Experimental and Computational Studies of NEAMS Pebble Bed Reactors

PIs: Victor M. Ugaz
Yassin A. Hassan
Texas A&M University

Program: NEAMS

Collaborators:
Dr. Elia Merzari, Argonne National Laboratory
Drs. Leon Cizelj and Boštjan Končar, Jožef Stefan Institute, Slovenia
Dr. Martin van Staden, X Energy, LLC

ABSTRACT:

The Advanced High-Temperature Reactor (AHTR) concept leverages a particle-based fuel format consisting of discrete spherical graphite pebbles arrayed in a packed bed architecture. Thermal regulation achieved via flow of gas (e.g., helium) or liquid (e.g., molten salt) coolants through the void spaces between pebbles in the bed. This design is of interest owing to inherent advantages including passive safety features and highly efficient heat transfer characteristics that enable high power densities to be achieved. Fully leveraging these advantages requires a fundamental understanding of the complex coolant flow structure within the pebble-shaped fuel bed. Unfortunately, complexities associated with non-invasively probing the micro-scale flow phenomena within the complex network of void spaces between pebbles have hindered efforts to characterize the underlying transport phenomena. Without this fundamental foundation, it becomes challenging to rationally construct macroscopic transport models based upon volume averages of micro-scale parameters that accurately capture the observed flow behavior. Consequently, this lack of fundamental knowledge has limited previous work to coarse comparisons between theory and extremely limited experimental data. Moreover, these comparisons have been made only in terms of integral or macroscopic results. Therefore, multipoint measurements with a high level of spatial and temporal resolution are critically needed to fully map the complex flow patterns and to provide data at high spatial density to permit accurate volume averaging in the pebble bed.

We propose a coordinated experimental and computational effort to quantitatively map the full-field 3-D velocity and temperature fields in the interstitial spaces within the pebble bed. These data, not broadly available in existing literature, will fill a critical knowledge gap to enable refinement and validation of standard simulation tools (Nek5000). Our studies will be enabled by a test facility infrastructure and skill set uniquely available to the PIs combining Time Resolved Particle Image Velocimetry (TR-PIV), Matched Refractive Index (MRI), Laser Induced Fluorescence (LIF), and Induction Heating (IH) to non-invasively probe the flow of model coolant simulants at the microscopic (pore) level with a fine level of temporal and spatial resolution.

Key outcomes of this project will include advanced correlations to predict flow and thermal transport within the pebble bed over an unprecedented broad range of conditions. These studies are directly relevant to the Nuclear Energy Advanced Modeling and Simulation (NEAMS-1) work scope because they will lay a foundation for rational validation of computational tools (e.g., Nek5000) to simulate performance of advanced reactor configurations and cooling systems. Specific outcomes from this work include (1) enhanced ability to predict reactor operation under normal and accident conditions, (2) a curated repository of high-fidelity / high-resolution data to support code verification and validation, (3) rational development and refinement of computational models with improved predictive capabilities, and (4) broad collaboration with US national lab, international, and industry partners.