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ROD BANK WORTH MEASUREMENTS UTILIZING BANK EXCHANGE

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1.0 INTRODUCTION

Westinghouse has been conducting a program gathering data and refining a control rod worth measurement technique known as rod exchange (or rod swap) since early 1978. In this program, tests comparing the adequacy of rod swap versus the conventional boron dilution technique have been performed at two, three, and four loop plants. As a result of these comparative tests and analytical sensitivity studies, Westinghouse has licensed the use of rod swap for two loop cores and for a specific four loop core. This report compiles the results of all applicable tests performed to date and presents the analytical sensitivity studies for the two, three, and four loop plants. With this report Westinghouse believes there is sufficient information to justify the generic approval of the rod exchange technique for control rod worth measurements on both reload and first cycle cores.

Section two of this report provides an explanation of the measurement technique and a derivation of the algorithm used to determine the worth of the exchanged, unknown bank through the use of the reference, or known bank. Section three notes the results of the analytical, verification and sensitivity studies comparing bank exchange versus the conventional boron dilution method for various two, three and four loop core configurations. Section Four gives the results of "side by side" comparison tests (boron dilution versus bank exchange) for several typical core configurations. Test review and acceptance criteria and the actions recommended in the event a criterion is not met are listed in Section Five. Conclusions noting Westinghouse positions concerning future use of bank exchange are given in Section Six. And finally a generic test procedure for informational purposes is provided as Appendix A to this report.

2.0 EXPERIMENTAL METHOD AND DATA ANALYSIS

2.1 Experimental Method

The rod exchange technique is simply a means of determining the integral reactivity worth of a control or shutdown bank of rods relative to a reference bank, whose worth is measured directly by conventional measurement techniques.

A typical measurement using this technique is performed as follows.

With an initial critical configuration of all rod banks fully withdrawn at hot zero power, the integral reactivity worth of the "reference" bank is measured over its entire range of travel, from fully inserted, by using conventional measurement techniques (boron endpoints, reactivity computer data, boron concentration data). The"reference" bank is that bank of rods which is predicted to have the highest integral reactivity worth of all control and shutdown banks when fully inserted individually into an otherwise unrodded core. Following the measurement of the worth of the reference bank, the reactor is critical with the reference bank at the near fully inserted position. Then, at constant reactor coolant system boron concentration and temperature, critical configurations are established with each remaining bank inserted individually by sequentially interchanging each bank with the reference bank.

The integral worth of each bank is therefore equal to the amount of reactivity resultant from the withdrawal of the reference bank to the new critical position after the exchange. An idealized sequence of events for a single bank (bank X) measurement, using the rod exchange technique, is shown schematically in Figure 2.1.

A detailed test procedure for RCC bank worth verification using the rod exchange technique is given in Appendix A.

2.2 Reactivity Relationships During Rod Exchange

The reactivity relationships between the reference bank (bank R) and bank X during rod exchange can be illustrated by an idealized thought experiment as follows.

As an initial condition, the core is just critical with bank R at h_0, near the fully inserted position of 0 steps. The effective multiplication factor of the core, k, is by definition identically equal to 1.0.

If bank R were withdrawn to the fully withdrawn position, H, the reactivity of the core would be increased to

+a,c

(2-1)

If bank X were inserted to the fully inserted position, the reactivity of the core would be decreased to

+a,c

(2-2)

Because the reference bank is chosen to have the highest integral worth of all other banks in an otherwise unrodded core, the value of K_2 will be greater than 1. If now, bank R is inserted to the just critical height h_x, k becomes again indentically equal to 1. That is,

$$\left[\qquad \right]^{+a,c} \qquad (2\text{-}3)$$

Rearranging equation 2-3, the worth of bank X can be expressed in terms of reference bank worth as

$$\left[\qquad \right]^{+a,c} \qquad (2\text{-}4)$$

Because it is generally not possible to determine the value of the last integral by direct measurement, it is convenient to introduce the analytical correction factor, α_x, defined as

$$\left[\qquad \right]^{+a,c} \qquad (2\text{-}5)$$

Writing the first integral of equation 2-4 as the difference of two integrals and introducing α_X, equation 2-4 becomes

[ ]$^{+a,c}$ (2-6)

2.3 Experimental Data and Analysis

As outlined previously, in the application of the rod exchange technique, the differential reactivity worth of the reference bank in an otherwise unrodded core is measured from the fully withdrawn to the fully inserted position. This data is used to produce the measured total integral reactivity worth and any partial integral worths of the reference bank as

[(2-7)]$^{+a,c}$ (2-8)

In addition to the reference bank worth, the following data is obtained for each bank X whose worth is being inferred from exchange:

(a) The average critical position of the reference bank $(H_X^M)_o$ prior to and following the exchange with bank X (bank X fully withdrawn), and

(b) The critical position of the reference bank, H_X^M, after exchange with Bank X (bank X fully inserted).

