SIMULATING THE SOLID CHEMICAL COMPOSITION OF PWR FUEL CRUD

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Chalk River Undesirable Deposits (CRUD) occur in commercial reactors as a result of corrosion products in the primary-loop coolant collecting on the outer surface of the fuel rods. These deposits can greatly limit the performance, reliability, and safety of reactor operation in a number of ways, the most significant being Axial Offset Anomaly (AOA). This phenomenon occurs because of CRUD's proficiency for boron retention and its nonuniform deposition along the axis of the core in a PWR. The Callaway Nuclear Power Plant during its Cycle 9 suffered the worst AOA to-date, and the compound bonaccordite (Ni_2FeBO_5) was found to constitute the majority of CRUD samples taken from this cycle's fuel. To better understand how CRUD grows and traps boron causing AOA, modeling of the solid chemical composition of PWR fuel CRUD is employed. MAMBA (MPO Advanced Model for Boron Analysis) simulates CRUD growth, tracks the internal transport of heat, coolant, and soluble species, and solves the thermochemistry throughout the CRUD. The thermochemical stability of various soluble species within the CRUD is assessed, and bonaccordite is confirmed to be the most stable phase, preferred over nickel ferrite ($NiFe_2O_4$), nickel metal (Ni), and nickel oxide (NiO). Ni metal is preferred over NiO, and $NiFe_2O_4$ is preferred over both Ni and NiO. MAMBA also predicts lithium tetraborate ($Li_2B_4O_7$) precipitation to be thermodynamically favorable for the inner (cladding-side) region of sufficiently thick CRUD. The kinetic rates of the precipitation reactions are calibrated by comparing to the chemical characterization of CRUD samples from Callaway's Cycle 9. MAMBA demonstrates a three-region radial CRUD structure by the end of the power cycle that corresponds with AOA-causing CRUD sample observations. It is predicted that both $NiFe_2O_4$ and Ni metal particulate depositions occur. The $NiFe_2O_4$ particulate concentration decreases as the CRUD thickness and growth rates increase. The precipitations of lithium tetraborate ($Li_2B_4O_7$) and bonaccordite (Ni_2FeBO_5) are the main mechanisms predicted to trap boron within the CRUD and are therefore suspected to be the fundamental causes of AOA.