U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

On the Path to a Nuclear Fuel Digital Twin: Modeling and Simulation of Silicon Carbide Cladding for Accelerated Fuel Qualification

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Collaborators: Idaho National Lab, Los Alamos National Lab

Pathway: Advanced Reactor Development Projects

Scope and Objectives

The General Atomics Electromagnetic Systems (GA-EMS)-led team proposes to deliver a novel nuclear energy advanced modeling-enabled silicon carbide (SiC) ceramic composite (SiC-SiC) surrogate modeling tool. The tool will form a basis to significantly advance the implementation of SiC cladding and components in an accelerated fuel qualification (AFQ) methodology. As part of the proposed work, the GA-EMS-led team will develop and incorporate a constitutive surrogate model into the BISON framework after verifying model accuracy against an ANSYS empirical model and validating against experimental data. This work will begin the process of developing a "digital twin" of SiGA® composite (GA-EMS SiC-SiC composite).

Project Description

The GA-EMS team will perform six objectives for development and utilization of the surrogate model:

- Develop a mechanism-based constitutive surrogate model to capture the material response of SiC-SiC composites utilizing simplifying equations to reduce model complexity
- Incorporate x-ray computed tomography (XCT)-informed fiber tow architecture into existing ANSYS models allowing surrogate model validation with a more empirical approach
- Extend the BISON fuel performance model capturing key thermal, mechanical, and irradiation behavior of SiC-SiC composites allowing integration with the surrogate model
- Identify and bound model uncertainties for all models using available mechanical and irradiation test data
- Incorporate and demonstrate initial application of the surrogate model to a specific fuel form (UO_2 for this project) using the BISON analysis framework
- Chart a path to establish a digital twin of the complete fuel-cladding model

The core of the surrogate modeling tool is based on LANL's reduced order modeling approach, which uses an empirically-informed database of likely SiC-SiC unit/cell responses to a range of load environments to predict SiC-SiC thermos-mechanical behavior. This model has the benefit of being significantly computationally cheaper than standard finite element analysis methods while still capturing the complex thermos-mechanical response of SiC-SiC. The surrogate model will be incorporated into BISON so true fuel performance modeling can be performed.

Potential Impacts of the Project

While there are a wealth of commercial in-reactor uses for SiC-SiC composites, including accident tolerant cladding, channel boxes, and other in-core reactor components, the development and licensing timeframe must be reduced. The development of this surrogate model would represent major progress towards successful completion of the AFQ program for SiC-SiC composites.

Project Deliverables

GA-EMS will provide the following reports to the DOE in addition to quarterly reports: Risk Management Report, Digital Twin AFQ White Paper, Model Validation and Verification Report, and Digital Twin Roadmap Report.