Collocation-based Surrogate Models for Uncertainty Quantification and Validation of Coupled, Multiphysics Fuel Performance Simulation Tools

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ABSTRACT:

The ultimate purpose of computer codes in nuclear engineering is to perform predictive simulations that faithfully reproduce the observed physical phenomena in a reactor. Since the processes inside nuclear reactors are inherently complex involve many different physics, recent efforts in the computational modeling of reactors has consisted of tightly coupling several high fidelity codes, each of which specializes in modeling a particular physical process. The use any engineering predictive simulation tool in the licensing analysis of a reactor requires extensive validation of the tool against experimental data. A Bayesian framework is typically used for code validation, however, such a framework generally requires numerous code simulations, which can be computationally very intensive for fully coupled, multiphysics codes. This can limit the extent of the validation effort, unless surrogate models can be developed which can effectively reproduce the essential features of the original coupled, multiphysics system and thereby focus and accelerate the validation analyses of the original coupled multiphysics codes. The validation of high fidelity, full physics calculations with a 3D fuel pin performance modeling code such as BISON requires neutronics and temperature/fluid field information that are of comparable fidelity, which implies the use of detailed intrapin and azimuthally dependent neutronics and thermal hydraulics in the fuel elements. The overarching objective of the work proposed here is not only to provide the necessary high fidelity, coupled, multiphysics fuel performance simulator but to also develop surrogates which will accelerate and focus the validation of the coupled codes. This will be achieved by utilizing the high fidelity coupled fuel performance, thermal-hydraulics and neutronics codes BISON/STAR-CCM+/MPACT and an innovative collocation-based surrogate methodology based on algorithms already implemented in Sandia National Lab's Dakota code. Dakota is a mature software framework and this work will leverage the significant software investment made in the Dakota suite of algorithms and capabilities at SNL, as well as take advantage of the existing code coupling work performed with BISON/MPACT/STAR at Idaho National Laboratory and the University of Michigan. The principal outcomes of the work here will be a significant advance in the state of the art in the predictive modeling of Light Water Reactor fuel pin performance and an innovative method for the uncertainty quantification and validation of the coupled codes based on surrogate model construction. The deliverables of this work will be the implementation of this computational toolset within the MOOSE and DAKOTA frameworks at INL and SNL, respectively.