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Consumers Power Company

General Offices: 212 West Michigan Avenue, Jackson, Michigan 49201 • Area Code 517 788-0550

June 15, 1978

Mr James G Keppler
Office of Inspection and Enforcement
Region III
US Nuclear Regulatory Commission
799 Roosevelt Road
Glen Ellyn, IL 60137

DOCKET 50-255 - LICENSE DPR-20 -
PALISADES PLANT - CYCLE 3 START-UP
PHYSICS TESTS

The attached report entitled, "Palisades Core - 3 Low Power and Power Escalation Test Report," June 1978 is submitted per the requirements of Palisades Plant Technical Specification 6.9.1.a.

This report meets the requirements of the January 17, 1978 NRC letter that requested a summary report of physics start-up tests.

David P. Hoffman

David P Hoffman
Assistant Nuclear Licensing Administrator

CC: Director, Office of Nuclear Reactor Regulation
Director, Office of Inspection and Enforcement

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PALISADES CORE - 3

Low Power and Power Escalation Test Report

June 1978

Consumers Power Company

TABLE OF CONTENTS

FIGURES

PHYSICS TEST PROGRAM - PALISADES CYCLE - 3

I. INTRODUCTION

The physics test program for cycle - 3 consisted of measurements made at zero power and at selected higher power levels. The zero power measurements included the following:

A. Core symmetry check.

B. Highest worth dropped rod measurement.

C. All rods out critical boron concentration.

D. Isothermal temperature coefficient with essentially all rods out and with regulating rods inserted.

E. Nonsequential worth of the regulating rods.

F. Shutdown rod worth with highest worth rod stuck out.

G. Inverse boron worth.

H. Sequential worth of the regulating rods.

These measurements were performed under special test procedures listed as references 3 through 8. Power testing was done at 50% and 90% of rated power (2530 MW_t). At each of these power levels, the isothermal temperature coefficient and the power coefficient were measured.

The zero power testing was performed from 4/12/78 through 4/16/78. Power testing at 50% and at 90% were completed on 4/24/78 and 5/1/78, respectively. No significant problems were encountered during either the zero power or the power test programs.

II. ZERO POWER TEST PROGRAM

A. Core Symmetry Check

The purpose of the core symmetry check is to determine whether a significant core reactivity tilt exists at the beginning of the cycle. The measurement proceeds as follows:

1. One control rod of a symmetric group is fully inserted and reactivity is balanced with Gr-4 rods.

2. The inserted rod is "traded" with a symmetric rod within the group and any excess reactivity is noted.

3. The procedure is continued with each rod in the symmetric group. The first rod in the symmetric group was reinserted after the last rod in the group to detect any drift in reactivity which may have occurred. The drift is then assumed to be linear and reactivity is corrected accordingly. Four symmetric rod groups were selected for this measurement (Figure 1). The results of the measurement are found in Tables 1 through 4. The tables list the control rod number and the percent difference that each is from the average worth of a rod in that group. The acceptance criteria for this test was that each individual rod should be within ± 10% of the symmetric group average. Note that the acceptance criteria is met in each case, with the largest percent difference being 3.9% from rod number 36 in Group 3.

TABLE 1

Symmetric Rod Group No 4

Rod Number	Difference From Average (%)
38	+ 2.4
39	- 2.2
40	+ 3.1
41	- 3.5

Average Group No 4 Rod Worth = 0.0737% $\Delta\rho$ (Corrected to Measured Values)

TABLE 2

Symmetric Rod Group No 3

Rod Number	Difference From Average (%)
33	+ 2.2
34	- 0.2
36	- 8.4
37	+ 6.2

Average Group No 3 Rod Worth = 0.0644% $\Delta\rho$ (Corrected to Measured Values)

TABLE 3

Symmetric Rod Group No 1

Rod Number	Difference From Average (%)
21	+ 3.5
22	+ 1.7
27	+ 6.9
25	+ 1.4
26	- 9.1
23	+ 0.5
24	- 8.1
28	+ 2.9

Average Group No 1 Rod Worth = 0.0593% $\Delta\rho$ (Corrected to Measured Values)

TABLE 4

Symmetric Rod Group A (Inner Rods)

Rod Number	Difference From Average (%)
5	- 0.4
6	+ 1.2
7	- 2.1
8	+ 1.2

Average Group A Rod Worth = 0.146% $\Delta\rho$ (Measured)

B. Highest Worth Dropped Rod Measurement

The measured value of the highest worth dropped rod (HWDR) was obtained by diluting the predicted HWDR to its fully inserted position from an essentially all rods out configuration. To insure that the predicted HWDR was indeed the actual HWDR, this rod was traded with the second highest predicted dropped rod and the reactivity difference was noted. The results are shown in Table 5.

The acceptance criteria is that the highest worth dropped rod shall be worth less than 0.2% $\Delta\rho$. The measured value of the dropped rod falls well within the acceptance criteria. The second predicted highest worth dropped rod was found to be worth less than the predicted highest worth dropped rod.

TABLE 5

Highest Worth Dropped Rod

Rod Number	Predicted Worth (% $\Delta\rho$)	Measured Worth (% $\Delta\rho$)
8[1]	0.132	0.146
35[2]	0.130	0.145

(1) Rod 8 was the predicted highest worth rod (see Reference 1, Page 24). The worth of this rod was obtained by a dilution.

(2) Rod 35 was the predicted next highest worth rod. The worth of this rod was obtained by a trade with rod 8.

C. All Rods Out Critical Boron Concentration

This measurement is performed to determine the excess reactivity available in the new core. The control rods are borated to essentially the full out position and the primary coolant boron concentration is then determined. The control rods are then withdrawn from the core in order to determine their residual worth. This worth is added to the boron concentration to obtain the all rods out excess reactivity. The all rods out critical boron concentration determined in this manner was 1,124 ppm. The predicted value was 1,080 ppm yielding a percent difference of 4.1%.

The acceptance criteria for this measurement is that the measured value be within 10% of the predicted value. The measured value falls within the acceptance criteria. The contribution of the residual worth of the rods to the measured value was approximately .6 ppm; therefore, the measurement is based almost entirely upon the chemical analysis. The chemical analysis consisted of five primary coolant samples taken over a one-hour period and showing no significant trend.

D. Isothermal Temperature Coefficient

The isothermal temperature coefficient (ITC) was measured at two different boron concentrations. The first measurement was at a primary coolant boron concentration of 1,124 ppm with control rods in the essentially all rods out configuration and the second was at a boron concentration of 856 ppm with the regulating control rod groups (1, 2, 3, 4) fully inserted. The measurements were carried out by initiating a uniform cooldown of the primary coolant system with adjustment of the steam flow and/or the feed-water flow to the steam generators. When required, the control rods were moved to compensate for reactivity changes. A subsequent heatup to the original temperature provided additional information for determination of the ITC. The results of the ITC measurements are found in Table 6. The MTC values as determined from the measured ITC are given in Table 7.

