November 19, 1997

LICENSEE: UNION ELECTRIC COMPANY

FACILITY: CALLAWAY PLANT, UNIT 1

SUBJECT: MEETING WITH UNION ELECTRIC AND WESTINGHOUSE ELECTRIC CORPORATION REGARDING THE CALLAWAY AXIAL OFFSET ANOMALY

On October 7 and 8, 1997, a meeting was held with Union Electric Company, Westinghouse Electric Company, and the Nuclear Regulatory Commission (NRC) to discuss the effects of the axial offset anomaly currently being experienced by the Callaway Plant. These discussions included a detailed review of the methodology for performing the shutdown margin calculations, a discussion of the justification for reducing the rod worth uncertainties used in the calculations and other actions being considered by the licensee to increase the available shutdown margin.

The staff reviewed the calculation methodology and actions being planned to ensure that conservative assumptions are being maintained when performing the calculations of shutdown margin. The staff requested that additional calculations of the shutdown margin be supplied as they were performed.

The meeting was held at the Westinghouse Electric Corporation offices in Monroeville, Pennsylvania. Attachment 1 is a list of meeting attendees. Attachments 2 and 3 are non-proprietary versions of the handout material presented by Westinghouse at the meeting.

ORIGINAL SIGNED BY

Barry C. Westreich, Project Manager
Project Directorate IV-2
Division of Reactor Projects III/IV
Office of Nuclear Reactor Regulation

Docket No. 50-483

Attachments:
1. List of Attendees
2. Rod Worth Uncertainty Meeting Handout (non-proprietary)
3. Axial Offset Anomaly Analysis Meeting Handout (non-proprietary)

cc w/atts: See next page

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DOCUMENT NAME: CAL107.MTS

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

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MEETING WITH UNION ELECTRIC AND WESTINGHOUSE ELECTRIC CORPORATION

LIST OF MEETING ATTENDEES

OCTOBER 7 AND 8, 1997

NRC

Barry Westreich
Tony Attard
Muffet Chatterton

Westinghouse

Louis Grobmyer
Jeff Secker

Union Electric Company

Jim Knaup
Dave Shafer
Tod Moser
Jim Moose
Ken Bryant

DRAFT ENGINEERING EVALUATION

REDUCTION OF ROD WORTH UNCERTAINTY ALLOWANCE

FOR CALLAWAY CYCLE 9

October 6, 1997

by: L. R. Grobmyer 10/7/97
L. R. Grobmyer
Plant Operations & Evaluation

BACKGROUND

In the performance of the shutdown margin (SDM) calculation, the bank worth available for reactor trip is determined from calculations. The core model used for these calculations is extensively tested at the beginning of the cycle. The validity of that model during the depletion is further ensured by the periodic power distribution and boron concentration measurements taken during the cycle. The primary objective of the Low Power Physics Test (LPPT) program performed at the beginning of life (BOL) is to demonstrate that the core design predictions are consistent with the core as constructed, thus validating the bank worth component of the SDM calculation. The Axial Offset Anomaly (AOA) affects the core, and thus the core model used to make the original predictions is no longer valid. The core model has been modified to account for the AOA and thus the updated model represents the new core conditions. By subsequent power distribution and boron concentration measurements, the updated core model has been shown to accurately, if not conservatively, represent the core.

BANK WORTH IN SDM CALCULATIONS

The calculation of the available bank worth for the SDM calculation uses the prediction of the total worth available by rods. By definition, this is the worth of all rods less the most reactive stuck Rod Cluster Control Assembly (RCCA). This N–1 worth is then reduced by an uncertainty allowance that accounts for possible measurement to prediction differences. Callaway, like all other plants, is using this method of calculating the bank worth available for SDM. Normally the uncertainty allowance is 10%, however based on work performed by Westinghouse in the late 1970's and documented in WCAP–9217, this allowance can be reduced to 7%. Currently, Callaway is using the 7% number in their SDM calculation.

Because the SDM calculation uses the N–1 worth reduced by the uncertainty allowance, certain implicit assumptions about the design validation are made. Specifically, when the measured total bank worth results are greater than the prediction less the uncertainty allowance and the individual bank worths are within their respective review criteria (no obvious core design/reconstruction issues), the bank worth predictions are validated. However, failure of an individual bank worth review criterion does not necessarily imply a failure of the bank worth prediction. The failure indicates that the design and reconstructed core are not quite consistent and that further measurements are required to characterize these differences and determine the significance. Westinghouse requires a power distribution measurement prior to exceeding 5% power if any individual bank worth measurement fails the review criteria of 15% or 100 pcm. The results of the power distribution measurement is then evaluated for anomaly or design/prediction differences. This approach ensures that the core is consistent with the designer's calculation prior to significant power being generated. Since the design is validated using the total and individual bank worth measurement results, a significant reduction in the SDM allowance would implicitly require a corresponding reduction in the individual bank worth tolerance. In the case where the measurement has yet to be performed, the individual bank worth tolerance would be reduced commensurate with the total allowance reduction.

Another possible method of calculating the bank worth available for the SDM calculation is to reduce the total predicted worth (N) by the uncertainty allowance, and then subtract the predicted stuck RCCA worth (−1). This method is philosophically different from the current methodology in a number of ways.

