Multiphysics Modeling In COMSOL To Understand Thermal Behavior Of The HFIR Core With Silicide Fuel

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Abstract

The High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL), operating at 85 MW, is the highest flux reactor-based source of neutrons for research in the United States and provides one of the highest steady-state neutron fluxes worldwide. Research and development efforts are underway to study the conversion of HFIR from its highly enriched uranium (HEU) fuel to a low-enriched uranium (LEU) fuel as part of the US Department of Energy's Material Management and Minimization Program . The HFIR LEU conversion aims to maintain current HFIR performance metrics and safety requirements with the same involute plate geometry as in the current HEU configuration.
A multiphysics model has been developed in COMSOL to solve for fluid flow, heat transfer, and structural interactions in both the inner (IFE) and outer fuel elements (OFE) of HFIR. As depicted in Figure 1, the HFIR COMSOL model features a two-plate, two-channel model for the IFE and OFE, with periodic boundary conditions enforced on each side. The LEU fuel under investigation is a U3Si2-Al (silicide) dispersion fuel with Al-6061 cladding and pressurized light water as the primary coolant. Two different fuel types were investigated : a high-density silicide with a U-density of 5.3 g/cm³ and a low-density silicide with a U-density of 4.8 g/cm³. The k-ε turbulent flow model was used to solve for the coolant domain with a set inlet temperature, inlet flow rate, and outlet pressure. The heat transfer in the solid module was employed to solve for heat transfer between the fuel meat and cladding. Internal heat generation of the fuel, cladding, and surroundings was incorporated as a spatial function through independent simulations in MCNP. The solid mechanics application was used to solve for stresses within the solids due to thermal expansion and irradiation swelling. Additionally, established correlations were implemented to account for irradiation swelling in the fuel plate, the formation of an aluminum oxide layer, and safety limits for incipient boiling, flow excursion, and burn-out criteria, essential for simulating behavior under the safety-basis conditions.
The COMSOL model was used to simulate both high and low-density U3Si2-Al fuel designs, assuming nominal operating conditions for the beginning of the cycle at 95 MW. Results for various field parameters such as fuel temperature, cladding surface deflection, and coolant channel thickness were obtained and shown in Figure 2. These results provide insights into the thermal behavior and structural integrity of the reactor core under the new LEU configuration, helping to ensure that the reactor continues to meet its performance and safety standards.

Reference

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