Advanced surface plasma nitriding for development of corrosion resistant and accident tolerant fuel cladding

PI: Lin Shao, Texas A&M University

Program: Nuclear Energy Enabling Technologies

Collaborators: Don A. Lucca – Oklahoma State University, Michael P. Short – Massachusetts Institute of Technology, Frank Garner – Texas A&M University

ABSTRACT:

A surface nitrided steel typically exhibits superior corrosion resistance, oxidation resistance, and wear resistance. Such a nitride layer can be formed via sputtering or vapor/ablation deposition. However, these traditional techniques are unrealistic for reactor applications, due to the issue of de-bonding between the coating layer and the original substrates when exposed to harsh reactor environments. The plasma nitriding technique can form a tightly bonded nitride layer through nitrogen plasma surface bombardment. However, the technique has severe spatial nonuniformity, particularly for tube-like structures, due to well-known edge effects. This project aims to develop a new plasma nitriding technique which is able to uniformly nitride fuel cladding tube surfaces, including both the outer and inner tube surfaces. The key is to use a cathodic cage to stabilize plasma distribution, providing a uniform layer, minimizing edge effects, increasing temperature uniformity, and reducing arcing. Furthermore, the proposed technique is suitable for scaling up to industrial fabrication. Starting with alloys of strategic DOE interest (Grade 92, Alloy 709, HT-9, T-91 and Zircaloy 2/4), the team will apply this advanced surface plasma nitriding technique to convert alloy surface layers into nitride layers, for better structural integrity and compatibility with both coolants and nuclear fuels. Both treated and untreated materials will be irradiated with Fe^{+2} self-ions or simultaneous beams of Fe^{+2} ions and He^{+2} ions, up to extreme damage levels (>400 dpa) and at various temperatures (300°C to 650°C). Various microstructural characterizations and mechanical property measurements will be performed. Outer surfaces of nitrided samples will be tested in high temperature water and liquid sodium coolant loops, to evaluate their corrosion resistance and compatibility with coolants for LWR and fast reactor applications, respectively. For inner surfaces, solid-to-solid diffusion couple experiments will be used to study interface reactions of nitrided samples with uranium, to test whether a nitrided layer can slow down fuel-cladding interactions with metallic fuels. The project will impact both the development of advanced methods for manufacturing and the development of advanced reactor in-core structural materials. The team combines expertise in high dpa irradiation and structural characterization from Texas A&M University, mechanical testing from Oklahoma State University, and corrosion testing from the Massachusetts Institute of Technology.