1) This approach is more conservative at any given uncertainty allowance because the resultant available worth is lower than the current methodology. The available bank worth is lower because the full calculated value of the stuck RCCA is taken into the equation after the total bank worth is reduced by the uncertainty allowance. A comparison of the calculation results using both approaches is shown on FIGURE 1.
2) Using this approach, the bank worth measurements are considered to verify the SDM calculations instead of validating the core design calculations. This is inconsistent with the definition that the measurement program is used to validate the core design model.
3) Using this comparison, the results evaluation criteria for the individual banks don't have any connection, implied or direct, to the SDM bank worth uncertainty allowance. The traditional individual bank worth review criteria are applicable, even with a lower uncertainty allowance in the SDM calculation.

MEASUREMENT EXPERIENCES

Westinghouse has performed an independent review of the Callaway bank worth measurement results of Cycles 4 through 9. Cycles 4 and 5 rod worths were validated using sequential dilution of the control banks. The prediction tools were provided by Westinghouse. Cycles 6 through 9 rod worths were validated using Rod Swap. Cycles 6 and 7 were predicted using an older version of SIMULATE™. Cycles 8 and 9 were predicted using an updated version of SIMULATE™ that accounted for shutdown cooling and other nuclear phenomenon. For consistency of comparison, cycles 6 and 7 were reanalyzed using the updated version of SIMULATE™. A total of 36 individual bank worth measurements, over cycles 6 through 9 were evaluated. Some key observations on these results are as follows:

- All results meet the acceptance criteria. The sums of the measured banks are greater than 90% of the predicted sums. This is independent of the design tool used.

- The updated version of SIMULATE™ performed significantly better than the older version in predicting the bank worths and matching the Westinghouse APA™ predictions.
- The average difference for the total worths of cycles 6 through 9 is [redacted] with a standard deviation of [redacted]. All results are bounded by a ±3% tolerance, except for Cycle 8, which had a difference of [redacted].
- All individual bank worth results meet the relevant Westinghouse review criteria. Specifically, each bank is within 15% or 100 pcm of the predicted value.
- An analysis of the measurements of cycles 7, 8, and 9 using the Westinghouse Rod Swap methodology shows results that are comparable to prior Westinghouse experience. Furthermore, these results are very consistent with the SIMULATE™ based results.

MEASUREMENT PROCESS VALIDATION

A review of the measurement processes in use at Callaway indicated that the necessary controls are in place to sufficiently ensure valid measurements with a minimum of measurement error being introduced. Some of the testing and evaluations performed to prevent the identified problems are described in the following sections.

Errors in the Reactivity Computer Function or Instrumentation

Callaway uses a reactivity computer function on the plant computer with inputs from the excore intermediate range channels. Channel calibrations of the intermediate range channels are performed every 18 months. During this calibration, all instruments are checked for accurate and reliable operations. The computer and associated interfaces are also checked as part of the startup program prior to and immediately following criticality. Errors in the reactivity computer function are evident during the static checkout performed prior to criticality. The response of the flux signal prior to criticality and reactivity after criticality are indicative of any instrumentation problems.

<u>Delayed Neutron Constants Error</u>

The performance of the internal reactivity computer checkout will determine if the delayed neutron constants from the nuclear design report (NDR) are not properly entered into the reactivity computer. Comparing the reactivity computer indication for a given period to the inhour based reactivity value from the NDR will validate that the constants have been entered correctly. If the constants are reported incorrectly, both the NDR and the reactivity computer will have identical errors and this will not be discernible by the stable period testing.

<u>Inadequate Compensation of Constant Leakage and Gamma Current</u>

Callaway uses the intermediate range channels to provide input to the reactivity computer. These channels are compensated ion detectors which have the gamma contribution to the signal compensated for by nature of the hardware design. The compensation adjustment is performed at the beginning of each refueling outage as the reactor is being shut down.

<u>Boron Concentration Validation of Reactivity Measurements</u>

Measurements of the reference bank worth by dilution provide an independent set of numbers for comparison (pcm and Δppm) that will quickly identify that there is a problem with either the measurement process or the delayed neutron constants. With the exception of the cycle 8 data, the results are consistent between the boron difference and the total bank worth. The specific results from cycle 8 indicate that either a small measurement bias existed that cause the measurement to indicate low worth, or one of the boron endpoint measurements was in error by approximately 10 ppm.

