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Preliminary Thermal-Hydraulic Assessment of Iron-Based ATF Claddings with Reduced Thickness

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Abstract

The Fukushima Daiichi accident in 2011 exposed how zirconium alloy clad fuel can oxidize rapidly at high temperatures and react violently with coolant, producing hydrogen and ultimately leading to hydrogen explosions. This event spurred the development of Accident Tolerant Fuel (ATF) for Light Water Reactors (LWRs). Iron based alloys (e.g., FeCrAl, APMT™, 310SS, 304SS) offer enhanced thermo mechanical strength and much lower steam oxidation reactivity, thereby reducing hydrogen generation; however, they suffer a reactivity penalty because their neutron absorption cross sections are roughly fifteen times greater than those of zirconium alloys. Previous studies have proposed multi-parameter mitigation strategies, including reduced cladding thickness, reduced pellet diameter, and increased uranium enrichment, to offset this penalty.

In the present work, a preliminary thermal-hydraulic investigation was carried out to quantify the effects of alternative cladding materials and reduced cladding thickness. A three-dimensional model of a single subchannel within a fuel assembly (based on the BEAVRS benchmark geometry) was developed, and ANSYS Fluent was employed to simulate steady-state coolant flow and heat transfer under nominal operating conditions. The thermal performance of FeCrAl, APMT™, 310SS, and 304SS claddings was evaluated against that of conventional Zircaloy-4.

Results show that all materials exhibit similar temperature distribution trends, differing only in magnitude according to their thermal properties. Reducing cladding thickness from 0.5715 mm to 0.350 mm produced an approximate 7 K rise in outer-surface temperature across all alloys and increased the Nusselt number by about 10.6.

Further studies are needed to assess the impact of thinner iron-based claddings on Departure from Nucleate Boiling (DNB) and Critical Heat Flux (CHF) margins during design-basis transients, as well as to evaluate high-temperature creep and embrittlement behavior. Subsequent Loss-of-Coolant Accident (LOCA) and Reactivity-Initiated Accident (RIA) simulations will be required to ensure compliance with IAEA standards and best practices.

Technical Track

Nuclear Thermal-Hydraulics

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