UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

May 14, 1990

Docket No. STN 50-605

MEMORANDUM FOR:

T. Murley	B. Grimes	P. McKee
F. Miraglia	F. Congel	A. Thadani
W. Russell, ADT	J. Roe	Acting Chief, EAB
J. Partlow, ADP	C. Grimes	J. Dyer, EDO
D. Crutchfield, ADSP	B. Boger	Operations Center
S. Varga	G. Lainas	F. Gillespie
G. Holahan	M. Virgilio	W. Bateman
C. Rossi	B. D. Liaw	L. Reyes, RII
J. Richardson	E. Butcher	T. Cox
J. Zwolinski	W. Lanning	W. Travers

THRU: Charles L. Miller, Director
Standardization Project Directorate
Division of Reactor Projects - III, IV,
V and Special Projects

FROM: Dino C. Scaletti, Project Manager
Standardization Project Directorate
Division of Reactor Projects - III, IV,
V and Special Projects

SUBJECT: DAILY HIGHLIGHT - FORTHCOMING MEETING WITH GENERAL ELECTRIC COMPANY (GE) TO DISCUSS THE STAFF'S REVIEW OF THE ADVANCED BOILING WATER REACTOR. (SEE ATTACHED LIST OF DISCUSSION TOPICS)

DATE & TIME: May 16-17, 1990
9:00 A.M. - 4:30 P.M.

LOCATION: General Electric Company
175 Curtner Avenue
San Jose, California

DF01
1/1

PARTICIPANTS*:

NRC
A. Thadani
T. Pratt, NRR
J. Kudrick, NRR
G. Bagchi, NRR
M. Rubin, NRR
W. Hardin, RES
J. Lee, NRR
D. Scaletti, NRR

GE
J. Quirk
J. Duncan
J. Fox
C. Sawyer

Dino C. Scaletti

Dino C. Scaletti, Project Manager
Standardization Project Directorate
Division of Reactor Projects - III, IV,
V and Special Projects

cc: See next page

* Meetings between NRC technical staff and applicants or licensees are open for interested members of the public, petitioners, intervenors, or other parties to attend as observers pursuant to "Open Meeting Statement of NRC Staff Policy," 43 Federal Register 28058, 6/28/78. However portions of this meeting may be closed to the public to protect General Electric Company proprietary information. Members of the public who wish to attend should contact D. C. Scaletti at (301) 492-1104.

Mr. P. W. Marriott
General Electric Company

Docket No. STN 50-605

cc: Mr. Robert Mitchell
General Electric Company
175 Curtner Avenue
San Jose, California 95114

Mr. L. Gifford, Program Manager
Regulatory Programs
GE Nuclear Energy
12300 Twinbrook Parkway
Suite 315
Rockville, Maryland 20852

Director, Criteria & Standards Division
Office of Radiation Programs
U. S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Mr. Daniel F. Giessing
Division of Nuclear Regulation
and Safety
Office of Converter Reactor
Deployment, NE-12
Office of Nuclear Energy
Washington, D.C. 20545

Mr. Patrick W. Marriott, Manager
Licensing and Consulting Services
GE Nuclear Energy
General Electric Company
175 Curtner Avenue
San Jose, California 95125

AGENDA

STAFF/GE

MAY 16-17, 1990

ABWR SEVERE ACCIDENT RESPONSE:

1. Drywell head failure

   - Seal leakage

   - Structural failure

2. Containment over pressure protection

   - Thermal hydraulic response of pool (flashing)

   - Need for demister

   - Manual operation (bypass of second rupture disk)

   - Sequence specific timing to disk rupture

3. Source Term

   - Delayed fission product release

   - Source term into containment, credit for nonsafety systems

   - Concern over ability to meet 25 rem at one-half mile

4. Shutdown Risk

   - GE's view on shutdown risk - why is it not considered in ABWR PRA

   - Other PRA topics as appropriate

PARTICIPANTS*:

NRC	GE
A. Thadani	J. Quirk
T. Pratt, NRR	J. Duncan
J. Kudrick, NRR	J. Fox
G. Bagchi, NRR	C. Sawyer
M. Rubin, NRR	
W. Hardin, RES	
J. Lee, NRR	
D. Scaletti, NRR	

|s|

Dino C. Scaletti, Project Manager
Standardization Project Directorate
Division of Reactor Projects - III, IV,
V and Special Projects

cc: See next page

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DISTRIBUTION

Docket file	NRC Participants
NRC & Local PDRs	ACRS (10)
PDSL r/f	GPA/PA
ACRS (10)	VWilson
TMurley/FMiraglia	LThomas
DCrutchfield	PShea
GHolahan	WTravers
DScaletti	WLanning
OGC	EJordan
BGrimes	HVandermolen
MCunningham	CMiller

[DS DAILY HIGHLIGHT]

PDSL:PM	PDSL:LA	PDSL:D
DScaletti:dmj	PShea	CMiller
5/14/90	5/14/90	5/14/90

BW

B&W NUCLEAR TECHNOLOGIES

3315 Old Forest Road
P.O. Box 10935
Lynchburg, VA 24506-0935
Telephone: 804-385-2000
Telecopy: 804-385-3663

JHT/90-66

May 7, 1990

Mrs. Valeria Wilson, Chief
Administration Section
Planning, Program and Management Support Branch
Program Management, Policy Development and
Analysis Staff
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

References:

1. A. C. Thadani to J. H. Taylor, Acceptance for Referencing of Licensing Topical Report BAW-10175, "Rod Exchange Methodology," August 7, 1989.

2. J. H. Taylor to J. A. Norberg, Rod Exchange Methodology Topical Report, BAW-10175, JHT/89-204, October 6, 1989.

3. A. C. Thadani to J. H. Taylor, Rod Exchange Methodology Topical Report, BAW-10175, December 6, 1989.

Dear Mrs. Wilson:

Enclosed are 12 copies of topical report BAW-10175-A, "Rod Exchange Methodology." Reference 1 was the original SER for this report and approved the rod exchange methodology for use on the Catawba and McGuire Nuclear Units. Reference 2 requested that the SER be revised to include applicabiltiy to all other Westinghouse PWRs and included a technical justification for the request. Reference 3 amended the SER to include applicability to all current classes of Westinghouse PWRs.

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1/12

In accordance with procedures established in NUREG-0390, the SER and the amendment (references 1 and 3) are included in the accepted version of the report. Reference 2 is also included.

Very truly yours,

J. H. Taylor, Manager
Licensing Services

cc: Dan Fieno, NRC
R. C. Jones, NRC
R. B. Borsum
T. L. Baldwin

BAW-10175-A

May 1990

ROD EXCHANGE METHODOLOGY

B&W Fuel Company

BAW-10175-A

May 1990

ROD EXCHANGE METHODOLOGY

B&W Fuel Company

BAW-10175-A

May 1990

ROD EXCHANGE METHODOLOGY

by
G. H. Hobson
S. T. Robertson

B&W FUEL COMPANY
P. O. Box 10935
Lynchburg, Virginia 24506-0935

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

August 7, 1989

Mr. J. H. Taylor, Manager
Licensing Services
Nuclear Power Division
Babcock & Wilcox Fuel Company
P. O. Box 10935
Lynchburg, Virginia 24506-0935

Dear Mr. Taylor:

SUBJECT: ACCEPTANCE FOR REFERENCING OF LICENSING TOPICAL REPORT BAW-10175, "ROD EXCHANGE METHODOLOGY"

The staff has completed its review of the subject topical report submitted by the Babcock & Wilcox Fuel Company (BWFC) by letter dated May 22, 1989.

The staff finds the report to be acceptable for referencing in license applications to the extent specified and under the limitations delineated in the report and the associated NRC evaluation, which is enclosed. The evaluation defines the basis for acceptance of the report.

The staff does not intend to repeat the review of the matters that are described in the report and that were found acceptable when the report appears as a reference in license applications, except to ensure that the material presented is applicable to the specific plant involved. The staff's acceptance applies only to the matters described in the report.

In accordance with procedures established in NUREG-0390, it is requested that BWFC publish an accepted version of this report within 3 months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed evaluation after the title page. The accepted version shall include an -A (designating accepted) following the report identification symbol.

Should the staff's criteria or regulations change so that its conclusions as to the acceptability of the report are invalidated, BWFC and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

A. C. Thadani

Ashok C. Thadani, Assistant Director
for Systems
Division of Engineering & Systems Technology
Office of Nuclear Reactor Regulation

Enclosure:
Topical Report Evaluation

ENCLOSURE

SAFETY EVALUATION OF TOPICAL REPORT BAW-10175, "ROD EXCHANGE METHODOLOGY"

1.0 INTRODUCTION

BAW-10175 (Ref. 1) describes Babcock & Wilcox Fuel Company's (BWFC's) control rod exchange methodology or, as it is more commonly known, rod swap method. This is an alternative method to the dilution/boration method for determining the reactivity worth of control rod groups or banks during startup of either the initial or reload cycles of a reactor. The reactivity information provided by either of the two measurement methods can be compared to calculations that simulate the particular measurement method. Because startup test predictions are made using the same calculational methods as those that are used to design the reactor cycle in question, the comparison of calculated and measured control rod bank worths provides a limited check of the bank worths used in the core design. The rod swap method provides a number of advantages over the dilution/boration method, not the least of which is reduced startup testing time.

