Benefits of Low Boron Core Design Concept for PWR

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1. Introduction

Nuclear design study was carried out to develop low boron core (LBC) based on one of current PWR concepts, OPR-1000. Most of design parameters were the same with those of Ulchin unit-5 except extensive utilization of burnable poison (BP) pins in order to compensate reactivity increase in LBC. For replacement of reduced soluble boron concentration, four different kinds of integral burnable absorbers (IBAs) such as gadolinia, integral fuel burnable absorber (IFBA), erbia and alumina boron carbide were considered in suppressing more excess reactivity. A parametric study was done to find the optimal core options from many design candidates for fuel assemblies and cores. Among them, the most feasible core design candidate was chosen in accordance with general design requirements [1].

In this paper, the feasibility and design change benefits of the most favorable LBC design were investigated in more detail through the comparison of neutronic and thermal hydraulic design parameters of LBC with the reference plant (REF). As calculation tools, the HELIOS/MASTER code package and the MATRA code were utilized. The main purpose of research herein is to estimate feasibility and capability of LBC which was mainly designed to mitigate boron dilution accident (BDA), and for reduction of corrosion products. The LBC 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 [2]. All in all, 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. Additionally, several merits of LBC are closely related to fluid systems and system related aspects, reduced boron and lithium costs, equipment size reduction for boric acid systems, elimination of heat tracing, and more aggressive fuel design concepts.

2. Optimized Low Boron Core Design

For core physics calculation, MASTER code evaluated core design parameters of all design options under same condition. The Fig.1 represents the comparison of k-effective behavior of selected core design candidates as well as one of REF. It was found that k-effective curve for the LBC-1 with gadolinia-bearing fuel assemblies had relatively lower initial excess reactivity and comparable cycle length than REF curve which is the line without marker. The LBC-1 design candidate became a better choice to meet design objectives as the most promising and feasible design within this framework.

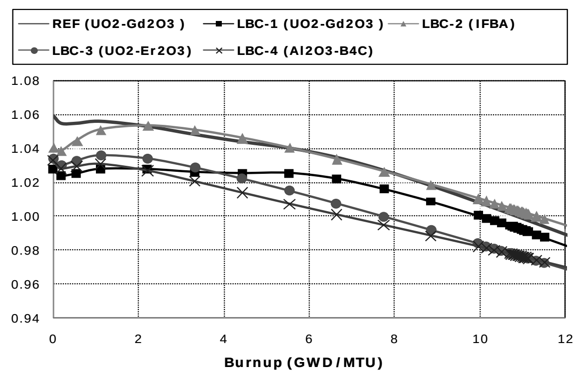

Fig.1.Comparison of core k-effective behaviors vs. core avg. burnup.

3. Results and Conclusions

As illustrated in Fig. 2, the moderator temperature coefficient (MTC) of LBC-1 design was more negative than REF core design throughout the effective full power days (EFPDs). The Fig. 3 represents the comparison of fuel temperature coefficient (FTC) in terms of power level between REF and LBC-1 designs at MOC. More negative FTC was obtained in LBC-1 design as the core average fuel temperature of LBC-1 began slightly lower after about 50 EFPDs, than that of REF design.

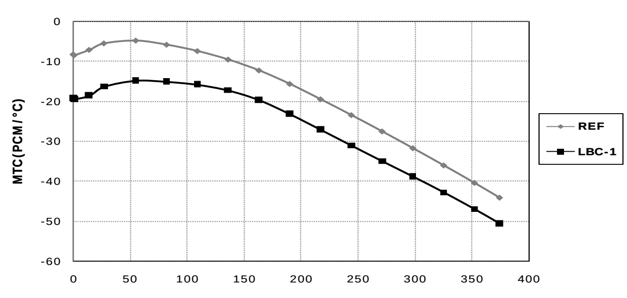

Fig. 2. Comparison of MTC.

The minimum departure from the nucleate boiling ratio (MDNBR) was evaluated by MATRA which was developed by KAERI. In Fig. 4, the most MDNBR value of LBC-1 design was 2.4 at MOC whereas that of REF reached 2.5. It was also observed that all MDNBR values of the hottest sub-channel in terms of axial core height at both REF and LBC-1 designs can be maintained above 2.3 which is an operating limit supported by safety analysis. It can predict that the MDNBR may be maintained above a design limit of 1.30 for anticipated operational occurrences too since the axially integrated radial peaking factor, F_r, was well below 1.55 during full power operations.

