PHYSICS TESTING REPORT FOR CORE 4 START-UP

July 1980

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SECTION 1 - INTRODUCTION

The following report presents the results of the Palisades Plant Core 4 low power and power physics testing. The following procedures were used for this testing:

Special Test No	Title
T-119	Low Power Test Program for Palisades Core 4
T-120	Base Power Level Selection
T-121	Zero Power Isothermal Temperature Coefficient Measurement
T-122	Zero Power Rod Worth Measurements
T-123	Zero Power ARO Critical Boron Concentration
T-124	Center Rod Worth and Zero Power Symmetry Check
T-125	Measurement of Moderator Temperature Coefficient At Power
T-126	Measurement of Power Coefficient

The results were obtained from the performance of the above tests, except the power distribution data, which came from the INCA computer routine. Measured results were compared to predicted results (see Reference 1.2) to ascertain whether or not review and acceptance criterion were being violated (see Reference 3). Sections 2 through 11 of this report contain the test results with each section covering a particular test result. The results presented are:

1. ARO HZP Critical Boron Concentration
2. Regulating Rod Bank Worths, No Overlap
3. Regulating Rod Bank Worths in Overlap Sequence
4. Central Rod Integral Worth Calibration
5. Symmetric Rod Worths

6. Moderator Temperature Coefficient ARO and Regulating Banks In
7. Reciprocal Soluble Boron Worth
8. Moderator Temperature Coefficient At Power
9. Power Coefficient
10. Power Distribution

These results for Core 4 testing differed from Core 3 testing in the following ways: 1) shutdown worth with highest worth rod out (or the N-1 test) was not performed, 2) the highest worth dropped rod was not verified, 3) all symmetrical groups were tested and 4) power testing was done at one power level, approximately 90%, rather than two.

The two tests not performed were not included on the NRC suggested testing list nor in our proposed testing schedule, submitted by letter dated October 31, 1979, for the Palisades Plant Core 4.

SECTION 2 - ARO HZP CRITICAL BORON CONCENTRATION

The all rods out (ARO) hot zero power (HZP) critical boron concentration was measured by obtaining a boron concentration with Group (Gr) 4 rods at almost ARO configuration. The residual worth of Gr 4 was then measured on the reactivity computer and the residual worth was correlated to a change in boron concentration via the reciprocal boron worth. The boron concentration with Gr 4 at almost ARO configuration was added to the residual worth boron concentration and this result is presented below. Review and acceptance criterion were not exceeded.

TABLE 1

Results of ARO HZP Critical Boron Concentration

Measured	Predicted
1161 ppm	1200 ppm

Review Criterion - Measured value within 70 ppm of predicted

Acceptance Criterion - None

SECTION 3 - REGULATING ROD BANK WORTHS - NO OVERLAP

The worths of the regulating rod banks were measured by diluting the primary coolant system at a constant rate, 40 gpm, and trading positive reactivity changes due to dilution with negative reactivity due to rod insertion. The rods were inserted in the manual group mode in the order of Gr 4, 3, 2 and 1. Results are presented in Table 2 of this report. Review and acceptance criteria were not exceeded. Figures 1 - 4 present graphs of the measured integral rod worths.

