MITIGTATION OF CIPS RISK THROUGH CORE DESIGN OPTIMIZATION

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ABSTRACT

During the loading pattern (LP) selection process, margin to safety analysis calculations is maximized through reactivity distribution, while staying within a set fuel management strategy. In addition to safety analysis parameters, the LP's are optimized to reduce risk with respect to core phenomena such as crud induced power shifts (CIPS) also known as axial offset anomaly (AOA). CIPS is a result of soluble boron "hiding-out" from the coolant into crud deposits on fuel, which are a byproduct of local subcooled boiling or steaming. CIPS can lead to axial offset (AO) mispredictions, which can have an impact on the reload's safety evaluation. Additionally, excessive crud deposits can have an adverse impact on fuel performance. To mitigate the CIPS risk in the LP selection process, an effort was made to correlate power distributions (both radially and axially) to core design parameters, which are then correlated to the CIPS risk. The maximum average assembly power (Pbar) was used as a representative for the radial power distribution. Through an extensive evaluation, it was determined that using assembly-averaged values were not on a spatial resolution to be effective, and that the average subnode power (Psub) where a subnode is one-quarter of the assembly is much more relevant. Minimization of Psub versus Pbar has a large impact on the CIPS risk. Optimizing the axial power distribution was done by increasing the number of burnable poisons (BP's).

1. INTRODUCTION

A. W. Vogtle Units 1 and 2 are high duty, four-loop PWRs. Both units have recently undergone a 1.7% measurement uncertainty power uprate (MUR-PU) to increase the rated thermal power to 3625.6 MWt. Moreover, in an effort to minimize dose as well as mitigate the effects of stress corrosion cracking (SCC), zinc is injected continuously throughout the duration of the cycle. The duty of the plant coupled with zinc injection makes the Vogtle Units susceptible to CIPS. CIPS is a result of soluble boron "hiding-out" from the coolant into crud deposits on fuel as a result of local steaming. An effort was made to minimize the CIPS risk through core design change by reducing the subcooled boiling. During the LP selection process, peaking factors are minimized while staying within fuel management restraints.

2. DESIGN PROCESS

A typical Vogtle loading pattern has a "ring-of-fire" (ROF) near the periphery and a "checkerboard" interior. These terms are used to describe the placement of the fresh (feed) assemblies, which are represented as "Region 17" below. Figure 1 is an example loading pattern.