TABLE 6

Isothermal Temperature Coefficient Measurement

Control Rod Configuration	PCS Boron Concentration	Measured ITC (% Δρ/°F)
ARO	1,124 ppm	-0.06×10^{-2}
4, 3, 2, 1 In	856 ppm	-0.83×10^{-2}

TABLE 7

Moderator Temperature Coefficient

PCS Boron Concentration	Predicted MTC (% Δρ/°F)	Measured MTC(1) (% Δρ/°F)	Acceptable Range ($\times 10^{-2}$% Δρ/°F)
1,124 ppm	-0.1×10^{-2}	$+0.1 \times 10^{-2}$	$-0.6 \leq MTC \leq 0.4$
856 ppm	-1.0×10^{-2}	-0.67×10^{-2}	$-1.5 \leq MTC \leq -0.5$

(1) MTC cannot be measured directly due to the inability to change the moderator temperature without effecting the fuel temperature. Therefore, the MTC is determined from the ITC using the relation; ITC = MTC + Doppler where Doppler = -1.575×10^{-5} Δρ/°F (Reference 1, Page 19).

Note that the measured value of the MTC at each of the two control rod configurations fall within the acceptable range.

E. Nonsequential Worth of the Regulating Rods

The worth of the regulating rod groups (1, 2, 3, 4) were measured in the nonsequential mode by a dilution. A constant primary coolant dilution rate was established and the groups were inserted to their lower electrical limits in the order of 4, 3, 2 and 1. Reactivity was maintained within a range of approximately +3¢ to -3¢. The dilution rate was not disturbed until Group 1 was fully inserted. The results of the measurement are given in Table 8. Integral rod worth curves for Groups 1 through 4 are shown in Figures 2 through 5, respectively.

The acceptance criteria for control rod bank worths is that the measured values must be within 15% of the predicted value or within 0.15% $\Delta\rho$ of the predicted value, whichever is greater. With the exception of Group 1, each rod bank measured falls within the acceptance criteria limits. Since the measured worth of Group 1 was 19.7% lower than the predicted worth, a preliminary safety evaluation was performed on the net shutdown margin available before power escalation. The evaluation showed that the shutdown margin calculated using the measured worth of the control rods is within the present Technical Specifications power dependent insertion limits and, therefore, power escalation was authorized. A final safety analysis concerning shutdown margin is found in Appendix A.

TABLE 8

Nonsequential Worth of the Regulating Rods

Rod Group	Predicted Worth (% $\Delta\rho$)	Measured Worth (% $\Delta\rho$)	Percent Difference
4	0.503	0.459	-8.7
3	0.760	0.693	-8.8
2	0.684	0.748	+9.4
1	1.467	1.178	-19.7

F. Shutdown Worth With Highest Worth Rod Stuck Out

This measurement is a direct method for determining the net shutdown worth available in control rods with the highest worth rod withdrawn from the core. The initial conditions for this measurement are regulating Groups 1, 2, 3 and 4 fully inserted with partial length rods and shutdown Groups A and B fully withdrawn. Group B is then traded with the predicted highest worth stuck rod until the highest worth stuck rod is fully withdrawn. A constant dilution rate is then established and the remainder of Group B and Group A are inserted. The dilution is stopped when Group A is approximately 20 inches above the fully inserted position. Group A is then fully inserted and withdrawn; the resulting reactivity trace gives the residual worth of Group A. The results of this measurement are found in Table 9. Control rod number 27 was used as the highest worth stuck rod, as predicted.

The acceptance criteria for this measurement is that the net rod worth (all rods minus the maximum worth stuck rod) must be within 10% of the predicted value. The measured value falls within this acceptance criteria with the percent difference being 6.2%.

G. Reciprocal Boron Worth

The reactivity worth of soluble boron in the core is obtained from the rod worth measurements. The two end points are the essentially all-rods-out configuration and the essentially all-rods-in with stuck rod out configuration. These two conditions yield the greatest primary coolant boron concentration difference observed during the test program. The change in boron concentration and the rod worth between these two points give the reciprocal boron worth. The measurement resulted in a reciprocal boron worth of 92.0 ppm/% $\Delta\rho$. The boron concentration change between the points was 477 ppm.

TABLE 9

Shutdown Worth With Highest Worth Rod Stuck Out

Configuration	Predicted Worth (% Δρ)	Measured Worth (% Δρ)	Percent Difference
4 + 3 + 2 + 1 + B + A -27 In	5.673	5.319	6.2

The acceptance criteria for the value of the reciprocal boron worth is that it must not be greater than 125 ppm/% Δρ. The measured value clearly meets this criteria.

H. Sequential Worth of the Regulating Groups

The sequential worth of the regulating rod groups was measured against a boration. A constant boration rate was established and reactivity changes were compensated for by withdrawing the regulating groups in the sequential mode. When withdrawing Group 1, a control rod with a defective synchro was selected as the target rod. Consequently the control rods moved out of sequence. The problem was immediately discovered and no loss of data occurred (Reference 2). The sequential integral rod worth curve resulting from this measurement is found in Figure 6.

There was no acceptance criteria on this measurement.

III. POWER TEST PROGRAM

A. Moderator Temperature Coefficient (MTC)

The isothermal temperature coefficient was determined by varying the reactor coolant temperature while maintaining reactor power constant with the turbine controller and control rod movements. The reactivity insertion was determined from a calculated integral rod worth curve, which was normalized to measured values (Figure 7) (ie, the rod worth from Figure 7 is multiplied by $\frac{0.459}{0.5327}$ where 0.459 is the measured worth of Gr-4 at zero power and 0.5327 is the XTG calculated Gr-4 worth at zero power). The MTC is calculated by adding the doppler contribution to the measured ITC (see Reference 1, Page 19).

The results of this measurement are given in Table 10.

The acceptance criteria is that the MTC must be within 0.5×10^{-2}% Δρ/°F of the predicted value.

TABLE 10

Moderator Temperature Coefficient

Reactor Power %	Measured ITC X $10^{-2}\%$ $\Delta\rho/^{\circ}F$	Measured MTC X $10^{-2}\%$ $\Delta\rho/^{\circ}F$	Predicted MTC[1] X $10^{-2}\%$ $\Delta\rho/^{\circ}F$	Acceptable Range X $10^{-2}\%$ $\Delta\rho/^{\circ}F$
50	-0.56	-0.42	-0.41	$-0.91 \leq MTC \leq 0.09$
90	-0.93	-0.79	-0.61	$-1.11 \leq MTC \leq -0.11$

[1] See Reference 13.

B. Power Coefficient

The power coefficient was measured at 50% and 90% of rated power. The measurement was made by reducing turbine power by approximately 5% and maintaining the coolant temperature at the programmed value. Temperature was maintained by adjustment of Group 4 control rods. Reactivity insertions were determined by control rod position and a calculated integral rod worth curve (normalized to measured values, Figure 7). The results of this measurement are given in Table 11.

The acceptance criteria for this measurement is that the average power coefficient between 0% and 100% power shall be $-1.0 \times 10^{-2}\% \ \Delta\rho/\% \ \text{Pwr} \pm 0.3 \times 10^{-2}\% \ \Delta\rho/\% \ \text{Pwr}$. The average power coefficient for the two measurements is $-1.25 \times 10^{-2}\% \ \Delta\rho/\% \ \text{Pwr}$.

