
Robust and scalable cladding surfaces to enhance boiling heat transfer performance in LWR conditions

PI: Matteo Bucci (MIT)

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Collaborators:

Florian Chavagnat (MIT), Matthew T. Hughes (MIT), Tolga Durak (MIT), Melissa Spencer (MIT), Zeses Karoutas (WEC), Yixing Sung (WEC), Gregory Stehle (WEC), William A. Byers (WEC)

ABSTRACT:

This project aims to develop a robust and scalable engineered nuclear fuel cladding to enhance boiling heat transfer and critical heat flux (CHF) in pressurized water reactor (PWR) conditions. We propose to use ultrashort pulse laser beam machining (LBM) to create micro-pillars on zircaloy surfaces, which will enhance both nucleate boiling and CHF. These micro-engineered surfaces will be tested under steady-state and transient conditions using MIT's high-pressure flow boiling loop and Westinghouse's WALT loop. The project will address key limitations of typical surface engineering methods, which lack the robustness and scalability required for nuclear applications. The use of ultrashort pulse LBM is expected to overcome these challenges by producing durable and repeatable micro-features directly etched onto the cladding material, achieving high machining rates with minimal deviation between samples. This research will not only advance the fundamental understanding of surface micro-features in high-pressure flow boiling conditions but also contribute to the development of accident-tolerant fuel (ATF) cladding materials. By combining micro-engineered surfaces with ATF chromium coatings, this work aims to improve both heat transfer and corrosion resistance. The project's success could increase the power rating of existing and future PWRs, enhancing their safety, efficiency, flexible operation, and cost-competitiveness.

Practically, we aim at demonstrating:

- the feasibility and scalability of machining micro pillars on zircaloy by using laser etching techniques on flat zircaloy samples and actual zircaloy claddings.
- the capabilities of these micro pillars to enhance nucleate boiling and CHF by conducting experiments in prototypical PWR conditions (including the effect of ATF chromium coatings and CRUD deposition)
- the robustness of such features in prototypical PWR conditions in nucleate boiling as well as in CHF conditions.

This project brings together a team with decades of experience in experimental two-phase flow and heat transfer, and leverages unique developments made possible through previous research including projects funded through DOE programs. To tackle the challenges of this project, the research team will involve graduate and undergraduate research assistants, who will benefit from both theoretical and hands-on experience offered by this study, with a firm commitment to enhance diversity and inclusion.