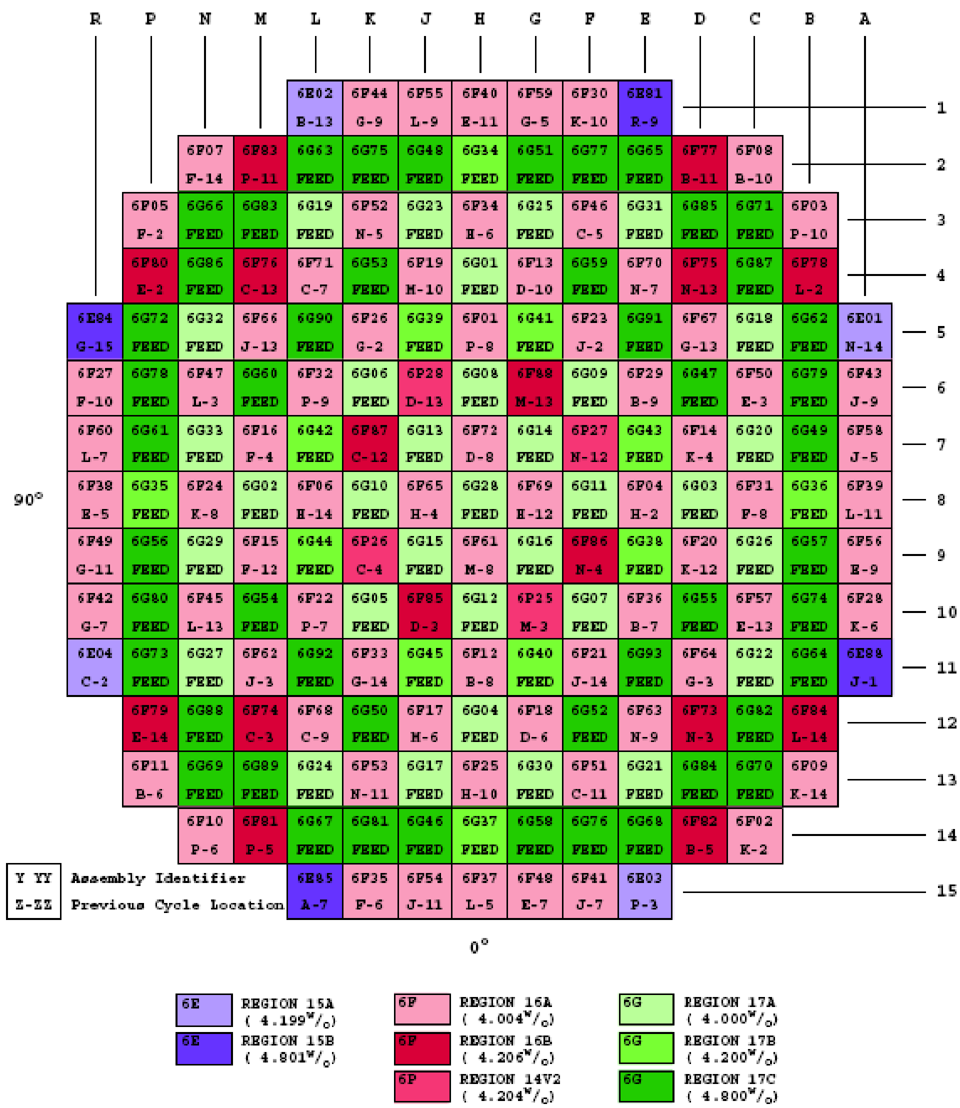

Fig. 1 Typical Southern Nuclear Loading Pattern

2.1 Design Overview

Psub is minimized by reactivity distribution, which occurs in the form of BP placement, fuel shuffling and the overall number of feed assemblies (i.e., more feed assemblies result in a lower nodal and subnodal maximum power since the power is able to more evenly distribute). The code Southern Nuclear uses for LP selection is ROSA, which optimizes the BP placement and fuel shuffling to minimize Psub. Once an LP meets the scoping requirements, more detailed calculations about the power distribution are done (radially and core-average axially) in our design neutronics code (ANC). These power distributions are then fed into VIPRE-W along with thermal hydraulic input and assumptions for a detailed nodal steaming rate calculation. An EPRI code (BOA) takes this information along with basic chemistry input and assumptions and calculates the amount of boron deposited on the fuel during the cycle as a function of exposure. This amount is then used as an index to assess the risk of encountering CIPS during that cycle[1].

2.2 Power Distributions

Initially, during the cycle scoping process, the maximum average assembly power (Pbar) was minimized. It was discovered that two LP's could have a comparable Pbar along with other comparable core parameters (e.g., critical boron concentration, MTC, etc.), but have very different CIPS risks. Since the thermal hydraulic input into VIPRE (e.g., core flow, temperature, etc.) and chemistry input into BOA (e.g., pH, boron and lithium concentrations, crud source terms, etc.) were virtually identical, the difference had to be within the power distribution *within* assemblies. The VIPRE-W code uses subnode radial power (2x2) for each assembly from the neutronics code. The once-optimized, Pbar, is simply an average of these four local powers. When optimizations were made on the subnodal level (i.e., Psub), the CIPS risk decreased dramatically – in case presented in this paper by over 50%). Therefore, minimizing Psub as opposed to minimizing Pbar can have a large impact on the CIPS risk.

It is important to note the distinction between minimization of Pbar and Psub. Due to core geometry, minimization of Pbar tends to draw power away from the center of the core where the power distribution within an assembly is flat and to the ROF where there are large power gradients within assemblies. Thus, when Pbar is calculated within these ROF feed assemblies, the subnodes closest to the core baffle help to lower the average assembly power; however, the subnodes in these ROF assemblies facing the core center (inner subnodes) typically are the highest powered subnodes in the core. These inner subnodes are where the most boiling and hence crud and boron deposition occur, which has a dramatic effect on the CIPS risk. Minimization of Psub through the subnode power optimization (SPO) recognizes the inner subnodes as limiting, and while it cannot lower the magnitude of the gradient within the ROF feed assemblies (Southern Nuclear does not currently design asymmetries within assemblies such as zone enrichment or asymmetric BP patterns), it lowers the overall magnitude of power within the ROF feed assemblies by suppressing them with additional BP's, and generally lowering the enrichment. Thus, it moves the power closer to the core center where the power distribution within assemblies is relatively flat.