SDM TOLERANCES

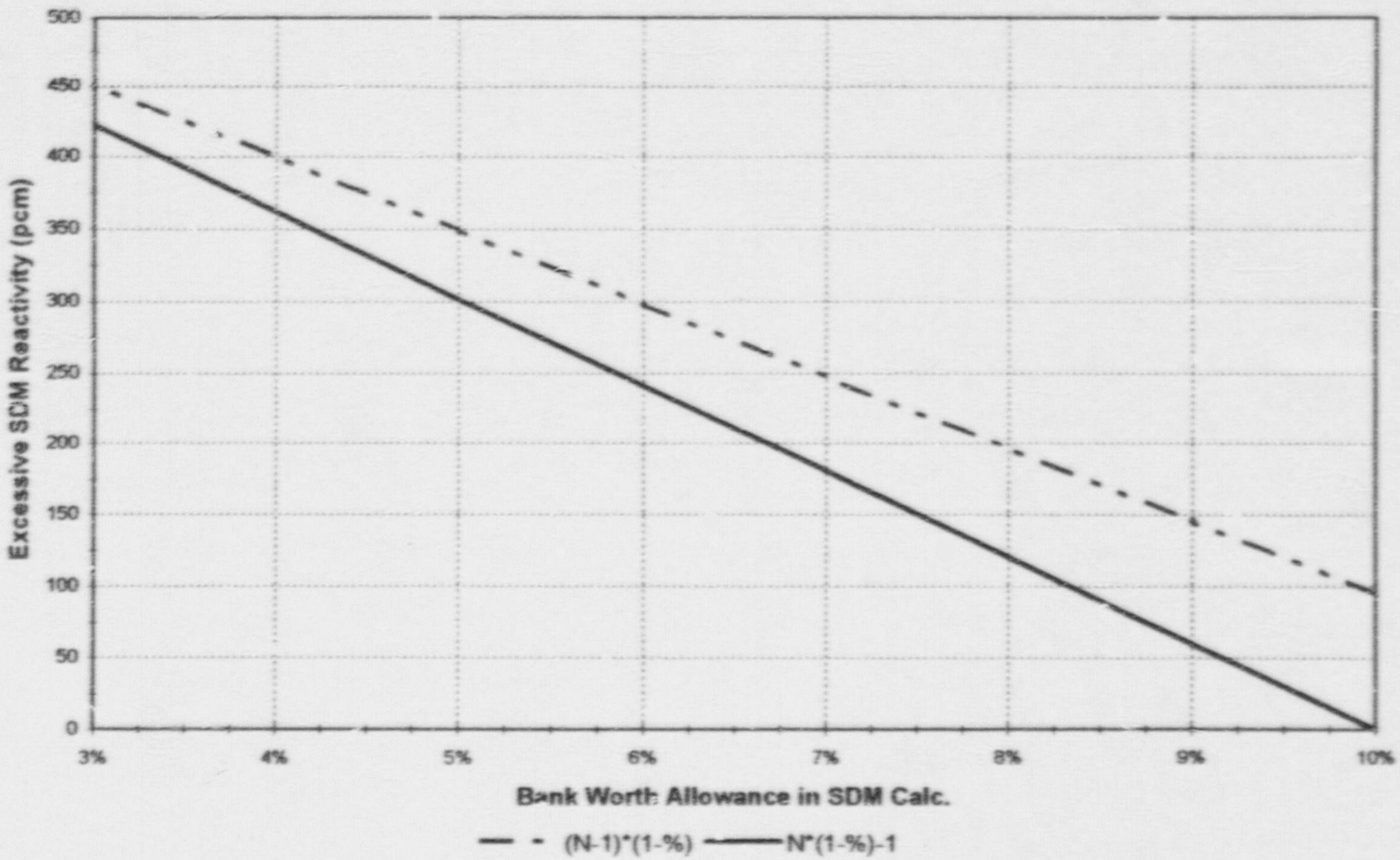
With the results of the measurements of Cycles 6 through 9, an overall rod worth uncertainty of 3% can be justified for the remainder of cycle 9 providing the following requirements are met:

1. The full value of the stuck RCCA is accounted for in the determination of the bank worth available, or all individual bank worth measurements are within 4.5% or 30 pcm of the prediction
2. The sum of the individual bank worth measurements is within the 3% of the predicted sum.
3. The measured to predicted boron concentration is within 50 ppm with the modified core design model for the current plant operating conditions.
4. The measured to predicted power distribution (reaction rate errors) are within 10% of the prediction from the modified core model.

For the case of Callaway Cycle 9, all of the above requirements are met.

1. The rod worth available for the SDM calculation will be calculated by determining the N worth, accounting for the uncertainty allowance, and then subtracting the stuck RCCA worth. Furthermore, all individual bank worth measurement results fall within 4.5% or 30 pcm of the predictions.
2. For the previous four cycles, the results of the bank worth measurements averaged [redacted] different from the prediction with maximum difference being for the cycle 8 startup, which was [redacted] less than the prediction. The total bank worth measurement result for cycle 9 was [redacted] less than the prediction.
3. The measured to predicted boron concentration difference is less than 50 ppm.
4. The measured reaction rate errors in the flux map analysis are within 10% of the prediction from the modified core model.

FIGURE 1: Excessive Shutdown Margin vs. Bank Worth Tolerance



ATTACHMENT 3

Axial Offset Anomaly

Core Modeling and Shutdown Margin Analysis

Nuclear Regulatory Commission

Westinghouse Energy Center

October 7-8, 1997

J. R. Secker

Core Engineering

Westinghouse Commercial Nuclear Fuel Division

Axial Offset Anomaly and Core Depletion

Thin crud layer builds up on upper spans of fresh fuel

Subcooled boiling concentrates boric acid and lithium in porous crud

Lithium-Boron precipitate forms in crud

Boron absorbs neutrons - flux shifts toward bottom of core

Axial Offset Anomaly Affect on Core Depletion

Axial power distribution shifts toward core inlet

Depletion with bottom skewed power distribution results in bottom skewed burnup distribution

Steady state xenon distribution is also bottom skewed

Core Model for AOA

Boron modeled in upper spans of fresh fuel

Boron number densities adjusted with burnup to match core behavior

- Core average axial offset
- Assembly average power
- Assembly axial offset

AOA Modeling in ANC

ANC control rod model used for AOA

No code modifications required

Control rod model applies cross section modifiers to nodes containing control rods

For AOA, cross section modifiers determined based on boron absorption cross sections

Boron microscopic cross sections from ZrB2 IFBA used for fast, thermal absorption

