High-Speed X-Ray Imaging System under a Chemically Protected Environment for Advanced High-Temperature Non-Water-Cooled Reactor Experiments

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ABSTRACT:

We propose a high-speed high-energy X-ray imaging system dedicated for advanced non-water coolant reactor studies at high temperatures (up to 1000 °C) and under a chemically protective environment. Compared to conventional water-cooled nuclear reactors, advanced reactors using high-boiling-point liquids (i.e., molten salt, sodium, or lead) as coolants have the potential to significantly improve the safety, efficiency, and neutron economics of nuclear energy. However, molten-salt reactors (MSR) and thermal storages using chloride or fluoride salts have the temperature range of 600 to 900 °C and the operation temperature of sodium heat-pipe-cooled microreactors (HPCMR) ranges from 600 to 800 °C, which are beyond the design limit of nuclear-grade steels. Also, the thermofluidic behaviors of the new coolants are much less understood when compared to water; molten salts have more corrosive reactions with structure materials. All these challenges are calling for more characterization of high-temperature liquids and their interactions with solid materials for both research and educational purposes.

The proposed X-ray imaging system will enable the measurement of multiphase flow of opaque fluids like molten sodium. Given high enough energy and intensity, X-ray radiography can also image both liquid and solid at the same time with μm spatial resolution, acting as an in-situ approach to investigate the solid-liquid interactions and corrosion processes near solid surfaces. Despite many promising applications, few high-energy X-ray imaging systems are available for studying non-water coolants at elevated temperatures especially under chemically hazardous conditions.

The imaging system in this project consists of a 225 keV/4um X-ray source, a high-speed detector up to 6,000 frame per second (fps), a high-speed camera with recording rate up to 9,000 fps with an image intensifier, and the heating capability up to 1000 °C. The entire system is hosted in a floor-mounted fume hood, which protects users when handing volatile and poisonous liquids while makes it possible to image large and complex testing set-ups such as molten salt loops. The proposed capabilities will enable a number of key experiments for the development of sodium-cooled fast reactors (SFRs), MSRs, and HPCMRs.

Besides directly increasing the capabilities for Non-LWR environment materials testing as one of the NSUF specific areas of interest, the proposed experimental infrastructure will also become an education platform to train future nuclear scientists and engineers for advanced reactor technologies by providing hands-on experience with the non-water chemical coolants in a safe manner.