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

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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

- 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

Possible location for Sporian flow sensor

NuScale Nonproprietary Image
# High-Level Requirements

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<tr>
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<th>Long-term Target Application: SMRs</th>
<th>Near-term Target Application: Industrial Processes</th>
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<tbody>
<tr>
<td><strong>Fluid</strong></td>
<td>Water (deionized + boric acid)</td>
<td>Molten metals or salts</td>
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<td><strong>Operating Temp</strong></td>
<td>300°C</td>
<td>500-700°C</td>
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<td><strong>Operating Pressure</strong></td>
<td>&gt;1600 psi</td>
<td>&lt;150 psi</td>
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<td><strong>Radiation</strong></td>
<td>Up to 5E+20 n/cm²</td>
<td>NA</td>
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<td><strong>Minimum Operating Life</strong></td>
<td>2 years</td>
<td>6 months - 4 years</td>
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<td><strong>Potential Customers</strong></td>
<td>NuScale, Westinghouse, Curtiss-Wright, Emerson</td>
<td>High-Temp Systems Design, Big Blue Technologies, various researchers</td>
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<td><strong>Commercialization Plan</strong></td>
<td>Licensing, partnership, or acquisition</td>
<td>Direct sales</td>
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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
- Helium flow sensor for gas reactors
- Molten salt flow sensor for solar systems and molten salt reactor testbeds

Related Work – Flow Sensors

- Gas Flow Sensor Prototype
- Nitrate Salt Flow Sensor
- 1000°C He Flow Sensor Demo
Related Work – Nuclear Power Systems

- Reliable 1800°C temperature sensor
- Rod position indicator (RPI)
- SiC-SiC composite joining
- Irradiation testing
  - >250 hours in TRIGA
Phase I Summary

- SMR flow sensor developed
- Final device tested in NuScale Integrated System Test facility (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
Phase II Irradiation Testing

• Key subassemblies (2017)
  – USGS TRIGA
  – 5E+18 n/cm²
  – Quantified configuration stability

• Complete probe (2019)
  – Texas A&M TRIGA
  – 1E+18 n/cm²
  – 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/cm²
  - 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
## Phase IIB Schedule

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<tr>
<th>Task #</th>
<th>Task Description</th>
<th>Year 1 (Months)</th>
<th>Year 2 (months)</th>
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<tr>
<td>Task 1</td>
<td>Work with OEMs &amp; stakeholders to guide transition</td>
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| Task 2 | Design and implement QA program                      |                 |               |
|        |                                                      |                 |               |

| Task 3 | Construct prototypes and perform lab-scale V&V testing|                 |               |
|        |                                                      |                 |               |

| Task 4 | Revise design based on test results, and construct systems for final testing/demonstration |                 |               |
|        |                                                      |                 |               |

| Task 5 | Final V&V testing and demonstration in representative system tests |                 |               |
|        |                                                      |                 |               |
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).


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).