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Nuclear Design Study for Reduced Boron Concentration Operation

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1. Introduction

In PWR, Boron Dilution Accident (BDA) which is an inadvertent reduction of the soluble boron concentration in the primary coolant, can lead to a positive reactivity insertion and a power increase [1]. In this study, an optimal Low Boron Concentration (LBC) core design will be developed by reducing an excess reactivity so as to possess passive inherently safety features as well as one of attentively preventive measures of BDA scenarios. The scope of the research project concerning the change of operational procedure in chemical shim system, will involve three main parts namely, nuclear design for LBC core, feasibility check on the proposed core in safety and costs, and PSA approach on design change benefits. In addition, successful system analysis of the reactivity effects due to boron dilution transients, require a full coupling between core thermal hydraulic, reactor dynamics, and the use of Computational Fluid Dynamics (CFD) codes.

As a preliminary research work, the new LBC-PWR core will be designed through the increased use of burnable poison (BP) rods and control rods, based on OPR-1000 Ulchin unit 5. The performance of that core with LBC operation, will be compared to that of standard core design. The proposed core design expects improved reactivity feedback properties (more negative moderating temperature; MTC), favorable safety margins, and comparable cycle length. Additionally, lower impact of boron dilution accidents on reactor safety and rather system design simplification are looked forward. Finally, the core is expected to provide less burden of CVCS and more flexible accident management strategies for maintenance. However, the core excess reactivity must be controlled by large number of BP rods and control rods loading; there will be uncertainty in benefits of LBC core. Moreover, sufficient shutdown and regulating banks are essentially required since rodded operation with LBC operation at hot full power condition could not increase shutdown safety margin.

2. Design Code Description

2.1Calculation Tools

In designing LBC-PWR core, the calcul-ations will be performed using HELIOS/MASTER code package. Investigation of code package validation was also done by comparing with the results of DIT/ROCS.

2.2 Benchmark Calculation

A benchmark calculation between two code packages namely HELIOS/MASTER and DIT/ROCS, was performed for standard commercial PWR calculation. In doing so, basic design data of Ulchin unit 5 Cycle 1, has been used [2]. When MASTER/HELIOS code package was benchmarked and calibrated, the steady-state core performance parameters, such as critical boron concentration (CBC), reactivity coefficient; MTC power peaking limit, were subsequently compared to those of Nuclear Design Report (NDR) of the UCN unit 5 at fresh cycle. When compared to NDR data of Ulchin Unit 5 for CBC at BOC, the difference between the calculation results by HELIOS /MASTER and NDR calculation results by DIT/ROCS, is less than 7 ppm although deviation in CBC at EOC reaches to 37 ppm. As MTC is one of the measurements for impacts on inherent PWR safety features, its characteristic is comparable to each other. At BOC, relative power distributions and error percentages between these two codes are represented in Fig. 2.

Though both code packages perform calculations based on different cross section libraries, their results are very close in agreement. It was found that there was an acceptable discrepancy among those core performance parameters such that the maximum percentage error in power at BOC is 3.4% but just 1.25% at EOC.

FA Type ► FA Power (Cal; Result) ► Percentage Error ►					B0 0.67 2.9	B0 0.93 2	C0 1.09 1.4
			B0 0.64 3.4	C0 1.03 0	C1 1.08 -0.8	C1 1.21 -1	B1 1.23 -0.7
		C0 0.76 0.9	C1 1.03 -1.2	A0 0.9 -0.6	B2 1.2 -0.3	A0 0.93 -0.2	A0 0.94 -0.1
	B0 0.64 3.4	C1 1.03 -1.2	B1 1.18 -0.9	B2 1.23 -1.2	A0 0.94 0.6	C1 1.23 -1.3	A0 0.91 0.7
	C0 1.03 0	A0 0.9 -0.6	B2 1.23 -1.2	A0 0.95 0.4	B1 1.24 -0.6	A0 0.9 0.2	B1 1.19 -0.7
B0 0.67 2.9	C1 1.08 -0.8	B2 1.2 -0.3	A0 0.94 0.6	B1 1.24 -0.6	A0 0.9 0.7	C1 1.15 -1.1	A0 0.83 1
B0 0.93 2	C1 1.21 -1	A0 0.93 -0.2	C1 1.23 -0.5	A0 0.9 0.2	C1 1.15 -1.1	A0 0.78 1	A0 0.75 1.5
C0 1.09 1.4	B1 1.23 -0.7	A0 0.94 -0.1	A0 0.91 0.7	B1 1.19 -0.7	A0 0.83 1	A0 0.75 1.5	A0 0.7 1.9