The report presents information that is similar to that in other reports on the rod swap method that the staff has reviewed and approved. It describes the measurement procedure that leads to the determination of the (1) integral and differential worths of the reference bank, which is obtained by the dilution/boration method; (2) measured critical position for each test bank fully inserted with the reference bank withdrawn so that the reactor is just critical; (3) adjustments that are made to the measured reactivity for reactor conditions that differ from nominal test conditions; and (4) reactivity worth of the test banks. The report describes the calculations that must be performed to obtain the predicted reference and test bank reactivity worths and compares the predicted with the measured control rod bank reactivity worths, obtained using the rod swap method, for three reactor startups in a Westinghouse four-loop pressurized water reactor.

The staff's evaluation of this licensing topical report follows.

2.0 EVALUATION

The staff has, in past reviews, established positions on the rod swap method (Refs. 2, 3, 4, 5 and 6). It has reviewed all major aspects of this method including (1) test procedures, (2) test analysis methods, (3) calculational methods, (4) results of sensitivity studies, (5) test acceptance criteria, and (6) comparisons of measured control rod bank reactivity worths with predicted worths. The staff also has reviewed and approved with comments (Ref. 7) the American Nuclear Society Standard ANS 19.6.1 "Reload Startup Physics Tests for Pressurized Water Reactors." This standard provides for the use of either the dilution/boration or rod swap method for the determination of control rod bank worths. It is the staff's position that the rod swap method is a well established and acceptable methodology for determining control rod bank worths that is based on the current start-of-the-art PWR calculation methods and types of core designs in use for the various classes of PWRs. The staff, in this evaluation, will establish the acceptability of the BWFC rod swap method.

BAW-10175 discusses the test procedures. A reference control rod bank is chosen on the basis of the predicted worth of each bank inserted individually into the core, with the boron concentration adjusted to achieve a just critical reactor. This reference bank is the predicted highest worth control rod bank. The testing begins from an essentially all-rods-out (ARO) critical reactor. The reference bank is stepped-in and the boron concentration is adjusted to keep the reactor nearly critical. The process continues until the reference bank is fully inserted. During this process a reactivity computer logs the information from which the integral and differential worths of the reference bank are determined. The final boron concentration and reactor temperature are logged. In the next phase of the rod swap method, a control rod bank, called the test bank, is stepped-in until it is fully inserted while the reference bank is stepped-out to a position at which the reactor is just critical. This final position of the reference bank is called the measured critical position for that test bank. This rod swap process is repeated for each control rod bank to be measured. All of the rod swap measurements are done at the nominal boron concentration and reactor temperature that were logged when the reference bank was fully inserted. These test procedures are similar to those used in other approved rod swap methodologies and are, therefore, acceptable.

Corrections, usually small, are applied to account for deviations from nominal test conditions. For example, if the reference bank is not fully inserted at the start of the testing, a correction is applied to the worth of the reference bank. Similarly, if the final position of the reference bank does not correspond to an ARO condition, a correction is made to the worth of the reference bank. Because these corrections are typical and necessary for this type of measurement so that a direct comparison to the calculated results may be made they are, therefore, acceptable.

The BWFC test analysis method to determine the measured reactivity worth of a control rod bank is the same as a methodology described in Reference 8 that has been reviewed and approved by the staff (Ref. 9). In the BWFC test analysis method, the measured worth of a control rod bank is a function of (1) the measured total reactivity worth of the reference control rod bank fully inserted alone, (2) a calculated parameter, and (3) the worth of the reference bank inserted alone from the measured critical position to the ARO position. The calculated parameter is the ratio of the integral of the reference bank worth with the test bank inserted to the integral of the reference bank worth with the reference bank inserted only, with the limits of integration going from the predicted critical position to the ARO position. This BWFC test analysis method is, therefore, acceptable.

Test predictions are based on core design methods. Calculations are performed to determine the following: (1) the total integral reactivity worth of each control rod bank individually inserted in the core, (2) the integral reactivity worth of the reference bank as a function of bank position with all other banks withdrawn from the core, and (3) the integral reactivity worth of the reference bank as a function of bank position with each test bank individually inserted in the core. Because the staff's bases for accepting the rod swap method are core design methods that have been reviewed and approved and because the calculations are a simulation of the measurements, the staff concludes that the BWFC rod swap calculational methodology is, therefore, acceptable.

BAW-10175 discusses both acceptance and review criteria that are used to evaluate the acceptability of test results. The acceptance criteria are a gross check of the test results. From the staff's point of view, meeting the more stringent review criteria will provide an appropriate measure of the acceptability of test results. These review criteria are:

(1) The absolute value of the difference between measured and predicted total integral reactivity worths divided by the predicted total integral reactivity worth for a reference bank, expressed as a percentage, shall be less than or equal to 10 percent.

(2) For each test bank either:

(a) The absolute value of the difference between measured and predicted total integral reactivity worths divided by the predicted total integral reactivity worth, expressed as a percentage, shall be less than 15 percent, or

(b) The absolute value of the difference between measured and predicted total integral reactivity worths shall be less than or equal to 0.1 percent reactivity.

(3) (a) The difference between measured and predicted total integral reactivity worths for all of the control rod banks divided by the predicted total integral reactivity worth for all of the control rod banks, expressed as a percentage, shall be less than +10 percent.

(b) In addition, according to the acceptance criteria, the difference between measured and predicted total integral reactivity worth for all of the control rod banks divided by the predicted total integral reactivity worth for all of the control rod banks, expressed as a percentage, shall be greater than -10 percent.

These criteria are comparable to those used when the control rod bank reactivity worths are measured by the dilution/boration method. Criterion 2b has usually been applied to low reactivity worth control rod banks. The criteria are sufficient for the purpose of providing a limited check on the design control rod worth calculations for the cycle in question. BWFC states in the report that, on failure to meet the criteria, the data will be analyzed and satisfactorily resolved. The staff concludes that the criteria proposed by BWFC for its rod swap method are acceptable because the same criteria are used in other approved rod swap methods.

The report presents the results of rod swap measurements and predictions for three reactor startups in a PWR. Results are presented for Cycles 2, 3, and 4 of McGuire Unit 1. The mean percent difference between predicted and measured test banks for the three reload cycles is -2.90 percent and the standard deviation for this sample of 24 test banks is 6.98 percent. All of the review criteria were met for the test and reference banks as well as for the total bank worths for the three reload cycles analyzed. Results are also presented in the report on the comparisons of predicted versus measured critical heights. The overall mean of the absolute differences between predicted and measured critical heights is only 0.5 steps with a standard deviation of 7.6 steps, where a step is equal to 5/8 inches. Although the number of cycles of data and the number of reactors analyzed are limited, the staff concludes that the results indicate that the B&W rod exchange methodology can provide acceptable results.

3.0 CONCLUSIONS

The staff has reviewed BWFC's control rod exchange methodology On the basis of this review, the staff concludes that this methodology is acceptable for use by BWFC for determining control rod bank reactivity worths at McGuire Units 1 and 2 and Catawba Units 1 and 2. The staff's acceptance requires that the following two conditions be met:

(1) All control rod groups or banks, that is, both shutdown and regulating control rod groups or banks, must be measured when using this rod exchange methodology.

(2) Because of the limited number of cycles of data that were presented in the report, BWFC should acquire additional cycles of data to confirm the adequacy of the BWFC rod exchange methodology.

4.0 REFERENCES

1. "Rod Exchange Methodology," BAW-10175, Babcock & Wilcox Fuel Company, April 1989.

2. Letter from R. L. Tedesco (NRC) to W. N. Thomas (VEPCO), "Acceptance for Referencing of Topical Report VEP-FRD-36, 'Control Rod Reactivity Worth Determination by Rod Swap Technique,'" November 7, 1980.

3. Memorandum from L. S. Rubenstein (NRC) to G. C. Lainas (NRC), "Revised Rod Exchange Methodology for Salem (TACS 49269)," February 25, 1983.

4. Memorandum from L. S. Rubenstein (NRC) to F. Miraglia (NRC), "SER for Westinghouse Topical Report Entitled 'Rod Bank Worth Measurements Utilizing Bank Exchange,' WCAP-9863, (TACS 43488)," March 10, 1983.

5. Memorandum from L. S. Rubenstein (NRC) to G. C. Lainas (NRC), "Rod Swap Analysis Method for Commonwealth Edison (TACS 52620 and 52621)," December 1, 1983.

6. Memorandum from L. S. Rubenstein (NRC) to G. C. Lainas (NRC), "Prairie Island Nuclear Generating Plant Rod Swap Methodology (TACS 55767 and 55768)," October 5, 1984.

7. Letter from R. E. Carter (NRC) to T. M. Raby (Secretary N-17 Standards Committee), April 18, 1985.

8. Letter from H. B. Tucker (Duke Power Company) to NRC (Attention: B. J. Youngblood), December 4, 1986.

9. NRC Safety Evaluation Report, "Rod Swap Methodology for Startup Physics Testing - McGuire and Catawba Nuclear Station, Units 1 and 2," May 22, 1987.

Babcock & Wilcox
a McDermott company

Nuclear Power Division
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P.O. Box 10935
Lynchburg, VA 24506-0935
(804) 385-2000

JHT/89-204

October 6, 1989

Mr. James A. Norberg, Special Assistant
Division of Engineering and System Technology
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: Rod Exchange Methodology Topical Report, BAW-10175

References: 1. J. H. Taylor to J. A. Norberg, JHT/89-98, May 22, 1989.

2. A. C. Thadani to J. H. Taylor, Acceptance for Referencing of Topical Report BAW-10175, "Rod Exchange Methodology", August 7, 1989.