Axially, subcooled boiling can be minimized by reducing the coolant boron concentration. A reduction of 100 ppm in the boron concentration results in a lower MTC at the beginning of cycle (BOC). The lower MTC causes the AO to become more negative as well during the early part of the cycle, where the magnitude of boron concentration is the highest. By causing the power to shift downwards, subcooled boiling near the upper spans of fuel is suppressed. The coolant boron concentration is reduced by designing the core using an increased number of BP's. The BP's Vogtle uses are ZrB_2 integrated fuel burnable absorber (IFBA) and Al_2O_3-B_4C wet annular burnable absorber (WABA). Typically, Vogtle LP's have a maximum coolant boron concentration of approximately 1200 ppm at hot full power (HFP), and by increasing the BP's, the designs were reduced to approximately 1100 ppm. A reduction in boron also reduced the lithium concentration needed to maintain the same pH, which lowers the CIPS risk as well.

2.3 Cost

There is some cost associated with the SPO. Increased use of IFBA and WABA (higher overall number and generally more rods per assembly) does have a financial impact on the design. This impact however, compared to alternative methods to reduce CIPS risk (e.g., increase number of feed assemblies, primary-side chemical cleaning, etc.) is quite small.

The SPO does impact other safety calculations. The most prominent of these for Vogtle is shutdown margin (SDM). SDM is reduced by approximately 100 pcm as a result of SPO. This is due to the impact of the radial and axial power redistributions on control rod worths. Vogtle has sufficient margin so this tradeoff is deemed acceptable.

3. RESULTS

The calculations relevant to determining CIPS risk for two LP candidates for a recent Vogtle cycle are presented below in Figures 2 – 7. Pbar along with other core parameters of these patterns are comparable; however, the second pattern has undergone SPO. Each "block" in Figures 2 – 7 represents one-quarter on an assembly, i.e., a subnode. One-quarter of the core is represented in those Figures as our designs are symmetric.

