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Experimental Investigations of HTGR Fission Product Transport in Separate-effect Test Facilities Under Prototypical Conditions for Depressurization and Water-ingress Accidents

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ABSTRACT:

In High Temperature Gas Reactor (HTGR) design, fission products (FPs) have compositions depending on reactor thermal-hydraulic conditions and physico-chemical interactions of gas coolant and impurities, i.e., Helium, fission gases and water, carbonaceous dust and metallic materials. The plateout activity represents all deposition regardless of physico-chemical mechanisms involved such that FPs deposit on structural surfaces or on previously deposited particulates. During the depressurization and water-ingress accidents, FPs are released by different mechanisms: (i) plateout FPs are enforced to re-entrain, liftoff or wash-off by chemical and mechanical forces due to a high shear stress caused by the blowdowns or impacts on plateout surfaces, (ii) vaporization of suspended aerosols and its condensation near surfaces. Understanding these phenomena is important to determine FP behaviors in the HTGR coolant circuit and circulating activity, and to correctly calculate total FP releases during reactor accidents.

This proposal seeks to establish a highly coordinated experimental and computational effort combining high-resolution measurements and simulations to deepen our physical understanding and address long standing modeling inaccuracies related to FP source terms and transport in HTGRs. The proposed FP model development strategy combines the effort and it represents a unique strength of this proposal. It is proposed to acquire targeted measurements and simulations of FP transport and inventory facilitating existing separate- and integral-effect facilities, and then use the realized extensive database acquired for practical reactor materials and components, and prototypical conditions, to derive advanced models and correlations needed for numerical codes (PADLOC, DAMD, MELCOR). The specific tasks are:

1. Experimentally investigate the multi-physics, multi-species, interactions among the coolant flow, FPs and solid interfaces of reactor components using the existing multi-scale test facilities of
    a) High-pressure impinging jet flows to obtain high-fidelity measurements of washoff, lift-off and vaporization of liquid and solid FPs from complex geometrical surfaces at test-scale conditions.
    b) High Temperature High Pressure facility (ASME certified, prototypical conditions 600^{o}C, 7 MPa) to acquire measurements of FPs (gas, liquid/solid aerosols) transport and inventory in the loop.
    c) Modular HTGR-Reactor Building to characterize the FP transport and inventory within the reactor buildings and to validate the developed models of FPs.
2. Perform LES coupling with Lagrangian particle tracking and molecular dynamics (StarCCM+, COMSOL, OpenFOAM) using conditions from experimental facilities in Objective 1(a,b,c).
3. Implement FP models from PADLOC-POLO and DAMD codes into MELCOR, perform calculations for experimental facilities in Objective 1(c), and compare against experimental and CFD results.
4. Derive advanced numerical models and correlations needed for FPs using the high-fidelity CFD results.

Key outcomes of the proposed work include (1) advanced models and correlations for FP transport and inventory 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 FP safety analysis, and (3) broad collaboration with US national lab and industries. The project outcome will be beneficial to reactor cores using TRISO as fuels, including gas- and salt-cooled reactors, where the knowledge of FP transport is of paramount importance.