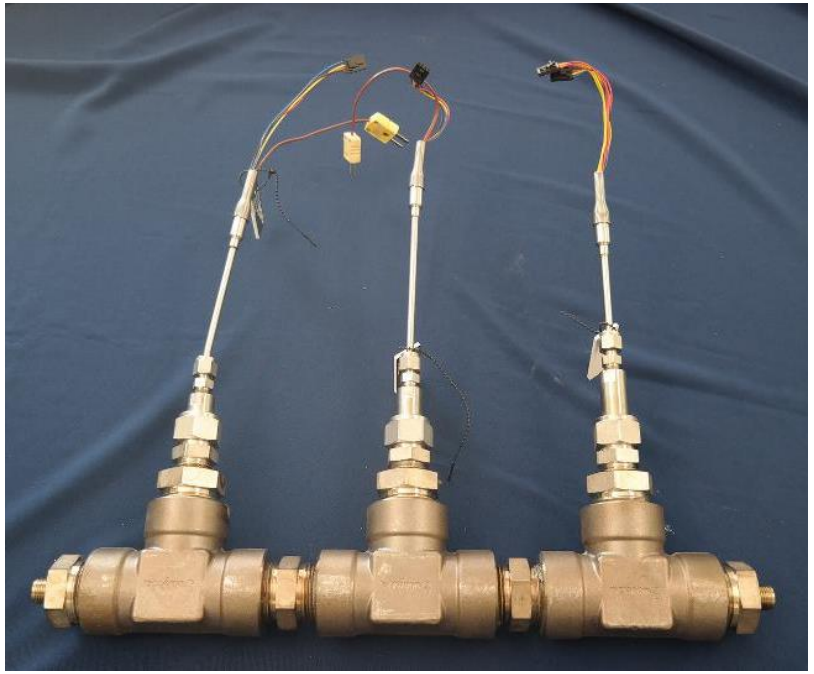
- Analysis and Measurement Services (AMS) Corp pressurized flow loop - 2017
  - 0-150 psi, 5-80°C
  - Highlighted calibration and noise issues