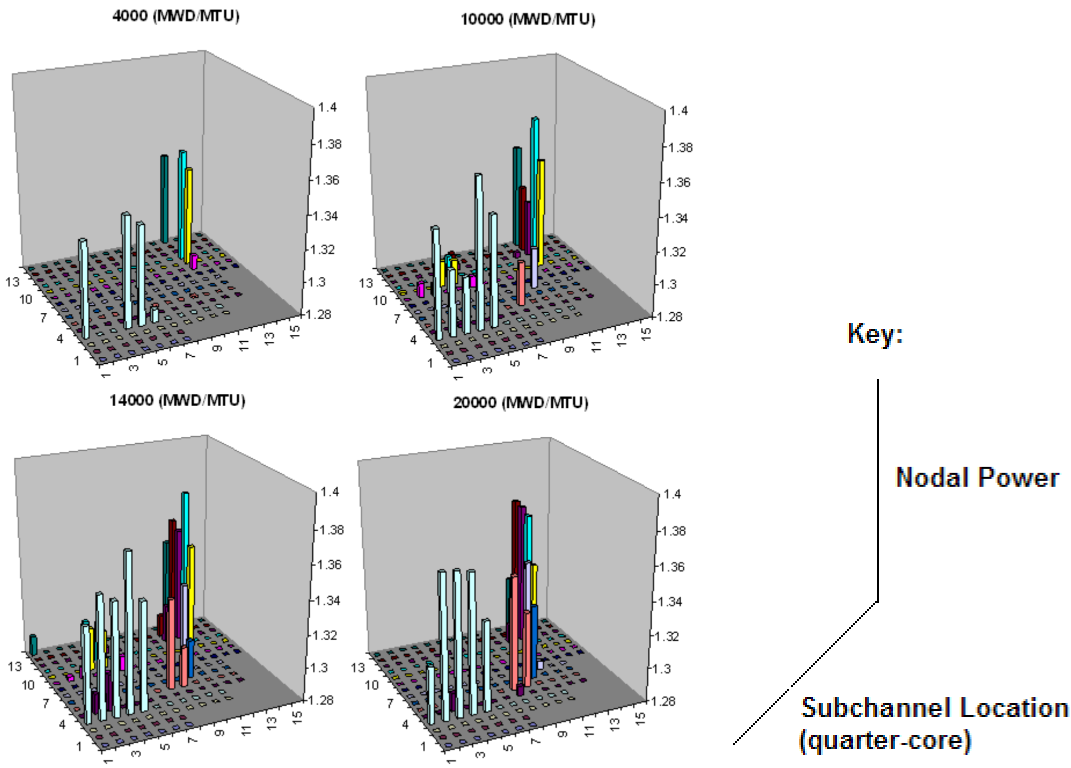

Fig 2. Radial Power Distributions for LP #1

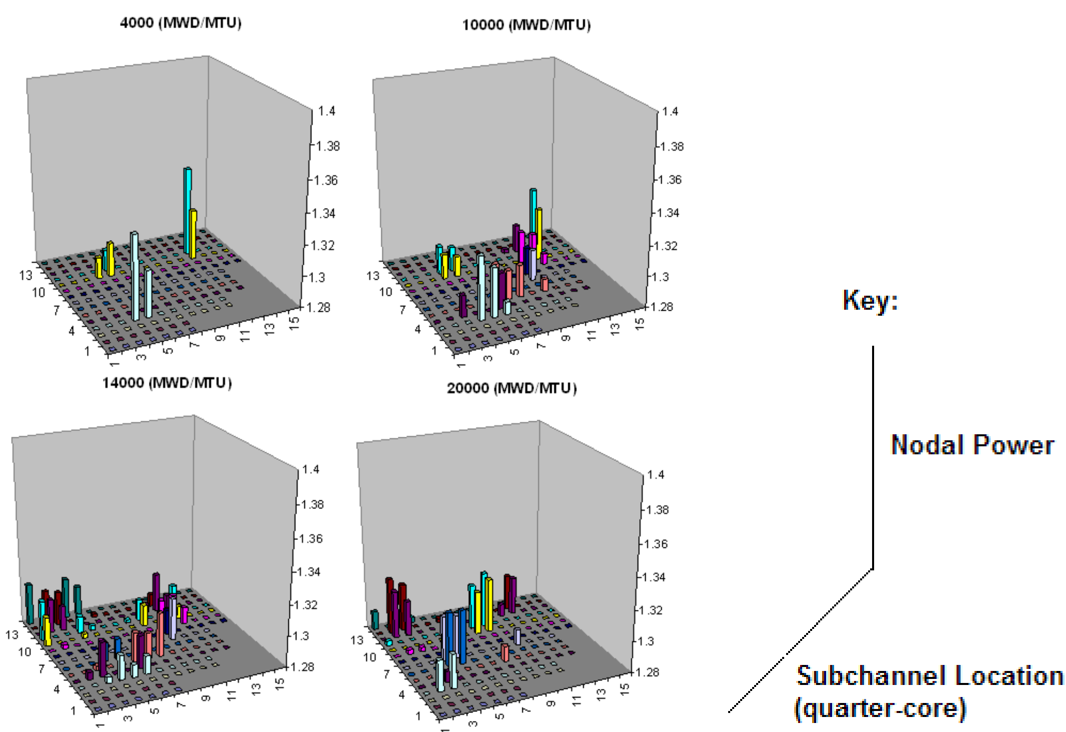

Fig 3. Radial Power Distributions for LP #2

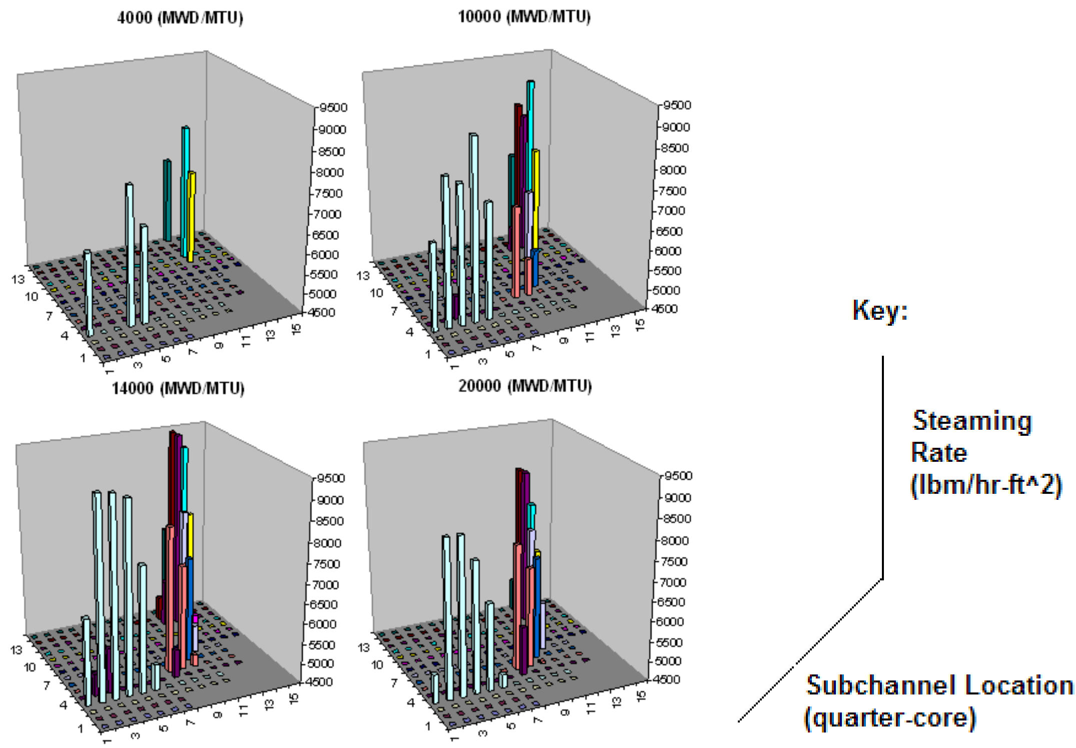

Fig 4. Steaming Rates for LP #1

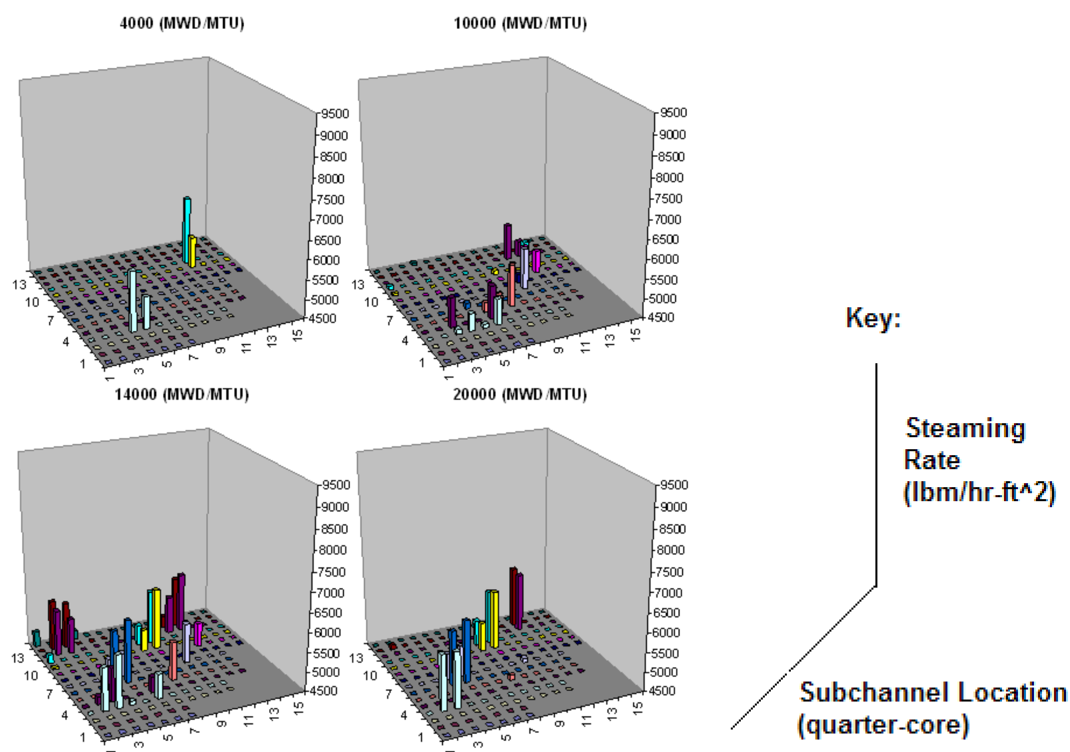

Fig 5. Steaming Rates for LP #2

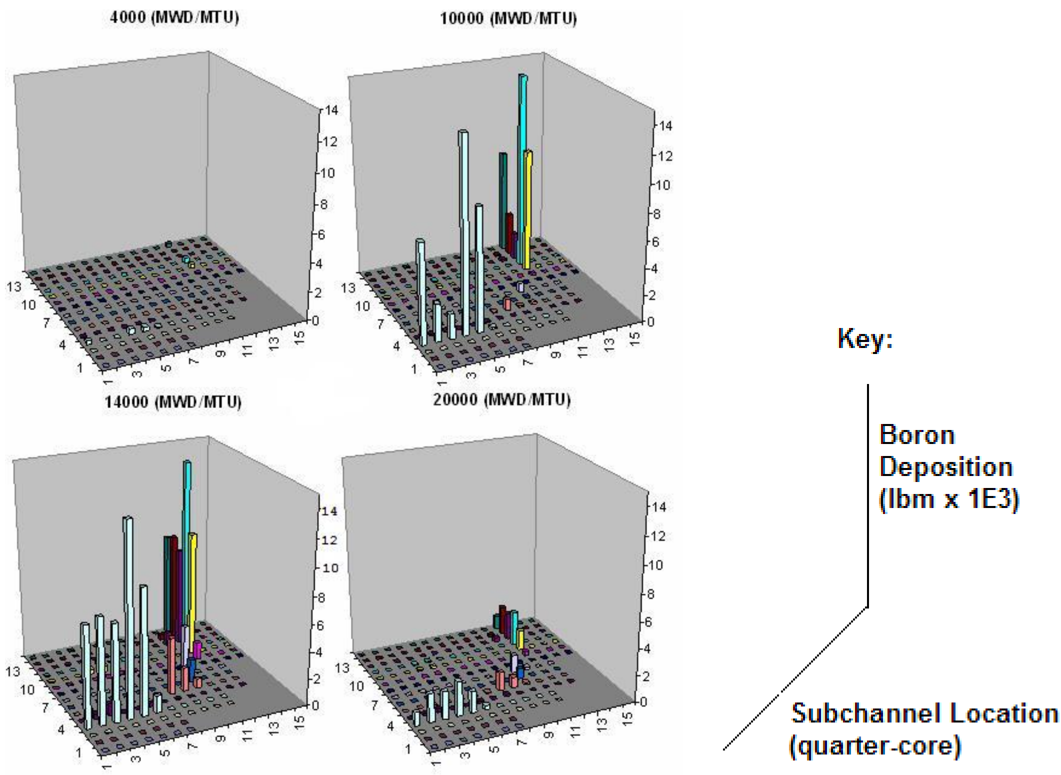

Fig 6. Boron Deposition for LP #1