Callaway Cycle 9 AOA Modeling in ANC

Boron modeled in upper portions of fuel

84 inches - 138 inches from bottom of fuel stack

Consistent with location of crud from Callaway visual exams

Uniform axial distribution

Four different boron densities modeled in Cycle 9

All affected assemblies are fresh assemblies

Location and Relative Boron Number Densities for AOA Model

Callaway Cycle 9

Predicted Power at 8000 MWD/MTU - Nominal Model

	1 H	2 G	3 F	4 E	5 D	6 C	7 B	8 A
1 8	2X .920	1X 1.020	Feed 3 1.343	1X 1.026	1X 0.986	1X 1.028	Feed 1 1.241	1X 0.520
2 9	1X 1.020	Feed 3 1.319	1X 1.018	Feed 3 1.341	1X 1.051	Feed 2 1.319	Feed 1 1.213	1X 0.512
3 10	Feed 3 1.343	1X 1.018	Feed 2 1.327	1X 1.121	Feed 4 1.355	1X 1.095	Feed 1 1.193	1X 0.447
4 11	1X 1.026	Feed 3 1.339	1X 1.121	Feed 4 1.370	1X 1.119	Feed 2 1.319	Feed 1.028	2X 0.303
5 12	1X 0.986	1X 1.047	Feed 4 1.354	1X 1.119	Feed 4 1.355	Feed 1.167	1X 0.553	
6 13	1X 1.028	Feed 2 1.316	1X 1.095	Feed 2 1.319	Feed 1.167	1X 0.638	1X 0.275	
7 14	Feed 1 1.241	Feed 1 1.212	Feed 1 1.193	Feed 1.028	1X 0.552	1X 0.275		
8 15	1X 0.520	1X 0.512	1X 0.447	2X 0.303				

Region
AOA Strength
Assembly Power

Callaway AOA Modeling for Cycle 9

Affected assemblies selected based on review of flux map data

Assemblies selected based on reaction rate errors in upper portion of fuel

Affected assemblies will show larger negative reaction rate errors compared to predictions

Review of raw flux traces used to confirm selection of assemblies

Affected assemblies will show large flux depressions in top portion of trace below grids