TABLE 2

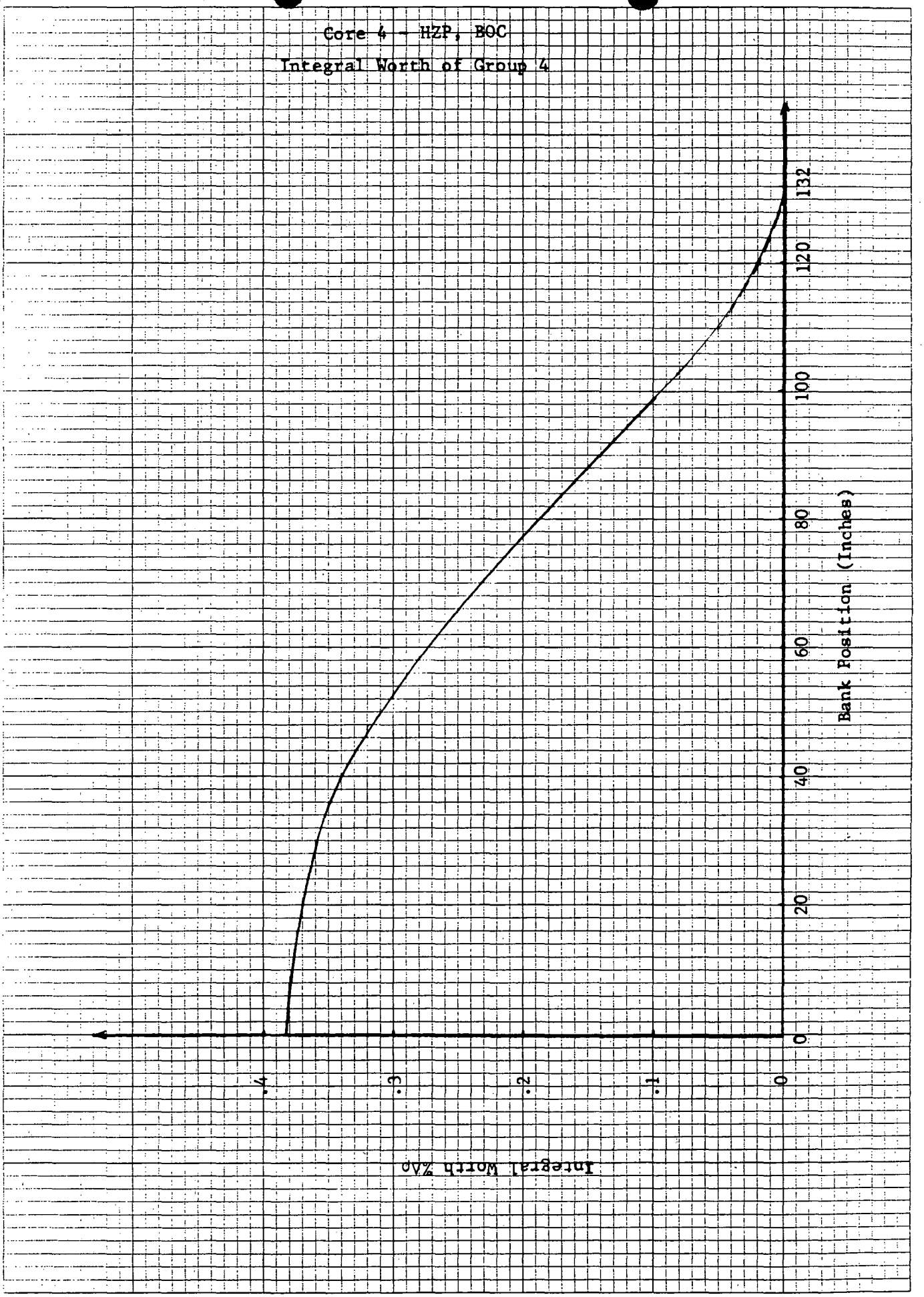
Results of Regulating Rod Bank Worths - No Overlap

Group	Measured %Δρ	Predicted %Δρ	% Deviation	%Δρ Deviation
4	.383	.383	0	0
3	.814	.877	-7.2	-.063
2	.613	.618	-.8	-.005
1	1.447	1.549	-6.6	-.102
4+3+2+1	3.257	3.427	-4.96	

Review Criterion - Individual rod banks within 15% or 0.15%Δρ of predicted value, whichever is greater

