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Topical Report

Benchmarking of NODE-P2 for

Calculating Core Operating Characteristics

of

Indian Point Unit 2

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Calculating Core Operating Characteristics

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Indian Point Unit 2

Consolidated Edison Company of New York, Inc.

Review/Approval Record

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Executive Summary

The Consolidated Edison Company (Con Ed) has developed a three dimensional simulator model for the Indian Point Unit 2 (IP2) reactor core. Since fuel cycle 11, Con Ed has been using the Electric Power Research Institute's (EPRI) NODE-P2 three dimensional nodal code[1] to predict and track the core operating characteristics at IP-2. The B constants required as input for NODE-P2 are developed using CPM-2 and the B-link interface code[2].

This report describes the benchmarking of the Con Ed methodology against operating data for fuel cycles 11, 12, and 13. For this analyses a PC version of NODE-P2 was used.[3] The code predictions have been compared to actual operating data taken during the beginning-of-cycle (BOC) startup physics tests for each of these fuel cycles, periodic core flux maps as measured with the moveable incore system and critical boron concentration as a function core burnup. In addition to the measured core data, NODE-P2 predictions have been compared with similar predictions performed by a vendor's system of codes.[4] These comparisons serve to benchmark NODE-P2 under non-typical core operating conditions including asymmetric core power distributions induced by severely misaligned control rods.

The benchmarking analyses for Cycles 11, 12, and 13 serve to support the following conclusions with respect to accuracy of the NODE-P2 predictions for core analyses at IP-2:

- NODE-P2 accurately predicts the core radial assembly power distributions from cycle-to-cycle and within each cycle for the 32 flux maps evaluated. On a percentage basis, the deviations between the predicted and measured values are at a minimum in the interior high power assemblies where margins to core operating limits are at a minimum.

- NODE-P2 accurately predicts the core axial power shapes and local axial nodal power distributions from cycle-to-cycle and within each cycle for the 32 core flux maps examined. On a percentage basis, the predictions are closest to the measured values in the central, high power nodes where margins to core limits are at a minimum.

- The NODE-P2 predictions of radial core power distributions under conditions with asymmetric misaligned control rods are in close agreement with the vendor's code predictions.

- NODE-P2 adequately predicts the measured control rod bank worths and moderator temperature coefficient measured during the BOC startup physics tests of Cycles 11, 12, and 13.

- Comparison of the measured and predicted critical boron concentration throughout Cycles 11, 12, and 13 demonstrate that NODE-P2 accurately predicts the fuel cycle length and cycle energy output.

It is therefore concluded that the Con Ed methodology for analysis of the IP2 reactor core provides a suitable and accurate means for predicting actual core operating conditions.

1.0 Introduction

This Topical Report describes the validation and verification of the core physics methods used by the Consolidated Edison Company (Con Ed) to track the performance of the Indian Point Unit No. 2 (IP2) reactor core. Indian Point Unit 2 is a four loop Westinghouse plant rated at 3071 MW_{Th}. The core consists of 193 fuel assemblies of the 15 x 15 Westinghouse design. The plant is in its 13th fuel cycle of operation and the duration of Cycle 13 is scheduled for 24 months. Since Cycle 11, Con Ed has been using the Electric Power Research Institute's (EPRI) NODE-P2 three dimensional nodal code[1] for core analysis and follow. The B constants required as input for NODE-P2 are developed using CPM-2 and the B-link interface code[2]. A PC based version of NODE-P2 has been developed to facilitate core follow calculations[3].

The PC version of NODE-P2 was used to simulate fuel Cycles 11, 12, and 13 at IP2 and the code predictions have been compared to actual core operating data taken during the beginning of cycle (BOC) startup physics tests for each cycle, periodic core flux maps as measured by the moveable incore detector system and critical boron concentration as a function of core burnup. The comparison of the startup physics tests data included moderator temperature coefficient and control rod bank worths. Verification of the core radial and axial predictions is based on the simulation of core conditions during some 32 flux maps.

[

.]^{a,b}

The following sections of this report describe the comparison of NODE-P2 with core operating data and [ ]^{a,b} results and serve to quantify the differences.

