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Interface-Resolved Experimental and Numerical Studies of Two-Phase Flow for Nuclear Engineering Applications

PI: Yang Liu, Virginia Tech

Collaborators: Igor Bolotnov – North Carolina State University

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ABSTRACT:

Two-phase flow is a fundamental phenomenon essential for the advancement of nearly all types of nuclear reactors. Current design tools, including system analysis codes and Computational Fluid Dynamics (CFD) codes, are primarily developed based on the time-averaged two-fluid model. However, these codes required a wide spectrum of closure correlations, such as interfacial force models, interfacial area models, and boiling models to close the problem. Due to the complexity of the two-phase flow phenomenon, empirical correlations derived from a limited set of experimental data often lead to significant uncertainties, especially when applied under conditions different from the original experiments. One solution to this challenge, caused by the complex interfacial structure in two-phase flow, is to employ interface-resolved methods like the volume-of-fluid model or the level-set method. These techniques directly compute the interface location and movement, offering greater accuracy and reduced sensitivity to varying conditions. The proposed research aims to enhance current predictive capabilities in two-phase flow and thermal-hydraulics by further developing and refining these interface-resolved simulations. Such capabilities could be readily utilized for accurate predictions when designing advanced reactors or encountering new application conditions.

In this project, one main effort will be focused on developing an interface-resolved validation database emphasizing bubble dynamics and bubble interaction mechanisms. A set of precision bubble injectors will be designed to create well-controlled bubble departure and coalescence events. An advanced stereo imaging system consisting of multiple high-speed cameras will be used to capture the entire 3-D interfacial structure in a flow field. Tests will be performed to acquire a fundamental understanding of the bubble coalescence mechanism and its dependence on bubble size, shape, approaching velocity, approaching angle, liquid velocity, turbulence intensity, etc. Other complex two-phase flow phenomena such as flow regime transition will also be investigated in the experiment. Water and a water-glycerin mixture will be used as test fluids to ensure that the acquired data covers a wide range of Morton numbers, thereby preserving scaling similarities for both Light Water Reactors (LWRs) and advanced reactors like Molten Salt Reactors (MSRs). The second major effort will be made to the development of a bubble coalescence model suitable for the interface-resolved codes. The newly developed model will be implemented in an advanced two-phase flow solver, which uses an interface-capturing method and has the scalability to address large-scale engineering problems. The code will be validated using the newly developed experimental data to ensure its accuracy and robustness in solving complex two-phase flows that could be encountered in nuclear engineering applications.