For each bank X, the following quantities are computed from the measurement data:

[ ]$^{+a,c}$

(2-9)

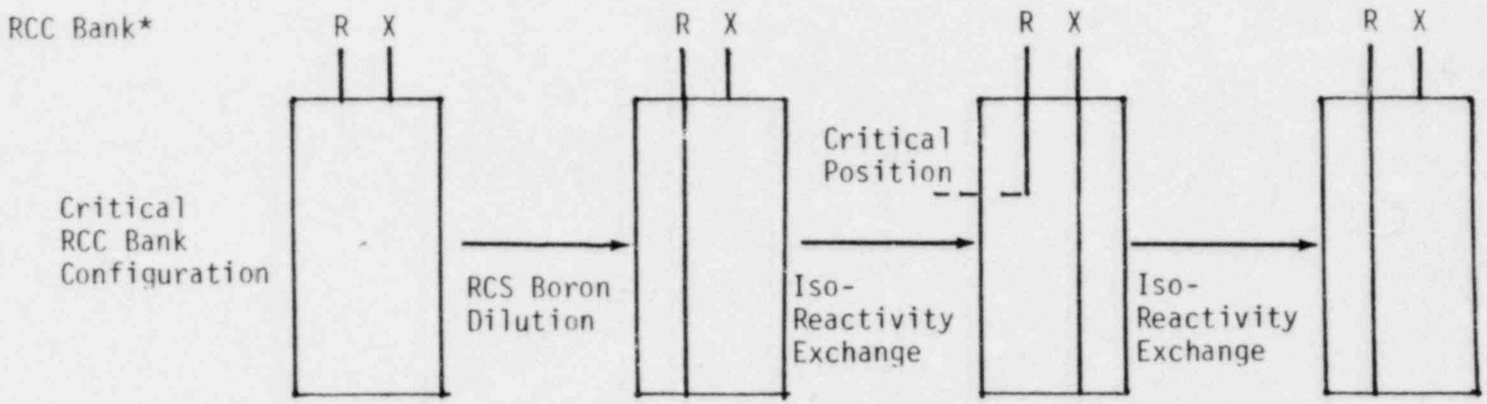
(2-10)

The inferred integral reactivity worth of bank X, is obtained through equation 2-6 as

[ ]$^{+a,c}$ (2-11)

[ ]$^{+a,c}$ A discussion of the calculational techniques used to generate α_X and the dependence of α_X on n_X is presented in Section 3.

FIGURE 2-1 SCHEMATIC OF SINGLE BANK (BANKX) WORTH MEASUREMENT USING THE ROD EXCHANGE TECHNIQUE



* R = Reference Bank

X = Bank to be measured

3.0 ANALYTICAL VERIFICATION

3.1 Introduction

Control rod bank worths are currently measured at the startup of every cycle of a nuclear plant. The information from these measurements (and others) are used to confirm consistency between the calculation models used for core analysis and the as-built core.

The purpose of the analysis described in this section is to examine the validity of the rod exchange concept for rod worth measurement. The analysis addresses the use of the rod exchange concept for individual and cumulative rod bank worth measurement. For the purpose of this study, the validity of the rod exchange concept rests on whether it gives results which are comparable to those of the currently accepted measurement technique of rod bank dilution. This comparison of measurement methods includes the areas of individual rod bank measurement, cumulative rod bank measurement, and the information inferred from these results concerning N-1 rod worth. The related question is addressed regarding whether different acceptance criteria or other measurement requirements must be stipulated for the rod exchange concept.

Before further discussion of the analysis some preemptory remarks are included here concerning the source of observed differences between calculated and measured rod bank worths.

One major source of these differences is measurement uncertainty. It should be noted that there are normally measurement uncertainties in both rod worth measurement techniques being discussed here. In the analysis presented in this section this effect is removed, thereby permitting a closer examination of the fundamental similarities or differences between the rod bank exchange and rod bank dilution concepts.

The other major surce of measured deviations from calculated values lies in differences between the calculation model and the physical core. These model-to-core differences are expected and are accounted for in design (Reference 1). Typically, the as-built fissile content of the freshly loaded is not exactly that assumed in design, primarily because the exact length of the plant cycle previous to the design cycle is not known at the time of design. These model-to-core differences produce small differences in core power distribution and neutron spectrum which can affect rod bank worths. For example the peripheral loading of fresh fuel with slightly higher than-nominal enrichment will cause some slight shift of power toward the periphery of the core and radially away from the center of the core. This in turn increases the peripheral rod bank worths slightly and may cause some slight decrease in the worth of centrally located rod banks. For a sequence of rod banks inserted evenly throughout the core there may be no change at all in their cumulative worth in this example.