AOA Modeling in ANC

Boron number densities varied with burnup to match

- Core average axial offset
- Assembly average power
- Assembly axial offset

AOA Model Results for Cycle 9

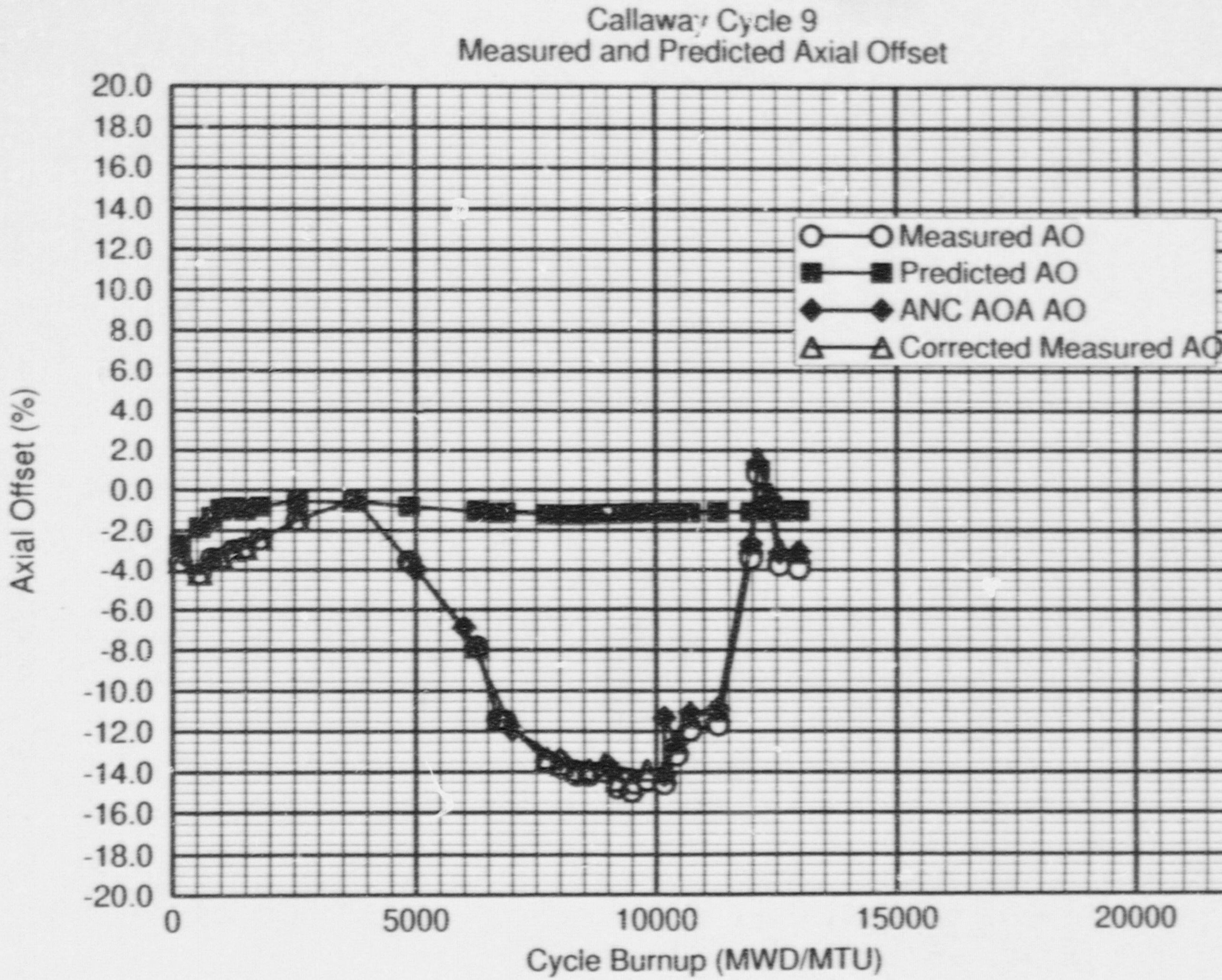
Core average axial offset

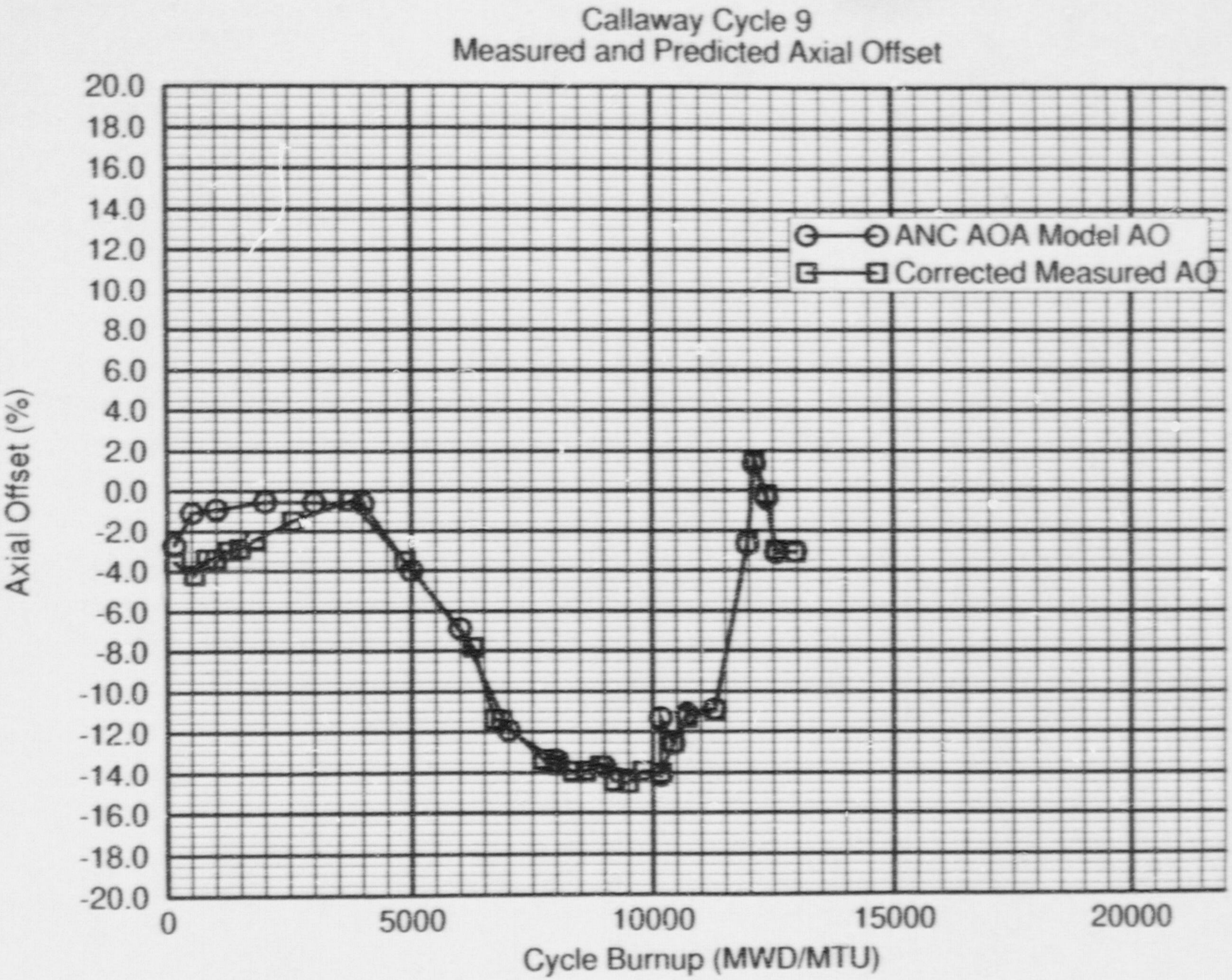
Assembly average power

Assembly axial offset

Critical boron concentration vs. burnup

Resulting boron content in crud


Callaway Cycle 9
Measured and Predicted Axial Offset
Measured AO
Predicted AO
ANC AOA AO
Corrected Measured AO
Axial Offset (%)
Cycle Burnup (MWD/MTU)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
-20.0
0
5000
10000
15000
20000


Callaway Cycle 9
Measured and Predicted Axial Offset
ANC AOA Model AO
Corrected Measured AO
Axial Offset (%)
Cycle Burnup (MWD/MTU)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-18.0
-20.0
0
5000
10000
15000
20000

Callaway Cycle 9 AOA Model
Comparison to Measured Core Behavior

Assembly Average Power Comparison
10158 MWD/MTU
100*((M-P)/P)

