Multilayer Composite Fuel Cladding for LWR Performance Enhancement and Severe Accident Tolerance

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ABSTRACT:

Accident tolerance of LWR fuels and structures is of paramount importance, as recently highlighted by the accident at the Fukushima Daiichi nuclear power station. The ability of fuel cladding and core internals to resist runaway oxidation during a beyond design basis accident (BDBA), as well as to minimize corrosion during steady state operation and design basis accidents (DBAs), determines its degree of accident tolerance. The goal of this NEUP project will be to develop a ***multi-metallic layered composite (MMLC)*** tailored to addressing accident tolerance of LWR fuel cladding and core internal structures using an innovative fabrication technology. The MMLC developed in this program is expected to enhance accident tolerance of LWRs, thereby reducing the cost by recovering lost operating margins and/or increasing operating windows of peak cladding temperature, peak linear power, reducing steady-state corrosion, and enhancing severe accident tolerance.

Bi-layered composite materials have recently been successfully designed to resist corrosion and maintain mechanical integrity, and fabricated on an industrial scale. The bi-layers of the new composite are designed to perform specific functions unattainable by single alloys. For example, a recent development effort has made very significant progress in this area by combining a newly developed Fe-12Cr-2Si alloy with a high strength steel (T91/F91) in a functionally graded composite (FGC)[1], for the lead-bismuth eutectic fast reactor (LBEFR). The new FGC has demonstrated excellent resistance to corrosion in Pb/LBE that suggest that corrosion will not be an issue for operation of materials at temperatures up to 700°C. This significant breakthrough on this new composite material encourages us to rethink the current and proposed coating technologies for enhancing Zircaloy accident-tolerance.

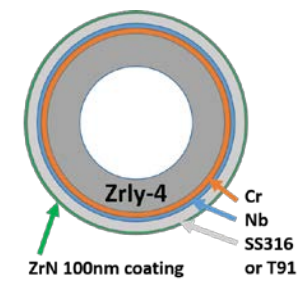

Figure 1: Diagram of the proposed LWR MMLC

The layers of the proposed MMLC (as shown in Figure 1) are designed to perform specific functions unattainable by single alloys. Fuel cladding composed of a stainless steel (SS) or a ferritic/martensitic alloy such as T91, overlaid onto a Zircaloy base, could reduce the amount of Zr in the reactor, resulting in less hydrogen evolution during a severe accident. In addition, a MMLC will be less susceptible to sudden, brittle failure of fuel cladding due to directional hydride formation in Zircaloys. Finally, the water-facing layer of stainless steel will resist severe accident corrosion better than Zircaloys. Diffusion barrier layers of Cr and Nb must be used in between Zr and an iron-based alloy, to avoid detrimental eutectic phase or intermetallic formation. We will: 1) fabricate the composite on an industrial scale, 2) Characterize and improve joining techniques, including MMLC endcaps, 3) Use multiscale modeling to simulate accident performance and radiation resistance of the MMLC, 4) Determine the long-term steady-state and severe accident corrosion resistance of the MMLC, and 5) Validate these multiscale models with laboratory-scale severe accident testing and corrosion and electrochemical tests.

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[1] M. P. Short, R. G. Ballinger, H. E. Hanninen. *Nucl. Technol.*, 177(3):366 (2012).