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

Experimental Investigations and Numerical Modeling of Near-wall and Core Bypass Flows in Pebble Bed Reactors

PI: Thien Nguyen, **Co-PIs**: Victor Ugaz, Yassin Hassan (Texas A&M)
Program: NEAMS 2: Near-wall Gas-Flow Correlations in Pebble Bed Reactors
Collaborators: Elia Merzari (Penn State University), Sebastian Schunert (Idaho National Lab), Martin van Staden (X-Energy), Fatih Sarikurt, Brian Jackson (Kairos Power), Jat du Toit (North-West University, South Africa)

ABSTRACT:

High temperature pebble bed reactors (PBR) are an attractive Gen-IV concept because of their inherent safety and high coolant outlet temperatures that allow coupling to industrial processes requiring process heat. The PBR concept leverages a particle-based fuel form consisting of discrete spherical graphite pebbles, while Helium flows through the void spaces and effectively removes heat from the core.

Design and licensing of PBRs requires demonstration that the plan is safe during design basis accidents; to a large degree, this demonstration must rely on computational models that encompass the whole reactor core including the pebble bed, graphite reflectors, pressure vessel, and emergency cooling system. Practical models adopt the porous media viewpoint from which bulk flow characteristics can be obtained. Currently available empirical correlations implemented in porous media codes cannot guarantee precise predictions of flow conditions associated with the near-wall and bypass flows because they are extracted from integral flow measurements and particularly neglect the effects of the near-wall and core bypass flows.

This proposal seeks to establish a highly coordinated, concurrent experimental and computational effort combining high-resolution turbulence simulations and experiments to deepen our physical understanding and address long standing modeling inaccuracies related to near wall and bypass flow effects in PBRs. The proposed closure model development strategy combines the effort and it represents a unique strength of this proposal. It is proposed to acquire targeted measurements and high-fidelity simulations of transport process for near-wall flow region in PBRs, and then use the realized extensive database to derive closure models and correlations needed for porous media code, such as Pronghorn. The specific tasks are:

1. Experimentally investigate the near-wall and bypass flows in PBRs.
   a. Using existing multi-scale versatile test facilities and intensive infrastructure to obtain high-fidelity measurements for test-scale conditions (moderate temperature and pressure conditions).
   b. Design, based on a scaling analysis, and construct a new PBR facility to obtain measurements at validation-scale conditions (higher temperatures/pressures representative of operating conditions).
2. Perform high-fidelity simulations (Nek5000 DNS, LES, and RANS) using reconstructed geometries and boundary conditions from PBR experimental facilities in Objective 1(a).
3. Derive closure models and correlations needed for Pronghorn using high-fidelity CFD results.
4. Perform calculations using the developed CFD and Pronghorn models for the new experimental facility, and conduct validations using the measurements acquired from Objective 1(b).

Key outcomes of the proposed work include (1) advanced models and correlations for near-wall and core bypass flows in PBRs over a broad range of conditions, (2) a curated repository of high-fidelity data to support code verification and validation, specifically addressing a significant gap in PBR safety analysis space, and (3) broad collaboration with US national lab, industries and international partners. The project outcome will be beneficial to reactor cores using fuel in the form of pebbles, including gas- and salt-cooled PBRs where the knowledge of the near-wall flow and core bypass flow is of paramount importance.