Dear Mr. Norberg:

Reference 1 transmitted the subject topical report to the NRC for review. Subsequently, Reference 2 provided the Safety Evaluation Report (SER) and approval for that application. This SER concludes that the rod exchange methodology is acceptable for use by BWFC for McGuire Units 1 and 2 and Catawba Units 1 and 2. B&W requests that the SER be revised to include applicability to all other Westinghouse PWRs. Justification for this extended applicability is included with the attachment to this letter.

Very truly yours,

J.H. Taylor
Manager, Licensing Services

cc: w/attach
R.B. Borsum
T.L. Baldwin
D.B. Fieno, NRC
R.C. Jones, NRC

Application of the Rod Exchange Methodology to Other Westinghouse PWRs

The ability to calculate the necessary information to support control rod worth measurements by rod exchange centers on accurately determining calculated individual bank worths and integral bank worth shapes. This calculational process basically consists of three inter-connected analytical techniques: 1) the development of specific fuel nuclear cross-sections; 2) the development of specific control rod cross-sections; and 3) the development of a core model for calculations of individual control rod bank worths and integral rod worth shapes. BWFC has successfully demonstrated the ability to calculate the information required to support control rod worth measurements using the rod exchange method for Westinghouse-designed plants in BAW-10175.

Presented on the following page are calculated and measured rod worths for three cycles each of two different Westinghouse-designed plants and for the three most recent B&W 177 F.A. plant reloads. Also attached are representative examples of measured integral rod worth versus predicted integral worth for three different types of plants. Measured rod worths were determined by the standard boron exchange method. This data demonstrates that BWFC has the ability to accurately calculate control rod worths and integral worth shapes for a variety of fuel types, control rod types, and core designs.

The techniques approved in BAW-10175 are insensitive to global parameters that may differ in Westinghouse-designed pressurized water reactors (PWRs) other than the McGuire and Catawba units, such as the number of reactor coolant system loops, the fuel assembly design (eg., 15x15 vs. 17x17), and the number of fuel assemblies in the core (eg., Westinghouse 157 vs. Westinghouse 193). Since BWFC can accurately determine individual control rod bank worths (and integral shapes), and since BWFC has demonstrated technical support for control rod worth measurements by the rod exchange method, the applicability for BAW-10175 should be extended to any Westinghouse reactors which BWFC may support in the future.

McGuire-1 Cy 2				McGuire-1 Cy 3				McGuire-1 Cy 4			
Bank	Meas	Pred	%Diff	Bank	Meas	Pred	%Diff	Bank	Meas	Pred	%Diff
CC	788	801	-1.6	SB	779	844	-7.7	CC	778	819	-5.0
CD	586	656	-10.7	CD	483	509	-5.1	CD	580	573	+1.2

% Diff Mean = -4.8%
Std. Dev. = 4.2%

Conn Yankee Cy 12				Conn Yankee Cy 13				Conn Yankee Cy 14			
Bank	Meas	Pred	%Diff	Bank	Meas	Pred	%Diff	Bank	Meas	Pred	%Diff
CD	2068	2050	+0.9	CD	2319	2122	+9.3	CD	2114	2183	-3.2
CA	1813	1818	-0.3	CA	1872	1813	+3.3	CA	1929	2008	-3.9
CB	767	776	-1.2	CB	802	748	+7.2	CB	929	961	-3.3

% Diff Mean = 1.0%
Std. Dev. = 4.7%

TMI-1 Cy 7				D-B Cy 6				ANO-1 Cy 9			
Bank	Meas	Pred	%Diff	Bank	Meas	Pred	%Diff	Bank	Meas	Pred	%Diff
5	1220	1208	+1.0	5	1445	1326	+9.0	5	1380	1294	+6.6
6	934	971	-3.8	6	1083	1111	-2.5	6	1012	1057	-4.3
7	926	978	-5.3	7	954	943	+1.2	7	825	867	-4.8

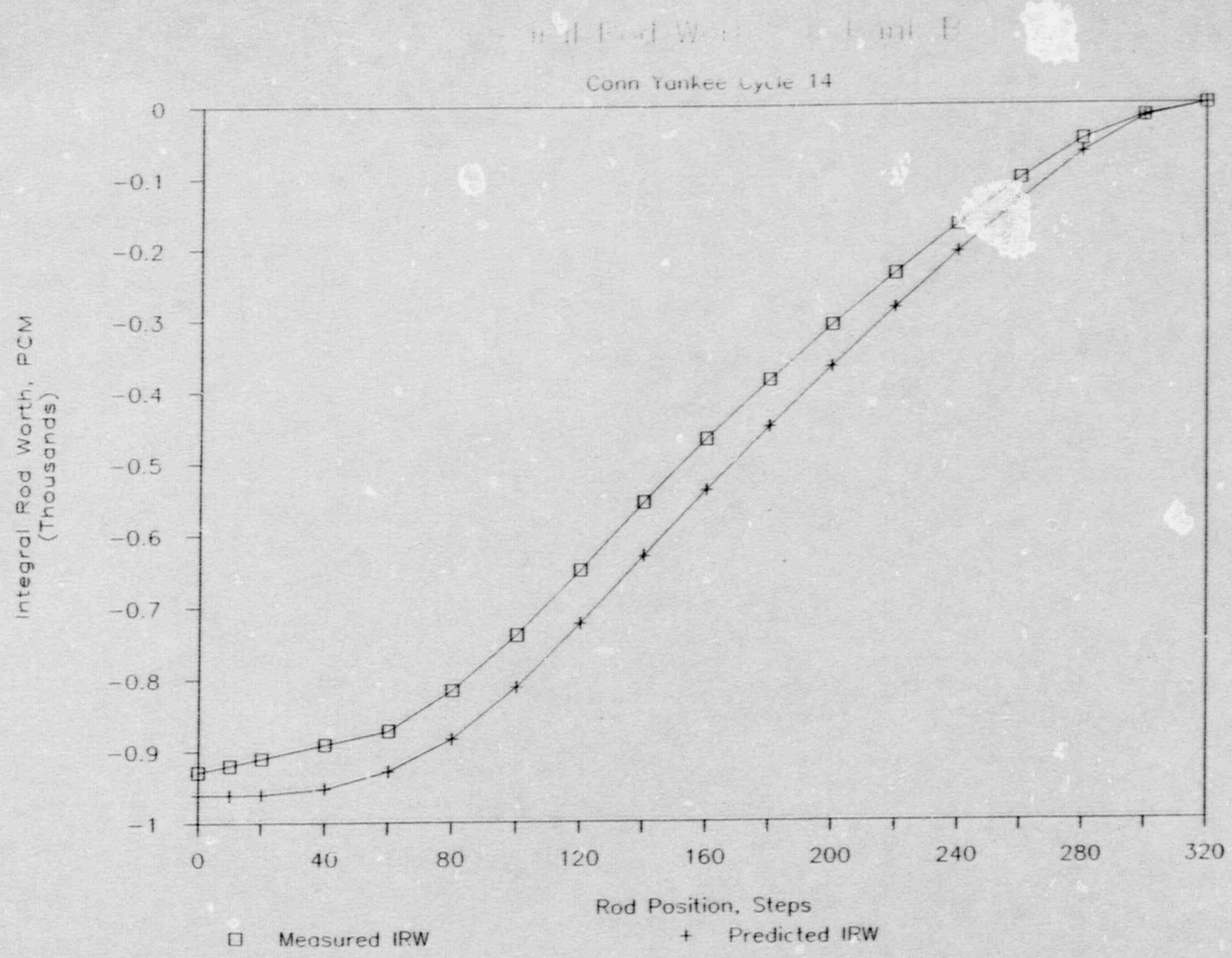
% Diff Mean = -0.3%
Std. Dev. = 5.2%

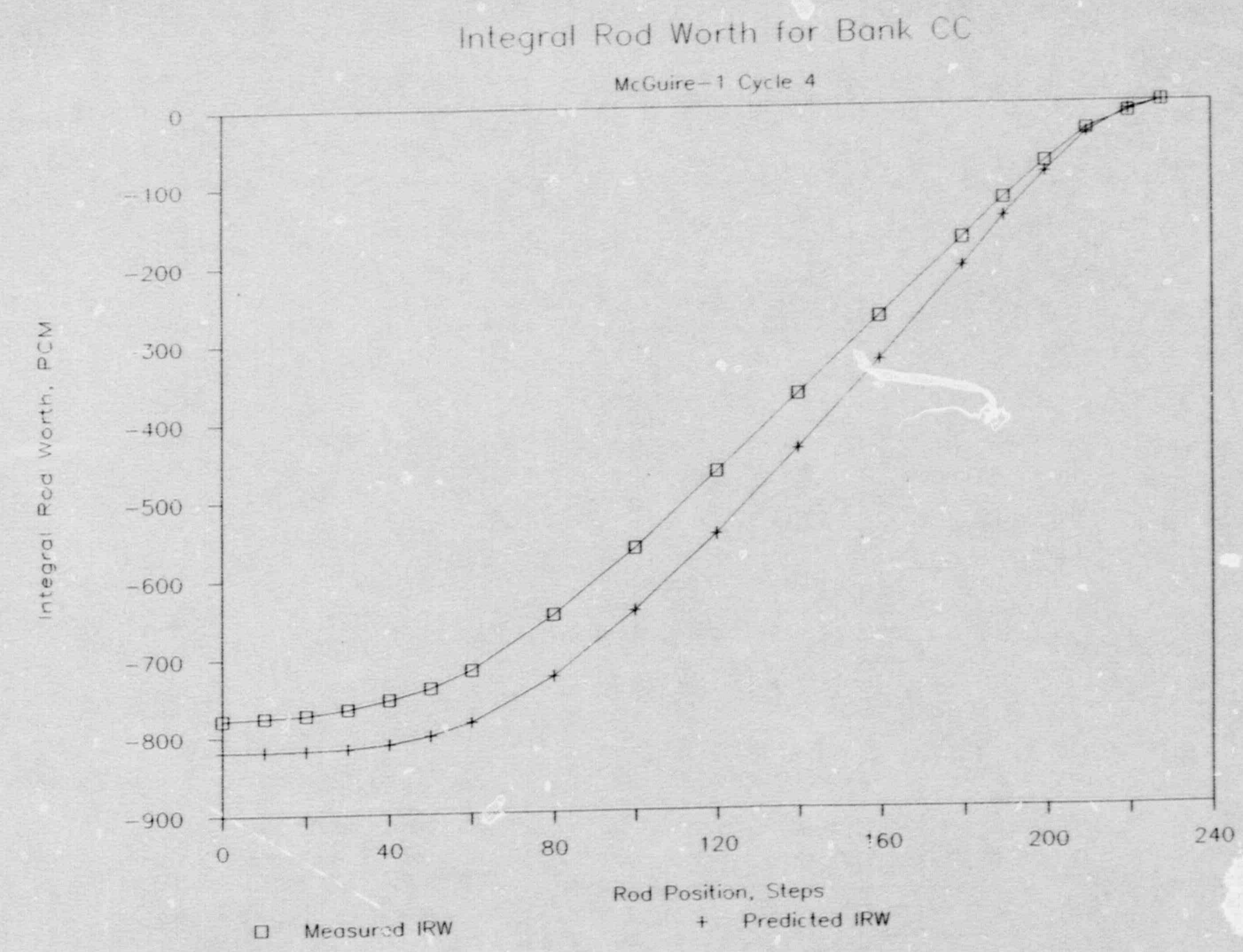
NOTES:

