Irradiation of Optical Components of In-Situ Laser Spectroscopic Sensors for Advanced Nuclear Reactor Systems

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ABSTRACT:

The development of next-generation fission reactors, including those based on molten salts and liquid metals, relies on answering important fundamental questions about fuel and coolant behavior and compatibility with advanced reactor designs and materials. Of particular interest is the understanding of conditions that would allow advanced reactors to reach ambitious longevity and safety goals. Beyond fundamental scientific research, there is a need to develop novel instrumentation that will enable new reactors continuously operate in optimal conditions and with ample safety margin.

A key requirement for sensor and instrumentation in new reactors is continuous, in-line measurement of circulated coolant or coolant-fuel composition to prevent reactor system degradation through corrosion. In molten salt reactors, first priorities for measurement have been established and include the detection of traces of dissolved alloys such as chromium, iron, and nickel, as well as the measurement of the uranium oxidation state (U^{3+}/U^{4+}) ratio. In liquid metal cooled reactors, measurement techniques and devices should be developed to detect traces of manganese, chromium, and nickel in lead or lead-bismuth eutectic. The currently available technology is inadequate for making such measurements in the challenging environments of nuclear systems that include high radiation, temperature, pressure, and limited access. Material composition measurements can be performed by sampling and conducting lengthy laboratory analysis, which is incompatible with *in-situ*, real-time concept of operations. Instrumentation based upon electrochemistry may be suitable for *in-situ* operation, but electrochemical methods can suffer from interferences in multi-component mixtures.

These limitations may be overcome by development and adoption of novel sensors which rely on laser spectroscopy. Such sensors critically depend on the passage of light through transparent optical material – to deliver the laser radiation, as well as to collect spectroscopic signal. Degradation of optical systems in high-radiation environments characteristic for nuclear reactor systems raises important questions about the performance and lifetime of sensors and instrumentation based upon optical techniques. *The objective of this project is to investigate the effect of radiation damage in optical materials on the operation and performance of laser spectroscopic sensors.* Significantly beyond the scope of prior studies in which the spectrally dependent changes of transparency and high-temperature annealing of optical damage were observed*, this project will seek to understand the effect of simultaneous radiation damage and annealing on optical materials operated in high-temperature environments, and further evaluate the effect of irradiation on nonlinear optical absorption, which is critical for propagation of high-power laser pulses.* As a result, we will determine whether such sensors hold promise for use in advanced reactor systems and whether subsequent investment in their development is warranted.