Nexus of Neutronics – Thermal Fluid Analysis for Optimizing Centrifugal Nuclear Thermal Propulsion

Abstract

This project focuses on a preliminary optimization study of Centrifugal Nuclear Thermal Propulsion (CNTP), a promising propulsion system for deep space exploration, including missions to Mars and beyond. The study begins by developing a computational model using OpenMC, a particle transport simulation solver, to examine the reactor core design and analyze neutron flux distribution across both spatial and energy phase spaces. The model successfully captures key parameters such as the void coefficient, reactivity, neutron flux distribution, k-effective, and density. Results indicate that the reactor design can reach criticality with the proper orientation and radii of the control drums. The power density distribution generated from these simulations is then incorporated into a thermal-fluid model in OpenFOAM to simulate the heat transfer between hydrogen bubbles and molten uranium fuel. The dynamics of these bubbles under high centrifugal force are validated through benchtop experiments. Additionally, the study finds that as fuel temperature increases, reactivity rises, creating a positive feedback loop that could complicate engine control. Control drums have been shown to effectively reduce reactivity by capturing neutrons, thereby moderating reactor behavior. Future research will refine the heat transfer model between hydrogen and molten uranium and address the engineering challenges required for a practical implementation of the CNTP system.