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Coupled Interface Capturing and Particle Tracking Methods for Fuel Dispersal Study During the Loss-of-Coolant Accident

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ABSTRACT:

There exist continuing interests in developing advanced fuel designs and extending allowable fuel burnup levels within United States' current civilian nuclear reactor fleet. High enrichment and high burnup fuels allow for longer reactor operating cycles between refueling, less fuels to be purchased, lower nuclear waste generation, and better resource utilization, ultimately making nuclear power generation more economical and efficient. However, achieving high burnup can introduce complexities and challenges related to fuel design and performance as the fuel undergoes significant changes during extended operations. One of the primary obstacles for the nuclear industry's goal of achieving a 24-month fuel cycle operation with higher initial fuel enrichment and high burnup is the concern of potential fuel dispersal during postulated loss-of-coolant accidents (LOCA). In light of this, the performance of the advanced fuel designs and high burnup fuels need to be evaluated through the nuclear industry's regulatory processes.

To investigate the implications of higher burnup fuels on licensing amendment, it is crucial to extend the current modeling and predictive capabilities of multiphase flow for the safety analysis of commercial light water reactors under design-basis LOCA conditions. This project aims to develop new high-fidelity modeling and simulation capabilities which account for the particle level physics of heated fuel fragments interacting with surrounding fluids. In this project, we propose to employ a multi-scale approach to model the thermal hydraulics behavior of high-temperature solid particles interacting with gas-liquid flows. This model, which involves tracking particles of varied shapes and sizes coupled with interface-capturing of gas-liquid flow, will account for particle polydispersity and the associated contact mechanics of particle-particle and particle-wall interactions, as well as the deforming gas-liquid interface due to particle loading. In addition, the model will consider the effect of interstitial fluid as particles carried by fission gases penetrate through the coolant fluid. The developed high-fidelity model will provide comprehensive meso-scale information on fuel particle dynamics, which will be used to inform the development of key closure relationships for the three-fluid flow simulations of fuel dispersal during postulated LOCA scenarios.

The proposed research aims to extend the knowledge level of fuel dispersal behavior related to the transport of fuel through the reactor coolant system, which was ranked "LOW" according to a recent phenomenon identification and ranking table panel discussion held by the U.S. Nuclear Regulatory Commission. The outcome of this study will ultimately yield an effective means of assessing two criteria, namely coolable geometry and long-term cooling, to comprehensively understand whether it is feasible to increase burnup within the existing regulatory processes.

Lastly, the team will commit to supporting DOE NEUP's objective of enhancing undergraduate research opportunities in nuclear energy research and development. Comprehensive plans have been developed to recruit and mentor undergradate research students at various phases of the project period.