1) All Predicted rod worths calculated by B&W/BWFC.

2) All rod worths presented above are in units of PCM.

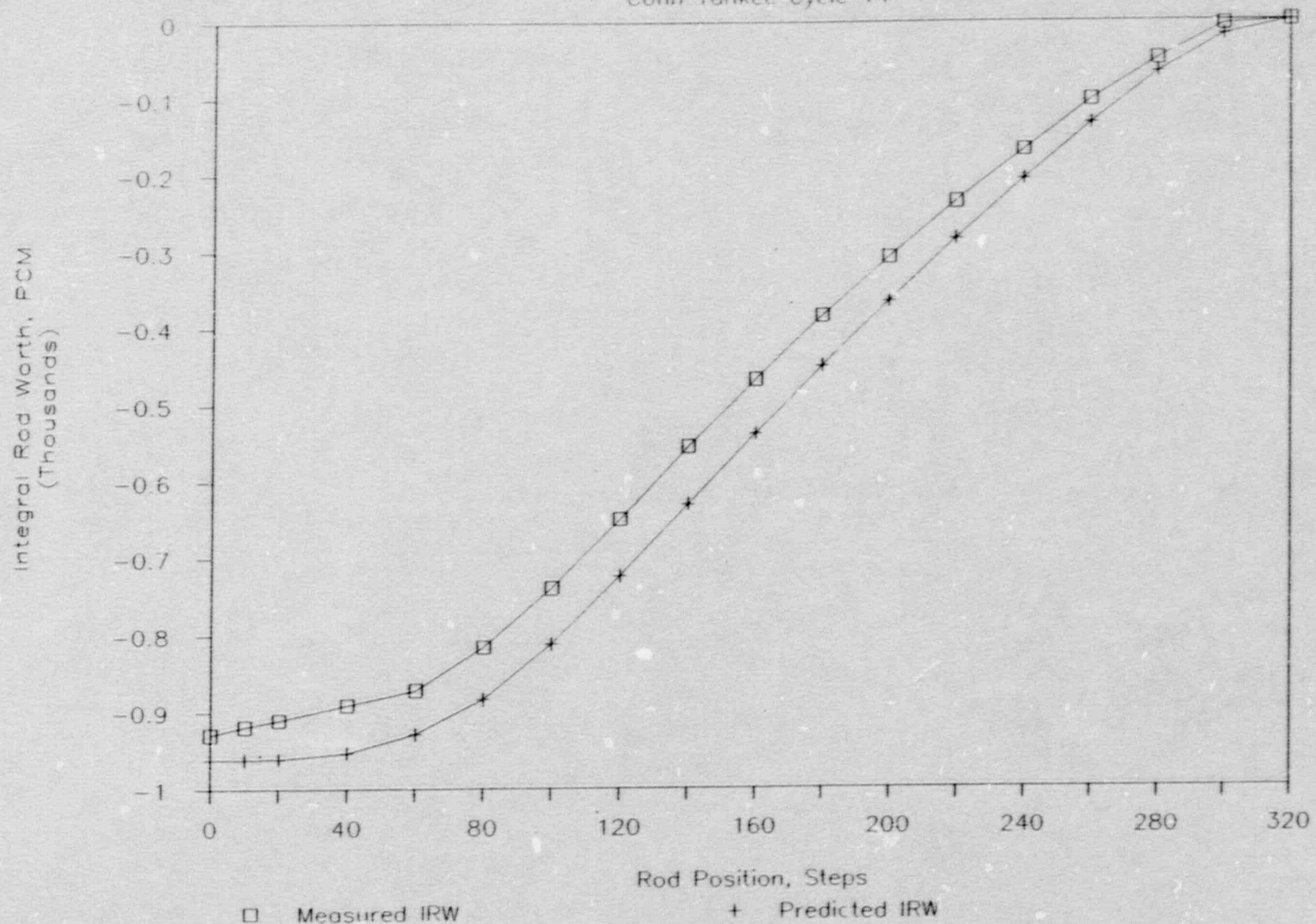
3) % Diff = (M-P)/P x 100%

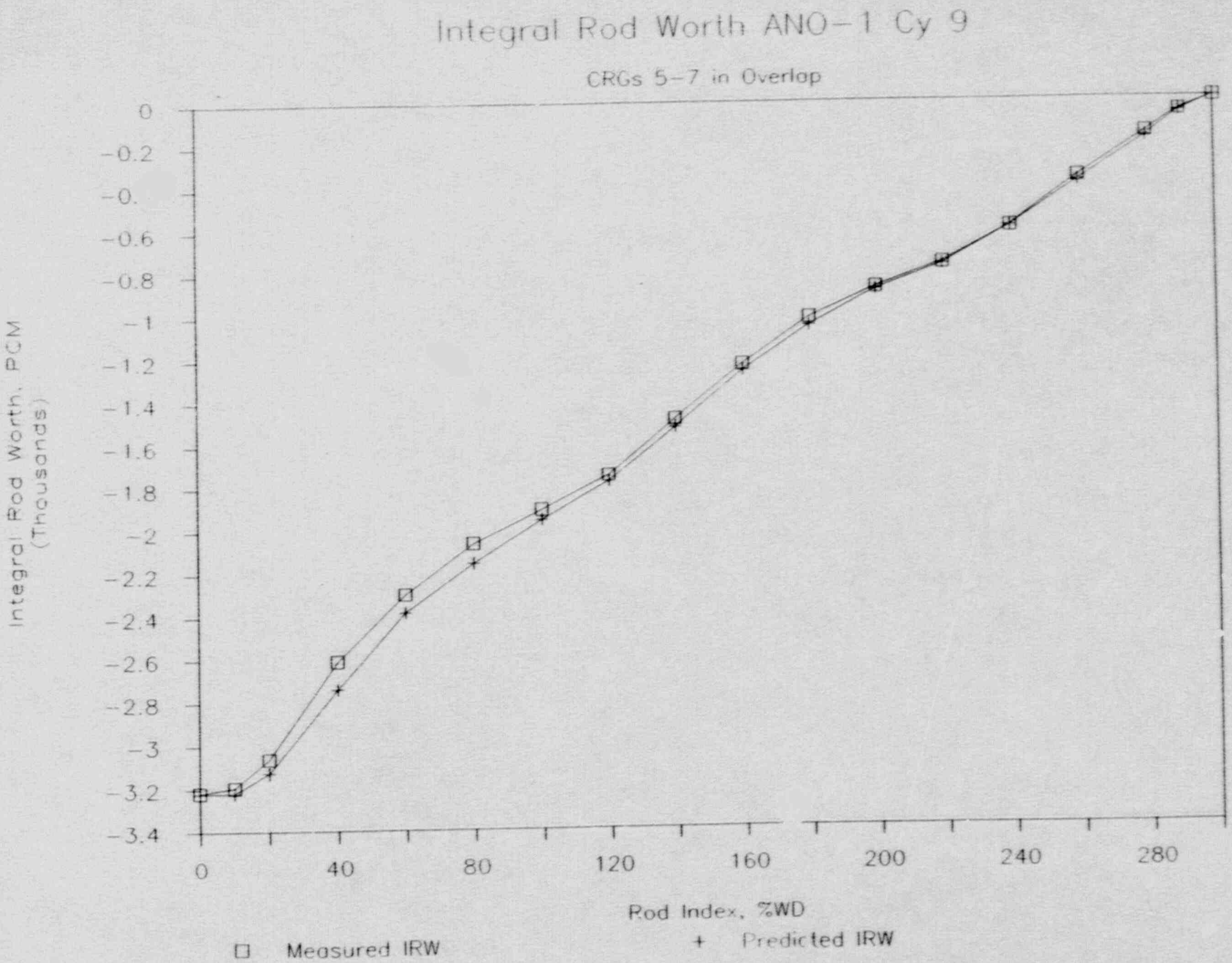

Conn Yankee Cycle 14
Integral Rod Worth, PCM
(Thousands)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
0
40
80
120
160
200
240
280
320
Rod Position, Steps
Measured IRW
Predicted IRW


