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Engineering Feasibility of Low Boron Core Design for OPR-1000

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1. Introduction

In previous research, the feasibility and benefits of nuclear design methodology of low boron core (LBC), has been checked in order to adapt to practical application of operational mode with reduced soluble boron concentration at current PWR concepts, OPR-1000. Most of design parameters were the same with those of reference core (REF) design, Ulchin unit-5 except extensive utilization of integral burnable absorbers (IBA) in order to compensate reactivity increase in LBC. A parametric study was performed at cycle 1 and 2 to find the optimal core options from many design candidates for fuel assemblies (FA) with IBA such as gadolinia, integral fuel burnable absorber (IFBA), erbia and alumina boron carbide, and cores. Among them, the most feasible core design candidate was chosen based on general design requirements as regards lower critical boron concentration, smooth reactivity control and feedback, engineering constraints such as thermal hydraulic and safety parameters [1]. The core design with IFBA-bearing FA had been suggested to proceed to further investigation into core design performance and its feasibility at equilibrium cycle in comparison with REF design under normal conditions.

A technically straightforward possible means to reduce the maximum boron concentration amount, can be achieved by either increasing more shim rod (fixed burnable absorber) worth or implementation of enriched boric acid (EBA) [2]. After we analyzed the feasibility and safety aspects of the most favorable LBC design at equilibrium cycle in more detail through the comparison of neutronic and thermal hydraulic design parameters with the REF design, as an additional research work, we also take into consideration of the alternative option by simply implementing EBA in reference design. As calculation tools, the HELIOS/MASTER code package is utilized. The main purpose of this study is to estimate engineering feasibility and capability of LBC by choosing either more shim rods or enriched boric acid instead of use of higher concentration amount of soluble boron, which can increase volume production of liquid radioactive waste contributing to higher radiation dose to operators and the increase in the corrosion damages.

2. Performance Low Boron Core Design

Although the gadolinia has large absorption cross section, and the required number of gadolinia-bearing fuel pins to hold down the initial excess reactivity is typically small when compared to IFBA, Al_2O_3-B_4C and UO_2-Er_2O_3, fuel displacement due to gadolinia, is larger than IFBA. By applying current PWR, OPR-1000 technology, and keeping major engineering designs and preserving equivalent fuel enrichment level used REF design, there was a challenging to meet design objectives such that the optimal design was targeted to achieve comparable discharge burnup as well as favorable design safety parameters such as acceptable nuclear power peaking factor, F_q.

In addition that the core design, I-11 with IFBA-bearing FA, possesses favorable core average burnup life because of no fuel displacement, the design treatment such as (1) applying not only radial enrichment zoning but also axial enrichment zoning method, and putting cutbacks with no BP at the top and bottom ends of FA, and (2) proper location of fresh FA mixed with burnt FA in order to prevent power tilts across the core, can bring lower nuclear power peaking factor, benefits in terms of axial offset control, and smooth reactivity variation throughout core life. As shown in Fig. 1, reduction of about 32% REF design critical boron concentration (CBC) in optimized LBC (I-11) gained by use of total of 16,248 IFBA rods, does not lead to any severe problems due to analysis of design safety parameters. Its letdown curve of CBC smoothly decreases in terms of burnup, implying that this optimal design possesses flat reactivity swing down. However, the total IFBA loading should be limited by helium produced.

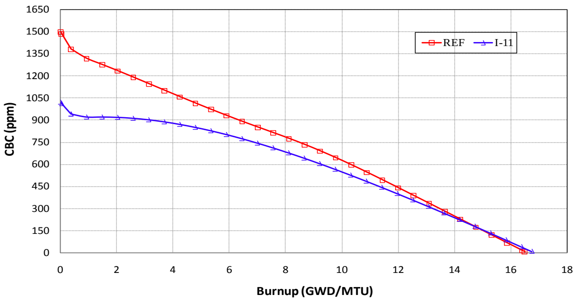

Fig. 1. Comparison CBC between I-11 and REF designs at equilibrium cycle

As a merit of use of IFBA without fuel displacement and residual absorption penalty, the predicted equilibrium cycle life time of I-11 with IFBA, is 16,750 MWD/MTU (455 EFPD), while the REF design provides 16,494 MWD/MTU (447 EFPD. Since I-11 design gains 8 EFPD more when compared to REF one, this longer life of operation can enhance long-run economic advantages. Moreover, this I-11 core design could bring 2 times narrower axial offset variation than that of REF design, and maintain acceptable power peaking factor around 23% lower than the limiting value, 2.52 [3] as illustrated in Fig. 2.

