High Fluence Active Irradiation and Combined Effects Testing of Sapphire Optical Fiber Distributed Temperature Sensors

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Program: NSUF 1.1

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ABSTRACT:

Advanced fuels and materials are now being developed to improve the performance of the current nuclear fleet and support the design of advanced reactors. These new fuel designs require better understanding of radiation effects. Right now, researchers rely on irradiation experiments ranging from separate effects to more integral (combined) effects that underpin prototypic conditions. Innovative measurement techniques that collect real-time data during experiments are needed to overcome the limitations of empirical approaches based on post-irradiation examination (PIE). In this project, researchers will test high-fluence and high-temperature effects—separate and combined—on the temperature-sensing capability of clad sapphire optical fibers using optical backscatter reflectometry. Current fiber optic sensors based on standard fused silica have demonstrated the capability to provide multimodal sensing (i.e. performing measurements such as temperature, pressure, and strain within a single sensor configuration) and multiplexing (communicating data collected at multiple locations through a single line) capabilities. They are intrinsically immune to electromagnetic interference, electrically passive, compatible with a number of different sensing methodologies, and are widely available at a reasonable cost. Widely known for their use in telecommunication applications, instruments based on silica fibers are already deployed in industrial applications at temperatures approaching 300–400°C for distributed temperature sensing in oil and gas recovery. At temperatures above 500°C, conventional silica fibers can suffer from instabilities caused by interactions with various environmental species, especially hydrogen and/or water. While the application of protective coatings can alleviate some environmental concerns, the amorphous structure of fused silica implies inherent instability when approaching the so-called "annealing" temperature (1,000–1,100°C) at which the silica network recrystallize, or relax to internal strain. Fused silica is also strongly impacted by radiation. Three mechanisms are responsible at the macroscopic scale for the degradation of the fiber performance: radiation-induced attenuation (RIA), which increases light adsorption in the material (darkening); radiation-induced emission (RIE), which generates unwanted light (optical noise); and radiation-induced compaction (RIC), which causes variations in the density of the fiber material, resulting in changes of optical properties.

This project will move beyond the state-of-the-art by testing the reliability of distributed sapphire optical sensors in extreme environments. Sapphire (α- Al_2O_3) fibers are recognized as a high-temperature alternative to amorphous silica due to the high melting temperature (about 2,054°C), outstanding chemical resistance, and mechanical strength of their crystalline network. They have a wide transmission window and a high-damage threshold. This makes sapphire fibers an ideal candidate for multiple sensing techniques that can measure temperature, strain, deformation, pressure, and chemical composition in extreme environments. This research will deliver modern optical fiber sensing techniques that can be used in multiple extreme environment applications. In the realm of testing of nuclear fuel and materials, these fibers will allow access to operational data with excellent time and space resolution during irradiation testing. The accurate online monitoring of test parameters, such as temperature and strain, will greatly reduce the time and cost associated with developing, demonstrating, and licensing new nuclear technologies. This project will test and characterize distributed temperature measurements in sapphire optical fiber for high-temperature and high-radiation environments using optical frequency domain reflectometry (OFDR). Work will be completed over three years and will consist of three irradiations using two NSUF facilities, the Ohio State University Research Reactor (OSURR) and the Massachusetts Institute of Technology Reactor (MITR).