2.0 Comparison of NODE-P2 Predictions with Core Operating Data

2.1 Assembly Radial Power Distributions

The NODE-P2 predicted radial assembly power distributions were compared with core operating data taken with the moveable incore detector system. Incore flux maps were taken periodically during Cycles 11, 12, and 13 and a total of 32 have been compared and evaluated from beginning of cycle (BOC) through to the end of each cycle. The assembly by assembly NODE-P2 predictions are compared with the flux maps in Appendix A-1. In making these comparisons, deviations between the measured and predicted values were calculated [

]:[a,b]

[ ] a,b

In addition to considering the above differences for the [

.]^{a,b}

Table 2-1 contains a summary of the deviations between the predicted and measured assembly power distributions for [

]^{a,b} Cycles 11, 12, and 13. The [

]^{a,b} cited in these tables are for a particular flux map for which [

.]^{a,b} The [

]^{a,b} for each cycle are also given as well as the [

.]^{a,b} The reported values in Table 2-1b, for [

.]^{a,b}

In addition to data contained in Table 2-1, the differences in the measured and predicted power identified above have been plotted for each flux map in each of Cycles 11, 12, and 13 as a function of core burnup. Figures 2-1 through 2-4 contains the differences versus core average burnup for Cycle 11. The comparison for Cycle 12 are contained in Figures 2-5 through 2-8 and in Figures 2-9 through 2-12 for Cycle 13.

Table 2-1

Predicted versus Measured Radial Assembly Power for:

a,b

Table 2-1 (cont'd)

Predicted versus Measured Radial Assembly Power for:

a,b

a,b

Figure 2-1: [ ]a,b Deviation Between Measured and Predicted Cycle 11 Assembly Power

a,b

Figure 2-2: [ ]a,b Deviation Between Measured and Predicted Cycle 11 Assembly Power

[ ] a,b

Figure 2-3: [ ]a,b Deviation Between Measured and Predicted Cycle 11 Assembly Power

[ ] a,b

Figure 2-4: [ ]a,b Deviation Between Measured and Predicted Cycle 11 Assembly Power

a,b

Figure 2-5: [ ]a,b Deviation Between Measured and Predicted Cycle 12 Assembly Power

a,b

Figure 2-6: [ ]a,b Deviation Between Measured and Predicted Cycle 12 Assembly Power

[ ] a,b

Figure 2-7: [ ]a,b Deviation Between Measured and Predicted Cycle 12 Assembly Power

[ ] a,b

Figure 2-8: [ ]a,b Deviation Between Measured and Predicted Cycle 12 Assembly Power

[ ] a,b

Figure 2-9: [ ]a,b Deviation Between Measured and Predicted Cycle 13 Assembly Power

[ ] a,b

Figure 2-10: [ ]a,b Deviation Between Measured and Predicted Cycle 13 Assembly Power

[ ] a,b

Figure 2-11: [ ]a,b Deviation Between Measured and Predicted Cycle 13 Assembly Power

[ ] a,b

Figure 2-12: [ ]a,b Deviation Between Measured and Predicted Cycle 13 Assembly Power

2.2 Axial Power Distributions

The NODE-P2 predictions of the core average axial power distributions are compared with the flux map data for Cycles 11, 12, and 13 in Appendices B-1, B-2, and B-3, respectively. As in the case with the radial core power distributions the [

.]a,b

Table 2-2 contains a summary of the computed deviations between the measured and predicted axial power shapes for all three fuel cycles. In this table, the data are compared for [.] a,b
Comparisons are given for the entire cycle as well as for [

.]a,b

[

.]a,b

In addition to the data contained in Table 2-2, plots of the predicted versus measured deviations as a function of core burnup for Cycle 11 are given in Figures 2-13 through 2-16. The comparison for Cycle 12 are contained in Figures 2-17 through 2-20 and for Cycle 13 in Figures 2-21 through 2-24.

Table 2-2

Predicted versus Measured Axial Power Distribution for:

a,b

Table 2-2

Predicted versus Measured Axial Power Distribution for:

a,b

a,b

Figure 2-13: [ ]a,b Deviation Between Measured and Predicted Cycle 11 Axial Power Distribution

a,b

Figure 2-14: [ ]a,b Deviation Between Measured and Predicted Cycle 11 Axial Power Distribution

a,b

Figure 2-15: [ ]a,b Deviation Between Measured and Predicted Cycle 11 Axial Power Distribution

a,b

Figure 2-16: [ ]a,b Deviation Between Measured and Predicted Cycle 11 Axial Power Distribution

[ ] a,b

Figure 2-17: [ ]a,b Deviation Between Measured and Predicted Cycle 12 Axial Power Distribution

[ ] a,b

Figure 2-18: [ ]a,b Deviation Between Measured and Predicted Cycle 12 Axial Power Distribution

a,b

Figure 2-19: [ ]a,b Deviation Between Measured and Predicted Cycle 12 Axial Power Distribution

a,b

Figure 2-20: [ ]a,b Deviation Between Measured and Predicted Cycle 12 Axial Power Distribution