Fig. 2. Assembly-wise Relative Power and Errors to DIT/ROCS at BOC

3. Fuel Assembly Optimization Studies

For initial-core design with low boron operation, it not only needs to suppress excess reactivity by utilizing more burnable poison rods instead of soluble boron but also requires a low-leakage type core loading pattern to maintain comparable pin power peaking such as that of standard OPR-1000. LBC core is to be operated with six different sub-batches classified according to use of fuel enrichment zoning patterns, and (Al_2O_3-B_4C) integral burnable absorbers (IBAs) rods loading patterns in a form of mixed central-zone loading.

Except A0 type fuel assembly, other five assemblies were optimized and compared to those utilized at fresh cycle for standard OPR-1000 as summarized in Table 1. There are several options to choose suitable IBAs for LBC core such as UO_2-Gd_2O_3, UO_2-Er_2O_3, Al_2O_3-B_4C and IFBA. Among them, gadolinia bearing rods and Al_2O_3-B_4C were analyzed and compared. It was found to increase a residual negative reactivity effect with increasing gadolinia loading (wt% Gd_2O_3 and number of gadolinia-bearing rods) and increasing initial fuel enrichment. In this optimization, fuel assembly designs which consist of (Al_2O_3-B_4C solid rods) clad in zircaloy, were chosen and proposed for LBC core to compensate the excess reactivity due to reduction of chemical shim system. Fig.3 illustrates the comparative results of excess reactivity between standard and proposed fuel assemblies, evaluated by HELIOS.

Table 1. Comparative Analysis of Fuel Assemblies

Sub-batch (FA)	B0		C0		B1		C1		B2	
Stand-ard/Pro-posed	B0-S	B0-P	C0-S	C0-P	B1-S	B1-P	C1-S	C1-P	B2-S	B2-P
Type of IBA	-	Al_2O_3 -B_4C	-	Al_2O_3 -B_4C	UO_2-Gd_2O_3	Al_2O_3 -B_4C	UO_2-Gd_2O_3	Al_2O_3 -B_4C	UO_2-Gd_2O_3	Al_2O_3 -B_4C
BP Con-tent	-	4	-	4	6	4	6	4	6	4
No. of BP per FA	No BP	8	No BP	8	8	12	12	24	8	12
No. of Fuel Rods per FA	184/ 52	176/ 52	184/ 52	176/ 52	176/ 52	172/ 52	124/ 100	112/ 100	128/ 100	124/ 100
k-inf	1.24	1.13	1.28	1.18	1.12	1.07	1.1	0.97	1.099	1.061
Max. Pin Power Peaking	1.07	1.14	1.07	1.13	1.15	1.19	1.19	1.24	1.173	1.203

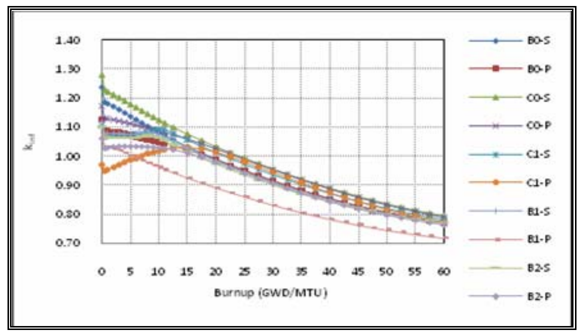

Fig. 3. Comparative Analysis of Reactivity Behavior

4. Core Design Evaluation

Optimal LBC core calculation for OPR-1000 will be carried out as a further step by using MASTER code system. It also needs to investigate adverse impacts on design goals resulted from that change of operational procedures such as core performance parameters; MTC, FTC and DNBR. This new low boron core design is aimed at achieving a high safety and performance record.

REFERENCES

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