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The Qualification of the NEXUS Once-Through Cross-section System for OPR1000 Core

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1. Introduction

NEXUS is a new nuclear data system developed at Westinghouse with its partner the Korea Nuclear Fuel Co. (KNFC). This system is designed to model both PWR and BWR cores. The system is intended to replace the various nuclear design systems currently used by Westinghouse and KNFC for performing nuclear core design and safety analyses.

As part of the qualification of this system for plants of OPR1000 type located in the Republic of Korea, the core designs of Yonggwang Unit 3 cycle 1 thru. cycle 3 were modeled using NEXUS. This paper provides some descriptions and results of this work.

2. Description of NEXUS

The NEXUS system is composed of a series of codes that transform simple user input into complete nuclear data sets for use in nodal codes. The system hides the complexity of the lattice code inputs and data transformations from the user. NEXUS is fully automated: the user executes the system for his/her input and a nuclear data file is generated at the completion of the calculation with no further user intervention. For PWR analysis, the NEXUS system uses the Westinghouse lattice code PARAGON [1] which was licensed by the NRC in April, 2004.

The basic idea behind NEXUS is that nuclear cross sections can be accurately represented as a function of three basic parameters – spectral index (defined as the ratio of the fast to thermal flux), the moderator temperature, and the fuel temperature [2]. Using this observation, an improved cross-section representation model has been developed in which a macroscopic cross-section is decomposed into a feedback-free cross-section and a number of additive feedback correction terms. The feedback-free cross-section and the fundamental components of the feedback correction terms are all given as the product of a reference cross-section and a spectrum correction factor, which is represented in terms of the three mentioned state parameters and fuel exposure. The fundamental coefficients of the feedback correction terms are microscopic cross-sections representative of the feedback material (e.g., actinides, xenon, water, boron). These are also parameterized as functions of spectral index, fuel temperature, and moderator temperature. Depletion history effects are captured in the nodal simulator by explicitly tracking a large number of actinides and fission products, as well as all burnable absorber nuclides. Nuclear data generated by NEXUS covers the full temperature range seen in PWRs from cold ambient conditions to above hot full power conditions.

NEXUS is a once-through cross section system in that all the nuclear data for a given fuel type are generated up-front and then are usable for all cycles in which that fuel resides. This differs from the current Westinghouse PWR nuclear data system in which all nuclear data are generated for each fuel type on a cycle-specific basis.

A more detailed explanation of the NEXUS system is found in Reference [3].

3. OPR1000 Core Modeling

Many of qualification tests have already been made as direct comparisons of NEXUS/ANC9 results in Westinghouse against PARAGON [4] results for problems that PARAGON can model exactly (such as mini-cores and unit assemblies). These tests confirmed that the NEXUS methodology represented the PARAGON cross sections very accurately over the range of conditions expected in PWR core analysis.

However, the real test of any nuclear design system is in the modeling of actual cores with comparisons against measured data obtained when those cores were operated. A series of calculations have been completed directed at the qualification of the NEXUS system for OPR1000 core model of Yonggwang Unit 3 cycle 1 thru. cycle 3 using a 9 series of the ANC nodal simulator [5] code version that has been adapted to the NEXUS nuclear data system. Over three operated cycles of Yonggwang Unit 3 have been modeled with NEXUS/ANC9 to date. This plant is characterized with 16x16 type lattice, annual cycle length, low-leakage loading pattern strategy and gadolinium burnable absorbers. Comparisons against measured data were made for critical boron concentration (CBC) versus cycle burnup. In addition, comparisons were made against results from the current nuclear data system for power distributions. The critical boron data for cycle 1of the plant is shown in Figure 1. As shown in the figure, there is a good agreement between NEXUS/ANC9 results and the measure data. In the figure, ANC(BL) stands for the PARAGON/ANC8.7.7 of Boron Letdown method.