C. Power Distribution

Figure 9 compares the predicted radial power distribution with an actual INCA calculated power distribution at high power. Note that the comparison shows general agreement; however, power is higher near the center of the core than predicted and lower on the outside perimeter. This agrees with the trend observed during the rod worth measurements, where Group 2 rods (an inner ring of rods) was measured to be 9.4% higher than predicted. The worth of all other rod groups were overpredicted.

TABLE 11

Power Coefficient

Reactor Power %	Predicted Pwr Coef % $\Delta\rho$/% Pwr	Measured Pwr Coef % $\Delta\rho$/% Pwr	Acceptable Range X 10^{-2}% $\Delta\rho$/% Pwr
50	-1.1×10^{-2}	-1.3×10^{-2}	$-1.3 \leq PC \leq -.7$
90	-1.2×10^{-2}	-1.2×10^{-2}	$-1.3 \leq PC \leq -.7$

IV. CONCLUSIONS

A. Zero Power Test Program

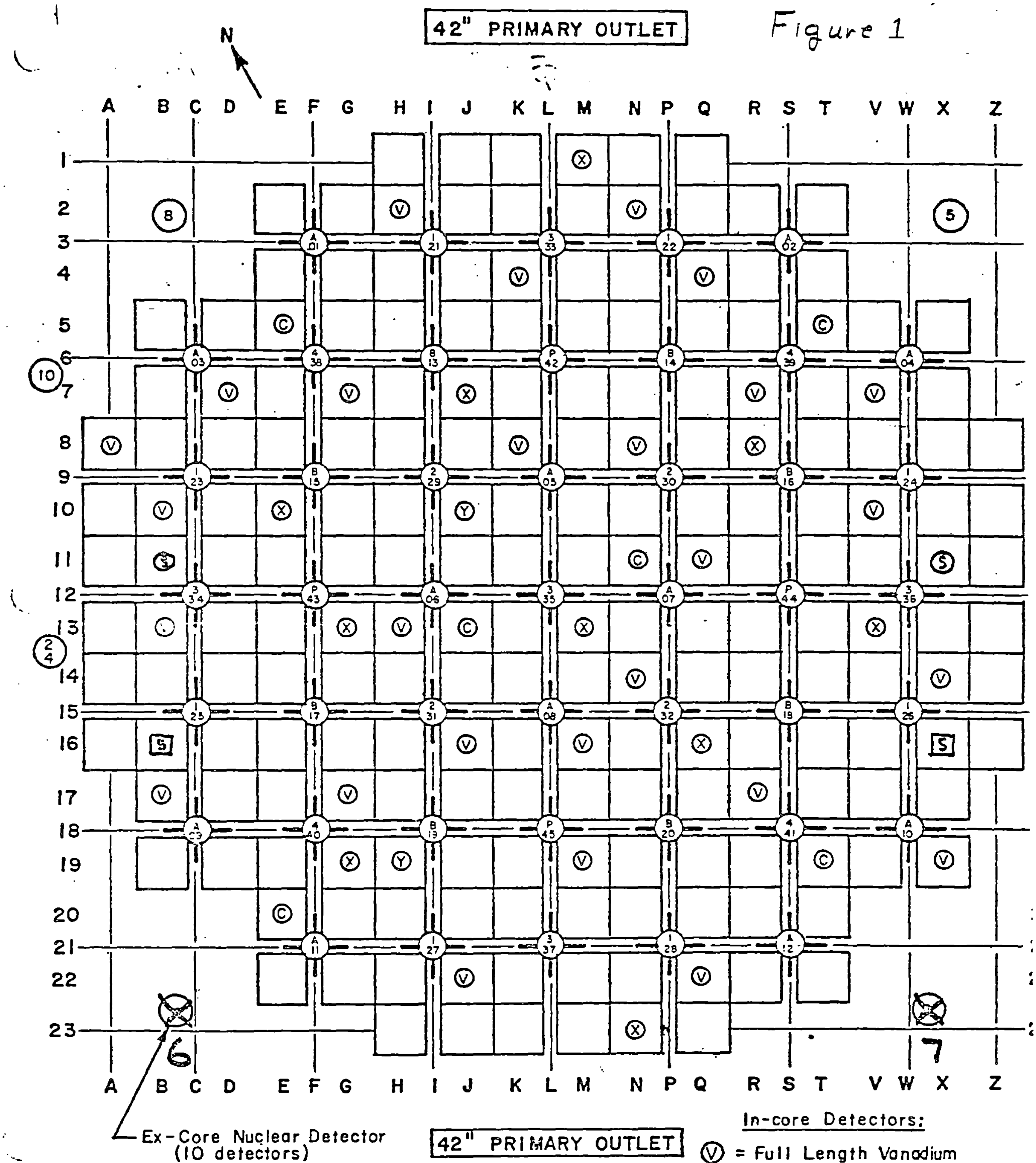
With the exception of the Group 1 control rod worth, all of the acceptance criteria were met and the test results in general are considered valid. It is expected that certain measurements, such as the stuck rod worth measurement, will not be repeated during the next physics test program since the vendor's calculations of such values have been verified.

B. Power Escalation Testing

The measured values of the moderator temperature coefficient and the power coefficient satisfied the acceptance criteria for both the 50% and 90% tests. To increase the accuracy of these measurements, it is expected that, in the future, the central control rod will be used to compensate for reactivity changes in place of group 4 rods, thus making the rod movement much greater.

FIGURE 1

Palisades Plant – Reactor Core Plan



42" PRIMARY OUTLET

Ⓢ Po-Be Source

[S] Sb-Be Source

In-core Detectors:

- Ⓥ = Full Length Vanadium
- Ⓒ = Full Length Cobalt
- Ⓧ = Long background
- Ⓨ = Short background

All in-core detectors contain 4 Rhodium detectors and 2 Thermocouples

FIGURE 2

GROUP 1 WORTH

MEASURED AT HZP (532° F)