Acceptance Criterion - Sum of regulating banks within 10% of prediction

FIGURE 1



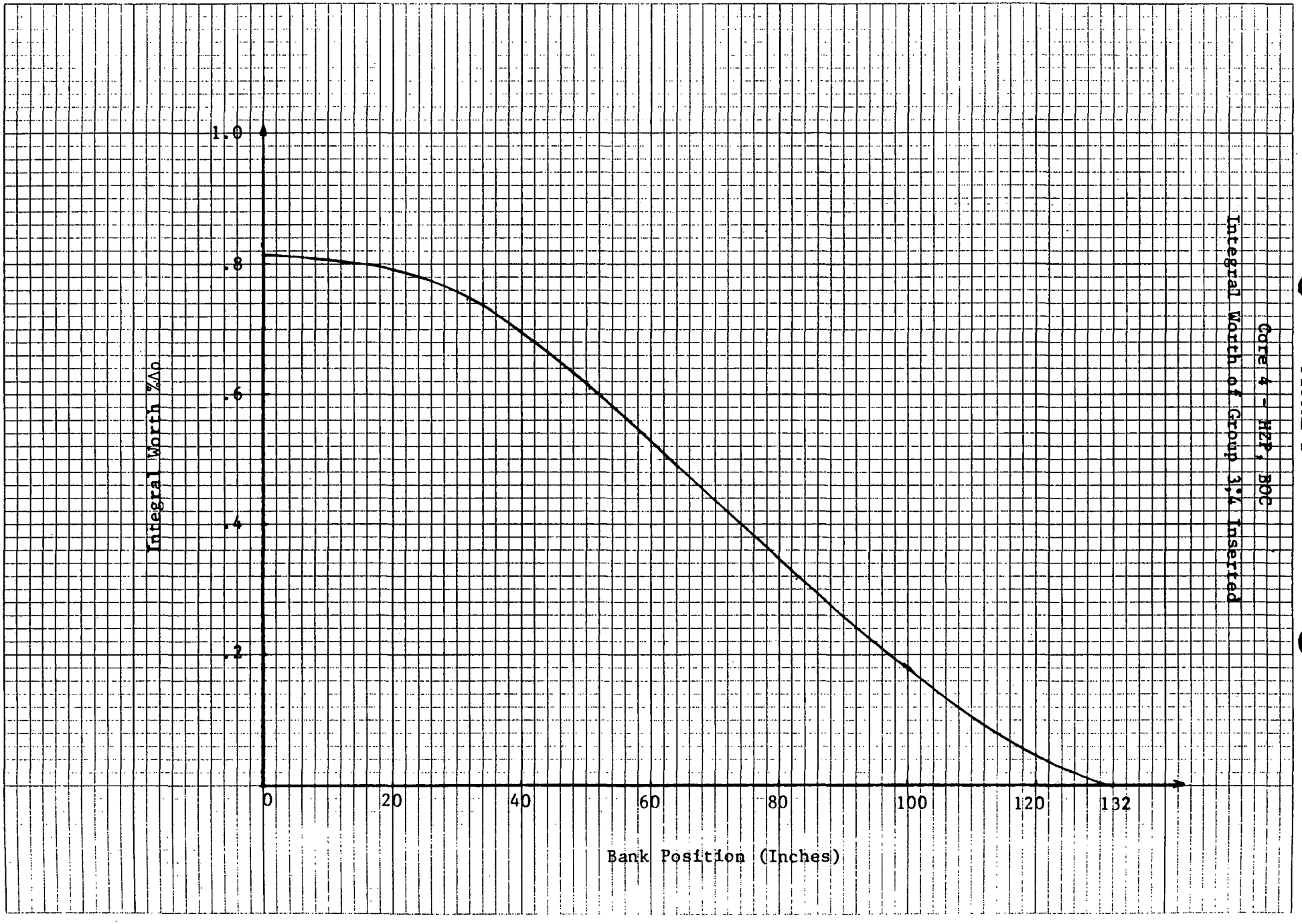

Core 4 - HZP, BOC
Integral Worth of Group 3,4 Inserted
Integral Worth %Δρ
1.0
.8
.6
.4
.2
0
20
40
60
80
100
120
132
Bank Position (Inches)

