Development and Experimental Benchmark of Computational Models to Predict Cladding Temperature and Vapor Removal from UNF Canisters during Drying Operations

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ABSTRACT:

Used nuclear fuel (UNF) is transferred from underwater pools to canisters for onsite dry storage or offsite transport. Essentially all water must be removed to avoid possible corrosion or formation of combustible gases. However, during all post-reactor operations, the fuel cladding must not exceed certain temperatures to minimize dissolution of existing *circumferential* hydrides in the cladding, and limit the cladding hoop stresses. That would lead to formation of *radial*-hydrides under the slow cooling conditions that exist during dry-cask storage, especially for high-burnup fuel. Radial hydrides have the potential to radically reduce the claddings ductility and suitability for long-term storage and eventual transport. Maintaining cladding below safe temperatures during drying operations has been identified as crucial to the viability of long-term dry-cask storage. Industry currently uses vacuum drying or forced helium dehydration for moister removal. In vacuum drying the canister is evacuated in stages to pressures as low as 67 Pa. While low pressures promote water vaporization, at these low pressures the remaining gas is rarefied to the extent that there is a temperature jump (thermal resistance) between heated surfaces and the gas (this jump is not significant at pressures used during storage), which can increase cladding temperatures. Forced helium dehydration was developed for high-burnup or other high heat generating fuel. In that process, helium is circulated through the canister, and moisture is removed from the helium while it is outside. The gas is not rarefied, but that process requires gas demoisturizing equipment, which is not needed for vacuum drying. In both processes the presence of water vapor in the canister may contribute significantly to the increase of cladding temperatures.

The objective of the proposed three-year research program is to develop and experimentally-validate computational fluid dynamics (CFD) tools to predict cladding temperatures within, and vapor removal rates from, UNF canisters during drying operations, for a range of gas pressures (including rarefication) and flow rate conditions. To perform this work, Shakhov-model and Direct Simulation Monte Carlo approaches will be used to develop new results for water evaporation and transport of vapor, momentum and energy in rarefied helium. These results will be experimentally-validated using an existing apparatus that measures transport across an annular moist-helium-filled gap. These results will be used to implement models at gas/solid interfaces of CFD simulations to calculate transport in slip-flow rarefied-gases. A geometrically-accurate model of a UNF canister will be constructed. It will be employed in high-performance CFD simulations of drying processes for a range of gas pressures, moisture levels, and flow rates. The computational tools developed in this work will be used to assess and design processes that quickly and effectively remove moisture from used fuel canisters while maintaining the cladding temperature below safe limits. This will provide rational basis to avoid overly-conservative estimates for the amount of time fuel must be stored in underwater pools before being safely transfer to dry casks, and will be the first studies of UNF canister drying flow and vapor transport in the open literature. The research team has conducted related simulations and measurements in the past, and they will interact with an industrial/academic/lab advisory committee. One Ph.D. student will be trained in computational and experimental research related to nuclear packaging and safety.