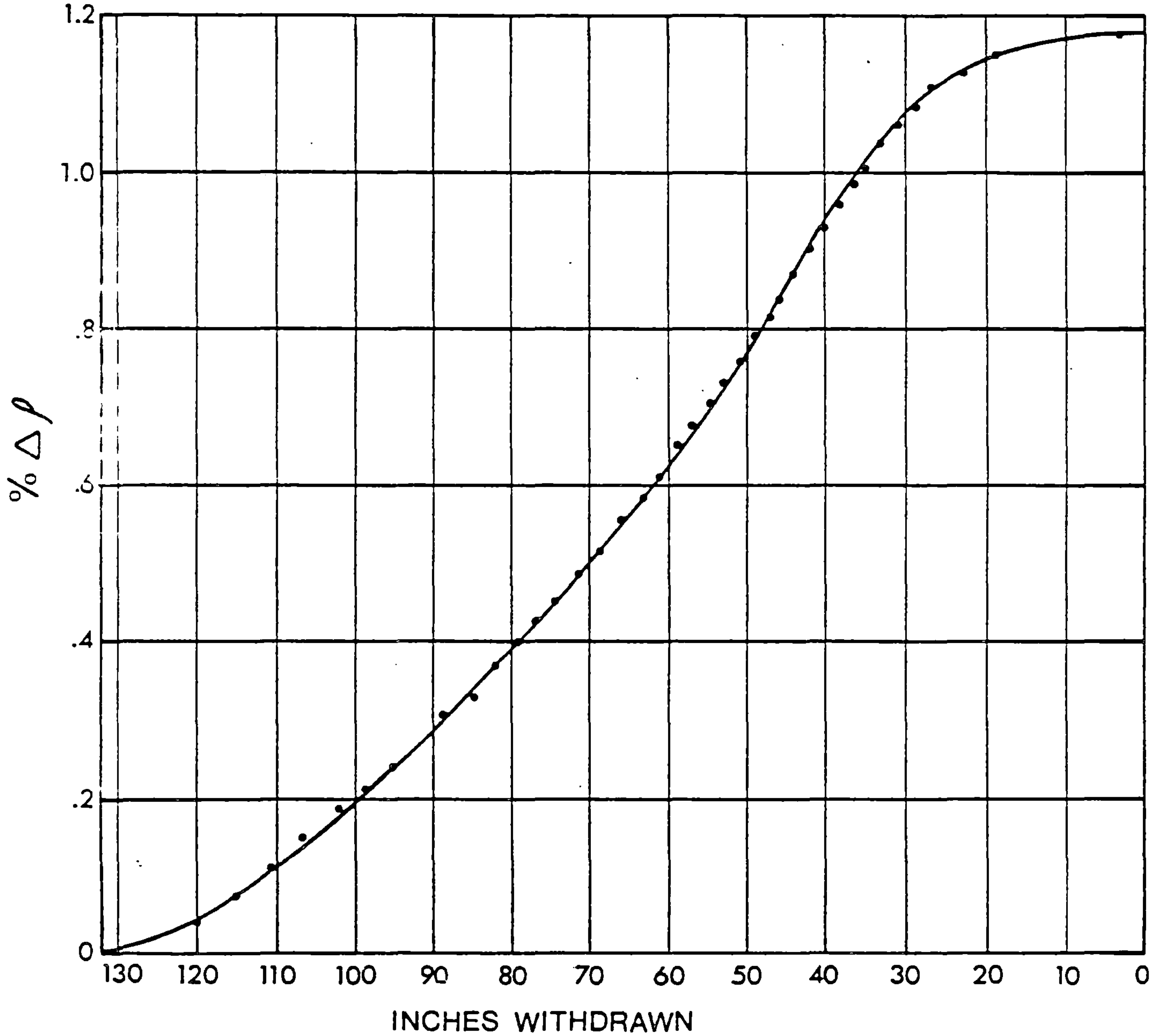


FIGURE 3

GROUP 2 WORTH

MEASURED AT HZP (532°F)

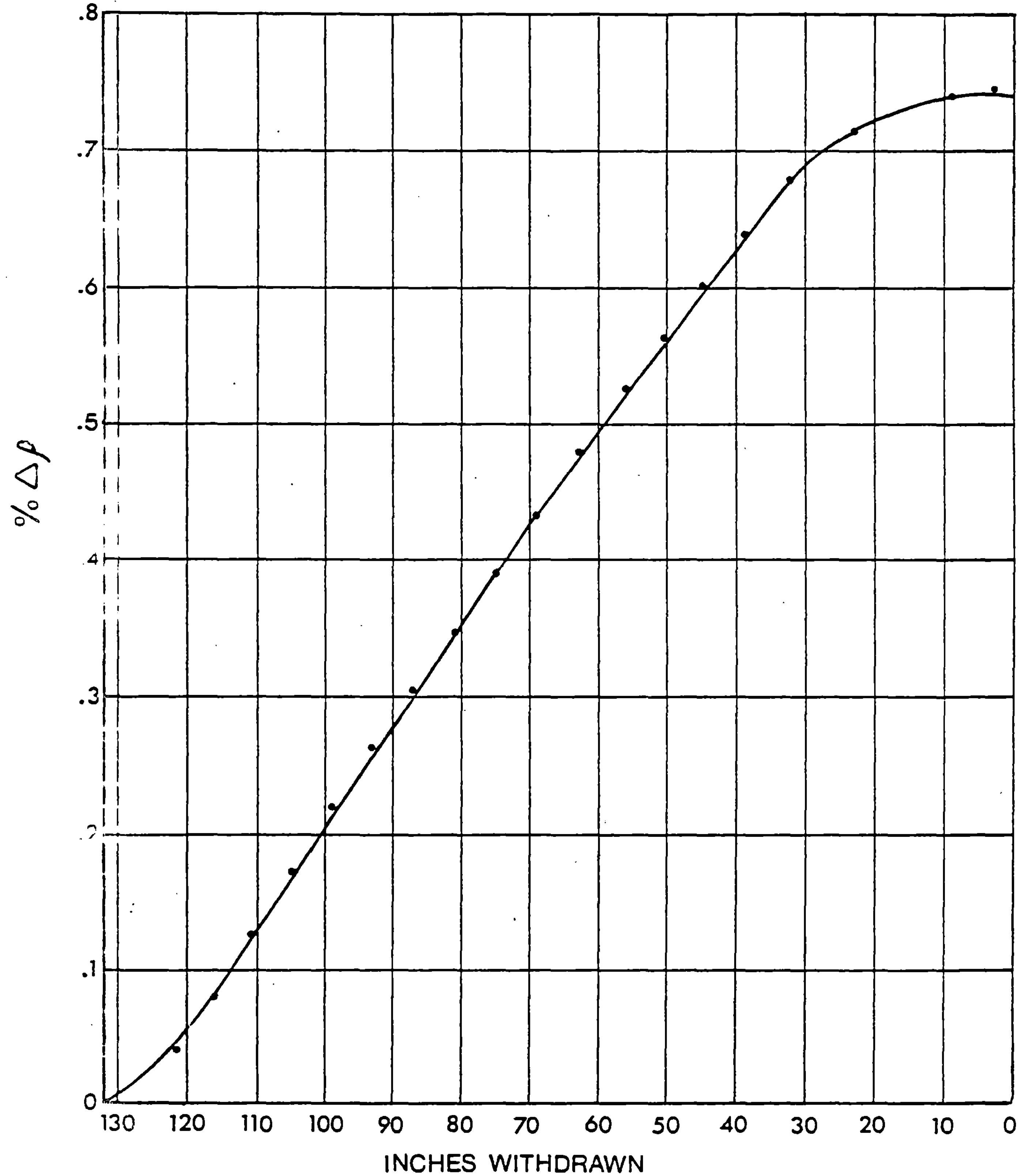


FIGURE 4

GROUP 3 WORTH

MEASURED AT HZP (532° F)