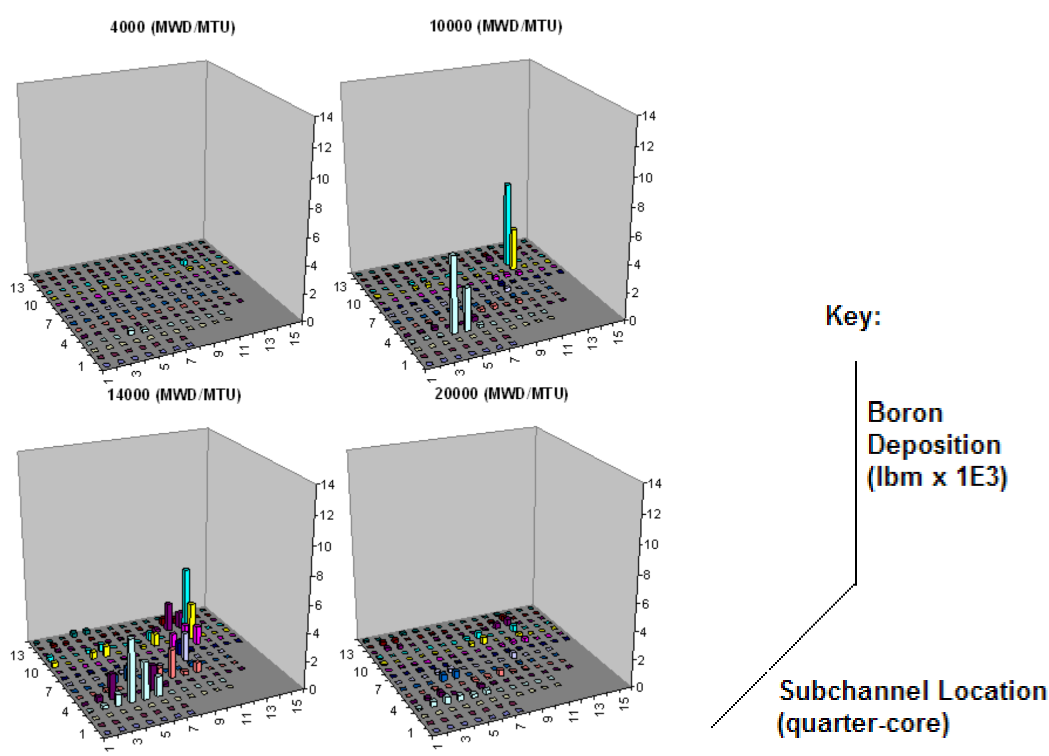

Fig 7. Boron Deposition for LP #2

The predicted core boron deposition in the first LP is about 0.45 lbm, and it is 0.20 lbm in the second LP. The threshold between low and mild CIPS risk is 0.30 lbm[1]. Below is a figure of the predicted core boron deposition as a function of core exposure for the two LP's along with Vogtle-1 Cycle 13, which experienced moderate CIPS.

