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Effects of Tritium-Graphite Interactions on Safety Transients in Graphite-Moderated Nuclear Reactors

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ABSTRACT:

Tritium is a radioactive isotope of hydrogen produced in all types of fission reactors. Tritium production rates are particularly high in reactors that employ materials that can produce it via neutron activation. In Molten Salt Reactors (MSRs) and Fluoride-Salt-Cooled High-Temperature Reactors (FHRs), tritium production rates are up to 10,000 times larger than Light Water Reactors (LWRs). In High-Temperature Gas Reactors (HTGRs), production rates are 10 times larger than LWR.

Multiple pathways exist for tritium, once generated: it can remain in the salt (for FHRs and MSRs) as HF and H_2 up to their solubility limits, accumulate in the cover gas, adsorb on and get trapped by graphite components, or diffuse through metal components. Adsorption on graphite components accounts for a significant fraction of tritium: in the Molten Salt Reactor Experiment (MSRE), 15% of the total tritium inventory was estimated to be trapped by the graphite stringers, with half of it in the outermost 1.5 millimeters. Using the Mark-I FHR as an example, this estimate corresponds to an average tritium concentration of 50 atomic parts per million (appm) in the outermost layer of graphite pebbles. The actual concentration of tritium in graphite used in new generation MSRs, FHRs, and HTGRs is unknown and can only be estimated via extrapolation, as published literature on graphite-hydrogen interactions stems from experiments conducted under environmental and operational conditions not representative for such reactors. As a light isotope with a very low absorption cross-section, tritium trapped in graphite will affect neutron moderation and in turn reactivity, which will lead to variations in how postulated events progress. Furthermore, with tritium-graphite interactions being temperature-dependent, it is not known what fraction of the trapped tritium would be released during reactor transients that involve a temperature increase. This project is structured to accomplish three key objectives in support of the DOE NE mission:

- Quantify the tritium content in graphite components of new generation FHRs and HTGRs as a function of time and operational conditions. We will measure adsorption of hydrogen isotopes in graphite at conditions of relevance to gas-cooled and salt-cooled reactors. In all adsorption experiments, hydrogen and deuterium will be used as surrogates of tritium. Using two different isotopes will allow to identify isotopic effects and to estimate tritium content. Graphite samples used in the adsorption experiments will include nuclear graphite irradiated up to 4.5 dpa, representative of reflector blocks, and irradiated graphite matrix, representative of fuel elements.
- Assess the impact of tritium content in graphite on reactor physics during normal operations and safety transients. We will use the tritium content from experiments as an input to parametric models on Serpent and SAM to estimate effects on reactivity feedback and transient dynamics. We will identify safety transients that lead to temperature increases and predict associated tritium releases.
- Quantify tritium release rates and release kinetics during operational transients inducing temperature increases. We will experimentally replicate the identified transients on FHR- and HTGR-representative hydrogen-loaded samples to quantify the tritium releases and validate the models.

At its conclusion, this project will provide accurate estimates of tritium content in FHR and HTGR graphite components, clearly quantifying tritium release rates and tritium effects on reactor physics.