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Extended Storage and Transportation: Evaluation of Drying Adequacy

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Abstract

Transfer of spent nuclear fuel (SNF) from wet to dry storage requires removal of water from the dry storage canister or cask, commonly using vacuum drying methods. Dry storage containers are backfilled with inert gas, and very little water is presumed to remain. Residual moisture following incomplete drying may affect behavior of SNF in dry storage. This paper examines the potential ramifications of incomplete vacuum drying such that a small amount of water remains in the closed system, including potential effects on cladding, SNF, and canister internal components, as well as possible changes to flammability conditions. The assessment considers the effects of the canister internal environmental conditions: (i) amount of residual water after drying, (ii) spatial and temporal distribution of SNF and cladding temperatures, and (iii) radiation field strength. The paper presents a time-dependent integration model for the behavior of small amounts of residual water in a dry storage canister.

Potential sources of residual water include water trapped in fuel rods with cladding pin-holes, and potential chemisorbed water from zirconium hydroxide. Under the current vacuum drying practices, the amount of residual water is expected to be within the range of 1.0 to 5.5 moles. As a conservative assumption, this paper also considers an order of magnitude greater amount of residual water (55 moles) remaining in the canister. Following vacuum drying, any residual water is expected to be in vapor phase. This residual water will undergo radiolysis, producing oxygen and hydrogen in different chemical forms. Among the nearly 50 products potentially formed by radiolysis (mostly short-lived), water, hydrogen and oxygen are considered in formulating the equations for radiolysis kinetics. The recombination of elements into water will be minimal, as it is governed by low element collision rates in the vapor state.

The radiolysis products will react with the cladding, SNF, and other cask internal components, especially during early periods of elevated temperatures. The model assesses oxidation of the SNF and cladding, aqueous corrosion, and hydrogen embrittlement of the internal components. The processes are dependent on temperature, time, relative humidity (RH) and radiolysis kinetics. Below a threshold RH, aqueous reactions do not occur, and oxygen reacts with the SNF, cladding and internal components. In a closed canister system, oxidation is controlled by the radiolysis kinetics or chemical kinetics. At lower temperature with higher RH, aqueous corrosion can occur. If exposed by small openings in fuel cladding, individual grains of SNF can oxidize as grain boundaries are partially open. The model also assesses potential crack

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propagation of breached cladding due to stresses generated by U_3O_8 formation. For each time step in the integration model, the oxide thickness, amounts of hydrogen, oxygen, and water are calculated. Hydrogen flammability is also evaluated. The integration model is benchmarked against the inventory of hydrogen estimated from available data from long-term (up to 20 years) demonstration tests of dry storage of SNF.

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