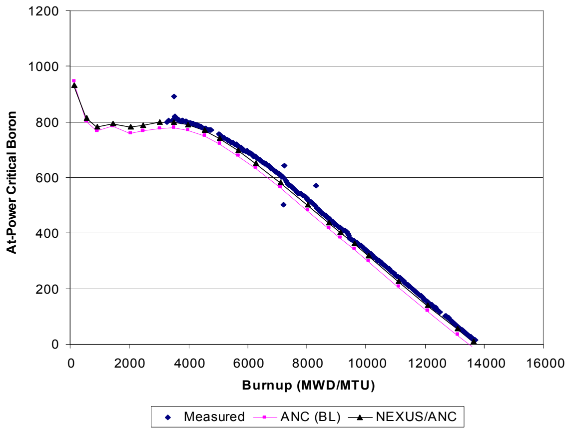

Figure 1. comparison of critical boron concentration for cycle 1

The power distribution comparison between NEXUS/ANC9 and the current system (PARAGON/ANC 8.7.7 of Boron Letdown Method) is shown at EOC of cycle 3 calculation in Figure 2. Figure 2 also shows good agreement between NEXUS/ANC9 and PARAGON/ANC8.7.7 with the maximum difference of 0.47%.

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            PARAGON/ANC8.7.7                  0.637 0.872 0.742
            NEXUS/ANC9                        0.640 0.876 0.744
            %diff                             0.47  0.46  0.27

                                  0.512 0.940 1.164 0.941 1.269
                                  0.512 0.941 1.164 0.936 1.263
                                  0.00  0.11  0.00 -0.53 -0.47

                            0.654 0.904 1.118 0.937 1.311 0.957
                            0.655 0.908 1.123 0.935 1.306 0.951
                            0.15  0.44  0.45 -0.21 -0.38 -0.63

                      0.512 0.904 1.246 0.927 1.062 1.036 0.931
                      0.512 0.908 1.249 0.930 1.066 1.032 0.922
                      0.00  0.44  0.24  0.32  0.38 -0.39 -0.97

                      0.939 1.118 0.927 1.307 0.973 1.321 0.975
                      0.941 1.123 0.930 1.307 0.975 1.319 0.970
                      0.21  0.45  0.32  0.00  0.21 -0.15 -0.51

                0.637 1.164 0.937 1.063 0.973 1.335 0.989 1.308
                0.640 1.164 0.936 1.066 0.976 1.335 0.988 1.307
                0.47  0.00 -0.11  0.28  0.31  0.00 -0.10 -0.08

                0.872 0.941 1.313 1.038 1.322 0.989 1.111 0.923
                0.876 0.937 1.308 1.035 1.321 0.988 1.111 0.924
                0.46 -0.43 -0.38 -0.29 -0.08 -0.10  0.00  0.11

                0.742 1.269 0.957 0.931 0.975 1.308 0.923 0.809
                0.744 1.263 0.951 0.922 0.970 1.307 0.924 0.805
                0.27 -0.47 -0.63 -0.97 -0.51 -0.08  0.11 -0.49
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Figure 2. power distribution comparison at EOC of cycle 3

Finally, power peaking factor($F_{\Delta h}$) comparison between NEXUS/ANC9 and PARAGON/ANC 8.7.7 at cycle 2 shows a maximum difference of 0.8% in Table 1.

Table 1. power peaking factor($F_{\Delta h}$) comparison of cycle 2

Burnup (MWD/T)	FΔh		
	PARAGON/ ANC8.7.7	NEXUS/ ANC9	Diff.(%)
0	1.480	1.478	-0.1
150	1.475	1.479	0.3
1000	1.468	1.470	0.1
2000	1.467	1.465	-0.1
3000	1.466	1.459	-0.5
4000	1.468	1.465	-0.2
6000	1.494	1.492	-0.1
8000	1.484	1.472	-0.8
10108	1.459	1.457	-0.1

4. Conclusion

Through a comparison of key nuclear parameter such as CBC, power distribution and power peaking factor for cycle 1 thru. cycle 3, NEXUS system using a once-through cross-section model is verified for OPR1000 plant as well as Westinghouse designed plants [6]. This system can be used for nuclear core design and safety analyses of all PWR plants in Korea.

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