Thermoelectric-Driven Sustainable Sensing and Actuation Systems for Fault-Tolerant Nuclear Incidents

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ABSTRACT

The Fukushima Daiichi nuclear incident in March 2011 represented an unprecedented stress test on the safety and backup systems of a nuclear power plant. The lack of reliable information from key components due station blackout was a serious setback, leaving sensing, actuation, and reporting systems unable to communicate, and safety was compromised. Although there were several independent backup power sources for required safety function on site, ultimately the batteries were drained and the systems stopped working. If, however, key system components were instrumented with *self-powered sensing and actuation packages* that could report indefinitely on the status of the system, then critical system information could be obtained while providing core actuation and control during off-normal status for as long as needed.
This proposal presents the development of a self-powered sensing and actuation system that is powered by intrinsic heat from reactor components. The key concept is to use *thermoelectric generators* that can be integrated directly onto key nuclear components, including pipes, pump housings, heat exchangers, reactor vessels, and shielding structures, as well as secondary-side components. The package will include a thermoelectric generator (TEG), microcontroller, signal processing, and a wireless radio package, and will be environmentally hardened to survive radiation, flooding, vibration, mechanical shock (explosions), corrosion, and excessive temperature. The energy harvested from the intrinsic heat of reactor components can power sensors, provide bi-directional communication, recharge batteries for other safety systems, and actuate valves, pumps, and other devices when all other power sources are unavailable. Such an approach is intrinsically fault tolerant: in the event that system temperatures increase, the amount of available energy will *increase*, which will make more power available for applications. The system can also be used during normal conditions to provide enhanced monitoring of key system components.

The integration of TEGs for nuclear applications has not been proposed to date. The concept provides a pathway for enhanced safety and increased reliability. The proposed work is particularly well suited for *small modular reactors* (*SMRs*) under work scope SMR-2, *Advanced Techniques and Analysis Methods* because of the requirement for next-generation safety and monitoring systems. The proposed self-contained, self-powered monitoring concepts fit naturally into this approach by providing critical plant conditions to monitoring and control systems for autonomous control and maintaining of safe conditions.
This three-year project focuses on the following main components of such a system, including thermoelectric generator selection and integration, incorporating sensing and wireless data transfer, and protecting the system from fire, flooding, excessive radiation and mechanical shock.
All of the key components required for the concepts presented herein are mature technologies, and are available as off-the-shelf items from a variety of vendors.