PRAIRIE ISLAND UNITS 1 AND 2

ROD SWAP METHODOLOGY

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ABSTRACT

This document is a Topical Report describing the Northern States Power Company (NSP) methodology for determining control rod reactivity worth with the Rod Swap technique.

The methodology employed is explained and data obtained from Prairie Island Unit 1 Cycle 9 and Unit 2 Cycle 8 are presented to validate the methodology. This methodology is applicable for both Prairie Island Unit 1 and Unit 2.

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1.0. INTRODUCTION

This report addresses the replacement of the boration/dilution method for control rod reactivity worth determination with the Rod Swap method. This determination is used to validate the calculational results and verify the shutdown margin.

The boration/dilution technique involves changing the boron concentration in the coolant while simultaneously changing the control rod position to keep the core nominally critical. In dilution, as primary grade water is put into the reactor coolant system to dilute the boron concentration, a control rod bank is inserted into the core. The rate of this reactivity exchange is limited by the operational considerations during testing. Typical measurement times of between eight and ten hours have been the norm.

The rod swap technique is an alternative method used to verify the control rod worth predictions of the calculational models. In rod swap, the control rod bank with the highest worth is measured by the dilution technique, and then each of the other rod banks is swapped in turn as the highest worth bank is withdrawn to keep the system critical.

The advantages of this technique are threefold:

1) The reactivity worth measurements are performed on the two shutdown banks as well as the control banks. In the dilution method only the control banks are measured.

2) The time associated with the reactivity worth measurements is reduced by six to eight hours.

3) The rod swap technique significantly reduces the water inventory required for dilution.

The rod swap technique was employed side-by-side with the dilution reactivity measurements during the startup physics testing for Prairie Island Unit 2, Cycle 8 and Prairie Island Unit 1, Cycle 9. This report outlines the proposed rod swap methodology and presents a comparison with the side-by-side dilution measurements taken. The applicability of this report encompasses the use of rod swap for both units of the Prairie Island power station.

2.0 CALCULATIONAL THEORY AND METHODS

2.1 Rod Swap Methodology

The rod swap tests are designed to measure the reactivity worth of each control rod bank and, by comparison to calculated values, validate the models used for the predictions. This will verify the shutdown margin as calculated by these models.

The rod swap procedure involves using the dilution technique to measure the reactivity worth of the most reactive control rod bank, referred to as the reference bank. At the completion of the dilution, a boron endpoint and isothermal temperature coefficient are measured. The isothermal temperature coefficient is measured for later use in correcting reactivity worth for temperature drift during the test. At this point test data is collected which describes the reactor condition. This statepoint is referred to as the reference bank statepoint. The test data collected is:

1) reference and test bank positions

2) reactivity computer reading in pcm

3) moderator temperature

Boron concentration measurements are taken continuously during the test for later use in correcting reactivity worth for boron drift which may have occurred during the test.

The swap technique proceeds as follows: With the reactor maintained at or near critical, the reference bank is withdrawn while one of the other rod banks, referred to as the test bank, is inserted ('swapped in'). The test bank is fully inserted and the reference bank is adjusted until the core is critical. This core condition is referred to as the test bank statepoint.

The height of the reference bank is the measured critical position (h^m) of the reference bank for this test bank. With the reference bank at h^m, the reactivity computer reading in pcm, and the moderator temperature are recorded. The reference bank is then alternately withdrawn and inserted a few steps to determine the differential reactivity worth per unit of insertion about h^m. The differential reactivity worth is measured for later use in correcting for changes in test conditions.

This rod swap process is repeated for each of the other test banks. When all control banks have been measured, all rod banks will be returned to the position they were in after the reference bank dilution. The reference bank test data: 1) reference and test bank positions, 2) reactivity computer reading in pcm, and 3) moderator temperature, is recorded again to ensure that the system has remained stable.

The major parameter of interest is in the inferred worth of the test bank in the presence of the reference bank at rod position h^m. The reference bank positions, reactivity computer readings, moderator temperatures, and boron concentrations recorded during the test are used to adjust the inferred worth for changes in test conditions. These adjustments are discussed in detail in section 3.1.

2.2 Calculational Theory

The design data required for rod swap is generated by the NSP DP5 nodal model and methodology as shown in Reference 1. The DP5 model predicts all information needed for the rod swap test including:

1) The integral worth of each rod bank inserted alone along with the identity of the most reactive, or reference, bank.