Integral Rod Worth for Bank CC
McGuire-1 Cycle 4
Integral Rod Worth, PCM
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
0
40
80
120
160
200
240
Rod Position, Steps
□ Measured IRW
+ Predicted IRW

Integral Rod Worth for Bank B

Conn Yankee Cycle 14





Integral Rod Worth ANO-1 Cy 9
CRGs 5-7 in Overlap
Integral Rod Worth, PCM
(Thousands)
0
-0.2
-0.
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
-2.8
-3
-3.2
-3.4
0
40
80
120
160
200
240
280
Rod Index, %WD
Measured IRW
Predicted IRW

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

December 6, 1989

Mr. J. H. Taylor, Manager
Licensing Services
Nuclear Power Division
Babcock & Wilcox
P. O. Box 10935
Lynchburg, Virginia 24506-0935

Dear Mr. Taylor:

SUBJECT: ROD EXCHANGE METHODOLOGY TOPICAL REPORT, BAW-10175

References:
1. "Rod Exchange Methodology," BAW-10175, Babcock & Wilcox Fuel Company, April 1989.
2. Letter from A. C. Thadani (NRC) to J. H. Taylor (B&W), "Acceptance for Referencing of Licensing Topical Report BAW-10175, 'Rod Exchange Methodology,'" August 1989.
3. Letter (JHT/89-204) from J. H. Taylor (B&W) to James A. Norberg (NRC), October 6, 1989.

We had previously reviewed your licensing topical report on the rod exchange methodology (Ref. 1) and issued a safety evaluation report (SER) (Ref. 2) accepting the topical report for referencing in licensing actions. The SER concludes that the rod exchange methodology is acceptable for use by the Babcock & Wilcox Fuel Company (BWFC) for McGuire, Units 1 and 2 and Catawba, Units 1 and 2. Your letter of October 6, 1989 (Ref. 3) requests that the SER be revised to include applicability to all other Westinghouse PWRs. The letter includes a justification for this extended applicability. We have reviewed the applicable information and concur with your assessment that your rod exchange methodology is applicable to all current classes of Westinghouse PWRs. Therefore, by this letter, the SER is amended to include applicability of Topical Report BAW-10175 to all current classes of Westinghouse PWRS.

Sincerely,

for Scott Newberry

Ashok C. Thadani, Director
Division of Systems Technology
Office of Nuclear Reactor Regulation

B & W FUEL COMPANY
Lynchburg, Virginia

Topical Report
BAW-10175-A

May 1990

ROD EXCHANGE METHODOLOGY

G. H. Hobson
S. T. Robertson

Key Words: Rod Exchange, Rod Worth

ABSTRACT

The B & W Fuel Company (BWFC) has developed a calculational methodology to support the measurement of control rod worth utilizing the rod exchange test method during post refueling low power physics testing. The adequacy of the BWFC rod exchange methodology is assessed by comparing predicted bank worths to measured worths for three reload fuel cycles. These benchmark comparisons demonstrate the validity of the BWFC methodology for providing calculated parameters required by utilities for performing control rod worth measurements using the rod exchange technique.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION AND SUMMARY

1.1 Introduction

Control rod worth determination (both calculated and measured) is required for each nuclear reactor fuel cycle to verify acceptable shutdown margin. Measurement of control rod worth during reload startup physics testing at pressurized water reactor (PWR) facilities is typically accomplished by one of three methods (Reference 1): 1) Boron dilution technique (boron swap), 2) Rod exchange (rod swap) technique, or 3) Boron endpoint method. The purpose of this report is to present the B&W Fuel Company (BWFC) methodology to support performance of control rod worth measurements using the rod exchange technique. This methodology involves the use of approved computer codes to determine both calculated control rod worths and correction factors for application to measured data to establish measured control rod worths.

The validity of the BWFC rod exchange methodology is assessed by examining calculated (or predicted) rod worth versus measured rod worth from zero power physics testing performed for three PWR reload fuel cycles. These benchmark calculations compare the BWFC-predicted control rod (or bank) worths to measured worths inferred from applying BWFC-calculated correction factors to the raw, measured test results. Additionally, this report provides a discussion of the rod worth by rod exchange test method, which includes a test abstract, data analysis guidelines, and the appropriate test acceptance criteria.

1.2 Summary

The BWFC methodology for calculating rod worths and correction (α) factors to support the measurement of control rod worth by rod exchange utilizes approved codes and is outlined in Section 2. The test method for performing rod worth measurements by rod exchange outlined herein (Section 3) is consistent with the test procedure outlined in References 1 and 2. Benchmark data presented in Section 4 compares BWFC-predicted bank worths to inferred, measured worths using BWFC-calculated α factors for three different reload fuel cycles. The results are consistent with data summarized in Reference 2.

2. ROD EXCHANGE CALCULATIONAL METHODOLOGY

2.1 Calculational Method Overview

This section outlines the calculational procedure used for generating information to support the measurement of control rod worth utilizing the rod exchange test method. Calculations are performed using the approved nodal codes NOODLE (Reference 3) and FLAME (References 4 and 5). The following information is generated to support the rod exchange test method.

Each rod bank worth is calculated with all other banks withdrawn. The rod bank with the maximum calculated worth is defined as the Reference Bank. The remaining banks are defined as the test banks.

The critical height of the Reference Bank with each test bank fully inserted is calculated. "Critical height" is defined as the endpoint position of the Reference Bank for which the following condition holds; the calculated core reactivity with the Reference Bank at the critical height and the test bank fully inserted equals the calculated core reactivity with the Reference Bank fully inserted and the test bank fully withdrawn (see Figure 2-1).

$$\text{Calculated core reactivity (PCM)} = \frac{(k - 1)}{k} * 10^5$$

where k is the calculated eigenvalue.

During the rod exchange measurement process, the Reference Bank total (integral) worth is first measured by boron dilution with all other banks withdrawn. The measured test bank worth is determined with the test bank fully inserted and the Reference Bank at its critical height. The test bank worth is equal to the withdrawn worth of the Reference Bank. Since the insertion of the test bank influences the integral worth of the Reference Bank, a correction factor is applied to the measured Reference Bank integral worth for determining the measured test bank worth. The correction factor accounts for the ratio of the Reference Bank integral worth with the test bank fully inserted to the Reference Bank integral worth with all test banks out. The correction factor for each bank is calculated at the corresponding calculated critical height.

2.2 Calculational Details

This section provides the detailed calculational procedure used to calculate bank worths, critical heights, and correction factors.

1) Calculate the bank worth for bank x (W_x). The bank worth is determined by the difference between the core reactivity at all rods out (ARO) condition and the core reactivity with bank x fully inserted. Repeat the calculation for each bank (control and safety). Define the Reference Bank as the bank with the maximum calculated worth (W_{REF}).

2) Calculate the bank worth for the Reference Bank with bank x (or, test bank) fully inserted ($W_{REF,x}$). The Reference Bank worth is determined by the difference between the core reactivity with the test bank fully inserted and the core reactivity with both the Reference Bank and the test bank fully inserted. Repeat the calculation for each test bank.

3) Calculate the integral bank worth for the Reference Bank with all test banks withdrawn. The Reference Bank is modeled by inserting the bank in small increments to provide a set of worths versus insertion. Fitting routines are used to provide a table of the integral bank worth at very fine insertion spacings.

4) Calculate the integral bank worth for the Reference Bank with bank x fully inserted. Repeat the calculation for each test bank.

5) Calculate the critical height (z) of the Reference Bank when bank x is fully inserted. The critical height is defined as the position of the Reference Bank at which the withdrawn worth of the Reference Bank equals

the worth of bank x (see Figure 2-2).

$$W_x = W_{REF} - (f^z_{REF,x} * W_{REF,x})$$

where $f^z_{REF,x}$ = the relative integral worth of the reference bank at height z with bank x fully inserted. $(0.0 \leq f^z_{REF,x} \leq 1.0)$

Repeat the calculation for each test bank.

6) Calculate the correction factor for bank x (α_x). The correction factor is defined as the ratio of the Reference Bank integral worth at the calculated critical height with bank x fully inserted to the Reference Bank integral worth at the calculated critical height with bank x fully withdrawn (see Figure 2-3).

$$\alpha_x = \frac{f^z_{REF,x} * W_{REF,x}}{f^z_{REF} * W_{REF}}$$

where f^z_{REF} = the relative integral worth of the reference bank at height z with all other banks fully withdrawn. $(0.0 \leq f^z_{REF} \leq 1.0)$

Repeat the calculation for each test bank.