FIGURE 2

FIGURE 3

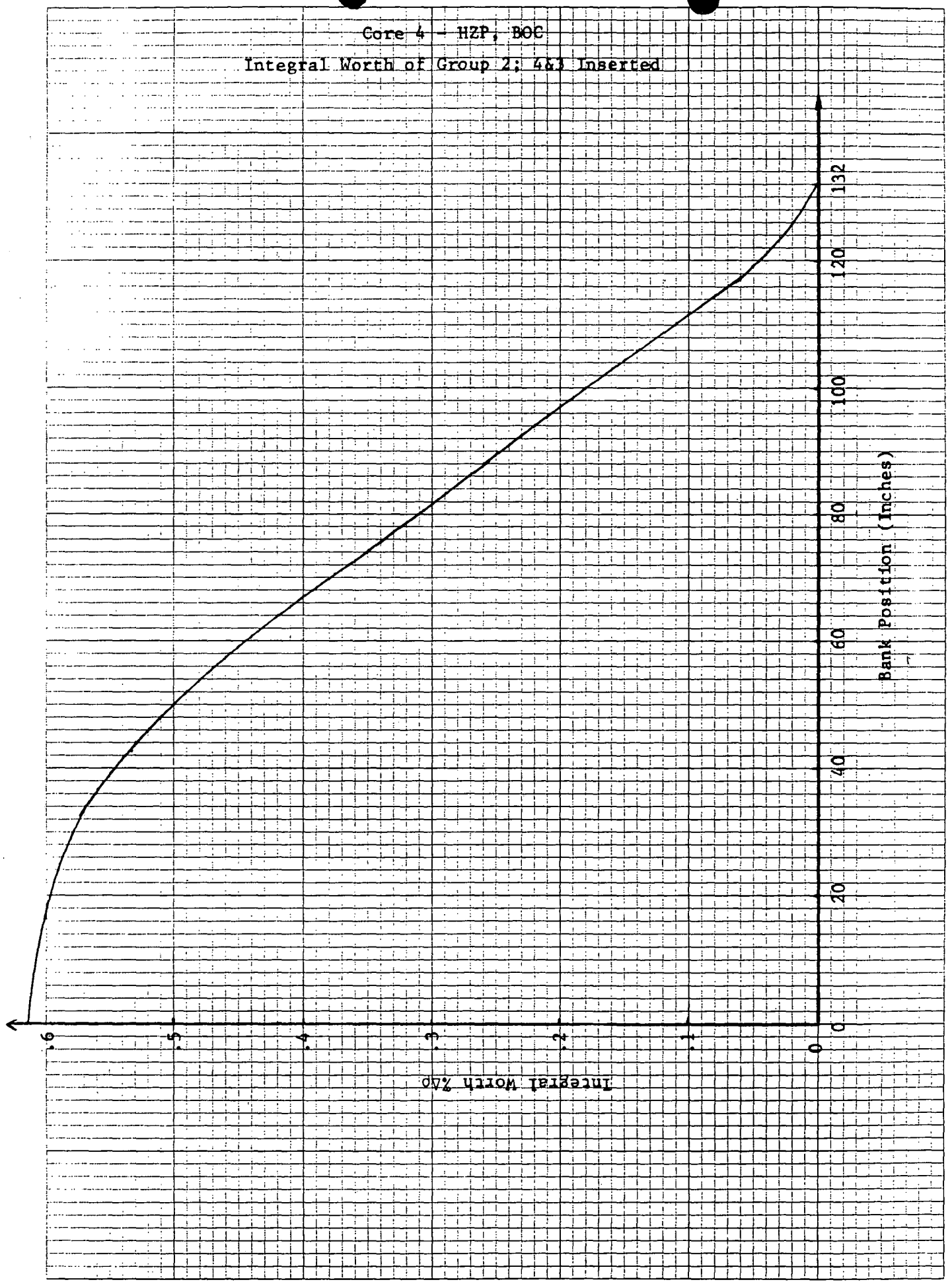
