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Modeling high-burnup LWR fuel behavior under normal operating and transient conditions

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ABSTRACT:

This project aims to develop a high-burnup light water reactor (LWR) nuclear fuel modeling capability to implement in the US DOE fuel performance code BISON, in order to provide a high impact in terms of informing the safety case and supporting the extension of burnup limits pursued by the US nuclear industry. For this purpose, mechanistic engineering models will be developed for key high-burnup phenomena during both normal reactor operation and design basis accidents (DBA), including loss-of-coolant accidents (LOCAs) and reactivity-initiated accidents (RIAs). The focus will be on (1) the evolution of the high-burnup structure (HBS), (2) high-burnup fuel fragmentation during DBA transients, and (3) fission gas release (FGR) resulting from fuel fragmentation and transient response. The modeling developments will target both the traditional UO_2-Zr system and leading accident tolerant fuel (ATF) concepts, in particular, Cr_2O_3-doped UO_2 and coated Zircaloy cladding. The work will be coordinated with the NEAMS program. The new modeling capability will be validated to high-burnup fuel experiments.

The proposed research aims to fill a critical gap in the state of the art of fuel performance analysis by introducing accurate models for fuel behavior at high burnup. Our strategy to attack the complex problems involved is articulated in the following four major tasks: (1) development of a mechanistic model for high-burnup fuel fragmentation and transient FGR in unrestructured fuel, (2) model development for the evolution and transient fragmentation of the HBS, (3) implementation of the developed models in the BISON code and validation to experiments, (4) capability extension and application to ATF concepts.

The modeling methods involve a combination of mechanistic understanding of the relevant physical processes, enhanced by coupling to lower-length scale calculations, and a reduced-parameter, engineering approach to model formulation. The effectiveness of this path has been demonstrated, e.g., by the development and impact of the current standard fission gas model in BISON. With that said, we will introduce a variety of new and transformative modeling concepts and features to adequately represent the complexities involved in high-burnup fuel behavior.

The proposed project will produce a simulation capability to (i) identify the fuel rod life-limiting factors at extended burnup, (ii) evaluate the additional safety margins brought by ATF and (iii) guide the design of experiments. The developed models will accelerate and inform the safety case by accurately estimating the quantity of fuel susceptible to dispersal, FGR and rod inner pressure, giving a tangible contribution to the formation of a technical basis for the extension of burnup limits pursued by the US nuclear industry.

Major deliverables from this project will include the release of a suite of validated computational models, documented through progress reports, peer-reviewed publications, technical presentations and a final report containing all simulation data including code verification and experimental validation results.