Figure 2-1. Definition of Critical Height

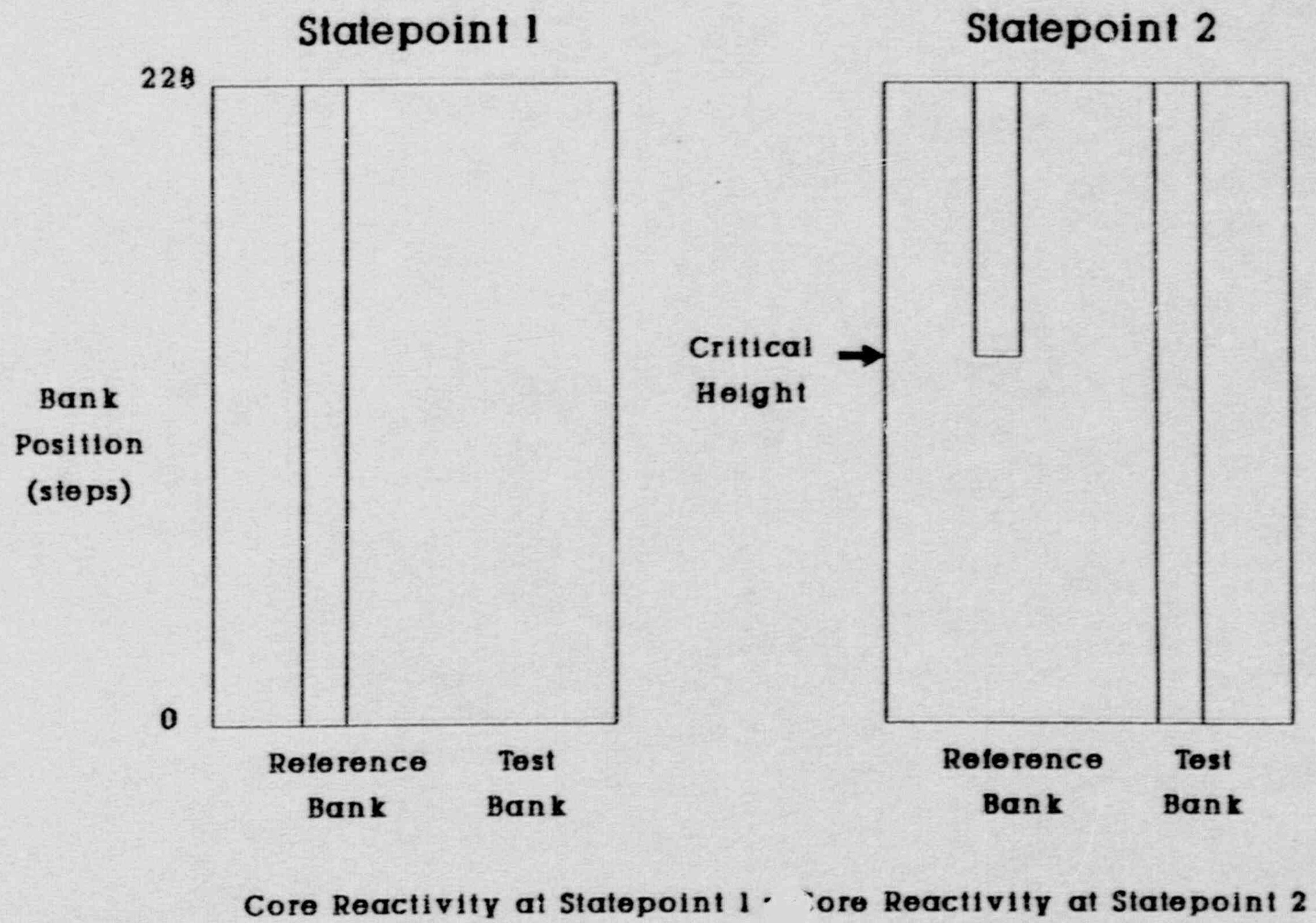


Figure 2-2. Critical Height Calculation

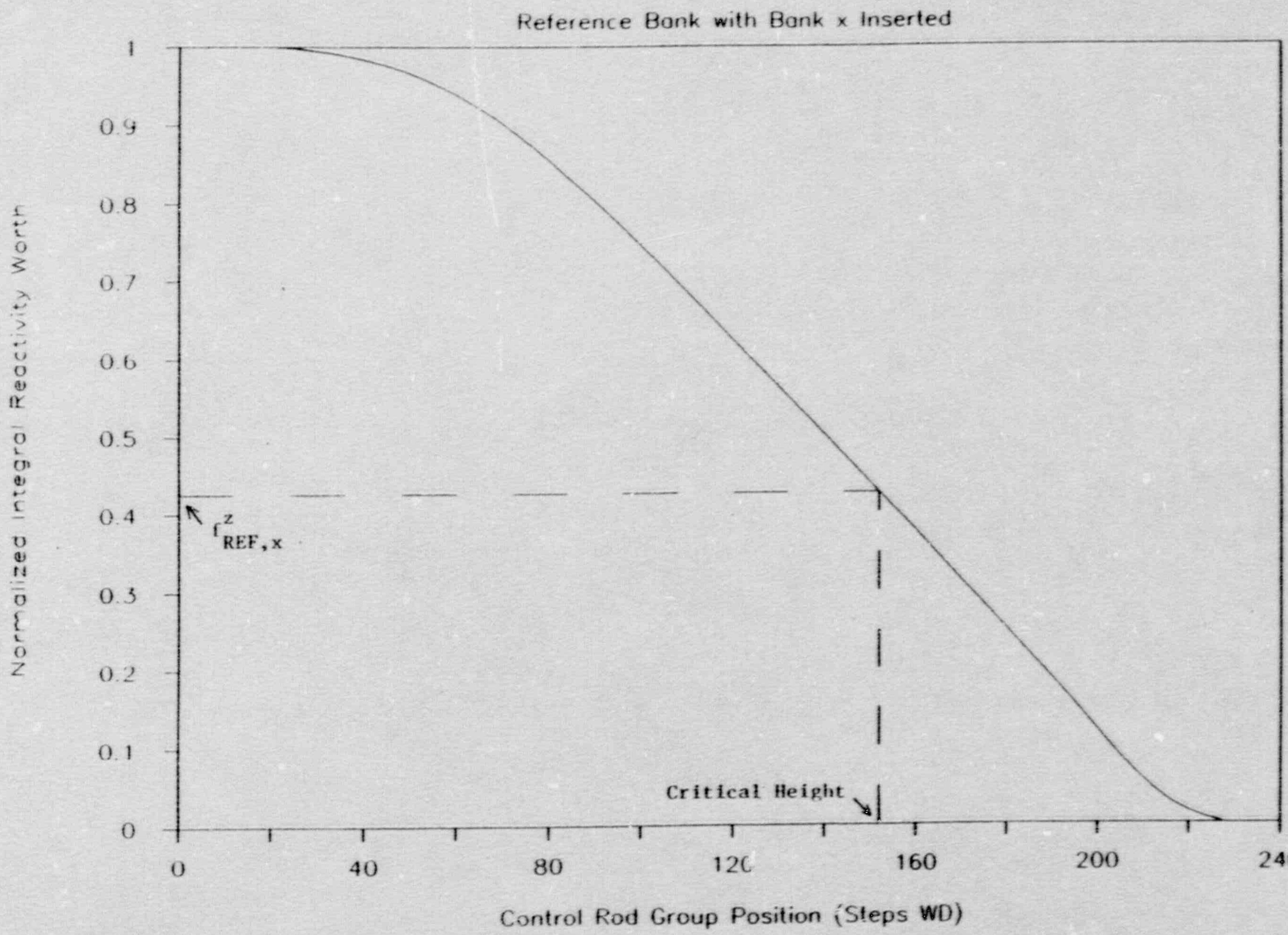
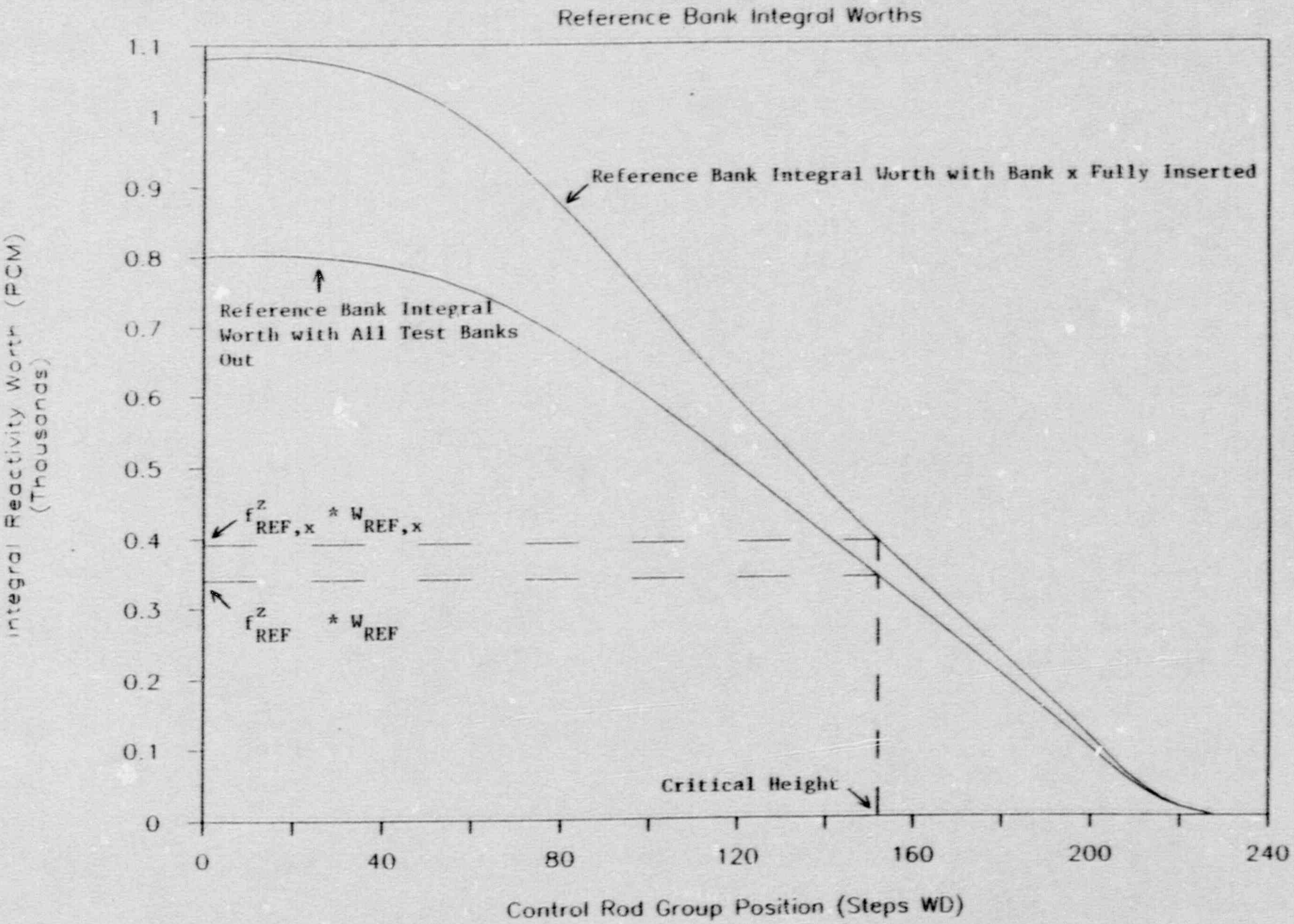


