NEUP Nuclear Energy University Program
U.S. Department of Energy

Development of Advanced Control Rod Assembly for Improved Accident Tolerance and High Burnup Fuel Cycle

PI: Kumar Sridharan, University of Wisconsin, Madison

Collaborators: Hwasung Yeom (*University of Wisconsin, Madison*); Hakan Ozaltun (*Idaho National Laboratory*); Radu Pomirleanu, Mohamed Ouisloumen, and Ho Lam (*Westinghouse Electric Company*)

Program: FC-2.2 (Accident Tolerant Control Rods)

ABSTRACT:

Extensive research to improve accident tolerance of light water reactors has been underway since the Fukushima-Daiichi nuclear power plant accident in 2011. The primary focus to-date has been on the development of accident tolerant fuel/cladding system (ATF) to endure a loss of active cooling in the reactor. However, it is also important to ensure the functionality and mechanical integrity of other core components particularly the control rod assembly (or rod cluster control assembly, RCCA) during design basis accident (DBA) and beyond design basis accident (BDBA). The current control rod assembly consisting of Ag-In-Cd (AIC) and B_4C neutron absorbers inside stainless steel control rod sheaths with Zr-alloy guide thimble tubes have proven to be safe in normal operating conditions in PWRs. However, the survivability of the control rod system in off-normal high temperature conditions is in question, due to not only excessive oxidation but also formation of low melting point eutectic between stainless steel control rod sheath and Zr guide thimble tube or neutron absorbing materials. Furthermore, control rod assemblies have to accommodate potential issues in longer fuel cycles including high radial power peaking factors due to the difference in reactivity between fresh fuel and high burnup fuel in the core. A reactor core with high enrichment fuel will also have an influence on the reactivity coefficients and control rod reactivity worth.

The proposed research will focus on the development of new material designs for control rod sheaths and neutron absorbers, coupled with neutronics analysis and thermo-mechanical modeling to improve accident tolerance and to achieve higher fuel burnup in light water reactors. Selection of control rod material design and neutron absorbing materials to provide the required functionality at higher temperatures and larger negative reactivity than the current control rod assembly will be performed in the initial phase of the research. Established surface coating technologies such as cold spray technology (CST) and physical vapor deposition (PVD) will be used for depositing Cr coatings on control rod sheath for high temperature oxidation and elemental interdiffusion resistance to prevent eutectic melting at lower temperatures. These coatings will be applied to not only on current stainless-steel control rod sheath, but also exploratory control rod sheath materials including Hf-alloys and TZM Mo alloy, which are known for their high neutron cross-section and high temperature strength. MA956 (FeCrAl ODS alloy) also known for its high temperature strength and oxidation resistance will also be investigated as a stand-alone material for the control rod sheath. In addition, pellet forms of new neutron absorbing materials (e.g., HfO_2, Gd_2O_3, Eu_2O_3) will be fabricated using spark plasma sintering (SPS) to evaluate their thermo-physical properties related to long-term operation and accident tolerance. Comprehensive experimental testing and microstructural characterization of the developed control rod components will be performed to ensure functionality. The advantages of the proposed designs are not limited to accident tolerance but also aimed towards extended burnup operation by virtue of increased control rod worth (and shutdown margin) and decrease in radiation-induced absorber swelling. The neutronics and thermo-mechanical behavior of the control rod assemblies of the above material systems will be modeled in detail, to guide the down-selection of the most promising design for industrial implementation.