[ ] a,b

Figure 2-21: [ ]a,b Deviation Between Measured and Predicted Cycle 13 Axial Power Distribution

[ ] a,b

Figure 2-22: [ ]a,b Deviation Between Measured and Predicted Cycle 13 Assembly Power Distribution

a,b

Figure 2-23: [ ]a,b Deviation Between Measured and Predicted Cycle 13 Axial Power Distribution

a,b

Figure 2-24: [ ]a,b Deviation Between Measured and Predicted Cycle 13 Axial Power Distribution

2.3 RCCA Bank Reactivity Worths

The integral reactivity worths of the control banks (A, B, C, and D) are measured at the beginning of the fuel cycle with the reactor critical and at hot zero power (HZP) conditions. In these tests the control banks are individually moved into the core stepwise and the worth and the reactivity inserted is compensated for by boron dilution to maintain criticality. The BOC rod worth measurements for Cycles 11, 12, and 13 are summarized in Tables 2-3, 2-4, and 2-5, respectively. Figures 2-25, 2-26, and 2-27 contain plots of the integral bank worth versus rod position as the individual banks are inserted into the core for Cycles 11, 12, and 13, respectively. [

.]^{a,b}

2.4 Critical Boron Concentration

Comparisons were made between IP2 measured and NODE-P2 predicted critical boron concentration for Cycles 11, 12, and 13. All comparisons were for the core in the hot full power (HFP) conditions with all control rods fully withdrawn (ARO) except for D-Bank which is at the bite position. Figure 2-28 shows NODE-P2 predicted boron concentration [ ]^{a,b} with IP-2 measured data. The actual cycle burnup of 17,706 (based on 513 EFPDs) compares closely with the predicted cycle burnup of [ ]^{a,b} MWD/MTU. Figure 2-29 contains the Cycle 12 IP2 measured and NODE-P2 predicted boron concentration. It can be seen that the predicted boron concentration [

.]^{a,b}

NODE-P2 predicted an EOC burnup of [ ]^{a,b} while actual cycle burnup was 20,623 MWD/MTU (based on 597 EFPD). It should be noted that Cycle 12 ran at 90% power beyond 11,054 MWD/MTU.

Figure 2-30 shows the Cycle 13 IP2 measured (up to 14,000 MWD/MTU) and NODE-P2 predicted boron letdown curves. [

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.]^{a,b}

2.4 Critical Boron Concentration

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Figure 2-30 shows the Cycle 13 IP2 measured (up to 14,000 MWD/MTU) and NODE-P2 predicted boron letdown curves. [

Table 2-3

Cycle 11 Predicted and Measured Control Bank Worth

a,b

Table 2-4

Cycle 12 Predicted and Measured Control Bank Worth

a,b

Table 2-5

Cycle 13 Predicted and Measured Control Bank Worth

a,b

a,b

Figure 2-25: Predicted and Measured Cycle 11 Integral Control Bank Worth at HZP

a,b

Figure 2-26: Predicted and Measured Cycle 12 Integral Control Bank Worth at HZP

a,b

Figure 2-27: Predicted and Measured Cycle 13 Integral Control Bank Worth at HZP

a,b

Figure 2-28: Cycle 11 Predicted and Measured Critical Boron Concentration versus Burnup

a,b

Figure 2-29: Cycle 12 Predicted and Measured Critical Boron Concentration versus Burnup

a,b

Figure 2-30: Cycle 13 Predicted and Measured Critical Boron Concentration versus Burnup

.]a.b The predicted EOC burnup for Cycle 13 is [ ]a.b at 100% power.

[

.]a.b

2.5 Moderator Temperature Coefficient

The moderator temperature coefficient (MTC) is measured during the BOC startup tests with ARO and ARI and at HZP conditions. These tests were simulated with NODE-P2 and calculated values compared with the measurements in Table 2-6.