Figure 2-3. Correction Factor Calculation



3. ROD EXCHANGE MEASUREMENT PROCEDURE

3.1 Test Method

The rod exchange test method during zero power physics testing begins with the measurement of the highest predicted worth bank (the "Reference Bank") by boron dilution. Rod worth measurement by boron dilution involves inserting the Reference Bank in small increments starting from equilibrium, near all-rods-out (ARO) conditions. Continuous coolant system boron dilution during control rod insertion results in a reactivity trace from which incremental control rod worths are determined for each rod insertion. The test procedure ensures that the deboration rate during the Reference Bank worth measurement is less than 500 PCM/hr. The differential boron worth is calculated by dividing the measured Reference Bank worth by the difference in the ARO and Reference Bank-in boron endpoints.

When the incremental rod worths are added and plotted versus Reference Bank position, an integral rod worth curve results. The total measured integral Reference Bank worth at 0 steps withdrawn (WD) is compared to the predicted Reference Bank worth. Equilibrium conditions are obtained at a Reference Bank position near fully inserted. Correction(s) for deboration over (or under) shoot may be made, but equilibrium conditions are typically obtained at a final Reference Bank position of 0-30 Steps withdrawn (WD). If the equilibrium conditions are obtained at a Reference Bank position > 0 Steps WD, then the worth from that position to 0 Steps WD may be determined by reactimeter measurement. Similarly, the worth of the Reference Bank from near all-rods-out conditions to fully withdrawn may be determined by reactimeter measurement prior to deboration. The test procedure ensures that the entire Reference Bank integral worth is determined.

From the initial condition of the Reference Bank near full insertion, each remaining control and shutdown bank is inserted (exchanged) versus Reference Bank withdrawal to determine the Reference Bank critical height for each bank. "Critical height" is defined as the endpoint position of the Reference Bank for exactly critical conditions with the measurement (or test) bank at 0 Steps WD. Following the determination of critical height for each test bank, that bank is alternately withdrawn versus Reference Bank insertion until the test bank is fully withdrawn, and the final Reference Bank position is recorded.

3.2 Data Analysis

This section outlines the basic procedure for calculating inferred rod worths by rod exchange once all data is collected for all test banks.

The measured (inferred) bank worth is determined by the following equation for any given test bank, x:

(Eq.3-1) $$W_x^I = W_{REF}^M - \alpha_x (\Delta\rho)_x$$, where

W_x^I = The measured (inferred) test bank worth.

W_{REF}^M = The measured worth of the Reference Bank determined from the average of initial (prior to rod exchange of the test bank) and final (following rod exchange of the test bank) positions of the Reference Bank to ARO.

α_x = Calculated correction factor; the ratio of the calculated Reference Bank integral rod worth at the predicted critical height with the test bank fully inserted to the Reference Bank integral rod worth at the same position with all other banks fully withdrawn.

$(\Delta\rho)_x$ = Measured integral rod worth of the Reference Bank from the measured critical height to ARO.

The determination of W_x^I for each test bank involves the following assumptions:

1) The values calculated for W_{REF}^M and $(\Delta\rho)_x$ are typically determined using linear interpolation from a table of measured Reference Bank integral rod worth (with all other banks out) versus position.

2) The predicted α_x, or α factor provided for the determination of W_x^I is

calculated at the predicted critical height. Measured reactivity to which this α factor adjustment is applied, $(\Delta\rho)_x$, is determined from the measured critical height. Variation of the calculated α factor versus critical height is depicted in Figure 3-1 for several different test banks for McGuire 1 Cycle 3. The impact on the calculated α factor due to varying the critical height $\pm$ 20 Steps WD is small (less than 2%) for three of the test banks shown. The α factor for Control Bank C varies more significantly over a similar range, but these calculations were performed at a Reference Bank position of nearly fully withdrawn. While the α factor changes more rapidly versus position for Reference Bank positions near fully withdrawn, the corresponding $(\Delta\rho)_x$ values of the Reference Bank for this situation will be small (the $(\Delta\rho)_x$ value was less than 6 PCM for Control Bank C, M-1 Cycle 3). Therefore, variation of the calculated α factor versus critical height, considering the expected deviation between measured and predicted critical height, is sufficiently small such that the impact of this assumption on the final W_x^I values is negligible.

3) W_x^I worth values are reported to the nearest whole PCM.

3.3 Acceptance Criteria

All measured values (M) will be compared to the predicted data (P) calculated using techniques described in Section 2. Acceptance and review criteria based on these comparisons are then evaluated. If any acceptance criterion is not met, an evaluation is performed before the startup test program is continued. Further specific actions, which may include additional startup testing, depend on the evaluation results. If any review criterion is not met, an evaluation is performed which may take place during continued startup testing. Also, final documented resolution of a failed acceptance criterion is typically required within 30 days, while final documented resolution of a failed review criterion is typically required within 60 days.

Acceptance criteria are listed below. Any comparisons that do not agree within the following acceptance criteria shall be analyzed and satisfactorily resolved. Measured values should agree with predicted values to within the following tolerances:

1.	Reference Benk Worth	$\lvert$% Deviation$\rvert$ < 15%	
2.	Total Rod Worth	% Deviation > - 10%	
3.	Individual Bank Worth (other than Reference Bank) satisfies <u>either</u>	$\lvert$% Deviation$\rvert$ < 30%	
		<u>or</u>	
		$\lvert$M-P$\rvert$ < 200 PCM	
4.	Differential Boron Worth	$\lvert$% Deviation$\rvert$ < 15%	

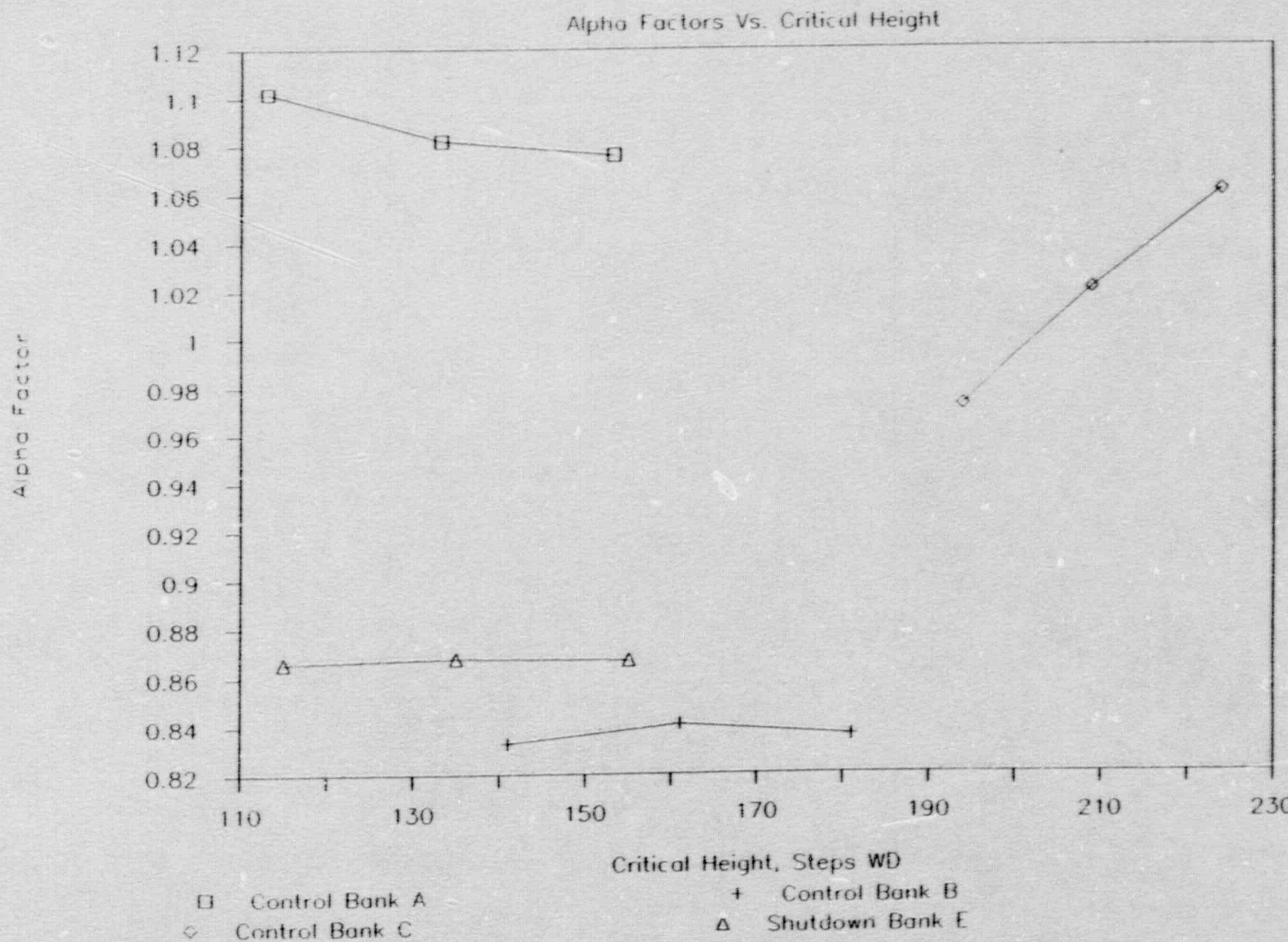
Note: $\% \text{ Deviation} = \frac{\text{Measured - Predicted}}{\text{Predicted}} \times 100\%$

This definition of % deviation is consistent with Reference 2.