These types of effects are examined in this study. It is emphasized that the results presented here employ Westinghouse calculational techniques verified by experiment (Section 4.0) and do not apply to measurement predictions calculated with other models.

3.2 Methods of Analysis

The analysis presented here essentially examines the effects of core perturbations on rod worth measurements. The model used to calculate rod exchange quantities is consistent with those used in the core design and safety evaluation. The NRC will be notified if there are significant changes in this process. The scope of this study covers all of the control rod banks and the N-1 configuration. This analysis can be divided into two parts. First, "predictions" of rod bank worths are calculated for the nominal core. This set of information includes the N-1 rod worth which is considered a known parameter in the analysis. For the rod bank dilution method, the individual rod bank worths are calculated as banks are inserted into the core in sequence. For the rod bank exchange method the rod bank worths are calculated [

]$^{+a,c,f}$ This body of information represents what the experimentor knows before the rod bank worth measurements.

The second part of the analysis provides simulated measurements of the same core design but with some perturbations introduced into the core model. In order to show clearly the trends introduced by these perturbations, unrealistically large changes were made to the model. The perturbations used are 0.05 w/o U-235 deviations in the average feed enrichment, [ ],$^{+a,c}$ and large changes in previous cycle burnup. These effects are combined so as to produce the largest perturbation in core power distribution. As alluded to in Section 3.1, such changes in the previous cycle burnup are expected and accounted for in the Westinghouse safety analysis (Reference 1).

After these perturbations are introduced into the model, pseudo-measurement information is generated. For the rod bank dilution method worths are calculated with rod banks inserted in sequence, and for the rod bank exchange method [ ]$^{+a,c,f}$ bank worths are calculated. This body of information represents what the experimentor would know after the measurement. In addition, the N-1 rod worth is calculated for comparison to the nominal case.

Percentage differences between "predictions" (P) and "measurements" (M) are calculated by the relationship

$$\% \text{ Difference} = \frac{M-P}{P} \times 100.$$

For rod exchange, measured bank worths are inferred by the following relationship.

+a,f

+a,c

cumulative bank worths for either measurement method are obtained by summing the individual bank worths and percentage differences are found as for individual banks.

The results obtained below were derived using 2-loop, 3-loop, and 4-loop core models.

3.3 Results

A core perturbation consisting of 0.05 w/o U-235 reduction in feed enrichment and a 2000 MWD/MTU reduction in the previous cycle burnup was introduced into the core model after prediction calculations were completed on the nominal core. Pseudo-measurement data was then generated and is presented along with the prediction data for the nominal core.

In Table 3.1, the changes in core power distribution and reactivity are indicated by the changes in the radial peaking factor and critical boron concentration between the nominal core and a perturbed core termed "measured core No. 1" in the Table. As can be seen the magnitude of these differences verge on anomalous behavior and would be detected easily in startup flux mapping and critical boron measurements. This information indicates that real observations of significant discrepancies in measured vs. predicted rod worths are very unlikely to be the result of actual model-to-core deviations, as has been demonstrated previously (Reference 2). Observed deviations of magnitude comparable to those in this analysis are most likely to be caused by isolated errors in measurement. As a corollary to this conclusion, the relatively small changes in N rod worth and N-1 rod worth for such large core perturbations indicate it is unlikely that either value could truly change significantly from model to core. Tables 3.2 and 3.3 show similar characteristics for 3-loop and 4-loop cores.

Tables 3.4, 3.5 and 3.6 present the comparison of rod bank dilution and rod bank exchange result[illegible]r individual bank worths for typical 2-loop, 3-loop and [illegible]-loop plants.

The percentage differences between measurement and prediction (abbreviated M/P) generally range from [ ] $^{+a,c}$ with some banks remaining almost unchanged. What is being seen in the fluctuation of these M/P values is the greater sensitivity of peripheral rod banks to the power perturbations being imposed. The peripheral location of a relatively worthy rod bank in the particular 3-loop core used in this study accounts for the exagerated M/P swings seen in Table 3.5.

The M/P values for rod exchange behave essentially the same as those for the rod dilution method.

Cumulative rod bank worths are presented in Tables 3.7, 3.8, and 3.9. It can be seen that the cumulative rod bank worths vary signficantly less than individual rod banks, as would be expected from the discussion in Section 3.1. Again, the M/P values from the rod exchange method are very comparable to those from the rod dilution method.