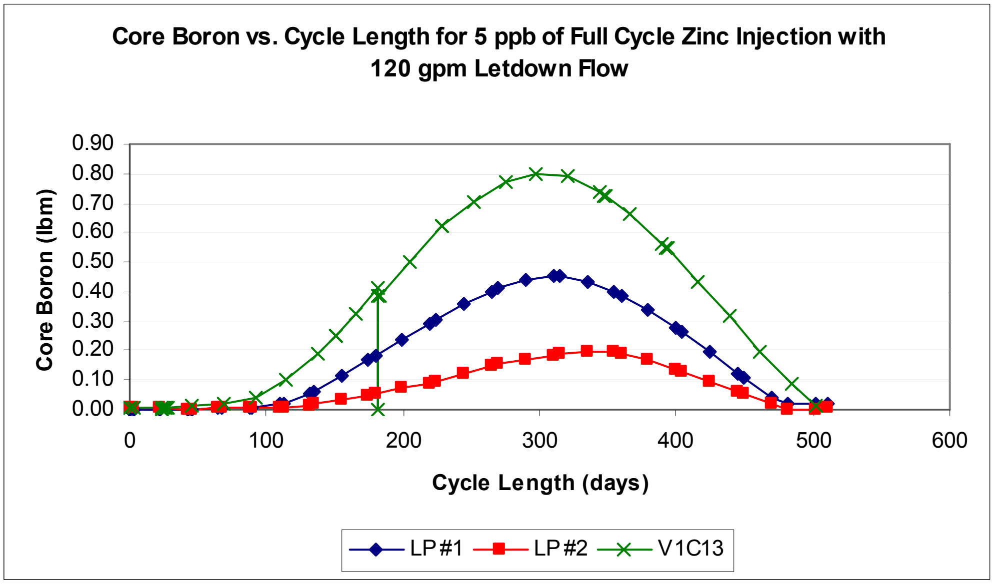

Fig 8. Boron Deposition vs. Burnup

4. CONCLUSIONS

As seen in the above figures, SPO flattens and spreads out the power distribution. Since boron deposition is nonlinear with respect to the steaming rates, the boron deposited onto the fuel (and hence the CIPS risk) is greatly reduced by SPO. Both LP's presented in this paper had a coolant boron concentration lower than V1C13, which also lowered their CIPS risks. Finally, the benefit of lowering the CIPS risk far outweighs the economic and margin tradeoffs associated with the SPO.

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REFERENCES

1. Boron-induced Offset Anomaly (BOA) Risk Assessment Tool, Version 1.0, EPRI, Palo Alto, CA. Product ID 1003211, April 2003.