
Facility for High-Fidelity Near-Surface Characterization of Corrosion in Materials for Advanced Reactors

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ABSTRACT:

We propose to develop a corrosion device capable of conducting experiments at elevated temperatures up to 1,000°C with precisely controlled gas impurities in the microbar range. Moreover, this corrosion device will be directly connected to a multi-chamber vacuum system equipped with advanced surface analysis techniques, including depth-profiling X-ray photoelectron spectroscopy (XPS). This setup will allow for in-vacuum sample transfer, enabling high-fidelity materials characterization from the surface down to tens of nanometers below the surface.

To enhance efficiency and economic performance, advanced nuclear reactors are often designed to operate at higher temperatures. High-temperature gas-cooled reactors (HTGR) have outlet temperatures ranging from 750°C to 950°C. Although helium gas coolant is used to suppress corrosion, impurities such as oxygen, water vapor, and carbon oxides can contaminate the coolant over time, causing various corrosion reactions (e.g., oxidation, carburization, decarburization) and significant performance degradation of materials. Corrosion is a complex chemical process occurring at the surface and near-surface regions of materials. Directly examining the chemical evolution induced by corrosion near the material's surface has been challenging because corroded materials typically need to be transferred from their original corrosion environment to the characterization facility, risking modification and contamination from the air. Additionally, while cross-section electron microscopy offers excellent spatial resolution and is widely used for characterizing chemical depth profiles, it often struggles to accurately analyze the near-surface region, which is frequently altered during the cross-section sample preparation. The proposed facility is designed to overcome these limitations. By establishing an in-vacuum sample transfer route between the corrosion device and the analysis chamber, we will effectively prevent exposure to air and thereby minimize alteration of the corroded surface. Combined with ion sputtering, depth-profiling XPS can uncover the chemical evolution from the surface down to tens of nanometers below, providing critical insights into the interconnections between the surface and bulk chemistry of material corrosion.

The facility's unique capabilities will open up new avenues for studying material corrosion in HTGR and other advanced reactors operating at elevated temperatures. Additionally, the proposed facility will support the development of a specialized laboratory course on materials for advanced reactors. By establishing remote control of equipment, we will allow both resident and online students to participate in experimental operations, enhancing educational accessibility and promoting facility sharing across various institutions.