	H	G	F	E	D	C	B	A
8	-1.4	-0.8	0.6	0.1	-1.1	-1.1	-0.9	-2.4
9	-0.5	0.8	0.1	1.1	-0.5	-0.2	-0.3	-2.1
10	0.6	0.2	-0.6	-1.3	-0.2	-0.9	0.2	-1.1
11	0.4	1.7	-0.7	-0.5	-1.5	-0.2	0.2	-0.6
12	-0.7	0.1	0.3	-1.1	0.5	-0.3	-1.0	
13	0.4	1.4	1.2	0.8	0.1	-1.2	-2.0	
14	1.0	1.6	1.7	0.4	-0.5	-2.0		
15	0.0	0.0	0.4	-0.3				

Assembly Axial Offset Comparison
10158 MWD/MTU
(M-P)

	H	G	F	E	D	C	B	A
8		1.6	0.6	0.8	1.4	-0.3	0.7	0.4
9	1.6	0.3	0.7	1.8	0.0	-2.0	0.6	0.2
10	0.6	0.7	1.7		-1.4	-0.7	0.9	0.2
11	0.8	1.8		-2.3		-0.1		0.4
12	1.4	0.0	-1.4		-1.0	-1.6	-1.1	
13	-0.3	-2.0	-0.7	-0.1	-1.6	-0.8	-1.0	
14	0.7	0.6	0.9		-1.1	-1.0		
15	0.4	0.2	0.2	0.4				

Assembly Average Power Comparison
11291 MWD/MTU
100*((M-P)/P)

	H	G	F	E	D	C	B	A
8	-0.1	0.3	1.6	0.6	-1.2	-2.1	-2.7	-4.3
9	0.7	1.8	1.0	1.6	-0.3	-1.2	-2.0	-3.6
10	1.7	1.0	0.2	-0.4	0.9	-1.6	-1.2	-2.1
11	1.2	2.4	0.2	1.2	-0.6	-0.4	-0.5	-1.2
12	-0.7	0.3	1.5	-0.2	2.0	0.1	-1.0	
13	-0.8	0.5	0.7	0.7	0.3	-0.8	-1.7	
14	-1.0	-0.3	0.3	-0.2	-0.7	-2.0		
15	-2.0	-1.5	-0.8	-0.9				

Assembly Axial Offset Comparison
11291 MWD/MTU
(M-P)

	H	G	F	E	D	C	B	A
8		2.3	1.2	0.8	1.2	-1.5	-2.2	-2.7
9	2.3	1.1	1.6	1.7	0.5	-1.9	-2.3	-1.9
10	1.2	1.6	2.0		-0.8	-1.5	-0.5	-1.3
11	0.8	1.7		-0.1		-1.7		0.3
12	1.2	0.5	-0.8		0.5	-0.5	-1.6	
13	-1.5	-1.9	-1.4	-1.6	-0.5	-0.6	-0.7	
14	-2.2	-2.3	-0.5		-1.6	-0.7		
15	-2.7	-1.9	-1.2	0.3				

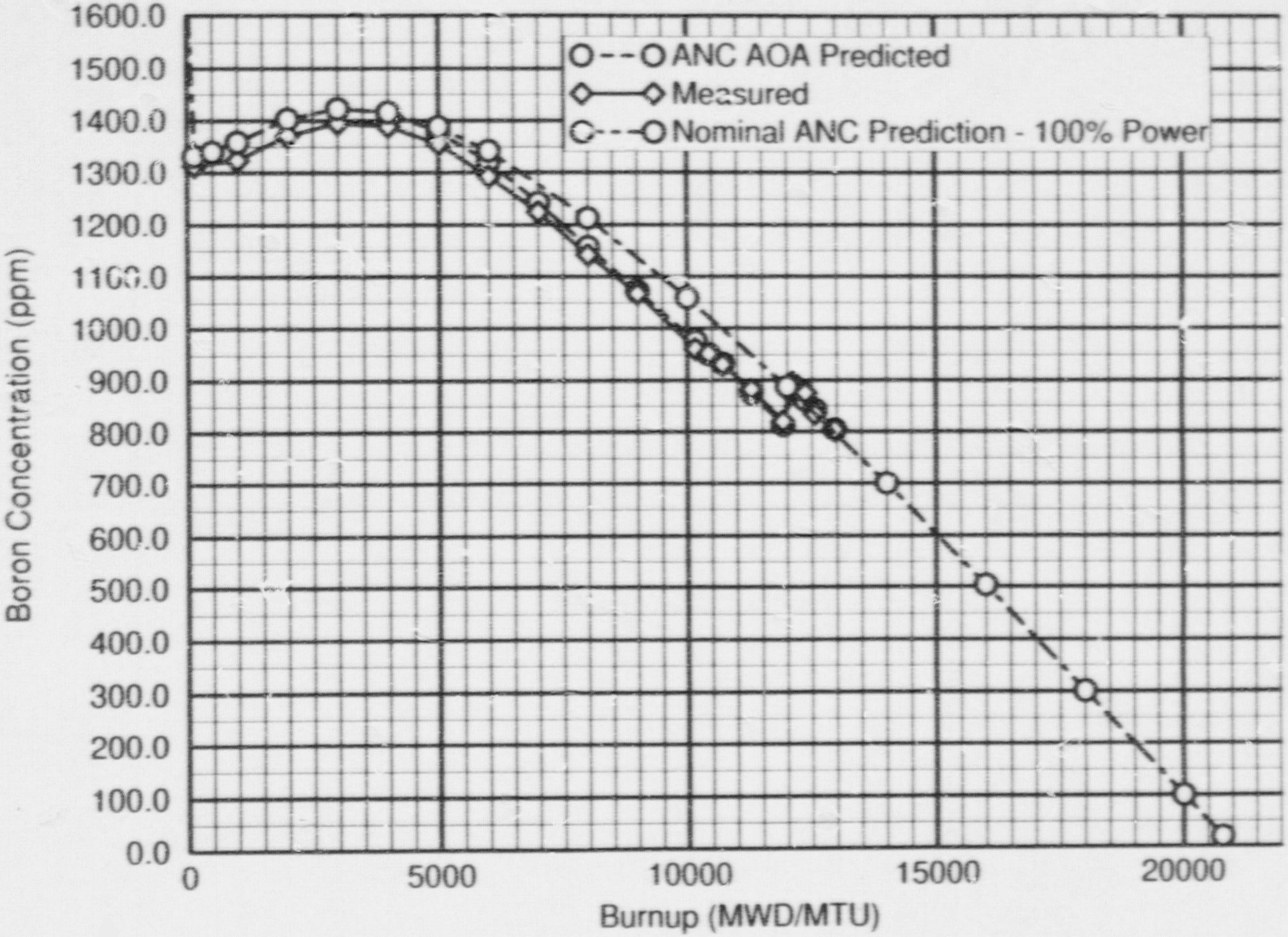
Assembly Average Power Comparison
12965 MWD/MTU
100*((M-P)/P)