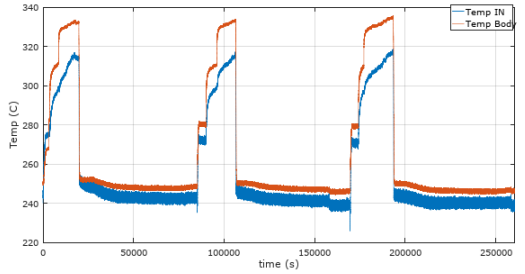


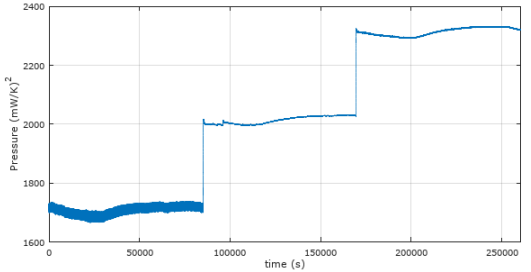


Phase II External Demonstrations

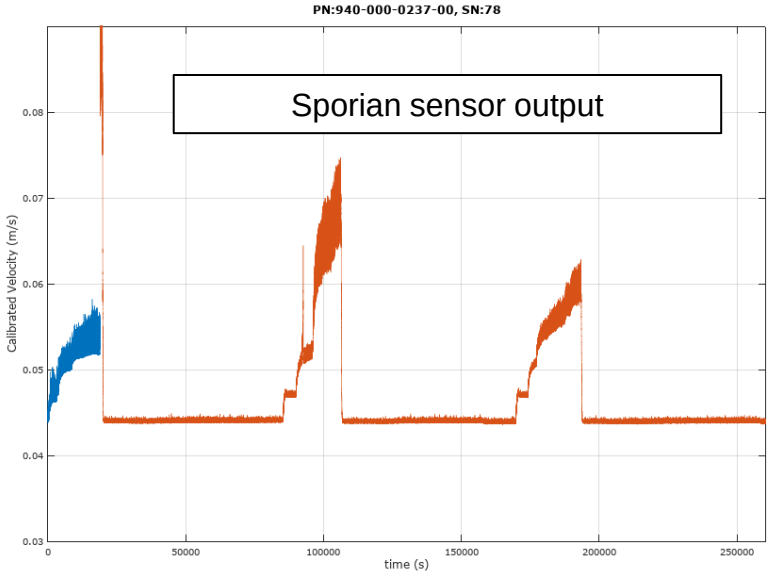
- Southwest Research Institute (SwRI) - July 2019
  - 1700-2300 psi, 250-330°C
  - 1 of 3 sensors failed, but the others were stable over 70+ hours







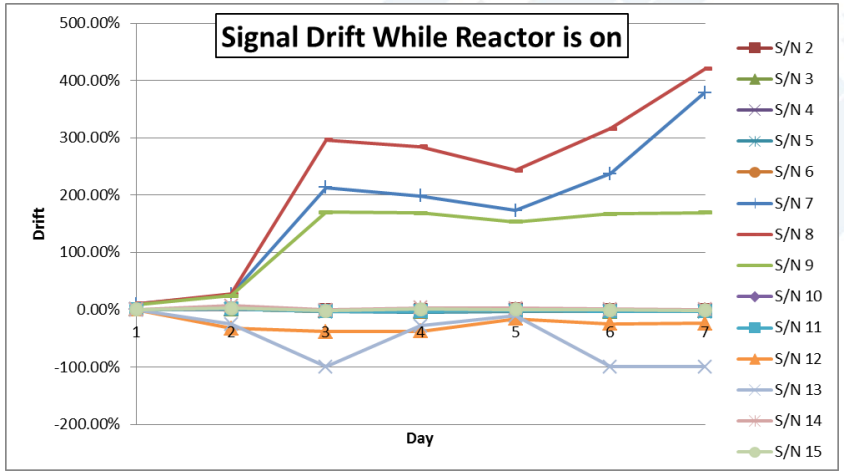
Ref temp (top) & pressure (bottom)



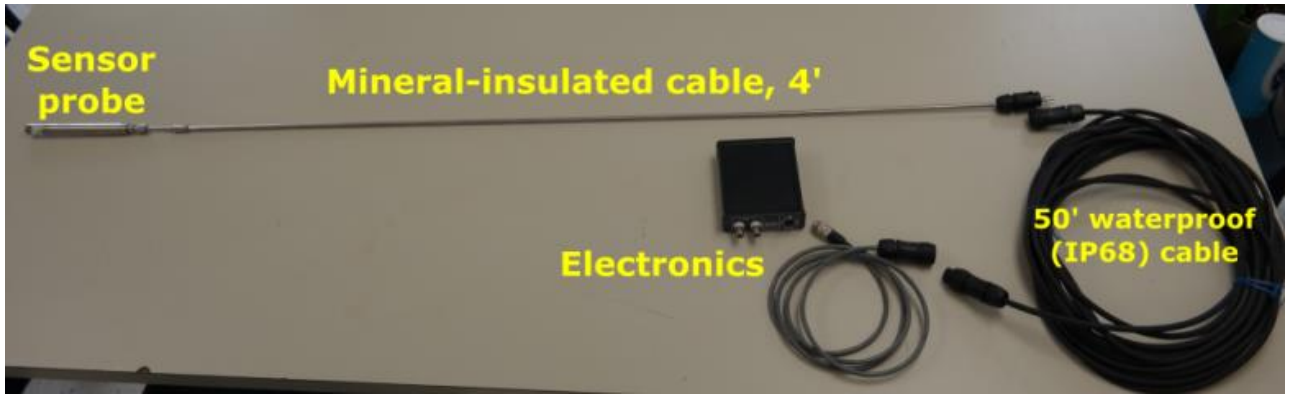
Sporian sensor output

Phase II Irradiation Testing

- Key subassemblies (2017)
  - USGS TRIGA
  - 5E+18 n/cm^2
  - Quantified configuration stability

