Experimental Investigation and CFD Analysis of 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 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 rapidly flash into steam and be discharged into the primary helium side. The steam that enters the primary system would 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 H_2). Furthermore, the primary system pressure will 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.

It is proposed that this study focus on steam ingress phenomena following an SG tube rupture event. Our ultimate goal is to better understand water/steam ingress accidents for the HTGRs that adopt Rankine cycle as the power conversion cycle. The specific objectives are to:

1. Experimentally investigate steam-ingress accidents caused by a postulated SG tube rupture initiating event, focusing on the integral effects of both the thermal-hydraulic behavior and graphite oxidation in the hot plenum and reactor core;

2. Study graphite oxidation by steam using separate-effects tests and benchmark, and improve if needed, existing models;

3. Develop and validate predictive Computational Fluid Dynamics (CFD) models for the steam ingress phenomena.