	H	G	F	E	D	C	B	A
8	-1.8	-1.7	-0.7	-0.9	-1.3	-1.6	-2.7	-2.8
9	-1.0	-0.1	-0.6	0.2	-0.4	-1.2	-1.9	-2.2
10	0.2	0.0	-0.6	-0.4	1.8	-0.6	-1.3	-1.4
11	0.1	1.4	0.2	1.9	0.3	-0.3	-0.8	-0.3
12	-0.7	0.5	2.3	0.8	2.7	-0.4	-0.9	
13	-0.2	0.8	1.8	1.2	0.1	-0.9	-1.0	
14	-0.6	0.1	0.7	0.0	-0.2	-1.3		
15	-0.2	0.4	0.8	0.9				

Assembly Axial Offset Comparison
12965 MWD/MTU
(M-P)

	H	G	F	E	D	C	B	A
8		1.6	-0.7	-0.4	0.9	-1.5	-0.5	-0.8
9	1.6	0.1	0.2	1.8	0.3	-3.1	-0.6	-1.3
10	-0.7	0.3	1.7		-0.1	-1.6	1.3	-0.9
11	-0.4	1.8		-0.4		0.0		0.9
12	0.9	0.3	-0.1		1.4	-0.6	-2.1	
13	-1.5	-3.0	-1.6	0.1	-0.6	-0.9	-0.6	
14	-0.5	-0.6	1.3		-2.1	-0.6		
15	-0.8	-1.3	-0.9	0.9				

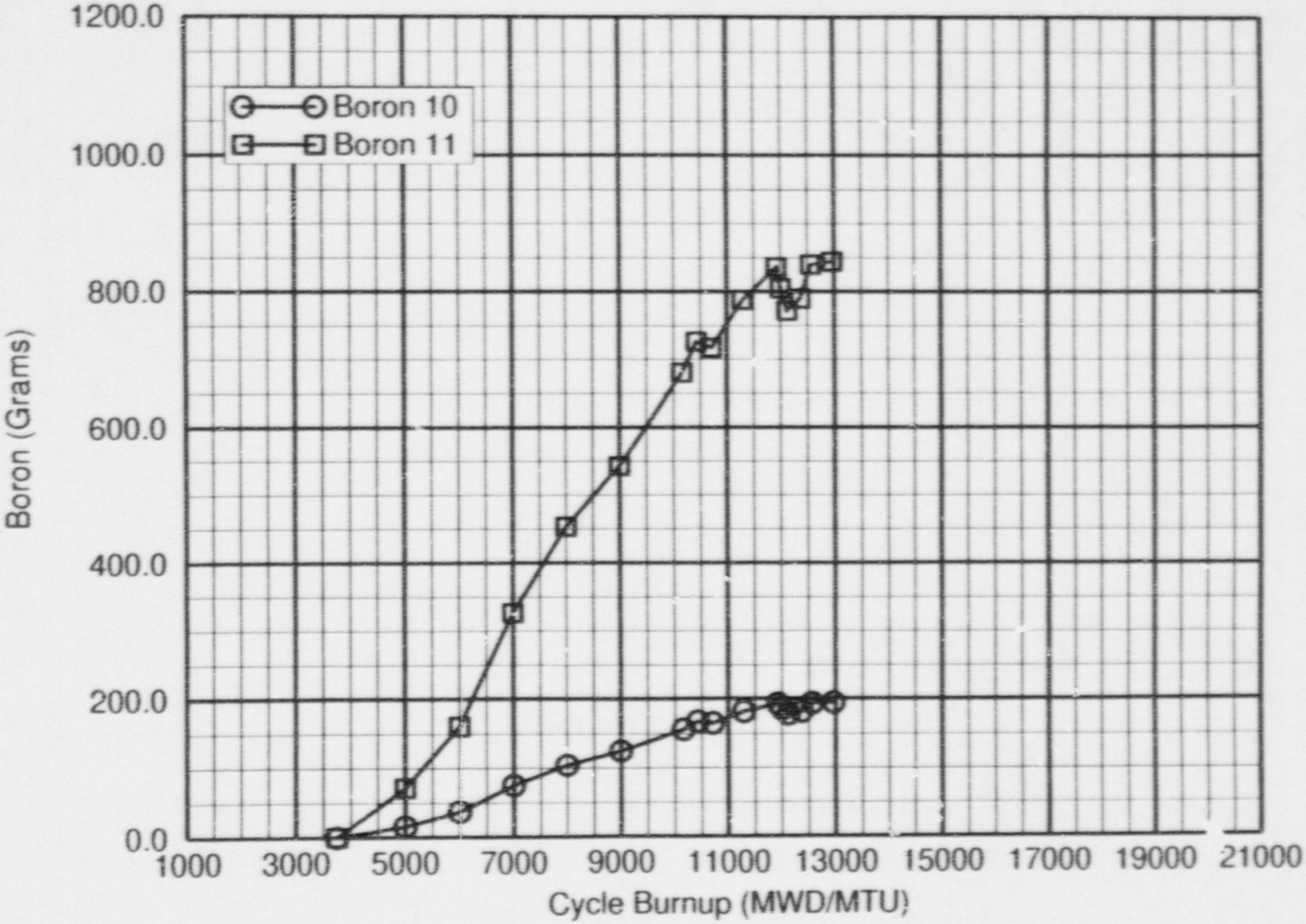
Callaway Cycle 9
Boron Concentration vs Burnup



