
Development of Advanced High-Spatiotemporal-Resolution X-PIV System and Computer Vision Aided Image Processing Techniques in Support of Advanced Nuclear Reactors Design and Operation

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ABSTRACT:

The U.S. nuclear industry is experiencing a rapid shift from traditional light water reactor (LWR) technologies to next generation advanced nuclear reactor (ANR) technologies. While ANR designs, as supported by the DOE Advanced Reactor Demonstration Program (ARDP), have numerous advantages including enhanced safety, higher efficiency, reduced waste, and greater flexibility, major challenges, however, present in the ANR thermal hydraulic design and safety analysis, due to their unique coolant thermophysical properties, highly complex designs, and harsh operating conditions. For instance, coolants used for liquid-metal cooled reactors (LMRs) and heat-pipe-cooled microreactors are opaque, corrosive, and non-uniformly distributed in complex geometries, leading to thermal stratification, turbulent mixing/dissipation, and potential hot spots within components. Addressing these 3-dimensional, highly-spatiotemporal-sensitive challenges across several length scales requires accurate flow/temperature data in complex geometries under high-temperature high-radiation conditions, which disqualifies most conventional diagnostic techniques. Furthermore, modern ANR real-time O&M coupled with DT systems intensifies demands for future ASI with faster data acquisition/processing and more accurate flow field representation. This lack of sufficient measurement and analysis capabilities leads to a huge knowledge gap for our fundamental understanding and adequate modeling of the “detail resolved” thermal hydraulic behavior for various ANR designs.

The proposed project will focus on the development and application of an innovative high-spatiotemporal-resolution (max resolution ~10 μm , max speed 6000 fps) X-Ray based Particle Imaging Velocimetry (X-PIV) technique, which will be intricately coupled with the Computer Vision Aided Image Processing (CVIP) applicable to both water and non-water fluids measurement. It includes four core Research Thrusts: **1). Develop lab-scale X-PIV imaging techniques** to achieve high-spatiotemporal-resolution flow field data acquisition and processing; **2). Develop and optimize X-PIV forced-/natural-convection testing facilities** featuring water/non-water fluid measurement capability in both macro and micro channels; **3). Conduct extensive experimental campaign** for rigorous X-PIV calibration, high-spatiotemporal-resolution flow field measurement and investigation; **4). Develop physics integrated CVIP (PI-CVIP) techniques** applicable to flow and heat transfer closures validation and development.

What truly distinguishes the proposed work is its pioneering combination of the non-intrusive X-Ray imaging with high-spatiotemporal-resolution PIV methodology applicable to high-temperature opaque flow conditions. Additionally, the development of advanced CVIP techniques will open a new avenue for ultra-fast data acquisition and full-scale reconstruction of instantaneous flow fields. The proposed work directly supports the DOE NEET CTD program by developing the next generation key enabling techniques for more accurate ANR system design and analysis. A carefully devised research and education integration plan will be implemented to maximize the research outcomes to the entire nuclear community by developing new curriculum, creating online/offline professional and researcher training platform, as well as providing the general public learning access.