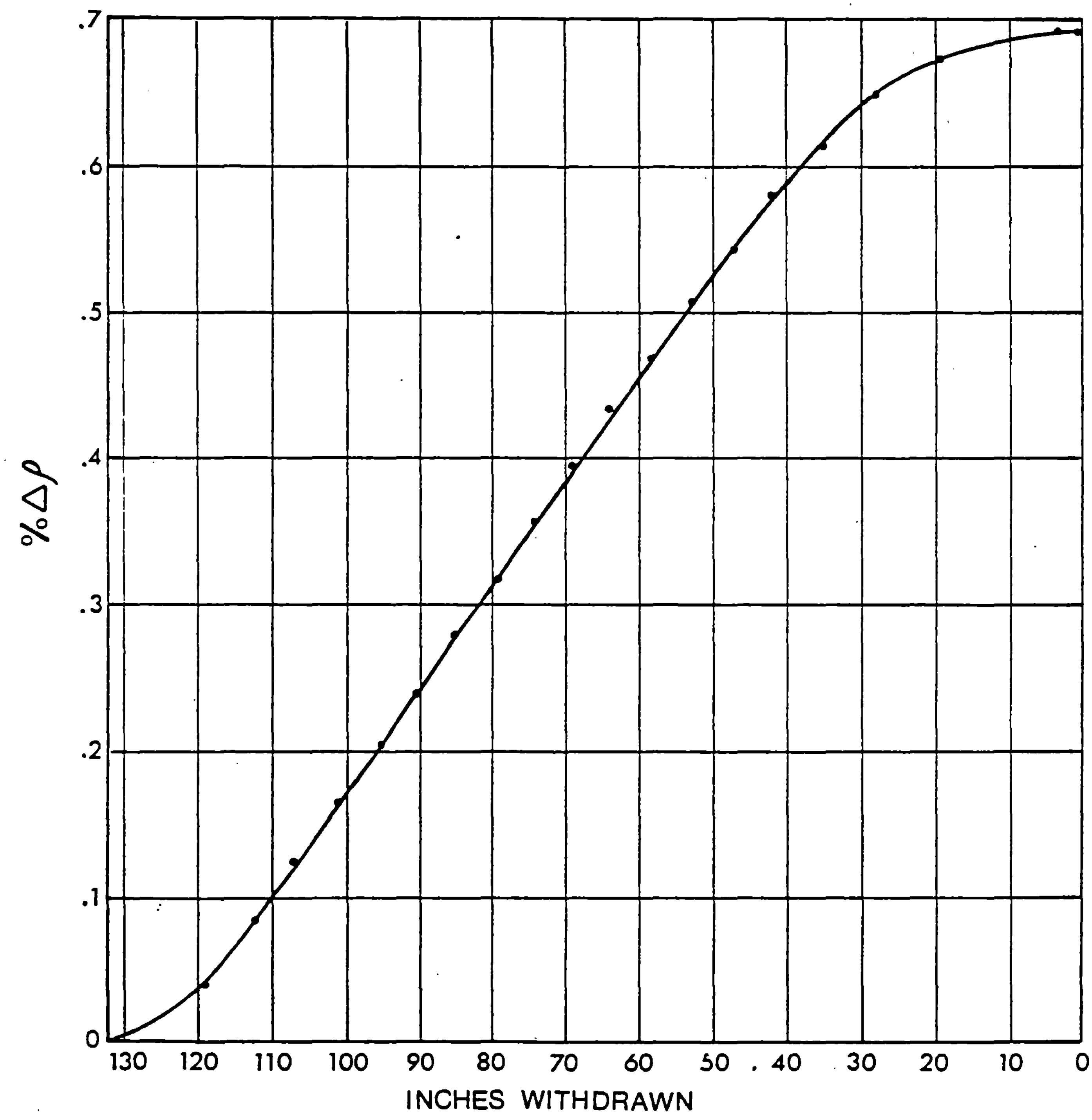


FIGURE 5
GROUP 4 WORTH
MEASURED AT HZP (532°F)

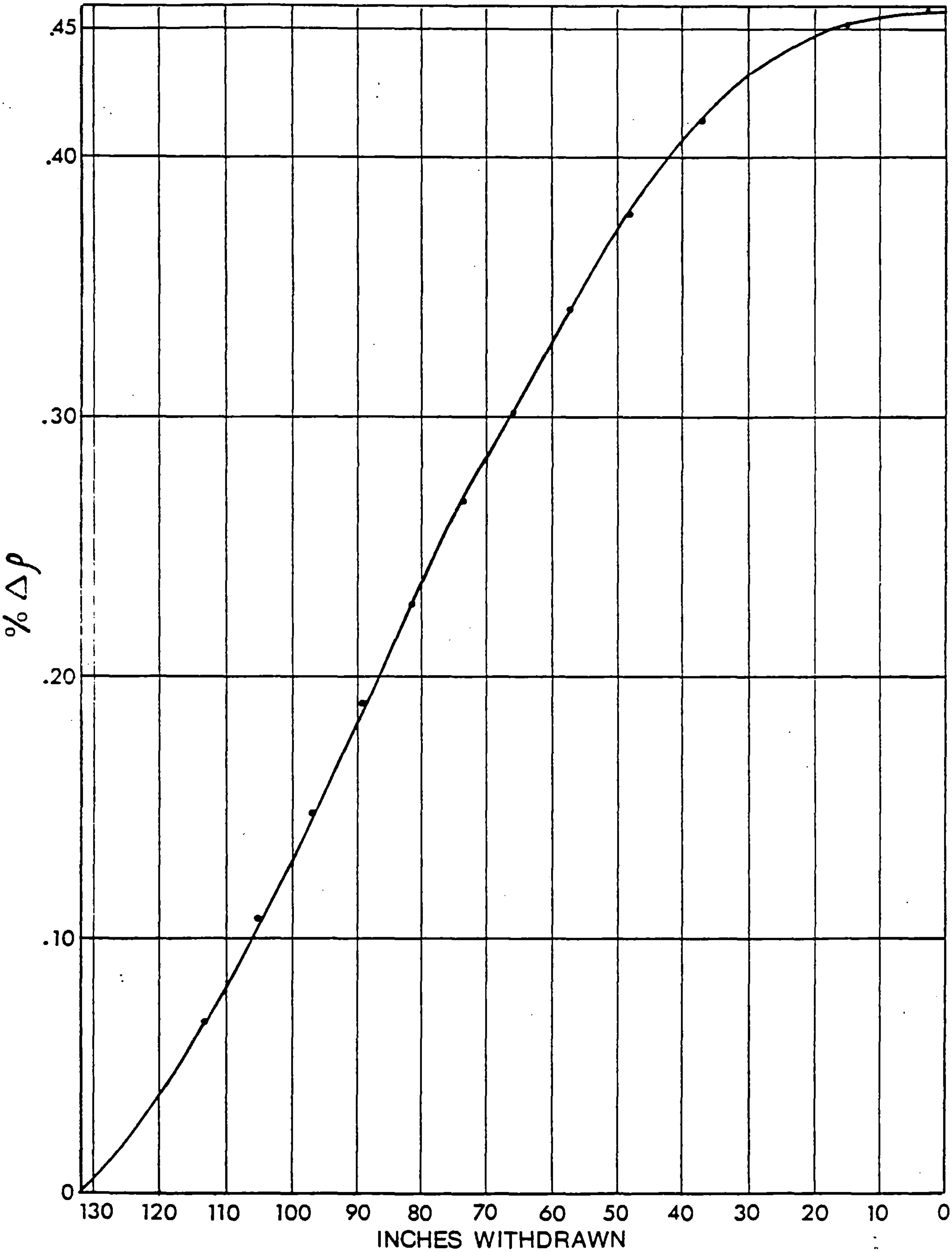


FIGURE 6
SEQUENTIAL ROD WORTH - CORE 3
(MEASURED AT HZP - BOC)