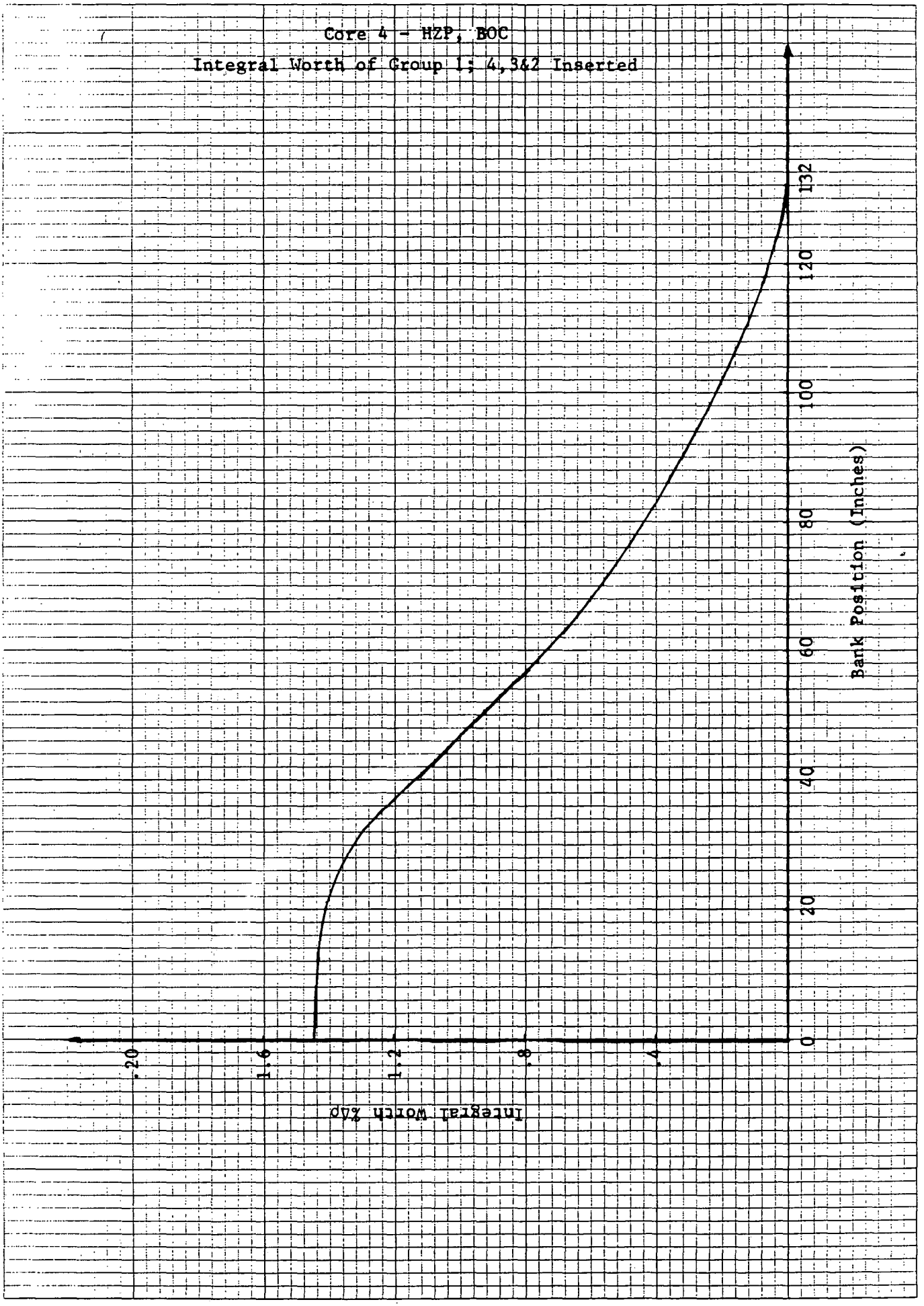