The most difficult test of the comparison of rod bank worth measurement technqiues is in the 3-loop case for the same reason pointed out in the above discussion of Table 3.5. As can be seen in Table 3.8, the M/P value for total control bank worth differs by about [ ] $^{+a,c}$ between the two measurement techniques and [ ] $^{+a,c}$ for the N rod worth comparisons. The N-1 rod worth data given in Table 3.10 shows that rod bank exchange cumulative worth data has tracked a little closer to the N-1 M/P values for this 3-loop case.

Further examination of the N-1 rod worth data in Table 3.10 will show that the M/P values vary considerably less than the individual rod bank M/P values, as was the case for the other cumulative rod worth data. All of the cumulative rod worth data including N-1, tend to vary in the same direction with about the same behavior except for the 3-loop core data. Once again, the peripheral location of a particularly worthy bank has caused a different trend in the 3-loop core with the N-1 changing in the opposite direction of the other cumulative rod worth data. The 3-loop core N-1 M/P values are also higher than the other cores though this is not surprising considering that the magnitude of individual rod bank M/P values in general are twice as great for the 3-loop.

To verify that these observed trends are reproducible, a series of different core perturbations were used to provide three more "measured" cores for comparison. These additional cases, termed "measured core No. 2", "measured core No. 3", and "measured core No. 4" are presented in Tables 3.11, 3.12 and 3.13. The values for the "measured cores" already discussed and the nominal core are reproduced in these tables for reference. As shown in the table, "measured core No. 4" represents a change from nominal of the same magnitude as "measured core No. 1" but in the opposite direction. The remaining two cases lie between these two extremes.

M/P values for all of the "measured cores," are given in Tables 3.14, 3.15 and 3.16. Examination of this data indicates clearly that the trends observed above with individual "measured cores" are quite reproducible and predictable.

3.4 Conclusions

The results presented in Section 3.3 demonstrate that there is no analytical reason to expect less informative data from a rod bank exchange measurement than a rod bank dilution measurement. Furthermore comparison of any series of successive rod exchange measurements to prediction is expected to provide the same cumulative worth information as the corresponding M/P comparison for rod bank dilution.

Thus, there is no analytical basis to support a different acceptance criteria for one method over the other for the same number of bank measurements.

The results of this study show that large, core power perturbations resulting in [ ]$^{+a,c}$ deviations in individual rod bank worths affect N-1 rod worth by only [ ]$^{+a,c}$. It is likely that individual bank worth M/P values of [ ]$^{+a,c}$ could be experienced before the N-1 rod worth varied $\pm$ 10 percent.

There is also strong evidence in the data that only [ ]$^{+a,c}$ selected control rod banks need be measured to confirm that the models and physical core are analagous, especially with respect to the N-1 rod worth value. A reasonable acceptance criterion for such individual bank measurements could very well be much greater than $\pm$ 15 percent If initial bank worth measurements failed to meet their acceptance criteria then successive bank worth measurements could be performed as has been proposed.

The results of this analysis summarily demonstrate that the rod exchange method performs adequately as a replacement for the rod dilution method of rod worth measurement. Again, it is emphasized that the results presented here employ Westinghouse calculational techniques verified by experiment (Section 4.0) and do not apply to measurement predictions calculated with non-Westinghouse models.

TABLE 3.1

CORE CHARACTERISTICS COMPARISON FOR "MEASURED" 2 LOOP CORE No. 1

	Nominal Core	"Measured" Core No. 1	
Previous Cycle Burnup (MWD/MT)	13700	11700	
Feed Fuel Enrichment (w/o U-235)	3.1	3.05	
ARO, HZP $F_{\Delta H}^{N}$			+a,c
ARO, HZP C_B (ppm)			

TABLE 3.2

CORE CHARACTERISTICS COMPARISON FOR "MEASURED" 3 LOOP CORE No. 4

	Nominal Core	"Measured" Core No. 4	
Previous Cycle Burnup (MWD/MTU)	15570	17570	
Feed Fuel Enrichment (w/o U-235)	3.20	3.25	
ARO, HZP $F_{\Delta H}^{N}$			+a,c
ARO, HZP C_B (ppm)			

Table 3.3

CORE CHARACTERISTICS COMPARISON FOR "MEASURED" 4 LOOP CORE No. 1

	Nominal Core	"Measured" Core No. 1	
Previous Cycle Burnup (MWD/MT)	13330	11330	
Feed Fuel Enrichment (w/o U-235)	3.40	3.35	
ARO, HZP $F_{\Delta H}^{N}$			+a,c
ARO, HZP C_B (ppm)			

