Using Machine Learning to Understand the Transient Critical Heat Flux and Post-CHF Heat Transfer

PI: Juliana Pacheco Duarte, University of Wisconsin-Madison

Collaborators: N/A

Program: Distinguished Early Career Program

ABSTRACT:

The objective of this proposal is to answer crucial questions on transient critical heat flux (CHF) and post-CHF heat transfer behavior under transient conditions in light water reactors (LWRs). The proposed effort is relevant to accident tolerant fuels (ATFs), high-burnup fuel applications (i.e., peak rod average burnup greater than 62 GWd/tU), and to the understanding of cladding-to-coolant interactions from atmospheric to pressurized water reactor (PWR) conditions. Transient CHF differs from the steady-state values due to the non-equilibrium quality and pressure among the liquid and vapor phases during fast transients. To groundbreaking the current knowledge in the area, the PI proposes to conduct transient CHF and post-CHF heat transfer experiments using high-resolution distributed temperature sensors in a directly heated fuel rod simulator at prototypical LWR conditions and use machine learning methods to improve the predictability capabilities of relevant computational codes (BISON, CTF, and TRACE). This proposal also addresses the critical knowledge gap by providing high-resolution and accurate transient data up to 18 MPa in a flow channel. The experiments will be conducted using different cladding materials and under different transient scenarios, such as Nordheim-Fuchs power pulses representative of reactivity-initiated accident (RIA), bottom-to-top flooding representative of the loss of coolant accidents (LOCA), and loss of pump power representative of anticipated operational occurrences (AOOs). The vital importance of the transition boiling in the post-CHF regime is demonstrated in the proposal for the prediction of maximum cladding temperature during these scenarios. In this sense, the PI proposes to develop semi-empirical models to represent the transient CHF and post-CHF based on the physical mechanisms that govern the boiling heat transfer and by leveraging high-resolution optical fiber data and machine learning algorithms. Physics-informed machine learning-aided framework (PIMLAF) will be also developed in this study by combining the conventional correlations and machine learning techniques, such as multi-layer perceptron (MLP) and random forest, to overcome limited regression capability and 'black-box' characteristics.

A broader goal of this project aims to build strong learning environments for both undergraduate and graduate students in nuclear science, technology, and engineering with an emphasis on thermal-hydraulics and reactor safety analysis. The PI is engaged in several activities to promote inclusion and diversity and to increase the representativity of minority groups in nuclear energy. To build this robust and inclusive learning platform, two major education developments are planned 1) the development of educational active learning-based materials that will be made publicly available and 2) the involvement of undergraduates from underrepresented groups in the research activities. The students educated in this project will gain experience working with laboratory equipment, learn the scientific method for approaching and solving problems, be exposed to a creative and innovative environment, and have a chance to present and deliver their findings through conference and journal publications.