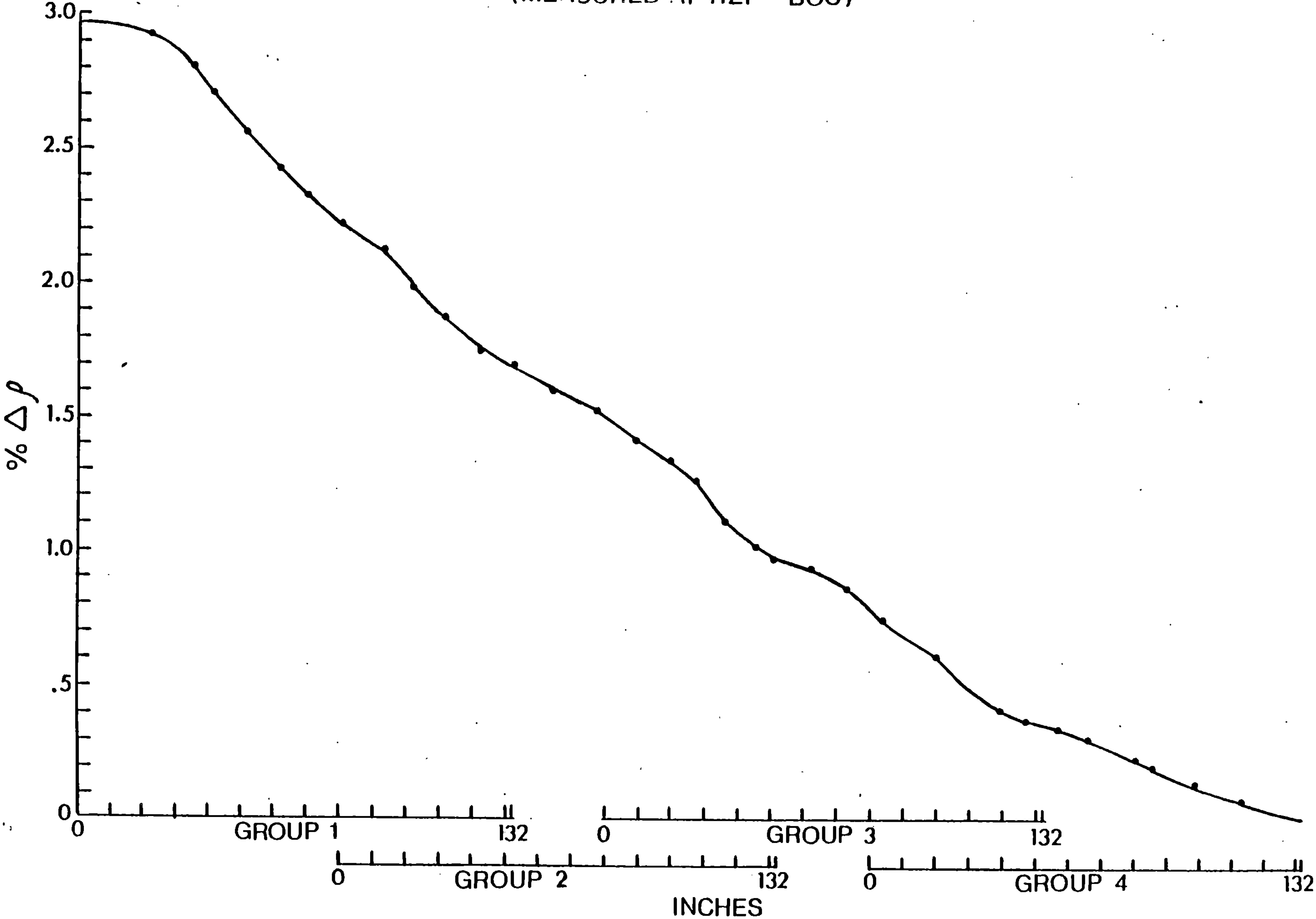


FIGURE 7

INTEGRAL ROD WORTH OF GROUP 4 RODS

PREDICTED AT BOC 3, 50 / AND 90 / POWER