Core 4 - HZP, BOC
Integral Worth of Group 2; 4&3 Inserted
Bank Position (Inches)
0
20
40
60
80
100
120
132
Integral Worth %Δρ
0
-.1
-.2
-.3
-.4
-.5
-.6

FIGURE 4


Core 4 - HZP, BOC
Integral Worth of Group 1; 4,3&2 Inserted
Bank Position (Inches)
0
20
40
60
80
100
120
132
Integral Worth %ΔρK
.20
1.6
1.2
.8
.4

SECTION 4 - REGULATING ROD BANKS WORTH IN OVERLAP SEQUENCE

The sequential worth of regulating rod banks was measured by borating the primary coolant system at a constant rate, 5 gpm, and trading negative reactivity due to boration with positive reactivity due to withdrawal of the rods. Results are presented in Table 3. Figure 5 displays a graph of the measured integral rod worth in sequential mode. Review and acceptance criteria were not exceeded.

TABLE 3

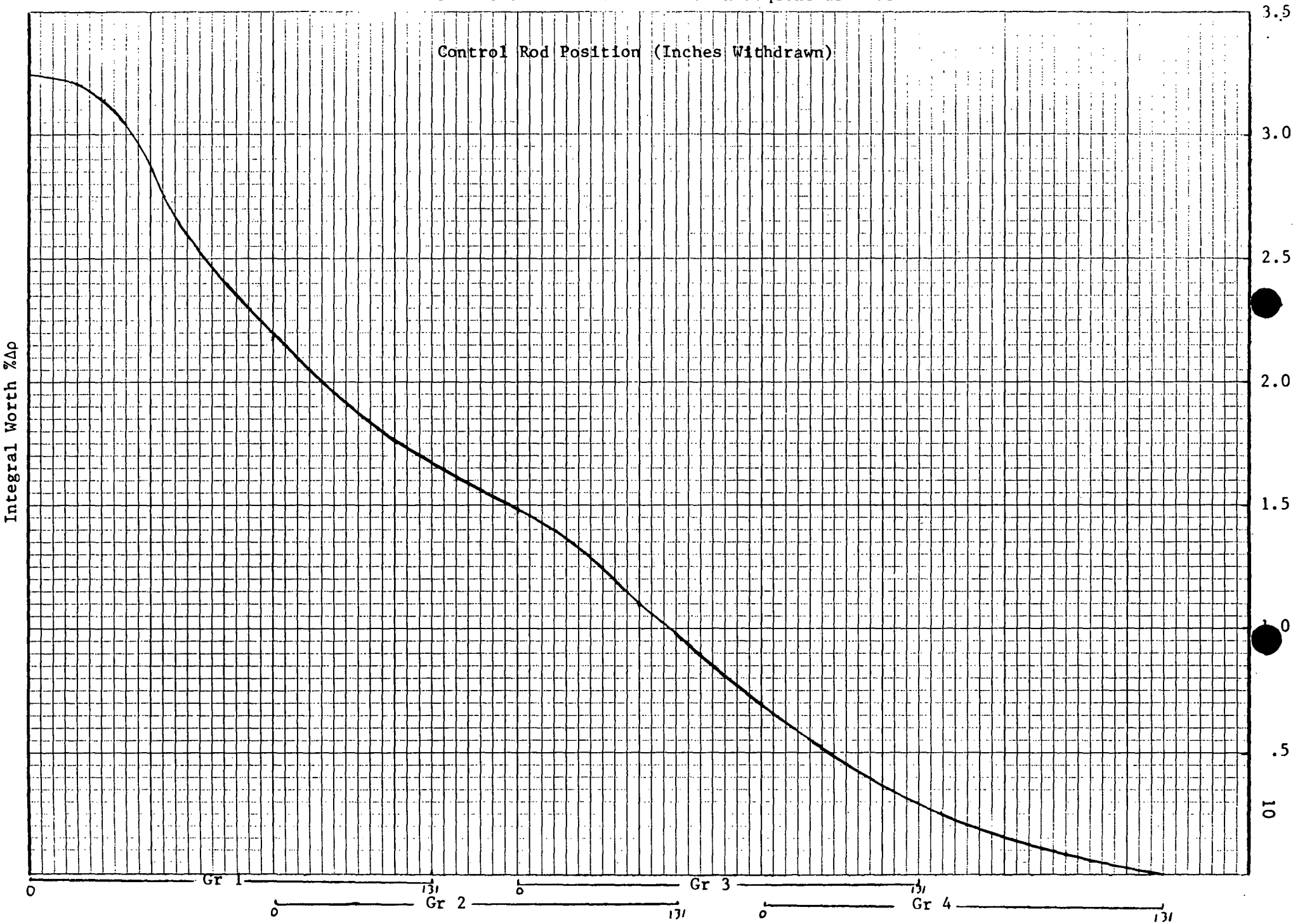
Results of Regulating Rod Bank Worths in Overlap Sequence