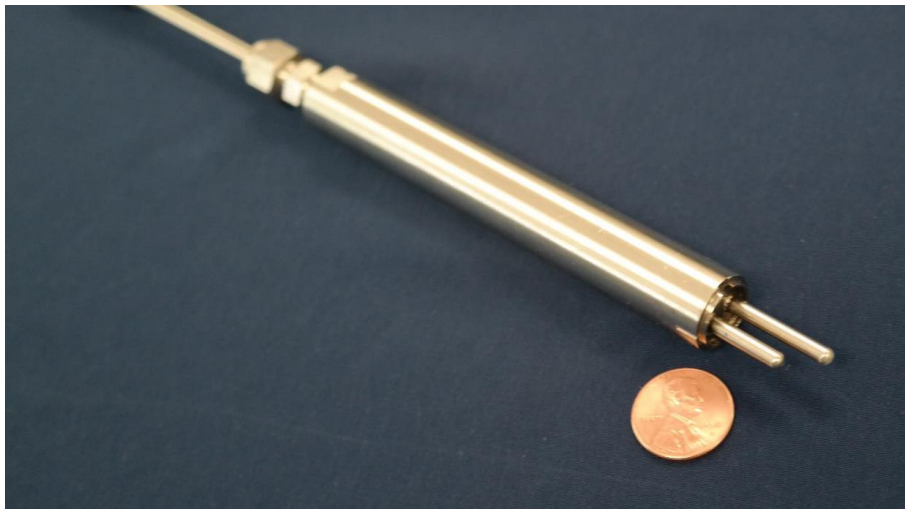


- Complete probe (2019)
  - Texas A&M TRIGA
  - 1E+18 n/cm^2
  - 8% signal drift over first hours
    - Temperature sensor instability
    - Plan to replace with qualified RTD



Phase II Products

- Flow sensor capable of operating under SMR conditions
- New HT probe design with broader applications
  - In development under new Phase I SBIR award
- US Patent #10,436,661
  - Additional application filed 2019



