Radiation Effects on the Aqueous Compatibility of Coated and Uncoated SiC for Accident-Tolerant Fuel Cladding in Light Water Reactors

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During the 2011 Fukushima Daiichi nuclear accident, a prolonged station blackout led to decay heat increasing the core temperature to near 1200°C where breakaway oxidation of the Zr-based fuel cladding fully consumed the clad, further increasing the fuel temperature, and creating a hydrogen bubble in the core, which subsequently exploded. Potential ATF cladding concepts, with orders-of-magnitude lower oxidation kinetics than Zr at high temperature, include SiC and FeCrAl-class materials. While SiC's corrosion behavior is adequate under accident conditions, it is potentially unacceptable under standard operating conditions due to hydrothermal dissolution. In the present work, three commercially-available coatings, Cr, CrN, and TiN, were applied to a variety of SiC substrates by the physical vapor deposition (PVD) cathodic-arc method and tested for corrosion protection. These samples along with various SiC materials were exposed to four conditions at the MIT reactor: 1) neutron radiation in an inert atmosphere, 2) in-situ neutron and gamma radiation in flowing hydrogen water chemistry (HWC)-quality water, 3) above-core gamma irradiation in HWC-quality water, and 4) HWC-quality water shielded from radiation. Optical and electron microscopy were used to quantify cracking in all surviving coatings. X-ray diffraction (XRD) and transmission electron microscopy (TEM) identified structural changes due to neutron damage, energy-dispersive X-ray spectroscopy (EDS) identified oxides throughout the coating. Electron backscatter diffraction (EBSD) was used to determine relative straining near the interface and develop correlations with the conditions explored. Finally, mass change evaluation coupled with these techniques was used to establish the potential viability of these specific coatings. While TiN did not develop visible cracks under any condition, impurities led to deviations from thermodynamic behavior, contributing to full loss of the coating under irradiation and corrosion. Irradiation damage produced extensive cracking in CrN, along with voids and cracks in the Cr. These defects led to spallation in a corrosive environment. All CVD SiC variants corroded at minimal rates under irradiation; comparisons between samples demonstrate a significant effect of grain boundary weakening on the corrosion rate. This talk will report new results showing the synergistic effects of radiation and water environments on uncoated and coated SiC materials and discusses mitigation strategies.

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