Three-dimensional Fuel Pin Model Validation by Prediction of Hydrogen Distribution in Cladding and Comparison with Experiment

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ABSTRACT:

This project will combine the efforts of two universities and one national laboratory to validate important three-dimensional aspects of the fuel pin modeling by using high-fidelity multi-physics coupling and comparison with targeted experiments. The proposed project is focused on validation of the NEAMS tool BISON for predicting fuel performance in a LWR environment. The project will use measured data for hydrogen distribution in the cladding (both from model experiments on artificially hydrided cladding and from the available results of Post-Irradiated Experiments (PIE) examinations of in-reactor material) in order to assess the predictions of temperature and hydrogen distributions using the BISON code.

The behavior of hydrogen in the cladding can be a useful parameter to evaluate three-dimensional temperature distribution calculations, because the hydrogen is very responsive to temperature and stress gradients, which result in hydrogen distribution gradients in the radial, azimuthal and axial directions in a fuel rod. Because of this, the multi-dimensional hydrogen distribution is a good ersatz for the temperature distribution and the related experimental data can be used for three-dimensional fuel pin model validation in BISON. The key is to accurately calculate the 3-D temperature distribution in the cladding tube, with a sufficiently fine mesh such that the induced variations in hydrogen concentration can be captured. High-fidelity multi-physics coupling is capable to provide accurate *azimuthal, radial, and axial temperature distributions in the cladding*.

Two multi-physics code systems will be utilized to calculate detailed temperature distributions, which can be validated using hydrogen experiments and models for hydrogen behavior. The two coupled reactor physics/thermal-hydraulics/fuel performance code systems, which will be completed and used within the framework of the project, are TORT-TD/COBRA-TF/BISON and MPACT/STAR-CCM+/BISON. The first one will be used for detailed core or pin array depletion analysis while the second one will be performed in addition to benefit from higher-fidelity modeling especially in selected axial regions of fuel rod where explicit modeling of features such as grid spacers is needed. The calculation techniques are complementary, in that for most cases the multi-physics sub-channel-based (COBRA-TF) model is sufficient and realistic for full core calculations, but for more detailed and complicated geometries, the multi-physics CFD-based (STAR-CCM+) calculations are essential. This is especially true in the proximity of the grid spacers, as the mixing vanes strongly affect the location of the hot spots on the fuel cladding.

To correctly describe hydrogen distribution we propose to conduct two separate experiments to measure important quantities and to validate the hydrogen model in BISON. During the duration of the project, we plan to identify and select the available detailed PIE data on hydrogen re-distribution in order to compare it to our high-fidelity multi-physics calculations. Inter-disciplinary expertise has been assembled in all key areas with unique capabilities in reactor physics, subchannel and CFD thermal-hydraulics, fuel performance, materials and experiments. PSU and UM have ongoing collaborations with INL. Such collaborations have yielded some of the tools necessary to perform this multi-physics analysis in this project including the creation of a kernel (module) for hydrogen. The project will be very useful for both validating the three-dimensional fuel pin models and proving the importance of high-fidelity multi-physics coupling. As a result both deficiencies in BISON fuel performance models (if any) as well as gaps in the experimental databases will be identified as areas needing further development.