EQUILIBRIUM XENON

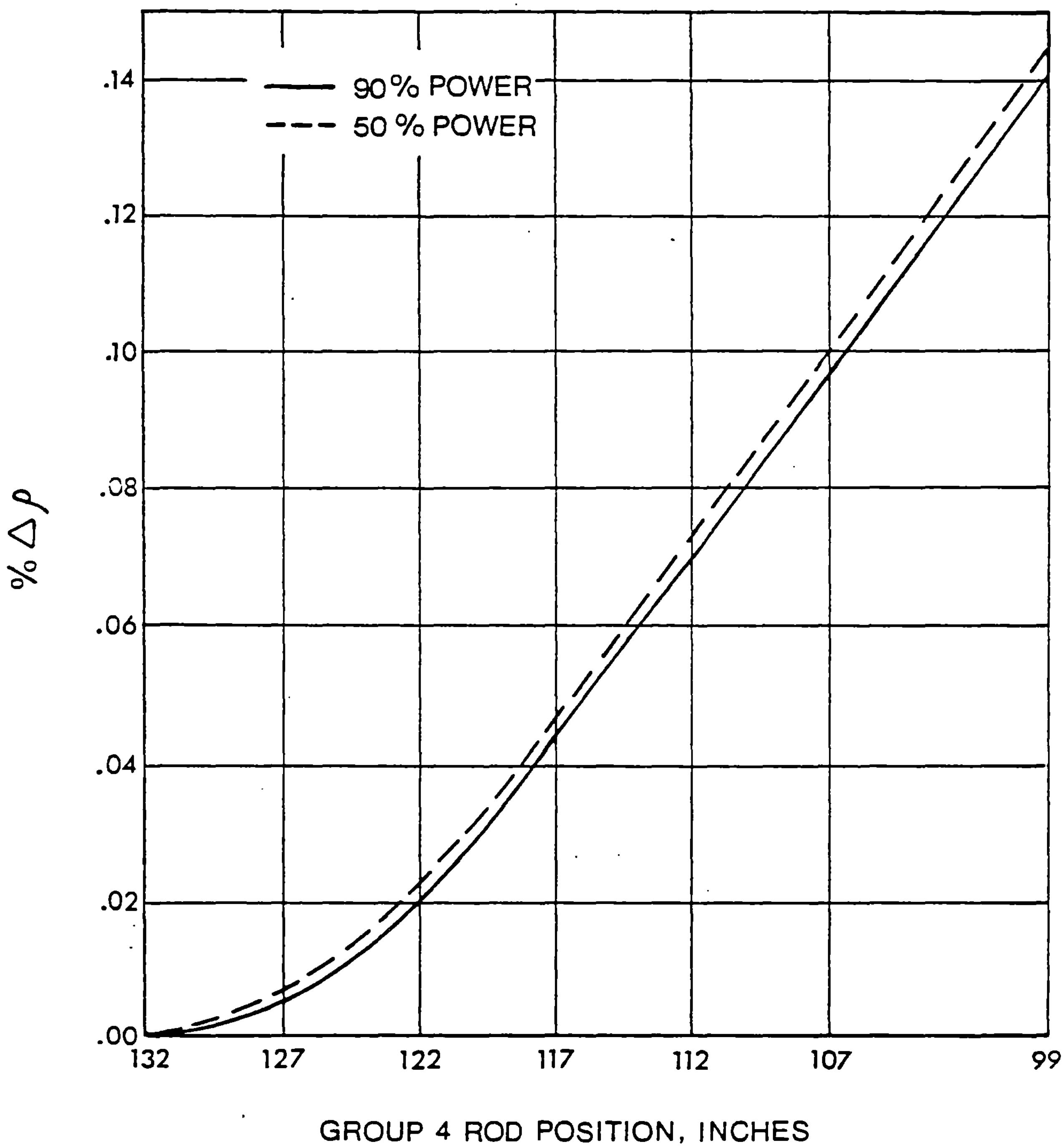
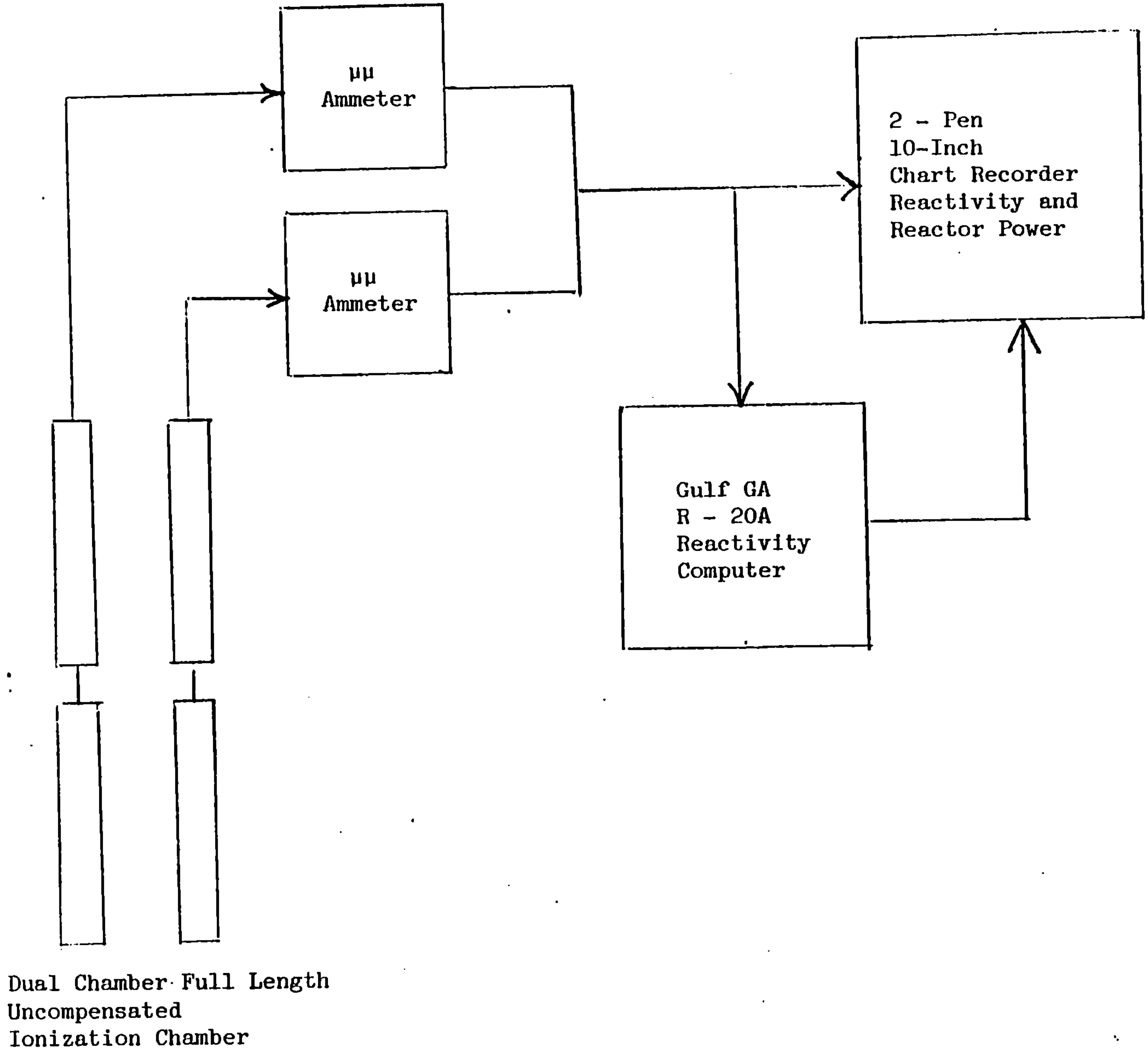


