The application of advanced high-resolution optical diagnostics to answer long-standing questions and make new discoveries in boiling heat transfer in LWR conditions

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ABSTRACT:

The importance of boiling heat transfer for the nuclear industry cannot be overstated. Boiling is key to the conversion of nuclear energy into electricity and, importantly, to light water reactors (LWRs) safety and cost-competitiveness. For these reasons, the nuclear industry has been at the forefront of boiling heat transfer research since its beginning, pioneering experimental and computational advances that are nowadays leveraged in many other fields of engineering. However, while boiling has been used for millennia in a growing number of applications, the mechanisms involved in this heat transfer process are still hotly debated. For instance, it is still unclear why exactly boiling fails at high heat fluxes, i.e., the phenomenon known as a boiling crisis. This boiling crisis is detrimental as it often leads to the burnout of the system to be cooled down. This lack of understanding translates into poor predictions, and poor predictions result in significantly oversized design and operational margins. Systems, e.g., nuclear reactors, are overdesigned to avoid the boiling crisis and are operated conservatively, way below their full efficiency and economic potential. This is a crucial knowledge gap that we want to close with this proposal. Precisely, we aim at answering three crucial scientific questions:

Q1. What is the triggering mechanism of the boiling crisis in high-pressure flow boiling conditions (i.e., the heat transfer regime used in Pressurized Water Reactors)?

Q2. What is the triggering mechanism of the boiling crisis in saturated flow boiling conditions (i.e., the heat transfer regime used in Boiling Water Reactors)?

Q3. What are the two-phase flow and heat transfer regimes in saturated flow boiling conditions?

An answer to these questions is long-overdue, and it is critical to unlocking the development of predictive modeling tools for the design of advanced and cost-competitive nuclear reactors. Gladly, these answers are nowadays within reach thanks to high-resolution optical diagnostics through which is it is possible to measure time-dependent temperature, heat flux, and vapor distribution on the boiling wall and the vapor and velocity distribution in the flow.

We will use these diagnostics to obtain first-of-a-kind data of the boiling process in LWR conditions. These data will be used to answer our scientific questions and test our hypothesis. We will share our understanding and data (including videos of the infrared and high-speed video camera measurements) with educators and students in the field and with the broader audience. To this end, results will be published using scientific journals and conferences and through an online channel to broadcast the videos of the physical phenomena and tutorials on how to implement and use high-resolution diagnostics.

This project leverages a decade of efforts in the development of experimental two-phase flow and heat transfer diagnostics and experimental facilities. To tackle the tasks of this project, the research team will involve graduate and undergraduate students, who will benefit from both theoretical and hands-on experience offered by this study to prepare for their future careers.