Self-powered wireless sensor system for health monitoring of liquid-sodium cooled fast reactors

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ABSTRACT:

The goal of this project is to develop self-powered wireless sensors for health monitoring of Mechanism Engineering Test Loop (METL) systems and components. We will develop sensors that can monitor materials degradation in liquid metal-cooled fast reactor in primary systems. The proposed solution will utilize printed self-powered wireless multimodal sensor arrays on high-risk components for sensing and monitoring with high spatial and temporal resolutions. The proposed sensors will detect degradation early, can operate in typical liquid metal-cooled fast reactor environments over extended periods of time, and can be tightly integrated on structural materials to enable structural health monitoring. The proposed strategy addresses important sensor deployment issues, such as powering the sensor and data exfiltration needs. To achieve our proposed research goal, we will complete the following five technical objectives: (1) Design and fabricate multimodal sensor array for real-time monitoring; (2) Design and fabricate high-temperature and high-power-density thermoelectric energy harvester; (3) Extract data from the sensors via wireless communication; (4) Demonstrate and validate sensor network at METL; (5) Develop a machine learning based digital twin of METL structures for structural health monitoring (SHM) and predictive maintenance with the objective of reducing operation and maintenance (O&M) cost.

Liquid sodium cooled fast reactors (SFR) provides an attractive option for nuclear power generation. Advancement of the state-of-the-art in SFR involves, in part, the development of new sensors and instrumentation to monitor and quantify materials degradations in the liquid sodium coolant cycle. We will utilize a 3D conformal aerosol jet printing approach to print and implement an array of multimodal temperature and strain sensors onto high-risk reactor components. These sensors will perform real-time monitoring of temperature, strain and crack formation, and thus will provide early diagnosis of structural degradation of high-risk components in order to minimize the risks of sodium leaks. The printed sensor can operate in both passive mode and active mode in order to perform complementary temperature, strain and crack measurements. We will address critical sensor deployment issues and develop wireless sensor system to extract data via wireless communication. In addition, we will fabricate and implement a robust and high-performance thermoelectric energy harvester to power both the sensor and wireless transmitter in order to realize a truly wireless sensor system.

The outcomes from this project have the potential to establish a transformative sensor manufacturing method and implementation strategy to develop and deploy a broad range of advanced sensors and instrumentation with improved accuracy and reliability for advanced nuclear reactor technologies. The self-powered wireless sensors proposed here can significantly accelerate sensor development and deployment in multiple nuclear reactor designs, which have crosscutting significance to all DOE nuclear energy programs. The research team aims to leverage prior DOE/NE investments to develop and demonstrate an innovative multimodal sensor design and advanced manufacturing technology, and significantly advance the instrumentation and control in advanced nuclear reactor technologies.