TABLE 3.4

INDIVIDUAL BANK WORTH PSEUDO-MEASUREMENTS (% ΔK) FOR 2 LOOP CORES

	Nominal Core	"Measured" Core No. 1	% Difference M/P
ROD BANK DILUTION METHOD			
D			+a,c
C with D present			
B with D, C present			
A with D, C, B present			
SA with D, C, B, A present			
SB with D, C, B, A, SA present			
ROD BANK EXCHANGE METHOD			
+a,c,f			

TABLE 3.5

INDIVIDUAL BANK WORTH PSEUDO-MEASUREMENTS (%ΔK) FOR 3 LOOP CORES

	Nominal Core	"Measured" Core No. 4	%Difference M/P
ROD BANK DILUTION METHOD			+a,c
D			
C with D present			
B with D, C present			
A with D, C, B present			
SB with D, C, B, A present			
SA with D, C, B, A, SB present			
ROD BANK EXCHANGE METHOD			
+a,c,f			

TABLE 3.6

INDIVIDUAL BANK WORTH PSEUDO-MEASUREMENTS (%ΔK) FOR 4 LOOP CORES

	Nominal Core	"Measured" CORE No. 1	% Difference M/P
ROD BANK DILUTION METHOD			
D			
C with D present			
B with D, C, present			
A with D, C, B present			
SD with D, C, B, A present			
SC with D, C, B, A, SD present			
SB with D, C, B, A, SD, SC present			
SA with D, C, B, A, SD, SC, SB present			
ROD BANK EXCHANGE METHOD			

+a,c

+a,c,f

TABLE 3.7

CUMULATIVE BANK WORTH PSEUDO-MEASUREMENTS (%ΔK) FOR 2 LOOP CORES

	Nominal Core	"Measured" Core No. 1	% Difference M/P
ROD BANK DILUTION METHOD			+a,c
Total Control Banks (D+C+B+A)			
N Rods			
ROD BANK EXCHANGE METHOD			
Total Control Banks (D+C+B+A)			
N Rods			

TABLE 3.8

CUMULATIVE BANK WORTH PSEUDO-MEASUREMENTS (%ΔK) FOR 3 LOOP CORES

	Nominal Core	"Measured" Core No. 4	% Difference M/P
ROD BANK DILUTION METHOD			
Total Control Banks (D+C+B+A)			
N Rods			
ROD BANK EXCHANGE METHOD			
Total Control Banks (D+C+B+A)			
N Rods			

+a,c

TABLE 3.9

CUMULATIVE BANK WORTH PSEUDO-MEASUREMENTS (%ΔK) FOR 4 LOOP CORES

	Nominal Core	"Measured" Core No. 1	% Difference M/P
ROD BANK DILUTION METHOD			+a,c
Total Control Banks (D+C+B+A)			
N Rods			
ROD BANK EXCHANGE METHOD			
Total Control Banks (D+C+B+A)			
N Rods			

TABLE 3.10

N-1 ROD WORTH (%ΔK)

	Nominal Core	"Measured" Core	% Difference M/P
N-1 Rods, 2 Loop core			+a,c
N-1 Rods, 3 Loop Core			
N-1 Rods, 4 Loop Core			

TABLE 3.11

2 LOOP CORE MODEL PERTURBATIONS FOR ALL "MEASURED" CORES

	Nominal Core	"Measured" Core No. 1	"Measured" Core No. 2	"Measured" Core No. 3	"Measured" Core No. 4
Previous Cycle Burnup (MWD/MT)	13700	11700	12700	14700	15700
Feed Fuel Enrichment (w/o U-235)	3.1	3.05	3.05	3.15	3.15

TABLE 3.12

LOOP CORE MODEL PERTURBATIONS FOR ALL "MEASURED" CORES

	Nominal Core	"Measured" Core No. 1	"Measured" Core No. 2	"Measured" Core No. 3	"Measured" Core No. 4
Previous Cycle Burnup (MWD/MTU)	15570	13470	14570	16570	17570
Feed Fuel Enrichment (w/o U-235)	3.20	3.15	3.15	3.25	3.25

TABLE 3.13

4 LOOP CORE MODEL PERTURBATIONS FOR ALL "MEASURED" CORES

	Nominal Core	"Measured" Core No. 1	"Measured" Core No. 2	"Measured" Core No. 3	"Measured" Core No. 4
Previous Cycle Burnup (MWD/MTU)	13330	11330	12330	14330	15330
Feed Fuel Enrichment (w/o U-235)	3.40	3.35	3.35	3.45	3.45