2) The critical boron concentration with the reference bank fully inserted in the core.

3) The integral and differential worth of the reference bank inserted alone.

4) The integral and differential worth of the reference bank with each test bank fully inserted.

The determination of the predicted critical position and test bank worth in the presence of the reference bank at h^p is performed as follows.

a) Determine the most reactive rod bank using the individual integral worths of each bank calculated as in item one above.

b) Determine the predicted critical position using the reactivity balance equation below:

$$R^p = T^p + \Delta R^p_T$$

where

R^p = the total predicted integral worth of the reference bank inserted alone.

T^p = the total predicted integral worth of the test bank inserted alone.

ΔR^p_T = the integral worth of the reference bank inserted from the fully withdrawn position to h^p in the presence of the fully inserted test bank.

The R^p and T^p are found from the individual integral worths from item one above. The ΔR^p_T is solved for in the above reactivity balance:

$$\Delta R^p_T = T^p - R^p$$

h^P is determined by finding the rod position corresponding to $\Delta R^P{}_T$ on the reference bank integral worth curve in the presence of the test bank from item four above.

c) Determine the predicted test bank worth in the presence of the reference bank at the predicted critical position using the reactivity balance equation below:

$$R^P = T^P{}_{\Delta R} + \Delta R^P$$

where

R^P = the total predicted integral worth of the reference bank inserted alone

$T^P{}_{\Delta R}$ = the total integral worth of the test bank in the presence of the reference bank at h^P

ΔR^P = the integral worth of the reference bank inserted alone from the fully withdrawn position to h^P

Both R^P and ΔR^P are found from the predicted integral worth curve for the reference bank inserted alone from item three above. $T^P{}_{\Delta R}$ is solved for in the reactivity balance above.

$$T^P{}_{\Delta R} = R^P - \Delta R^P$$

$T^P{}_{\Delta R}$ is used for comparison to the inferred measured worth. $T^P{}_{\Delta R}$ does not represent the dilution worth of the test bank, however it is merely a parameter used to evaluate the uncertainty of the core physics model for calculation of rod worths and validate the assumtions used in the calculation of shutdown margin.

3.0 MEASUREMENT DATA ANALYSIS

3.1 Bank Worth Determination

As previously outlined, statepoint data collected during rod swap is used to adjust the measured critical position (h^M) to take into account any differences between the reference bank statepoint and the test bank statepoints. In addition, another adjustment is made to compensate for any differences between the reference-bank-in all-other-banks-out condition and the actual control rod bank configuration when the reference bank statepoint data is collected.

The corrections made are as follows:

1) Adjustments for moderator temperature variations between critical statepoints.

2) Adjustments for variations in the boron concentration between critical statepoints.

3) Adjustments for deviations from criticality between critical statepoints.

4) Adjustments for deviations in control rod position from the reference-bank-in all-other-banks-out condition at the reference bank statepoint.

These corrections make certain that statepoint data for each rod configuration is based upon the same core reactivity and boron concentration. For the first adjustment, a reference-bank-in ITC is measured and the temperature recorded for this statepoint as well as for each test bank statepoint. The second correction requires that periodic boron measurements be taken throughout the test so that any variations in boron concentration can be taken into account. The accuracy of these measurements does not allow comparison of specific boron measurements. The third correction requires that the reactivity computer reading in pcm be recorded at the reference bank statepoint and each of the test bank statepoints. The fourth correction requires that the difference in reactivity between the actual control rod bank positions at the reference bank statepoint and the reference-bank-in all-other-rods-out condition be measured, and the actual control rod bank positions be recorded.

The following equation is used to make these adjustments.

$$h^{a} = h^{M} - [([\Delta T * \alpha_{T}] + [\Delta CB * \alpha_{CB}] + \Delta\rho_{C} + \Delta\rho_{R}) * (1/\Delta\rho/\Delta h)]$$

where:

h^{a} = The measured critical position of the reference bank with the test bank fully inserted, after all adjustments have been made.

h^{M} = The measured critical position of the reference bank with the test bank fully inserted.

ΔT = The increase in the measured moderator temperature between the reference bank statepoint and the test bank statepoint.

α_{T} = The isothermal temperature coefficient measured at the reference bank statepoint.

ΔCB = The increase in the measured RCS boron concentration between the reference bank statepoint and the test bank statepoint.

