U.S. Department of Energy

In-pile Thermal Conductivity Characterization with Time Resolved Raman

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Program: FCR&D: Characterization and Instrumentation

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ABSTRACT: In nuclear reactors, degradation of thermal conductivity can exacerbate thermal stress development, thermomechanical failure, and species migration. To optimize fuel designs that offer improvements in safety and efficiency, it is critical to achieve in-pile characterization for monitoring the evolution of thermal properties. In support of the goal of understanding the behavior and predicting the performance of the nuclear fuel system at a microstructural level, the objectives of this project are to 1) develop a novel time resolved Raman technology for direct measurement of fuel and cladding thermal conductivity; 2) validate and improve the technology development by measuring ceramic materials germane to the nuclear industry; and 3) conduct instrumentation development to integrate optical fiber into our sensing system for eventual in-pile measurement.

To achieve the objectives, four specific tasks will be conducted. Task #1 will be focused on development of single-laser based pump-probe Raman system for thermal characterization. Task #2 is to conduct measurement capacity assessment and extension. The measurement capacity of this advanced time-resolved Raman system will be assessed by measuring fuel surrogate materials (DUO_2, CeO_2) and other nonmetallic materials (ZrO_2 and graphite). For materials of weak optical absorption, a picosecond fiber laser will be integrated to provide multi-photon surface heating. Task #3 will be focused on spatial resolution design and control. Task #4 will do instrumentation development to integrate optical fiber for in-pile measurement. Upon accomplishment of the project, a time-resolved Raman-based thermal conductivity measurement system will be developed with micron scale spatial resolution. This advanced system will represent a significant advance in remote in-pile thermal conductivity measurement. Its temporal resolution will be down to 50 ns, and is capable of microscale spatial scanning. A physical model and data processing package will be developed for fast and efficient in-time data processing to determine the temperature rise in the Raman-based measurement, and conduct data fitting to determine the thermal conductivity. A prototype system will be developed to integrate the time-resolved heating/probing system with an optical fiber delivery system. The stability and accuracy of this system will be fully evaluated for in-situ and in-pile thermal conductivity measurement. The ability to make in-reactor measurements of radiation induced material properties will provide new insights into the behavior of materials exposed to extreme radiation and temperature environments. This capability will also provide a powerful new tool for the partnering national lab users to assess radiation effects on materials in real time. New in-reactor measurement capabilities will help DOE fulfill its leadership role in nuclear technology and supports DOE-NE's Advanced Nuclear Energy Initiative.

A budget of $640,000 will be allocated to Iowa State University and $160,000 to Idaho National Lab. The system design will be mainly conducted in PI's lab. A comprehensive physical model and highly-efficient data processing package will be developed under collaboration between the PI and the collaborators. The collaborators will be involved in sample selection, preparation, measurement, and data analysis. The measurement results will be benchmarked by the technologies in the collaborators' laboratory. The two collaborators will play a key role in coordinating and facilitating collaboration with researchers at the national lab that have extremely strong expertise in optical fiber delivery in high radiation environments. This collaboration will be essential for the PI's group to identify problems in optical fiber delivery development and to assess the efficacy of the technical approach.