TABLE 3.14

PERCENT DIFFERENCE BETWEEN PSEUDO-MEASUREMENT AND PREDICTION (M/P) FOR 2 LOOP CORES

"Measured" Bank	"Measured" Core No. 1 Bank Dilution	"Measured" Core No. 1 Bank Exchange	"Measured" Core No. 2 Bank Dilution	"Measured" Core No. 2 Bank Exchange	"Measured" Core No. 3 Bank Dilution	"Measured" Core No. 3 Bank Exchange	"Measured" Core No. 4 Bank Dilution	"Measured" Core No. 4 Bank Exchange
D								
C								
B								
A								
SA								
SB								
D+C+B+A								
N Rods								
N-1 Rods								

+a,c

TABLE 3.15

PERCENT DIFFERENCE BETWEEN PSEUDO-MEASUREMENT AND PREDICTION (M/P) FOR 3 LOOP CORES

	"Measured" Core No. 1		"Measured" Core No. 2		"Measured" Core No. 3		"Measured" Core No. 4	
"Measured" Bank	Bank Dilution	Bank Exchange	Bank Dilution	Bank Exchange	Bank Dilution	Bank Exchange	Bank Dilution	Bank Exchange
D								+a,c
C								
B								
A								
SB								
SA								
D+C+B+A								
N Rods								
N-1								

TABLE 3.16

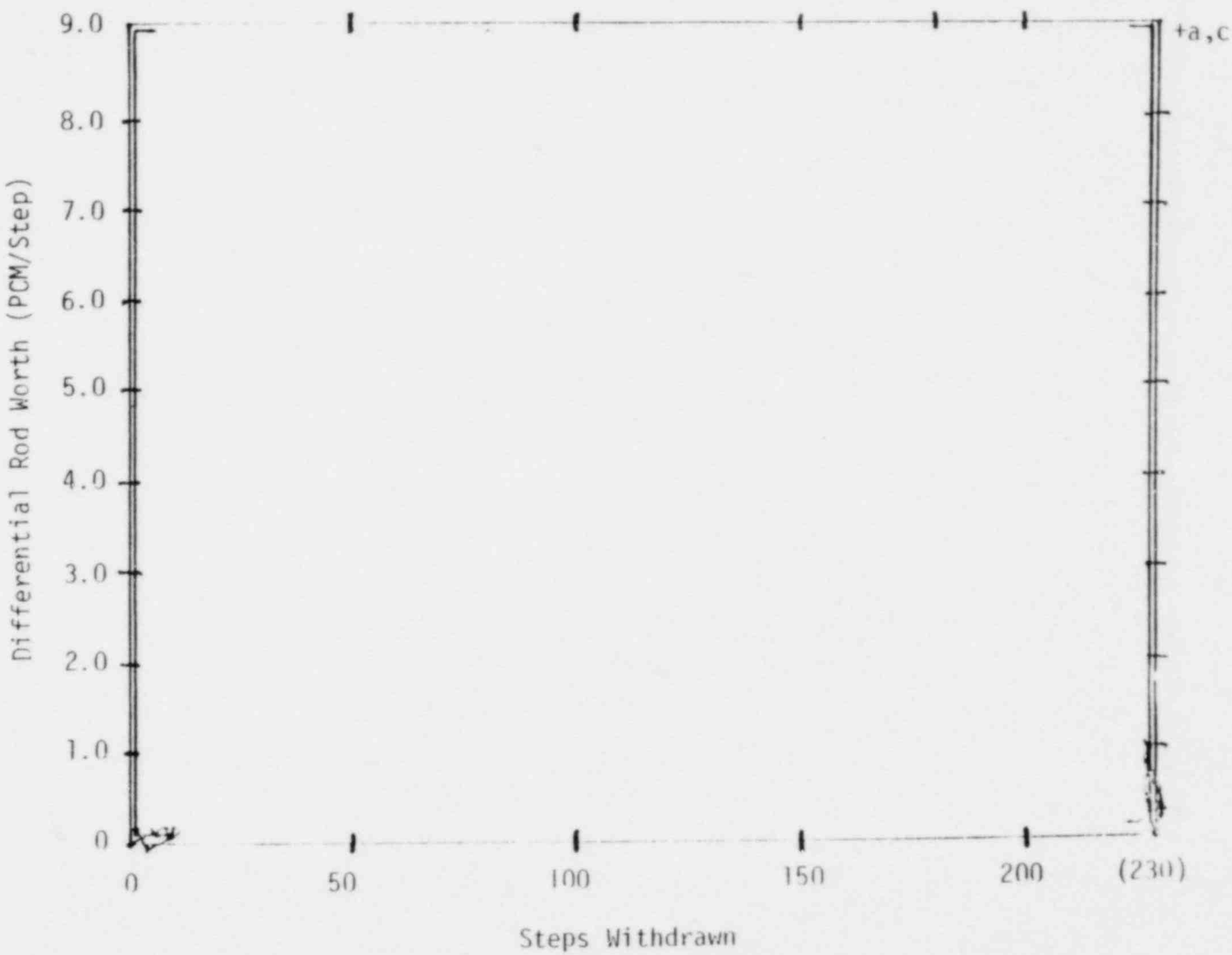
PERCENT DIFFERENCE BETWEEN PSEUDO-MEASUREMENT AND PREDICTION (M/P) FOR 4 LOOP CORES