α_{CB} = The boron worth coefficient calculated using DP5 and supplied before the test using methodology shown in Reference 1.

$\Delta\rho_C$ = The decrease in reactivity between the reference bank statepoint and the test bank statepoint as measured by the reactivity computer.

$\Delta\rho_R$ = The measured reactivity of the actual control rod bank positions at the reference bank statepoint minus the reactivity at the reference-bank-in all-other-rods-out condition.

$\Delta\rho/\Delta h$ = The measured differential reactivity worth of the reference bank in the region about h^M per unit of insertion.

These data adjustments were demonstrated with the exception of the moderator temperature correction for which data was not available. This data for both Prairie Island Unit 1 Cycle 9 and Unit 2 Cycle 8 are presented on Table 3.1.

The measured reactivity worth of the test banks are found in the same manner as the predicted worths using an analogous reactivity balance equation.

$$R^M = T^a{}_{\Delta R} + \Delta R^a$$

where:

R^M = The total measured integral worth of the reference bank inserted alone.

$T^a{}_{\Delta R}$ = The total integral worth of the test bank with the reference bank at h^a.

ΔR^a = The measured integral worth of the reference bank inserted alone from the fully withdrawn position to h^a.

TABLE 3.1

MEASURED CRITICAL POSITION ADJUSTMENTS

Cycle	Test Bank	h^M (steps)	Boron (pcm)	Reactivity (pcm)	Rod Position (pcm)	Total Adjustments* (steps)	h^a (steps)
Prairie Island 2 Cycle 8	B	144	0	0	0	0	144
	C	199	0	6	0	1	200
	D	158	0	-2	0	0	158
	SA	152	0	2	0	0	152
	SB	152	0	-7	0	-1	151
Prairie Island 1 Cycle 9	C	152	0	0	24	3	155
	B	107	0	-1	24	2	109
	D	138	0	4	24	4	142

* No temperature adjustments were made due to lack of data.

Both R^M and ΔR^a are found from the measured integral worth curve for the reference bank inserted alone. Therefore:

$$T^a_{\Delta R} = R^M - \Delta R^a$$

$T^a_{\Delta R}$ is found from this reactivity balance and is compared to $T^P_{\Delta R}$. Both of these quantities are based upon critical control rod bank statepoint comparisons beginning at the same configuration, reference-bank-in all-other-rods-out.

3.2 Acceptance Criteria

For the dilution/boration technique, the acceptance criteria is based upon a comparison of the measured and predicted control rod bank worths as expressed by the following equation.

$$\Delta\rho(\%) = \frac{\rho_{meas} - \rho_{design}}{\rho_{meas}} * 100\%$$

Two sets of criteria are presently used for the diluiton/boration reactivity worth measurements. The first is a review criteria which is violated if the percent difference between measured and predicted reactivity worths for each of the individual control rod banks is not within ±15%. If not met, it requires that the Prairie Island Operations Committee be informed. The decision to continue is made based upon overall plant startup data and the significance of the discrepancy.

Second, an acceptance criteria exists which requires that the percent difference between measured and predicted reactivity worths for the total of banks A-D be within ± 10%. If this is not met, an N-1 rod worth measurement must be performed.

For the rod swap test, the reference control rod bank reactivity worth is measured by the dilution/boration technique. The standard dilution/boration test review criteria of ±15% for individual banks will apply to this test. For the test banks the review criteria of ±15% for the individual control rod banks as measured by dilution/boration will be used. If this review criteria is not met the required actions shall remain the same as for the dilution/boration method.

If the acceptance criteria is exceeded, the dilution/boration method of control rod bank reactivity worth measurements shall be performed using the same criteria as presently in place. This allows the presently accepted method to be used if any large discrepancies in the rod swap method are present.

The accuracy of the test method will be continually reviewed and the review and acceptance criteria updated as test data is collected.

4.0 TEST RESULTS AND COMPARISONS

The Prairie Island Unit 2 Cycle 8 and Unit 1 Cycle 9 rod swap analysis was performed using the methodology presented in this report including design predictions and test data inferencing. Tables 4.1 and 4.2 present the measured and predicted control rod reactivity worths for both cycles as well as the associated errors and review criteria. For both cycles control rod bank A is the reference bank. As can be seen from the information presented on these tables, all of the test results met the review criteria and were within acceptable limits.

