Project Title

Radiation-induced swelling and microcracking in SiC cladding for LWRs

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ABSTRACT:

After the Fukushima accident in 2011, SiC has attracted considerable attention as a potential material for fuel cladding that can offer increased accident tolerance in light water reactors (LWRs) compared to zircaloy cladding. Existing measurements on nuclear grade SiC/SiC composites made of high-purity, stoichiometric SiC have already shown very good radiation tolerance in various harsh environments. However, there are a number of challenges that need to be addressed before SiC composites can be successfully used in LWR technologies. One of them is irradiation-induced swelling, which can lead to development of significant stresses in the matrix, followed by microcracking and subsequent release of fission products. Up to this point, models of irradiation-induced swelling have been largely empirical, so they cannot be used to predict the microstructural dependence of microcracking. The models are empirical because we lack understanding of defects that form due to irradiation in the range of temperatures relevant to fuel cladding in LWRs (<1000°C). Many of the defects in this regime of temperature are too small to be detected with traditional transmission electron microscopy (TEM) techniques. In fact the defects observed in TEM account only for 10-45% of the swelling measured in irradiated SiC.

In this project the PIs will develop a multi-scale simulation methodology combined with state of the art experimental imaging techniques based on high resolution scanning transmission electron microscopy (STEM) to provide the scientific basis for models of radiation swelling and microcracking in SiC. The multiscale simulation approach includes phase field model of microcracking (implemented in the MOOSE/MARMOT framework), cluster dynamics simulations of swelling, and atomistic simulations that provide parameters for the phase field and cluster dynamics model. Experimental approaches include high-resolution TEM and STEM of radiation-induced defects, atomic force microscopy and X-ray diffraction studies of swelling and of depth-resolved strain, and state of the art mechanical testing, including testing inside a TEM with simultaneous imaging that allows monitoring of microstructure and cracks during deformation. The outcome of this research will be a master equation that relates swelling, volume of microcracks and their size distribution to irradiation and temperature history. This equation can be then implemented in BISON fuel performance code and, in the future, it can be related to fission product release under given irradiation conditions. Integration from the atomistic to continuum framework with experiments is necessary to predict performance of SiC as a clad material as a function of microstructure and environment.