NEUP Nuclear Energy University Program
U.S. Department of Energy

Unraveling Laminar-Turbulent Transition in Rod bundles

PI: Elia Merzari**,** Penn State University

Collaborators: Lane Carasik, *Virginia Commonwealth University*

Program: Topic Area 12

ABSTRACT:

Achieving a comprehensive theory for laminar-turbulent transition in rod bundles remains an unresolved challenge critical to optimizing nuclear reactor designs. This research proposal seeks to establish such a theory through an integrated approach that combines high-resolution experiments, advanced numerical simulations, and theoretical developments. Rod bundles are fundamental to most reactor designs, making this theory essential for improving fuel assembly designs across a broad spectrum of reactor types, including light-water reactors and advanced microreactors. The outcomes will contribute to better economic and operational efficiencies, aligning with the objectives of the Department of Energy (DOE).

Our approach builds on recent breakthroughs in laminar-turbulent transition theories and leverages high-fidelity simulations validated against cutting-edge experiments, such as positron emission particle tracking (PEPT). The project includes developing novel numerical and theoretical tools to deepen our understanding of flow transitions in simplified rod-bundle geometries (e.g., 2x2 and 3x3 arrays) and scaling to more complex configurations, a full microreactor core.

This research addresses key gaps in the understanding of flow behavior in nuclear systems, particularly within the context of emerging microreactor technologies such as MARVEL. By elucidating the laminar-turbulent transition mechanisms in rod bundles, this work aims to enhance safety analysis, support innovative fuel assembly designs, and utilize large-scale turbulent structures for improved thermal mixing and efficiency in nuclear reactors. The close integration of experimental, computational, and theoretical components will drive significant advancements in the fundamental theory of nuclear reactor thermal-hydraulics, with profound impact on reactor design and flow optimization for next-generation nuclear systems.