Measured %Δρ	Predicted %Δρ	% Difference
3.24	3.427	-5.46

Review Criterion - None

Acceptance Criterion - Sum of regulating banks within 10% of prediction

FIGURE 5 - Measured Worth of Rods In Sequential Mode



SECTION 5 - CENTRAL ROD INTEGRAL WORTH CALIBRATION

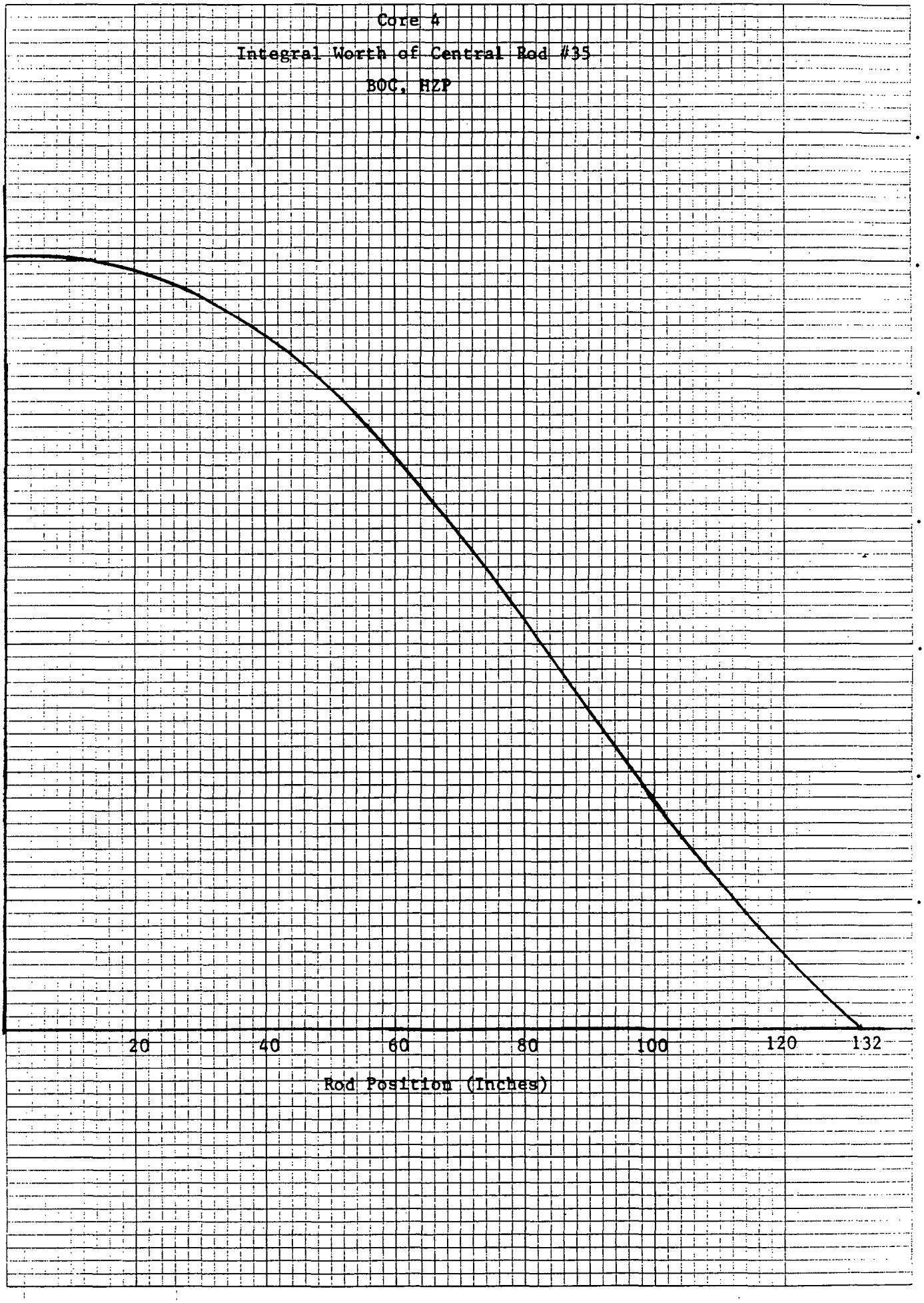
The integral worth of the center rod, #35, was determined by diluting the primary coolant system at a constant rate and trading positive reactivity due to dilution with negative reactivity due to control rod insertion. The worth of the center rod is given in Table 4 and a graph of integral worth of the center rod is given in Figure 6. The central rod integral worth calibration had no associated review or acceptance criterion. The purpose of the test was to determine the ratio of measured vs predicted worth which from the results in Table 4 equals 0.698%$\Delta\rho$. This ratio was used during the power testing to scale the predicted center rod worth. (Note: The center rod position along with center rod reactivity information supplied in Reference 4 is used to determine the power coefficient and moderator temperature coefficient.)