	"Measured" Core No. 1		"Measured" Core No. 2		"Measured" Core No. 3		"Measured" Core No. 4	
"Measured" Bank	Bank Dilution	Bank Exchange	Bank Dilution	Bank Exchange	Bank Dilution	Bank Exchange	Bank Dilution	Bank Exchange
D								
C								
B								
A								
SD								
SC								
SB								
SA								
D+C+B+A								
N Rods								
N-1 Rods								

+a,c

Figure 3-1

Reference Bank Differential Rod
Worth Shapes



4.0 EXPERIMENTAL VERIFICATION

The equivalency between the rod exchange method and the conventional technique of boron dilution for design verification of integral rod bank worths was demonstrated by tests performed on two, three and four loop Westinghouse PWR cores. For each plant, rod bank worth measurements were made during beginning of cycle testing at hot zero power using both conventional and rod exchange techniques as described below.

4.1 MEASUREMENTS USING BORON DILUTION

For each core (2, 3 and 4 loop), the integral reactivity worths of the control banks were obtained from reactivity computer data as the banks were inserted into the core, in the normal insertion sequence, during reactor coolant system boron reduction (dilution).

Data were thus obtained for the integral worth of control bank D (CD); control bank C (CC) in the presence of CD; control bank B (CB) in the presence of CD and CC; and control bank A (CA) in the presence of CD, CC and CB. The remaining worth to the N-1 condition (all rods in less the highest worth stuck rod) was obtained by measuring the worths of the shutdown banks (SA, SB and for 4 loop cores SC and SD) during boron dilution after first interchanging one or more shutdown banks with the predicted highest worth stuck rod. The results obtained from these measurements are given in Tables 4.1, 4.2 and 4.3 for 2, 3 and 4 loop cores respectively and compared with relevant design predictions.

4.2 MEASUREMENTS USING ROD EXCHANGE

Following the boron dilution measurements discussed above, integral reactivity worth measurements of each control and shutdown bank were made using the rod exchange technique. For these measurements, the integral worth of the reference bank was obtained directly using the boron dilution technique and the integral worth of each of the other banks (control and shutdown) was obtained from the rod exchange data as each was interchanged with the reference bank. The rod exchange test results are presented alongside the dilution results in Tables 4.1, 4.2 and 4.3 and compared with relevant design predictions. It should be noted that the integral bank worths (measured and predicted) correspond to the worth in an otherwise unrodded core and that the N worth is simply the arithmetic sum of the individual bank worths.

4.3 SUMMARY AND CONCLUSIONS

As shown in Tables 4.1, 4.2, and 4.3, the agreement between measured and predicted integral bank worths is excellent and well within expected tolerances, for both the dilution data and rod exchange data, demonstrating the equivalency of the two techniques for design verification.

Table 4.1

Summary of Bank Worth Measurement Data and Comparison with Design Predictions - Two Loop Plant (BOC4)

	Integral Reactivity Worth - Conventional Technique			Integral Reactivity Worth - Rod Exchange Technique[a]		
RCC Bank	Measured Value (M) (pcm)	Predicted Value (P) (pcm)	% Diff. [ ]x100 (%)	Measured Value (M) (pcm)	Predicted Value (P) (pcm)	% Diff. [ ]x100 (%) +a,b,c
CA						
CB						
CC						
CD						
SA						
SB						
N-1						
N						

(a) Inferred bank worths were obtained from the rod exchange data using an earlier version of the data reduction algorithm. The results are however comparable with predictions and are presented here for the sake of completeness.

(b) Reference bank.

Table 4.2

Summary of Bank Worth Measurement Data and Comparison with Design Predictions - Three Loop Plant (BOC2)

RCC Bank	Integral Reactivity Worth - Conventional Technique: Measured Value (M) (pcm)	Predicted Value (P) (pcm)	% Diff. [ ]x100 (%)	Integral Reactivity Worth - Rod Exchange Technique: Measured Value (M) (pcm)	Predicted Value (P) (pcm)	% Diff. [ ]x100 (%)
CA						
CB						
CC						
CD						
SA						
SB						
N-1						
N						

+a,b,c

(a) Reference bank.