The maximum nuclear power peaking factor of LBC-1 along the core cycle length, reached a value of 2.10 which was slightly higher than value of REF, 2.03 but still lower than the limiting value, 2.5. When compared to the variation of axial offset (AO) band (-9.15% & +1.78%) in REF core, the AO in LBC-1 was controlled within the band (-12.2% & +6.7%) which was a little wider because of its variation of higher power peaks in bottom half of core at BOC and in top half of the core at MOC and EOC. However, the AO variation of LBC-1 was still within acceptable band, ± 10% throughout the cycle length. If axial BP zoning is applied, AO band might be reduced effectively.

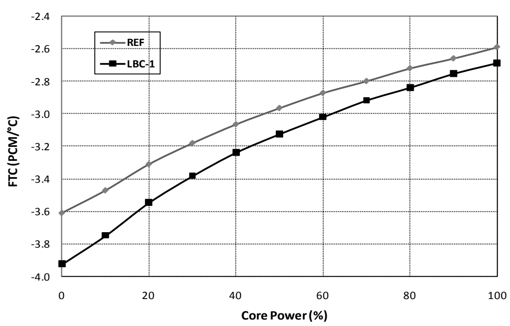

Fig. 3. Comparison of FTC.

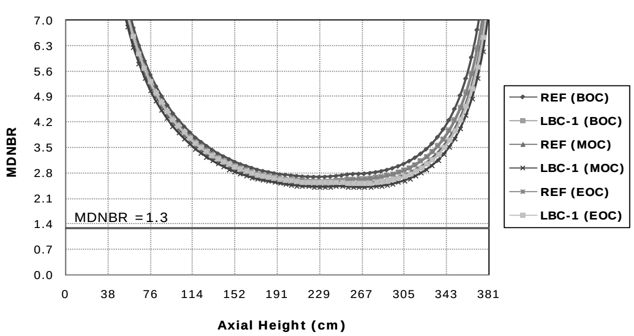

Fig. 4. Comparison of MDNBR of the hottest sub-channel at BOC, MOC and EOC.

The main duty for safe shutdown is taken by control rods only even though soluble poison will be injected for additional safety. The rod cluster control assembly worth without most reactive one; (N-1) RCCA was estimated at BOC and EOC respectively in Table I. The calculated shutdown margin of REF design at EOC was slightly less than value at BOC whereas that of LBC-1 at BOC became larger at EOC. The use of the same control element assemblies (CEA) programming scheme of REF design for LBC-1 design ensured that sub-criticality at any time, and under any condition, will be assured above the required value of shutdown margin, 6,500 pcm.

Table I: Shutdown Margin Prediction

Calculation Procedures	**BOC** (pcm)		**EOC** (pcm)	
	REF	LBC-1	REF	LBC-1
Control Rod Requirements				
Power Defect	1473	1637	2173	2398
Rod Insertion Allowance (HFP)	65	71	115	129
Total Requirements, [A]	1538	1708	2287	2527
Control Rod Worth (N-1)				
Calculated Value	10271	10518	10953	11450
With 10% Uncertainty, [B]	9244	9466	9858	10305
Shutdown Margin (SDM)				
Calculated SDM, [B-A]	7706	7758	7571	7778

It was observed that reduced boron concentration operation in current PWR plant had no distinctive negative impacts on neutronic and thermal hydraulic design safety parameters. As it was expected, the LBC design can achieve more negative MTC and FTC, comparable power peaking factor and axial or radial power distribution. About 33% soluble boron concentration reduction in LBC-1 required about 40% increase in number of BP rods of REF design to compensate excess reactivity. However, there was one drawback in this design. LBC-1 design had shorter cycle length by about 22 EFPDs than REF because of elimination of fissile with higher amount of BP. This will be improved with design optimization. As a conclusion, design feasibility was shown in safety aspects. However, more safety evaluation needs to be done as a future work against probable accident scenarios. The BDA will be also simulated in order to check feasibility on safety risk mitigation [3].

REFERENCES

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