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ABSTRACT

Thermal-hydraulic Analyses and Experiments for GCR Safety

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The objective of this collaborative experimental and computational research is to provide benchmark data for the assessment and improvement of thermal-hydraulic codes proposed for evaluating decay heat removal concepts and designs in the Gas-Cooled Reactor (GCR) programs of the international Gen IV Initiative. These reactors feature complex geometries and wide ranges of temperatures, leading to significant variations of the gas thermodynamic and transport properties plus effects of buoyancy during loss-of-flow and loss-of-coolant scenarios and during reduced power operations. The complex geometries proposed have included non-circular fuel channels, high temperature exit regions, inlet regions for heavy gas injection, plenum regions, decay heat removal heat exchangers, regenerative heat exchangers, intermediate heat exchangers, reactor cavities with cooling panels, etc.

Existing system safety codes provide reasonable predictions for high-Reynolds-number flows but their correlations can give misleading results for low-Reynolds-number gas flows with buoyancy, as in accident scenarios, even with simple circular tubes. Conceptually, computational fluid dynamics (CFD) codes with turbulence models can yield predictions for improvement of correlations and preliminary design; however, recent assessments have shown that most turbulence models used in general purpose codes give unreliable, optimistic predictions for these cases. To avoid this problem and to improve predictive capabilities, further benchmark data are needed for complex geometries. These bases can be obtained from direct numerical simulations (DNS) or large eddy simulations (LES), after validation with measurements, or from experiments.

Under the Thermal-Hydraulic Experiments task of Gas-Cooled Fast Reactor (GFR) Work Package I0401J01, Systems design and integration, McEligot is currently evaluating needs for thermalhydraulics experiments in support of predictions for GFR decay heat removal schemes. INEEL is also extending the Relap/Athena codes to treat flows in GCRs and Super-Critical Water-Cooled Reactors (SCWRs). In recent International Nuclear Energy Research Initiative (I-NERI) and Nuclear Energy Research Initiative (NERI) projects, Prof. Pletcher and INEEL partners have developed LES and DNS codes for low-Reynolds-number, strongly-heated, buoyant gas flows in circular tubes to serve as benchmarks in those situations. INEEL has employed its unique Matched-Index-of-Refraction (MIR) flow system for velocity/turbulence data in scaled fuel channels for a Very High-Temperature Gas-Cooled Reactor (VHTR) concept. CEA is extending the CATHARE code to treat flows in GCR circuits. For GCR thermal hydraulic studies, CEA is improving CFD codes such as TRIO_U and CAST3M. CEA INEEL/PRO-04-01848 is also developing global CFD models to describe GCR systems including reactor core, reactor vessel, reactor pit and containment allowing the simulation of nominal and accidental regimes with coupled thermal-hydraulics, neutronics

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and heat transfer including radiation. Under Gen IV Work Package A0802J01, Modeling improvement, ANL is currently developing global CFD models of a VHTR concept to identify key fluid flow and heat transfer phenomena (in-vessel and reactor cavity cool-down system [RCCS]) for limiting accident scenarios during passive shutdown heat removal. The studies also assess the analytical capabilities available in the commercial CFD code Star-CD for this application and potential applicability to the VHTR of the ANL NSTF (Natural Convection Shutdown Heat Removal Test Facility) for future VHTR experimental efforts. NSTF is a full-scale simulation facility of a RVACS system which is similar to the RCCS system of VHTR. Additional ANL efforts are examining turbulence modeling options for a wide variety of systems.

Outcomes of this proposed research will be (1) validated LES and Reynolds-averaged Navier-Stokes (RANS) techniques for gas flows with property variation and buoyancy effects through complex geometries important in GCR development, (2) computational and experimental benchmark data for assessing existing and future CFD codes, (3) improved quantitative understanding of the limitations of current and proposed system safety codes and (4) user-friendly LES and RANS codes for these geometries. In addition to current Gen IV Work Packages I0401J01 and A0802J01, the proposed work will also support Gen IV Work Packages I0201J01, I0206J01, I0802J01, N1002J01, O0905J01, andothers.