Table 4.3

Summary of Bank Worth Measurement Data and Comparison with Design Predictions - Four Loop Core (BOC1)

	Integral Reactivity Worth - Conventional Technique			Integral Reactivity Worth - Rod Exchange Technique		
RCC Bank	Measured Value (M) (pcm)	Predicted Value (P) (pcm)	% Diff. [ ]x100 (%)	Measured Value (M) (pcm)	Predicted Value (P) (pcm)	% Diff. [ ]x100 (%)
CA						
CB						
CC						
CD						
SA						
SB						
SC						
SD						
N-1						
N						

+a,c

(a) Reference bank

5.0 TEST REVIEW AND ACCEPTANCE CRITERIA

In reviewing the data presented in sections 3 and 4, Westinghouse has determined a two tiered system of criteria to use for determination of test result acceptability when the bank worths are measured with the bank exchange technique. The first level, or review criteria, is based on meeting design criteria and have no defined safety significance. However Westinghouse believes that it is prudent to address these review criteria as part of a continuing evaluation of the design process and measurement techniques.

Acceptable review criteria are:

A. The absolute value of the percent difference between measured and predicted integral worth for the reference bank is $\leq$ 10 percent.

B. For all banks other than the reference bank; either

  1. the absolute value of the percent difference between inferred and predicted integral worths is $\leq$ 15 percent, or

  2. the absolute value of the reactivity difference between inferred and predicted integral worths is $\leq$ 100 pcm,

  whichever is greater.

C. The measured/inferred N rod worth must be $\leq$ 110 percent of the predicted N rod worth.

In the event a review criterion is not met Westinghouse recommends that an evaluation of the impact of the test results on applicable transients be performed. This evaluation should be performed within 60 EFPD after completion of the test. Westinghouse should be notified concerning the test and evaluation results.

The second level, or acceptance criteria, is based on meeting safety analysis assumptions and have defined safety significance.

Acceptable acceptance criteria are:

A. The measured/inferred N rod worth must be $\geq$ 90 percent of the predicted N rod worth.

B. For all banks other than the reference bank; either

1. the absolute value of the percent difference between inferred and predicted integral worths is $\leq$ 30 percent, or

2. the absolute value of the reactivity difference between inferred and predicted integral worths is $\leq$ 200 pcm,

whichever is greater.

In the event an acceptance criterion is not met Westinghouse recommends that an evaluation of the test results and their impact on applicable transients be performed. This evaluation should be performed within 30 EFPD after completion of the test. Westinghouse should be notified concerning the test and evaluation results.

Westinghouse believes that the time noted to perform the evaluation is sufficient and allowable based on the significance of the measurement, i.e., assuming that all other acceptance criteria are met (e.g. MTC), power distribution limits on $F_Q(Z)$, F_{xy}, and $F^N_{\Delta H}$ are met and the indicated N worth is sufficient to verify meeting the Technical Specification Shutdown Margin requirements, then there is no defined need for exact compliance with the acceptance criteria on individual bank worth, or N bank worth for that matter, at the beginning of a particular fuel cycle. The primary impact of bank worth measurements on safety analysis assumptions is in the steambreak analysis. A large degree of conservatism is introduced into this analysis through the assumption of a very negative (EOL) moderator temperature coefficient. Allowance of full power operation for 30 EFPD will not result in an MTC near the analysis assumption nor what could be construed as a demonstrably unsafe operating condition. Based on the above, Westinghouse does not believe that the plant should be unduly restricted in power escalation or operation upon failure to meet either the review or acceptance criteria.

6.0 CONCLUSIONS

Westinghouse believes that sufficient information has been presented to warrant generic approval for the use of the bank exchange technique on all Westinghouse plants utilizing Westnghouse analyses. Westinghouse intends to use this technique on two, three, and four loop core designs for both first and reload cycles. The data presented notes the equivalence of the bank exchange technique to the conventional dilution technique utilizing reactivity computers and/or boron endpoints for several core designs, both reload and first cycle. Therefore, Westinghouse expects to use the bank exchange technique for all plants requesting its use in the future.

7.0 REFERENCES

Reference 1: F. M. Bordelon, et al, "Westinghouse Reload Safety Evaluation Methodology", WCAP-9272 (Proprietary) and WCAP-9273 (Non-Proprietary), March 1978.

Reference 2: W. B. Henderson, "Results of the Control Rod Worth Program", WCAP-9217 (Proprietary) and WCAP-9218 (Non-Proprietary), February 1978.

NOTE

THE ENTIRE CONTENTS OF APPENDICES "SAMPLE TEST PROCEDURE FOR ROD WORTH VERIFICATION UTILIZING RCC BANK EXCHANGE" IS CONSIDERED AS INFORMATION PROPRIETARY TO WESTINGHOUSE ELECTRIC CORPORATION UNDER THE CLASSIFICATION OF A,C.