The LBC design is more advantageous to ensure more negative MTC, which is desirable from the safety point of view. Nevertheless, reaching too strong negative MTC must be looked to because it could lead to large reactivity insertion problems under the cold water injection scenario. The Fig. 3 represents one of design change benefits that the MTC of I-11 core design suitably ensures more negative than REF design throughout EFPD, following a consequence of reduction in CBC of REF design. It is found that the variation of MTC throughout core life behaves with highly dependency on the change in amount of CBC.

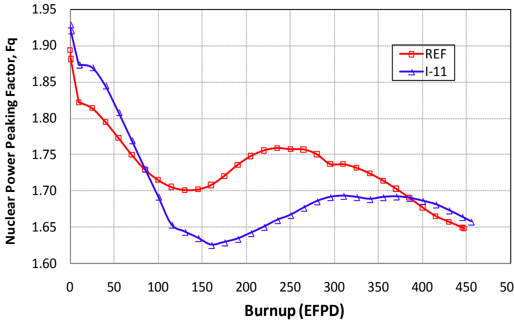

Fig. 2. Variation of peaking factor vs. EFPD

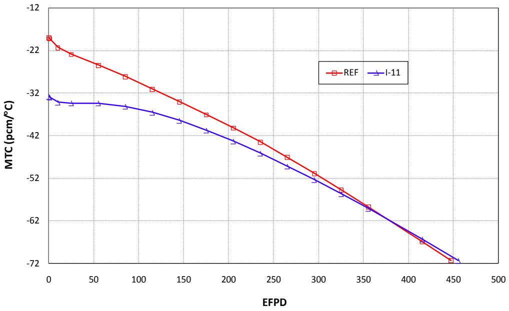

Fig. 3. MTC vs. EFPD

3. Fuel Assemblies with EBA

An alternative option to reduce the maximum boron concentration amount will be implementation of EBA which is acid that contains a higher amount of ^{10}B isotope which has an abundance of approximately 20 atom percent in natural boric acid (NBA). The design concept using lower boron concentration with an elevated enrichment in ^{10}B allows a reduction in the concentration of lithium in the primary coolant required to maintain the optimum coolant pH. The LBC with operation at optimum pH is expected to achieve some benefits from radiation source reduction of reduced corrosion product, the limitation of the Axial Offset Anomaly (AOA) and fuel cladding corrosion too [2]. One example reference FA is applied with several maximum amount of soluble boron by elevating 31.7% enrichment in ^{10}B, and NBA. It is found that 40% reduction of maximum boron concentration amount (300 ppm) can provide same excess reactivity at BOC and discharge burnup life of reference fuel assembly (REF_FA) as displayed in Fig. 4.

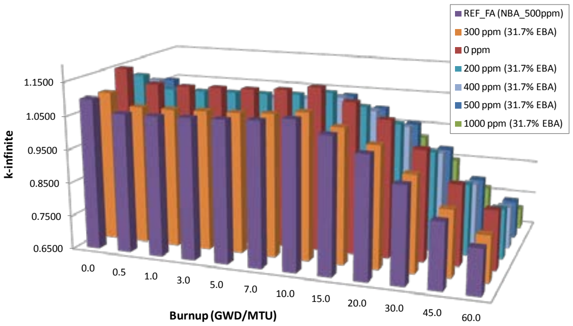

Fig. 4. Comparison of boron ppm with EBA and NBA

4. Conclusions

The calculation results of LBC design candidate (I-11) at equilibrium cycle, could comply with current OPR-1000 reactor acceptance criteria associated with smooth reactivity swing, favorable reactivity coefficients, more flatten power distribution, comparable power peaking factor, and desired limiting value for MDNBR, although it required more shutdown safety margin at BOC, that can be simply enhanced with higher enriched control rod. The complete calculation of LBC with EBA is still going on in order to investigate engineering feasibility and practical application of use of EBA at OPR-1000.

REFERENCES

1. Aung Tharn Daing and Myung-Hyun Kim, "Safety Aspect Evaluation on a Low Boron Core Design Concept for PWR," ANS Winter Meeting, Washington, DC, US, November 15-19, 2009.
2. J.Sejvar, C.A.Bergman, W.J.Leech, J.D.Perock and R.J.Jacko, "Re-Evaluation of Benefits of Implementing Enriched Boric Acid," EPRI Report TR-109992, March 1998.
3. NDR, Ulchin Nuclear Power Plant Unit 5 Cycle 1-4, KEPCO NFC, (2003-2007).