
High-resolution Experiments for Extended LOFC and Steam Ingress Accidents in HTGRs

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ABSTRACT:

High-Temperature Gas-cooled Reactors (HTGRs) are very attractive due to their inherent safety features, high power conversion efficiency, and potential of providing high-temperature process heat. Both a helium-helium (He-He) Brayton cycle and a helium-steam (He-steam) Rankine cycle have been considered for electricity generation. The adoption of the high-temperature helium gas turbine for the He-He Brayton cycle would have considerable technological risks due to its unproven technology. Therefore, use of the He-Steam Rankine cycle is being considered for the near-term deployment of commercial HTGRs. For the He-Steam Rankine cycle in HTGRs, the water pressure on the secondary side (i.e., the power conversion side) is typically proposed to be much higher than the helium pressure on the primary side. Due to the pressure differential, if a Steam Generator (SG) tube rupture occurs, the water on the secondary side will ingress into the primary helium side. The steam that enters the primary system would potentially result in a positive reactivity insertion since steam is an excellent neutron moderator. In addition, any chemical reaction between the graphite (moderator in the core and support structures in the hot plenum) and steam will weaken the integrity of the graphite support structures and fuel elements, producing flammable gases (CO and H₂). Furthermore, the primary system pressure could increase due to core heat up and the graphite-steam chemical reaction. Thereafter, the safety valves could potentially open if the mitigation systems for pressure control fail to work. This could lead to the release of radioactive isotopes and flammable gases into the low-pressure rated confinement. In addition to steam ingress accident, an extended loss of forced circulation (LOFC) accident would involve complex primary coolant behavior, including flow reversal through the core, hot helium pluming and jetting, and natural circulation flow.

It is proposed that this study focuses on: (1) Steam ingress phenomena following an SG tube rupture event and (2) Natural circulation of hot helium plumes and jets within the reactor vessel during an extended LOFC. Our ultimate goals are to: (1) Better understand water/steam ingress and extended LOFC accidents and (2) to provide high-resolution measurements of fluid flows in these accidents for CFD model validation. The specific tasks are to:

1. Experimentally investigate, using an existing integral-effect test facility with some improvements, the steam-ingress accident caused by a postulated SG tube rupture initiating event;
2. Carry out integral-effect tests for the extended LOFC accident to study the establishment of global natural circulation flow in the primary loop;
3. Design, based on a scaling analysis, and constructed a separate-effect test facility to study the complex helium flows in the core and hot plenum during the extended LOFC accident; and
4. Perform detailed, high-resolution, separate-effects experiments using results obtained in Task (2) as boundary/initial conditions.