Predicted Boron Corrected for Measured B10 Depletion

Boron Weight in Crud

Callaway Cycle 9



Ignores B10 Depletion in Crud (No Affect on B10)

AOA Affect on Shutdown Margin

Additional reactivity insertion after trip

- Boron absorber dissolves
- Currently assumed to be instantaneous

Bottom skewed burnup distribution effects

- Burnup in top of core is lower
- Flux shift to top at zero power is larger

Bottom skewed xenon distribution effects

- Additional flux redistribution
- Xenon distribution to skew AFD to most positive allowed value is more adverse

ANC Model Shutdown Margin Analysis

Cycle 9 ANC AOA model used with actual operating history modeled

Standard 3D methods used for SDM analysis

Very conservative assumption used that all AOA boron immediately disappears after trip

ANC Model Shutdown Margin Analysis

Case 1- Base Case: HFP, D-bank at RIL, xenon skewed so AFD is at positive limit, inlet temperature increased for temperature uncertainty, AOA boron present

Case 2 - Power Defect: HZP, inlet temperature decreased for temperature uncertainty, AOA boron removed, no change to soluble boron, xenon, RCCA

Case 3 - Total Rodworth: Insert all RCCA, no other change from Case 2

Case 4- N-1 Rodworth: Remove highest worth stuck rod

Shutdown Margin Analysis Conservatism

D-Bank assumed to be at RIL

AFD skewed by xenon to positive limit despite D-Bank at RIL

Maximum temperature uncertainty assumed

Void reactivity assumed

Worst stuck rod assumed to remain out of core

Rodworth uncertainty assumed

AOA boron removed instantaneously

Shutdown Margin Conservatism

Callaway Cycle 9 12965 MWD/MTU 70% Power AOA

Shutdown Margin Calculations at 100% Power

	Shutdown Margin (pcm)	SDM Change (pcm)
NDR Model Nominal	4995	Nominal
AOA Model Nominal	5192	+197
AOA Fully Removed 0% Power	3096	- 2096
+ Temperature Uncertainty	2991	- 105
+ HFP Rod Insertion (201 Steps Withdrawn)	2929	- 62
+ Axial Flux Difference to +6 (D-201)	2650	- 279
+ Worst Stuck Rod	1710	- 940
+ Void Collapse	1660	- 50
+ 7% N-1 Worth Uncertainty	1275	- 385
Sources of Additional SDM		
Reduced Rodworth Uncertainty - 3% N	1467	+ 192
Relaxation of Instantaneous AOA Boron Loss		
Assumption after trip	2117-2667	+~650-1200

Flux Map Dates and Shutdown Margin Updates

Table 1: Dates for Flux Maps and SDM Updates

Union Electric Flux Map Date	Westinghouse Model Update and SDM Calc	Westinghouse Verified Transmittal to UE	Union Electric Curve Book Update
8/25/97	8/26/97	8/27/97	8/29/97
9/9/97	9/12/97	9/15/97	9/18/97
9/22/97	9/24/97	9/26/97	10/02/97

- Excore AFD trended between maps
- Axial Offset indication available when flux map evaluation is completed
- Shutdown margin update completed within a few days of flux map
- Formal documentation/verification required by both Westinghouse and Union Electric prior to curve book update

Shutdown Margin Changes with Burnup

Date	Shutdown Margin (pcm)	Flux Map Basis	SDM Change
9/2/97	1532 (70.4%)	8/25/97	
9/5/97	Power Reduced to 30%		
9/8/97	1738 (70.8%)		burnup/RIL change
9/15/97	1733 (69.7%)	8/25/97	burnup/power
9/15/97	1601 (69.7%)	9/9/97	-182 pcm model change for 30% downpower +50 pcm AFD assumption
9/22/97	1578 (69.9%)	9/9/97	-23 pcm burnup (-3.3 pcm/day)
10/6/97	1476 (~70%)	9/22/97	-52 pcm burnup (-3.7 pcm/day) -50 pcm AFD assumption