Review criteria are listed below. Comparisons of predicted and measured rod worths that are not within the review criteria shall be analyzed and satisfactorily resolved. Measured values should agree with predicted values to within the following tolerances:

1.	Reference Bank Worth	$\lvert$% Deviation$\rvert$ < 10%
2.	Total Rod Worth	% Deviation < + 10%
3.	Individual Bank Worth (other than Reference Bank) satisfies <u>either</u>	$\lvert$% Deviation$\rvert$ < 15%
		<u>or</u>
		$\lvert$M-P$\rvert$ < 100 PCM

Figure 3-1 McGuire 1 Cycle 3



4 COMPARISON TO MEASURED DATA

4.1 Benchmark Method

Measured data in the form of completed plant procedure packages containing control rod worth measurements performed using the rod exchange technique for three McGuire Nuclear Station Unit 1 reload fuel cycles (Cycles 2-4) were used for benchmarking. From data available in these procedures, the appropriate measured data (W^M_{REF} and $(\Delta\rho)_x$ values) for each test bank were extracted. Once α factor values were calculated in accordance with Section 2, inferred worths for these reloads were obtained using Equation 3-1 in Section 3.2. Only measured (inferred) bank worths using BWFC-calculated α factors are compared to BWFC-predicted bank worths. BWFC-predicted critical heights are also compared to the measured critical heights from these startups for each test bank.

4.2 Discussion of Results

Comparisons of predicted versus measured bank worths for the three reload cycles evaluated are presented in Tables 4-1 through 4-3. The maximum percent difference between a predicted and measured test bank is -18.9% (Control Bank A, M-1 Cycle 3 on Table 4-2), but this bank is a relatively low worth bank having an absolute difference between predicted and measured worth of only 67 PCM. The maximum absolute difference between a predicted and measured test bank worth is 79 PCM (Control Bank D, M-1 Cycle 2), with a corresponding -12.0% difference. The mean percent difference between predicted and measured test banks for these three reload cycles (24 test banks) is -2.90% and the standard deviation of this sample (n-1 weighting) is 6.98%. The mean percent difference value of -2.90% and the mean absolute difference of 17.7 PCM (Std Dev. = 32.1 PCM) for these test banks compare favorably to the respective review criteria of ± 15% difference or ± 100 PCM, as presented in Section 3.3. In fact, all individual test banks evaluated for BWFC benchmarking meet the review criteria.

Each of the Reference Banks measured by boron dilution for these reloads meets both the acceptance and the more restrictive review criterion (± 15% and ± 10%, respectively from Section 3.3) when compared to BWFC predictions. Similarly, the measured total rod worth obtained by summing the measured Reference Bank worth and the inferred test bank worths is acceptable for these three benchmark cycles, since the percent difference when compared to predicted is > (more positive than) -10% in all cases.

Comparisons of predicted versus measured critical heights for McGuire 1 Cycle 2-4 are contained in Tables 4-4 through 4-6. No adjustment to the measured critical height data obtained during testing was made when comparing to BWFC-calculated critical heights. However, it is recognized that a slight bias between measured and calculated critical heights exists due to the Reference Bank being slightly less than fully inserted prior to rod exchange measurements, while the calculations assume the Reference Bank is fully inserted. Excellent agreement between predicted and measured critical heights exists as only three of 24 test banks have an absolute difference exceeding 10 Steps withdrawn (WD). The overall mean of the absolute differences between predicted and measured critical heights is only 0.5 Steps WD, with a standard deviation of 7.6 Steps WD. Adequacy of critical height calculations gives added assurance that the assumption associated with using the calculated α factor at the predicted critical height to infer measured bank worth is valid.

Table 4-1
Control Rod Worth by
Rod Exchange for
McGuire 1 Cycle 2

Bank	Alpha	Predicted Worth, PCM	Measured Worth, PCM	Diff (M-P)	%Diff *
D	1.157	656	577	-79	-12.0%
C (REF)	---	801	788	-13	-1.6%
B	1.680	627	596	-31	-4.9%
A	0.812	281	279	-2	-0.7%
SE	0.902	233	233	0	0.0%
SD	1.173	383	385	2	0.5%
SC	1.169	377	372	-5	-1.3%
SB	0.952	496	495	-1	-0.2%
SA	1.706	561	533	-28	-5.0%
Total		4415	4258	-157	-3.6%

* -- % Difference = (M-P)/P

Table 4-2
Control Rod Worth by
Rod Exchange for
McGuire 1 Cycle 3

Bank	Alpha	Predicted Worth, PCM	Measured Worth, PCM	Diff (M-P)	%Diff*
D	1.181	509	461	-48	-9.4%
C	1.020	805	744	-61	-7.6%
B	0.841	598	615	17	2.8%
A	1.082	355	288	-67	-18.9%
SE	0.868	463	406	-57	-12.3%
SD	1.051	371	383	12	3.2%
SC	1.055	369	372	3	0.8%
SB (REF)	---	844	779	-65	-7.7%
SA	1.058	276	304	28	10.1%
Total		4590	4352	-238	-5.2%

* -- % Difference = (M-P)/P

Table 4-3
Control Rod Worth by
Rod Exchange for
McGuire 1 Cycle 4

Bank	Alpha	Predicted Worth, PCM	Measured Worth, PCM	Diff (M-P)	%Diff *
D	1 146	573	564	-9	-1.6%
C (REF)	---	819	778	-41	-5.0%
B	1.300	685	678	-7	-1.0%
A	0.899	309	295	-14	-4.5%
SE	0.924	505	471	-34	-6.7%
SD	1.119	361	327	-34	-9.4%
SC	1.117	357	390	33	9.2%
SB	1.055	816	752	-64	-7.8%
SA	1.153	297	318	21	7.1%
Total		4722	4573	-149	-3.2%

* -- % Difference = (M-P)/P

Table 4-4
Critical Height
Comparison for
McGuire 1 Cycle 2

Bank	Predicted Critical Ht., Steps WD	Measured Critical Ht., Steps WD	Difference (P-M), Steps WD
----	------------	------------	--------
D	194	183	11
C (REF)	---	---	---
B	198	197	1
A	90	83	7
SE	92	86	6
SD	149	147	2
SC	148	144	4
SB	156	156	0
SA	192	191	1

Mean = 4.00

S. Dev = 3.78

Table 4-5
Critical Height
Comparison for
McGuire 1 Cycle 3

Bank	Predicted Critical Ht., Steps WD	Measured Critical Ht., Steps WD	Difference (P-M), Steps WD
D	162	163	-1
C	209	224	-15
B	161	180	-19
A	133	127	6
SE	135	132	3
SD	133	141	-8
SC	133	139	-6
SB (REF)	---	---	---
SA	118	127	-9

Mean = -6.13

S. Dev = 8.56

Table 4-6
Critical Height
Comparison for
McGuire 1 Cycle 4

Bank	Predicted Critical Ht., Steps WD	Measured Critical Ht., Steps WD	Difference (P-M), Steps WD
D	179	179	0
C (REF)	---	---	---
B	198	201	-3
A	116	108	8
SE	158	151	7
SD	146	136	10
SC	145	147	-2
SB	226	218	8
SA	138	136	2

Mean = 3.75

S. Dev = 5.09

5. CONCLUSIONS

The BWFC methodology to support measurement of control rod worth utilizing the rod exchange technique has been developed and verified using measured data. The results of side-by-side comparisons of BWFC-calculated worths and critical heights versus operating plant data demonstrate that the BWFC rod exchange calculational methodology is adequate to support startup physics testing where rod worth measurements are determined using the rod exchange test method outlined herein.

6. REFERENCES

1. "American National Standard Reload Startup Physics Test for Pressurized Water Reactors", ANSI/ANS-19.6.1-1985, American National Standards Institute, Inc., December 1985.

2. J. H. Randles and R. J. Tomonto, "Rod Swap Methodology Report for Startup Physics Testing", DPC-NE-1003-A, REVISION 1, December 1986.

3. C. W. Mays, et al., "NOODLE -- A Multi-Dimensional Two Group Reactor Simulator", BAW-10152A, Babcock & Wilcox, Lynchburg, Virginia, June 1985.

4. C. W. Mays, "FLAME 3 -- A Three-Dimensional Nodal Code for Calculating Core Reactivity and Power Distributions", BAW-10124A, Babcock & Wilcox, Lynchburg, Virginia, August 1976.

5. C. W. Mays, "Verification of Three-Dimensional FLAME Code", BAW-10125A, Babcock & Wilcox, Lynchburg, Virginia, August 1976.