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#05-234 Advanced sensor technologies for real-time temperature measurement in nuclear reactors

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In 2012 the US Department of Energy Office of Nuclear Energy (DOE-NE) initiated the Advanced Sensors and Instrumentation (ASI) program as part of the Nuclear Energy Enabling Technologies (NEET) research as part of crosscutting RD&D activities to advance the state of nuclear technology, improve its competitiveness, and promote continued contribution to meet the nation's energy and environmental challenges. The objective of the ASI program is to provide reliable, cost-effective, real-time, accurate, and high-resolution measurement of the performance of existing and advanced reactor core and plant systems. Instruments are designed, fabricated, and tested in relevant and operational conditions to advance their technological readiness to a point in which they can be integrated in I&C systems without the significant cost and risk associated with development activities. This technology maturation is made possible by the deployment of developmental instrumentation in Material Test Reactors (MTRs) irradiation experiments aimed at the characterization of advanced reactor components, such as advanced fuel forms. In the near term therefore the requirements on sensor technologies are driven by the irradiation test conditions and their research objectives.

This paper reports on the effort to develop technological solutions to the measurement of temperature in irradiation experiments aimed at the development of core components of nuclear reactors, including its fuel assemblies. The scope of the work extends from the current fleet (primarily Pressurized Water Reactors) to advanced reactor concepts, including Small Modular Reactors and micro-reactors. Considering experiments that address both operational conditions and design basis accident cases, the requirements on temperature measurements extend up to 2000℃ under a wide range of neutron flux and integrated fluence depending on the facility under consideration –from a peak thermal flux of 1x1015 n/cm2-s and fast flux of 5x1014 n/cm2-s in the Advanced Test Reactor to the sub-second burst of neutron and gamma radiation in the Transient Reactor Test Facility (TREAT), both located at the Idaho National Laboratory. In addition to operating temperature and radiation resistance, continuous or discrete distributed sensing capability is another important requirement to consider for technologies development.

Progress in three areas of research are reported: High Temperature Irradiation Resistant (HTIR) thermocouples, Ultrasound Thermometers and optical fiber sensors. HTIRs are thermocouples based on Molybdenum and Niobium alloys and they have been investigated at INL for more than 10 years and have demonstrated reliable performance up to 1600℃. The recent deployment in irradiation test aimed at the characterization of TRISO fuel, in parallel with commercialization efforts, enabled the collection of sufficient data to satisfy the Preliminary Design Review towards their qualification process. Ultrasound Thermometers are acoustic sensors that utilize a radiation resistant transducer and a passive waveguide to derive temperature from the measured sound speed in the waveguide materials. Discrete features in a solid waveguide or a waveguide design based on a bundle of thin wires with stacked ends allows discrete multi-point sensing. The selection of refractory alloys for the waveguide (Molybdenum or Tungsten) allows temperature measurement beyond 2000℃, providing the transducer is maintained at or near reactor coolant temperature. Optical fiber sensing is now considered for many irradiation tests in TREAT, and through accurate selection of fiber materials (radiation hardened fibers) and interrogation techniques their performance characterization has been extended to neutron fluences that are compatible with extended testing in high flux facilities such as ATR. Temperature and radiation limits depend strongly on the sensing method and the fiber material, limiting their current applicability to less than 800℃. Several examples of the use of optical fibers for temperature measurement in irradiation experiment are presented and their results discussed.

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