Modeling and Analysis of Exelon BWRs for Eigenvalue & Thermal Limits Predictability

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ABSTRACT:

Exelon nuclear generation is the largest US nuclear utility with 23 operating nuclear reactors, 15 of which are Boiling Water Reactors (BWRs). Historically, BWRs have had greater flexibility in terms of fuel product design as evidenced by the evolution from the earliest 6x6 lattice designs to the current 11x11 designs. This evolution saw the introduction of many new product features including multi-streaming of burnable absorbers, multi-level part length fuel rods, and advanced grid designs for improving thermal performance. This continual evolution, along with more demanding operating domains (such as EPU and MELLLA+), has challenged traditional nuclear analysis codes and methods that can experience difficulties in predicting core reactivity, energy, and thermal power. This is especially true for transition cycles involving power uprates, changes in cycle energy plan, and introduction of new fuel products. The most severe consequences of such mispredictions are the potential for power derate or cycle energy shortfall, both of which have large, negative economic impacts on the nuclear utility.

CASL (Consortium for Advanced Simulation of Light Water Reactors) tools have been developed to advance the state of the art in the modeling and simulation (M&S) for light water reactors (LWRs). While primarily focused on challenge problems related to pressurized water reactors (PWRs), VERA (Virtual Environment for Reactor Applications) is uniquely positioned to address the M&S challenges of BWRs. It is noted that the key differences in the modeling of BWRs are associated with prediction of two-phase flow within the various BWR flow regimes (e.g. annular flow) and the feedback of the predicted void on the nuclear data and power distribution calculation. To this end, the CASL focus for BWRs has been on improving the predictions of two-phase flow and the nuclear cross-section data library generation across

the range of void conditions. While additional BWR development remains, the advanced capabilities of VERA should allow for modeling of BWRs beyond what exists today with current industry codes.

Some of the features of VERA that should yield substantial improvement over existing industry predictions is the modeling of void and depletion parameters on a rod-by-rod basis instead of a bundle-average basis, and detailed modeling of different bypass flow regions. Within VERA-BWR the coupled pin-by-pin neutronic and subchannel thermal-hydraulics enables a more rigorous calculation of within bundle power distribution. This is especially important in the presence of large power gradients such as occurs with the insertion of control blades. The feedback of the radial void distribution, particularly at high void, is expected to have a significant impact on calculated results. In addition, it is expected that the elimination of history models in the cross-section generation and the inclusion of radial void distribution within bundles will improve eigenvalue and detector predictions.

The prediction of eigenvalue and thermal limits in BWRs remains a challenge for nuclear industry that has serious economic implications on the operating fleet. BWRs represent approximately one third of the US operating fleet and the ability to predict, with confidence, BWR core behavior is essential to continued advancement of new fuel products and designs, such as Accident Tolerant Fuel (ATF) and more demanding operating domains, such as EPU and MELLLA+. The current proposal leverages the existing CASL technology that has matured for PWRs by focusing on those modeling aspects of BWRs where there are known approximations. The result of this effort will be a deeper understanding BWR behavior, especially as it relates to two-phase flow and void feedback. This will lead to improved predictions for the current BWR fleet including reactivity and thermal margins, which has a direct, positive economic impact in terms of cycle energy production and fuel costs.