Development and Experimental Benchmark of Simulations to Predict Used Nuclear Fuel Cladding Temperatures during Drying and Transfer Operations

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Program: Used Nuclear Fuel Disposition

ABSTRACT

Used nuclear fuel is transferred from underwater pools to canisters with internal support baskets for onsite dry storage or offsite transport. All water must be removed from a canister before it is sealed. However, the fuel cladding must not exceed certain temperatures to minimize dissolution of existing circumferential-hydrides in the cladding, and limit the cladding hoop stresses, which may lead to formation of radial hydrides under slow cooling conditions during drying, transfer and early dry-cask storage, especially for high-burnup fuel. Radial hydrides in high-burnup used fuel cladding have the potential to radically reduce its ductility and suitability for long-term storage and eventual transport. Industry currently uses vacuum drying or forced helium dehydration for moister removal. In vacuum drying the canister is evacuated to pressures as low as 67 Pa to promote evaporation and vapor removal. At these low pressures the remaining gas is rarefied to the extent that there is a temperature discontinuity between the solid surfaces and the gas (this temperature-jump is not significant at pressures used during storage or transport). 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 pressure is maintained at the same level used during storage and transport. This process requires gas demoisturizing and cooling equipment, which is not needed for vacuum drying. However, the cladding temperatures may actually be reduced compared to storage or transport conditions in locations where the forced helium flow “turbulates” the gas.

A three-year research program is proposed to develop and experimentally benchmark computational models of vacuum drying and forced helium dehydration. It will employ an experimental apparatus that was used for earlier DOE-funded research, which models the heat transfer between a used fuel assembly and the basket walls. The experiment will acquire rod temperatures under a range of low pressure conditions used during vacuum drying. A computational fluid dynamics model of this process will be developed that employs a temperature-jump thermal resistance based on rarefied gas theory. Another set of experiments with helium flowing through the apparatus will be used to study forced helium dehydration. The data will be compared to simulations to determine the effect of flow turbulation on heat transfer enhancement. The computational models developed and benchmarked in this work, along with the Argonne National Laboratories cladding limit temperature research, will be used to help evaluate used fuel drying operation that assure the safety of long term dry storage and transport. This work will train two Ph.D. students and one postdoctoral research associate in computational and experimental heat transfer research.