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Transient Reactor (TREAT) Experiments to Validate MBM Fuel Performance Simulations

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ABSTRACT:

In 2012, Congress mandated DOE-NE to initiate the Enhanced Accident Tolerant Fuel (ATF) program for aggressive RD&D for LWR fuels in the wake of Fukushima Daiichi nuclear disaster. The ATF program goals include performance demonstration by insertion of a lead test assembly (LTA) into a commercial power reactor by 2022. New ATF fuel designs are scheduled to be tested under simulated reactivity initiated accident (RIA) conditions at the transient reactor test (TREAT) facility at INL to prepare for the LTA insertion.

We propose to conduct benchmark experiments in TREAT to generate critical validation data for RIA using commercial reactor fuels and supporting separate effect experiments at participating universities. The data will be used to improve and validate DOE-NE software, specifically MBM fuel performance codes. The project will address key challenges of transient fuel performance modeling, which is essential to the DOE ATF and LWR programs. The validation data will be included in the database of the DOE Nuclear Energy Knowledge and Validation Center (NEKVaC).

Our research will focus on three key physical processes controlling fuel performance and safety in RIAs: 1) Fuel fracture/fragmentation; 2) Cladding failure under hydride build-up; and 3) Transient boiling of cooling water. The proposed work will be leveraged with ATF-3 testing in TREAT to provide tremendous savings on the costs of the reactor experiments and, more importantly, to make significant

progress toward establishing benchmarks for validation of high-fidelity multi-physics codes, such as MBM, in postulated accident conditions.

The specific **objectives** of this project are:

1. Characterize intensively 1) fuel fracture/fragmentation patterns, 2) cladding mechanical behavior under different hydride conditions, and 3) fast transient boiling of water under PWR conditions from separate effect validation experiments to provide detailed initial, boundary, and property data for the reactor experiment, as well as a basis for MBM model improvement;
2. Design TREAT benchmark experiments (using the ATF-3 SERTTA vessel) and conduct twelve integral experiments for transient fuel performance under RIA conditions with detailed pre- and post-test characterization and advanced in-pile instrumentation;
3. Utilize the data to improve models and quantify accuracy and validation uncertainty of multi-physics MBM codes in modeling RIA events; and
4. Integrate the research result with the OECD-NEA RIA benchmark effort and into NEKVaC database, and translate the lessons learned to a college course, Verification & Validation, as well as a V&V education module for wider dissemination.

Our team will use computational modeling and separate effect experiments to inform the design of twelve integral experiments using ATF-3 Multi-SERTTA in TREAT, with samples highly characterized before, during, and after irradiation. Commercial fuels from DOE ATF-3 teams will be used, with artificially impregnated hydrides at different levels, size and orientation and well-characterized microstructure and mechanical properties. The system response quantities will be determined under varied pulse energy levels, hydride characteristics, and boiling surfaces with quantified experimental uncertainty levels under INL TREAT quality assurance plan. The separate effect experiments will provide well-defined initial conditions of the fuel and cladding and temperature dependent mechanical and thermal property data for the integral TREAT experiment. We will use the separate effect and integral experiment data to improve and validate fuel fracture, cladding mechanical behavior and fast transient boiling models and the strongly coupled multi-physics RIA phenomena using the engineering scale MBM codes. The technical approach is divided into **five major tasks**:

Task I: Fuel Fracture/Fragmentation--Fracture morphology data under different microstructure (grain size and grain boundary gas bubbles) and temperature ramping rates using surrogate fuels,UO_2 and ATF fuel pellets, for improving and validating MBM fuel fracture models;

Task II: Clad Failure—Clad mechanical behavior and property under different hydride levels and microstructural characteristics using thermomechanical testing with surface strain mapping, for improving and validating constitutive models of hydrided cladding;

Task III: Transient Water Boiling--Fast transient boiling data under PWR conditions to obtain CHF and post-CHF correlations using clad surface temperature and void sensors under different pulse energies and clad surfaces;

Task IV: Integral TREAT Experiments--Integral validation data on transient fuel performance under LWR RIA conditions with varied energy injection, fuel characteristics, clad hydride conditions, and surface types using detailed pre- and post- characterization and in-pile instrumentation; and

Task V: MBM Model Integration and Validation--MBM code validation using the experimental RIA validation data to quantify the total validation uncertainty for RIA simulation.

The project complements the ATF-3 program, which focuses on failure thresholds of new ATF fuel concepts under RIA conditions. The schedule of ATF-3 matches this IRP program timing with sufficient contingency for unexpected delays. The unique **impact** of the proposed work is that it will be the first systematic validation experiment on RIA and first MBM modeling of RIA. The international partners are highly interested in using the data to validate their fuel performance models and the industry partners are interested in the validated modeling capability for ATF and LWR fuel testing in TREAT.