Irradiation-Corrosion of Alumina-Forming Austenitic Stainless Steels in Static Lead

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ABSTRACT:

The objective of this project is to evaluate the susceptibility of alumina-forming austenitic (AFA) stainless steels to liquid metal embrittlement under coupled extremes of irradiation and corrosion. AFA stainless steels have emerged as the only candidate alloy with the high-temperature strength, formability, cost, and compatibility with both the primary and secondary side coolants for lead fast reactors (LFR). However, their relatively high Ni concentration makes AFA steels potentially susceptible to liquid metal embrittlement (LME) due to the rapid adsorption of Pb to Ni. Additionally, during irradiation, Ni tends to enrich at grain boundaries due to radiation-induced segregation (RIS). Hence, RIS could further exacerbate LME in AFA steels under combined irradiation-corrosion extremes. Thus, before the nuclear industry can safely implement AFA steels and harness the potential of LFRs, we must resolve the critical need of understanding mechanical implications of various degrees of a high Ni concentration under coupled extremes of irradiation and liquid metal corrosion.

We hypothesize that increasing bulk Ni concentration will increase the magnitude of Ni RIS and consequently accelerate intergranular Ni-Pb interactions, causing extreme LME. We take the approach of studying two AFA steels having different bulk Ni concentrations, using an innovative irradiation capsule design that allows for concomitant neutron irradiation and liquid Pb exposure. Post-irradiation/corrosion examination will include miniature tensile testing at temperatures ranging from ambient through service temperatures, depth-sensitive corrosion product characterization by low energy ion scattering spectroscopy (LEISS), and characterization of irradiated microstructure and RIS using advanced transmission electron microscopy (TEM). This project leverages unique NSUF capabilities including alloy development, irradiation capsule design, irradiated materials testing and characterization, and surface-sensitive LEISS available only at the participating institutions.

The scientific outcome of this project will be a fundamental understanding of the interplay between RIS and LME. We will also generate amongst the first knowledge of LME in coupled irradiation and corrosion extremes representative of LFRs, which will facilitate the broader engineering impact of establishing safety margins, design-basis risk evaluation, and model validation and verification to enable realization of LFR structural alloys. This project is synergistic to the ongoing bilateral demonstration irradiation between NSUF and the United Kingdom's National Nuclear User Facilities (NNUF), which will include AFA steels. This project is relevant to DOE-NE because one of the greatest hurdles facing advanced reactor concepts such as LFRs is a lack of suitable materials possessing high-temperature strength, formability, cost, and primary and secondary side coolant compatibility; this project seeks to provide foundational understanding of irradiation-corrosion behavior of the leading candidate alloy that could fill this critical technological gap.