Comparisons were performed between the rod swap test results and the side-by-side dilution/boration reactivity worth measurements which were performed for these two cycles. As presented in tables 4.1 and 4.2, the basic similarities in the results with respect to the acceptable limits for both tests are demonstrated. For Prairie Island Unit 2 Cycle 8, presented on table 4.1, the mean of the percent differences was 0.1% for the dilution/boration technique and was 2.6% for the rod swap technique. The standard deviation was 3.5% for the dilution/boration technique and 2.4% for the rod swap technique. The percent difference associated with the total reactivity worth of the control rod banks was 1.3% for the dilution/boration technique and 1.3% for the rod swap technique. With the shutdown banks included the value was 2.3% for rod swap. For Prairie Island Unit 1 Cycle 9, presented on table 4.2, the mean of the percent differences was 6.5% for the dilution/boration technique and was 8.3% for the rod swap technique. The standard deviation was 3.6% for the dilution/boration technique and 4.0% for the rod swap technique. The percent difference associated with the total reactivity worth of the control rod banks was 6.0% for the dilution/boration technique and 7.4% for the rod swap technique.

In summary, the results of all of the tests were within acceptable limits with the rod swap results comparing very well with the side-by-side dilution/boration results. Both sets of tests adequately demonstrated the validity of the calculational models. Since the same type of information about the reactivity worths of the control rod banks is obtained and the trends in the worths between the rod swap technique and the side-by-side dilution/boration technique are very similar, rod swap is a valid method for determining control rod bank reactivity worths.

TABLE 4.1

PRAIRIE ISLAND 2 CYCLE 8

ROD SWAP vs. DILUTION/BORATION

Rod Swap Technique

Control Rod Bank	Worth (pcm) Measured	Worth (pcm) Predicted	Δ(pcm)	Δ(%)	Review Criteria (%)
A	1074	1089	-15	-1.4	±15
B	707	677	30	4.2	±15
C	1021	1000	21	2.1	±15
D	798	789	9	1.1	±15
SA	760	721	39	5.1	±15
SB	753	721	32	4.2	±15
Total (A-D)	3600	3555	45	1.3	±10
Total (A-SB)	5113	4997	116	2.3	±10

Mean = 2.6% σ = 2.4%

Dilution/Boration Technique

Control Rod Bank	Worth (pcm) Measured	Worth (pcm) Predicted	Δ(pcm)	Δ(%)	Review Criteria (%)
A	1074	1089	-15	-1.4	±15
D, A in	539	560	-21	-3.9	±15
B, A+D in	1221	1200	21	1.7	±15
C, A+D+B in	1807	1733	74	4.1	±15
Total	4641	4582	59	1.3	±10

Mean = 0.1% σ = 3.5%

TABLE 4.2

PRAIRIE ISLAND 1 CYCLE 9

ROD SWAP vs. DILUTION/BORATION

Rod Swap Technique

Control Rod Bank	Worth (pcm) Measured	Worth (pcm) Predicted	Δ(pcm)	Δ(%)	Review Criteria (%)
A	1339	1295	44	3.3	±15
B	645	565	80	12.4	±15
C	997	927	70	7.0	±15
D	904	810	94	10.4	±15
Total	3885	3597	288	7.4	±10
			Mean = 8.3%		σ = 4.0%

Dilution/Boration Technique

Control Rod Bank	Worth (pcm) Measured	Worth (pcm) Predicted	Δ(pcm)	Δ(%)	Review Criteria (%)
A	1339	1295	44	3.3	±15
B, A in	1011	895	116	11.5	±15
D, A+B in	768	719	49	6.4	±15
C, A+B+D in	1795	1711	84	4.7	±15
Total	4913	4620	293	6.0	±10
			Mean = 6.5%		σ = 3.6%

5.0 CONCLUSIONS

Based on the results of the side-by-side demonstration programs it has been shown that the rod swap methodology as outlined in this report is an acceptable method to be used to demonstrate the validity of the results of the calculational models used to predict control rod bank reactivity worths. This method has the potential to save time and reduce water usage. The conclusion to use the rod swap methodology is applicable to both Prairie Island units since both have been used for the demonstration purposes. These conclusions are limited to the two Prairie Island units.

6.0 REFERENCES

1. "Qualification of Reactor Physics Methods for Application to PI Units", NSPNAD-8101P Rev.1, December 1982.

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