[

.]a.b

Table 2-6

IP2 Measured and NODE-P2 Predicted Moderator Temperature Coefficient (pcm/F°) at HZP

a,b

3.0 Comparison of NODE-P2 with [ ]a,b

To supplement and expand the validation of NODE-P2 where actual data taken at operating conditions are not available, the NODE-P2 predictions were compared to calculations performed by [.]a,b This includes the simulation of asymmetric misaligned control rod conditions leading to asymmetric core power distributions. Specifically, [

.]a,b The cases evaluated are summarized in Table 3-1. [

.]a,b

Appendix C contains the detailed core power maps with the NODE-P2 [ ]a,b comparisons at BOC (150 MWD/MTU), MOC (10,000 MWD/MTU) and EOC (21,790 MWD/MTU). Table 3-2 compares the NODE-P2 predictions with [

]a,b

have been computed at BOC, MOC, and EOC in Cycle 13. Table 3-3 contains [

.]a,b

Table 3-1

[

]a,b

a,b

Table 3-2

[ ]a,b

a,b

Table 3-3

[ ]a,b

a,b

4.0 Conclusions

Predictions of the IP2 core operating parameters computed with the NODE-P2 core simulator have been compared with measured core characteristics over Fuel Cycles 11, 12, and 13. The predicted core radial and axial power distributions have been compared with data from 32 core flux maps taken with the moveable incore detector system over the entire range of burnup for each of these cycles. [

]^{a,b} measured during the BOC startup physics tests of Cycles 11, 12, and 13. The [

]^{a,b} was also compared with measured values obtained during the BOC physics tests of each of these fuel cycles. The [

.]^{a,b}

These comparisons of the NODE-P2 predictions with measured core operating data and [ ]^{a,b} serves to support the following conclusions with respect to the adequacy of the IP2 NODE-P2 model:

- [

.]^{a,b}

- [

.]a,b

- [

.]a,b

- [

.]a,b

- [

.]a,b

It is therefore concluded that the Con Ed methodology for analysis of the IP2 reactor core provides a suitable and accurate means for predicting actual core operating conditions.

5.0 References

1. "ARMP-02 Documentations; Part II, Chapter 11 - NODE-P2 Computer Code Manuals, Vol. I and II", EPRI NP-4574-CCM. Electric Power Research Institute, Palo Alto, CA; October 1988.

2. "Indian Point Unit 2 Cycle 11 Final Design Report", NA-F-038, Consolidated Edison of New York, Inc., New York, NY; February 1992.

3. [

.]a,b

4. [

.]a,b

5. "Nuclear Parameters and Operations Package for Indian Point Unit 2, Cycle 11", WCAP-12891, Westinghouse Electric Corporation, Pittsburgh, PA; May 1991.

6. "Nuclear Parameters and Operation Package for Indian Point Unit 2, Cycle 12", WCAP-13664, Westinghouse Electric Corporation, Pittsburgh, PA; June 1993.

7. "Nuclear Parameters and Operations Package for Indian Point Unit 2, Cycle 13", WCAP-14302, Westinghouse Electric Corporation, Pittsburgh, PA; April 1995.

List of Appendices

Appendix A-1: Cycle 11 IP-2 Measured and NODE-P2 Predicted Radial Assembly Distributions A-1

Appendix A-2: Cycle 12 IP-2 Measured and NODE-P2 Predicted Radial Assembly Distributions A2-1

Appendix A-3: Cycle 13 IP-2 Measured and NODE-P2 Predicted Radial Assembly Distributions A3-1

Appendix B-1: Cycle 11 IP-2 Measured and NODE-P2 Predicted Axial Power Distributions B1-1

Appendix B-2: Cycle 12 IP-2 Measured and NODE-P2 Predicted Axial Power Distributions B2-1

Appendix B-3: Cycle 13 IP-2 Measured and NODE-P2 Predicted Axial Power Distributions B3-1

Appendix C: [ ]a,b C-1

Appendix A-1

Cycle 11 IP-2 Measured and NODE-P2 Predicted Radial Assembly Power Distributions

(Note: Appendix A-1 Information is Proprietary)

Appendix A-2

Cycle 12 IP-2 Measured and NODE-P2 Predicted Assembly Power Distributions

(Note: Appendix A-2 Information is Proprietary)

Appendix A-3

Cycle 13 IP-2 Measured and NODE-P2 Predicted Assembly Power Distributions

(Note: Appendix A-3 Information is Proprietary)

Appendix B-1

Cycle 11 IP-2 Measured and NODE-P2 Predicted Radial Assembly Power Distributions

(Note: Appendix B-1 Information is Proprietary)

Appendix B-2

Cycle 12 IP-2 Measured and NODE-P2 Predicted Assembly Power Distributions

(Note: Appendix B-2 Information is Proprietary)

Appendix B-3

Cycle 13 IP-2 Measured and NODE-P2 Predicted Assembly Power Distributions

(Note: Appendix B-3 Information is Proprietary)

Appendix C

[

]a,b

(Note: Appendix C Information is Proprietary)