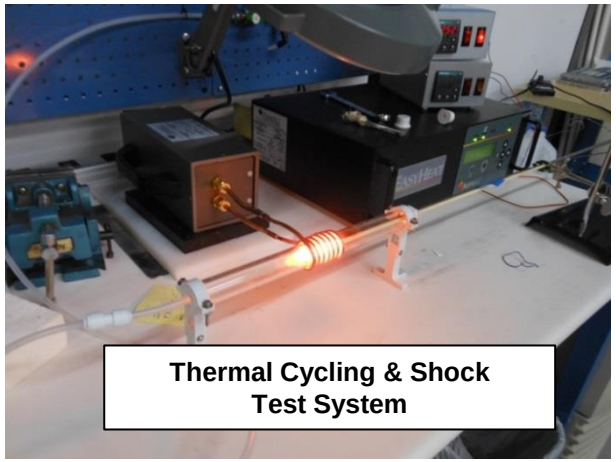
Phase IIB Work Plan

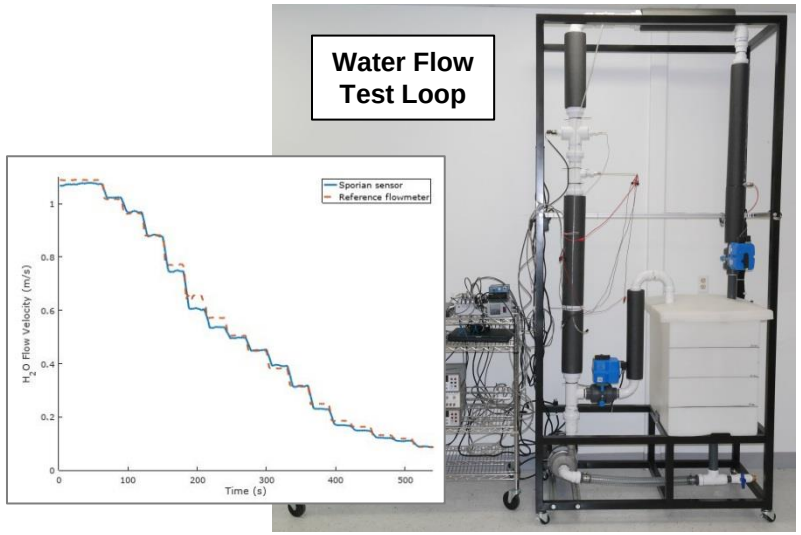
- Task 1: Continue working with OEMs and stakeholders to guide the development of a useful first implementation of the proposed technology, and facilitate transition efforts
  - Identify and explore new markets and applications

- Task 2: Implement quality assurance (QA) and control protocols to bring Sporian into closer compliance with relevant regulatory standards
  - Target: NQA-1 / 10-CFR-50 Appendix B
  - Consultant: United Controls International
  - Goal is to facilitate commercialization, *not* certification

Phase IIB Work Plan

- Task 3: Construct prototypes and validate system reliability through lab-scale verification and validation (V&V) testing
  - Risk assessment
  - Verification & validation (V&V) test schedule
    - UCI to inform Equipment Qualification (EQ) requirements
    - Focus on larger sample sizes for statistical significance





Phase IIB Work Plan

- Task 4: Revise sensor/packaging/electronics designs and construct iterative and final systems

- Task 5: Final V&V testing and demonstration in SMR-relevant test systems
  - Irradiation up to 1E+19 n/cm^2
  - Texas A&M Critical Heat Flux (CHF) facility
    - >3 m/s @ 170°C and 500 psi
  - SMR-representative flow test (likely NTS)
    - 100 gpm @ 300°C and 1200+ psi

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Phase IIB Schedule

Task #	Task Description	Year 1 (Months)												Year 2 (months)											
		Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21
Task 1	Work with OEMs & stakeholders to guide transition activities						M1																		
Task 2	Design and implement QA program						M2																		
Task 3	Construct prototypes and perform lab-scale V&V testing													M3											
Task 4	Revise design based on test results, and construct systems for final testing/demonstration															M4									
Task 5	Final V&V testing and demonstration in representative system tests																								M5

Product Release Plan

- **Long-term goal: SMR applications**
  - Several years out
  - Likely requires technology licensing

- **Short-term goal: non-nuclear energy generation and industrial processes**
  - <2 years out
  - Direct sales possible
  - Applications: Metal production/refining, solar power, MSR test loops

- **Shorter-term: demonstration & evaluation in systems**
  - Starting late 2019

Questions?

References

i. “A Small, Rugged, Accurate Bleed Flow Measurement System Based on a Novel Polymer Derived Ceramic MEMS technology” (Navy contract reference N68335-10-C-0326).

ii. “Advanced SiCN Materials and Sensors for Generation IV Reactors” (DOE contract reference DE-SC0006330).

iii. “Advanced Ceramic Materials and Packaging Technologies for Realizing Sensors for Concentrating Solar Power Systems” (DOE contract number DE-SC0009232).

iv. “High-Temperature Flow Sensor for Molten Salt Reactors” (DOE contract reference DE-SC0019712).

v. “A High Temperature High Reliability Control Rod Position Sensor for Improved Nuclear Power System Instrumentation” (DOE contract reference DE-SC0011901)

vi. “Polymer Derived Ceramic Materials for Joining of Nuclear Grade SiC-SiC Composites”(DOE contract reference DE-SC0019580).