FIGURE 8

Simplified Block Diagram of Instrumentation



PALISADES PLANT

Figure 9

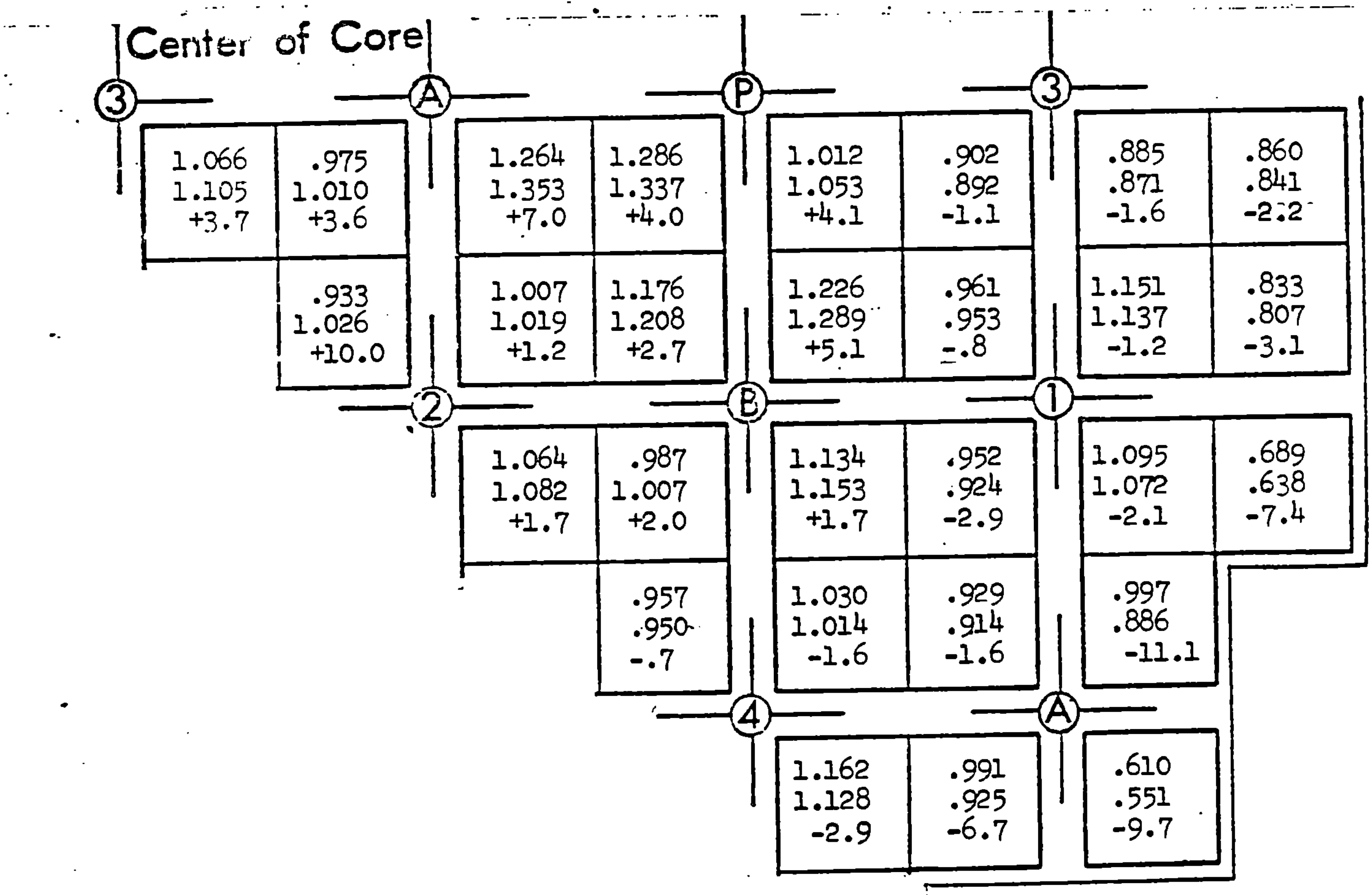
Predicted vs Actual Assembly Radial Power Distribution

CONTROL ROD GROUPS

① ② ③ ④ Regulating

Ⓐ Ⓑ Shutdown

Ⓟ Part Length



Predicted-	XXX
Measured-	YYY
% Difference-	ZZ

APPENDIX A

The following is an evaluation of the available excess shutdown margin for Core - 3. This evaluation was done because the measured value of Group 1 rods was 19.7% lower than the predicted value.

Table A1 lists predicted rod worths and various reactivity insertions and compares them with measured values. The result shows that the excess shutdown margin is 17% lower than predicted but still positive. Therefore, even though the Group 1 rods were worth less than predicted, adequate shutdown margin is available.

Tables A2, A3 and A4 give comparisons of excess shutdown margin available at the beginning of cycle at hot full power (BOC at HFP), end of cycle at hot zero power (EOC at HZP) and EOC at HFP, respectively. Since rod worths were not measured under those conditions, the predicted values were scaled down using the measured zero power values as a normalization factor. Note that, in all cases, excess shutdown margin is available.

TABLE A1

Shutdown Margin BOC at HZP

Control Rod Worth (% Δρ)	Predicted	Measured
Total Minus Stuck Rod	5.62	5.32
Uncertainty (10%)	0.57	0.53
Net Shutdown Rod Worth (1)	5.05	4.79
Reactivity Insertion (% Δρ)		
Doppler Defect	0	0
Moderator Temperature Defect	0	0
Moderator Void Defect	0	0
Axial Flux Redistribution	0	0
Required Shutdown Margin	2.00	2.00
Total Reactivity Allowances (2)	2.00	2.00
Available for Maneuvering (1)-(2)	3.05	2.79
PDIL Rod Insertion	1.54	1.54
Excess Margin	1.51	1.25

TABLE A2

Shutdown Margin BOC at HFP

Control Rod Worth (% Δρ)	Predicted	Estimated
Total Minus Stuck Rod	5.62	5.32
Uncertainty (10%)	0.57	0.53
Net Shutdown Rod Worth (1)	5.05	4.79
Reactivity Insertion (% Δρ)		
Doppler Defect	0.74	0.74
Moderator Temperature Defect	0.20	0.20
Moderator Void Defect	0.1	0.1
Axial Flux Redistribution	0.5	0.5
Required Shutdown Margin	2.0	2.0
Total Reactivity Allowances (2)	3.54	3.54
Available for Maneuvering (1)-(2)	1.51	1.25
PDIL Rod Insertion	0.15	0.15
Excess Margin	1.36	1.10

TABLE A3

Shutdown Margin EOC at HZP

Control Rod Worth (% Δρ)	Predicted	Estimated
Total Minus Stuck Rod	5.74	5.43
Uncertainty (10%)	0.58	0.55
Net Shutdown Rod Worth (1)	5.16	4.88
Reactivity Insertion (% Δρ)		
Doppler Defect	0	0
Moderator Temperature Defect	0	0
Moderator Void Defect	0	0
Axial Flux Redistribution	0	0
Required Shutdown Margin	2.00	2.00
Total Reactivity Allowances (2)	2.00	2.00
Available for Maneuvering (1)-(2)	3.16	2.89
PDIL Rod Insertion	2.00	2.00
Excess Margin (% Δρ)	1.16	0.89

TABLE A4

Shutdown Margin EOC at HFP

Control Rod Worth (% Δρ)	Predicted	Estimated
Total Minus Stuck Rod	5.74	5.43
Uncertainty (10%)	0.58	0.54
Net Shutdown Rod Worth (1)	5.16	4.89
Reactivity Insertion (% Δρ)		
Doppler Defect	0.72	0.72
Moderator Temperature Defect	0.64	0.64
Moderator Void Defect	0.1	0.1
Axial Flux Redistribution	0.5	0.5
Required Shutdown Margin	2.00	2.00
Total Reactivity Allowances (2)	3.96	3.96
Available for Maneuvering (1)-(2)	1.20	0.93
PDIL Rod Insertion	0.21	0.21
Excess Margin (% Δρ)	0.99	0.72

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2. Event Report No 78-24.

3. Special Test T-105, Low Power Test Program for Palisades Core - 3.

4. Special Test T-106, Zero Power ARO Critical Boron Concentration.

5. Special Test T-107, Zero Power Rod Worth Measurements.

6. Special Test T-108, Zero Power Isothermal Temperature Coefficient Measurements.

7. Special Test T-110, Zero Power Symmetry and Dropped Rod Worth.

8. Special Test T-112, Base Power Level Selection.

9. Letter to Director, Nuclear Reactor Regulation, Dated March 15, 1978, Description of Physics Testing for Palisades Core - 3 and Acceptance Criteria.

10. Special Test T-111, Power Escalation Test Program for Palisades Core - 3.

11. Special Test T-98, Measurement of the Moderator Temperature Coefficient at Power.

12. Special Test T-101, Measurement of the Power Coefficient.

13. Personal Communication With Larry Nielson of Exxon Nuclear Co Concerning Predicted Values of the MTC at Power. Written Documentation Pending.

14. INCA Case, ARO, 90% Power, 142 MWD/MTU, Cycle 3.