Innovative Approach to Establish Root Causes for Cracking in Aggressive Reactor Environments

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Proposal Number: 2002-075

The successful development of Generation IV nuclear power systems must address and mitigate several materials-degradation issues now strongly impacting existing light water reactors (LWRs) after very long periods of operation. In addition, the more aggressive radiation and environmental exposures envisioned for various advanced reactor concepts will require materials with improved high-temperature properties and resistance to cracking. Although previous fast reactor and fusion device programs have focused on the development of improved structural materials for their relevant conditions, no comparable effort has been directed toward the conditions unique to water-cooled fission reactors since the inception of nuclear-powered propulsion units for submarines. The paramount issues impacting both LWR economics and safety have been corrosion and stress-corrosion cracking in high-temperature water. These degradation processes have continued to limit performance as the industry has changed operating parameters and materials. Mechanistic understanding and non-traditional approaches are necessary to create durable corrosion-resistant alloys and establish the foundation for advanced reactor designs. Less down time and longer component lifetimes are the drivers motivating this research for both Generation III and IV nuclear power systems.

Proposed research will focus on the characterization of critical Fe- and Ni-base stainless alloys tested under well-controlled conditions where in-service complexities can be minimized. Quantitative assessment of crack-growth rates will be used to isolate effects of key variables, while high-resolution analytical transmission electron microscopy will provide mechanistic insights by interrogating crack-tip corrosion/oxidation reactions and crack-tip structures at near atomic dimensions. Reactions at buried interfaces, not accessible by conventional approaches, will be systematically interrogated for the first time. Novel mechanistic "fingerprinting" of crack-tip structures tied to thermodynamic and kinetic modeling of crack-tip processes will be used to isolate causes of environmental cracking. Comparisons will be made with results on failed components removed from LWR service (funded separately by industry collaborators).

The proposed research strategy capitalizes on unique national laboratory, industry, and university capabilities to generate basic materials and corrosion science results with immediate impact to next generation nuclear power systems. This proposed work will be integrated with existing NERI projects, with fundamental research funded by the DOE Office of Basic Energy Sciences, and with focused U.S. and international projects dealing with current LWR degradation issues. This leveraged approach will facilitate the revolutionary advances envisioned by NERI by creating a multi-faceted effort combining the basic and applied science necessary to drive mechanistic understanding and promote development of next generation materials that meet the performance goals of advanced reactors.