Investigation of Intergranular Cracking of Highly Irradiated Austenitic Stainless Steels in Ambient Conditions

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ABSTRACT:

The project is intended to perform an in-depth investigation, develop a comprehensive understanding, and attempt to mitigate the intergranular (IG) brittle fracture phenomenon occurring at ambient conditions in highly irradiated austenitic stainless steels – materials of light-water reactors (LWRs).

In the past two decades, during several past and current testing campaigns of irradiated materials, irradiated austenitic stainless steels have been observed to undergo IG cracking at room temperature without any corrosion environment. Such cracking has been observed in samples extracted from different reactor components, including fuel cladding, flux thimble tubes, and core baffle plates. The susceptible components were fabricated from Type 304 or Type 316 austenitic stainless steels, which are the construction materials for most LWR internal components.

IG cracking is typically identified with irradiation-assisted stress corrosion cracking in irradiated stainless steels. Observing such cracking in ambient conditions is unexpected because most available literature reports a ductile fracture mode if no significant swelling occurred. IG cracking is also a brittle failure mode. Therefore, its observation to occur in ambient conditions represents a new form of irradiation embrittlement that has not been thoroughly investigated and is not understood. The tests to date that have identified this phenomenon have all identified it with unusually low mechanical properties (e.g., ductility or fracture toughness). As more reactor material in the LWR fleet reaches these levels of irradiation, the understanding of this phenomenon and the ability to mitigate it will be important in maintaining fleet viability.

To elucidate the mechanism of IG cracking in inert environments, in-service irradiated 304 baffle plate material and 316 flux thimble tube material will be used. Such materials are available at the Westinghouse-owned hot cell facility and will be provided to perform the project.

The research activity will combine traditional techniques (e.g., scanning electron microscopy (SEM)/fractography, magnetometry, transmission electron microscopy) and advanced cutting-edge tools (e.g., in situ mechanical testing using SEM/electron backscatter diffraction). Five hypotheses will be addressed via a thoughtful test matrix: (1) a strain-induced austenite-to-martensite transformation is responsible for brittle fracture; (2) localized embrittlement occurred because of void swelling; (3) helium bubble formation along grain boundaries occurred, compromising mechanical performance; (4) hydrogen embrittlement occurs; and (5) localized micro void coalesces and micro-shear band formation occurs in this high-dose material.

Once the nature and driving forces of the IG fracture phenomenon are established (i.e., the five hypotheses are examined, and complex, synergetic interactions between different factors such as trapped hydrogen and radiation-induced defects are investigated), the team will attempt to mitigate the phenomenon. Degassing (i.e., hydrogen removal using low-temperature annealing) and controlled postirradiation annealing will be performed. If successful, the mitigation of the IG fracture will be a valuable, practically important outcome of the project devoted to supporting the continued operation of LWR's fleet.