Optical Sensors for Impurity Measurement in Liquid Metal-cooled Fast Reactors

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Sodium (Na)-cooled fast reactors are receiving considerable attention due to their potential to expand the availability of nuclear power by improving multiple performance parameters, especially economics and safety. A key challenge is the control of impurities in the Na coolant, which can be introduced at the time new components are installed, from any impurities in the inert cover gas, and when Na is added to the system. The high concentration of impurities such as oxygen (O) can accelerate the corrosion process and cause unwanted plugging in the cooling system. It is therefore important to develop effective strategies and components to allow for in-situ monitoring of the impurities in the Na inventory.

ANL has developed the Mechanisms Engineering Test Loop (METL) as a dedicated facility to perform small- and intermediate-scale tests of Na-based liquid metal-cooled fast reactor (LMCFR) components, systems, and processes. One of the important technical goals of METL is to develop novel sensor technologies that can work in the Na environment under design temperature conditions (>500 ºC). These include sensors that can monitor Na level and sensors that can measure the concentration of impurities in the Na coolant, especially O. For the latter, METL has adopted the plugging meter as the baseline technology, which is implemented in a purification and diagnostics system consisting of a cold trap, plugging meter, and economizer. The plugging meter has several disadvantages, the main of which is its inability to discriminate among different types of impurities. Any impurity in the system could result in plug restriction, and an assumption must be made concerning impurity type to infer its concentration. As a result, the plugging meter cannot determine whether a corrosion concern exists due to a high O concentration, or a leak has developed as indicated by a high H concentration, for instance.

This proposed work aims to develop a trace impurity measurement system suitable for use in sodium-cooled fast reactors and to test it at the METL facility. The system will be optimized for sensitivity to reactive impurities such as O and H. The method is based on optical spectroscopy that enables a continuous, near-real-time, in-situ operation and overcomes the limitations of the plugging meter sensor. For the first time to our knowledge, we will combine laser-induced breakdown spectroscopy with two-photon absorption laser-induced fluorescence, which will allow probing of high-lying energy levels in H and O. Development and preliminary testing will be conducted at the university and industry laboratories, followed by testing in relevant conditions at the METL. The deployment at METL will provide not only a direct comparison of sensitivity with the current plugging sensor, but also generate the first experimental data to help understand the technique's specificity to different impurities that may enter the liquid Na, the rates of migration of different impurities from Na to the cover Ar gas, and the rates at which the impurities are removed by the METL purification system. The proposed measurement method may result in improved sensitivity and specificity in other nuclear power applications that require sensitive impurity measurements, such as in high-temperature gas-cooled reactors.