TABLE 4

Control Rod #35 Worth

Measured %$\Delta\rho$	Predicted %$\Delta\rho$
.060	.0862

FIGURE 6



SECTION 6 - SYMMETRIC ROD WORTHS

The testing of symmetric rods consisted of inserting one rod in a symmetric group while withdrawing a second rod in the same symmetric group and repeating this sequence for all rods in a symmetric group and all symmetric groups. If the rods in a symmetric group had identical worths, reactivity on the reactivity computer would display the same value following the insertion and removal of any two rods in a symmetric group. Table 5 presents the % deviation of rods in a symmetric group from the group average. This is also displayed in Figure 7 in which a slight tilt is observed. No significant tilt was observed at power (see Section 11). Review and acceptance criterion were not exceeded.

TABLE 5

Results of Symmetric Rod Worths

Group A Outer Rods

Rod No.	% Deviation from Group Average
1	-8.14
2	-1.74
3	-1.16
4	3.49
9	-1.74
10	5.23
11	-.58
12	4.65

Group A Inner Rods

Rod No.	% Deviation from Group Average
5	-3.99
6	.31
7	1.84
8	1.84

Group B Rods

Rod No.	% Deviation from Group Average
13	-7.86
14	-3.56
15	-3.26
16	1.66
17	1.35
18	5.65
19	1.35
20	4.73

Group 1 Rods

Rod No.	% Deviation from Group Average
21	-8.66
22	-3.50
23	-1.80
24	4.20
25	-.51
26	5.90
27	.34
28	3.77

Group 2 Rods

Rod No.	% Deviation from Group Average
29	-5.38
30	-.90
31	1.79
32	4.48

Group 3 Outer Rods

Rod No.	% Deviation from Group Average
33	-8.42
34	-1.27
36	7.07
37	2.70

Group 4 Rods

Rod No.	% Deviation from Group Average
38	-6.43
39	.52
40	.09
41	5.73

Review Criterion - Each individual rod within 10% of the symmetric group average

Acceptance Criterion - Each individual rod within 20% of the symmetric group average

FIGURE 7

DISTRIBUTION OF % DEVIATION FOR SYMMETRIC ROD WORTHS

	A-01 -8.14	1-21 -8.66	3-33 -8.42	1-22 -3.50	A-02 -1.74	
A-03 -1.16	4-38 -6.43	B-13 -7.86	P-42	B-14 -3.56	4-39 .52	A-04 3.49
1-23 -1.80	B-15 -3.26	2-29 -5.38	A-05 -3.99	2-30 -.90	B-16 1.66	1-24 4.20
3.34 -1.27	P-43	A-06 .31	3-35	A-07 1.84	P-44	3-36 7.07
1-25 -.51	B-17 1.35	2-31 1.79	A-08 1.84	2-32 4.48	B-18 5.65	1-26 5.90
A-09 -1.74	4-40 .09	B-19 1.35	P-45	B-20 4.73	4-41 5.73	A-10 5.23
	A-11 -.58	1-27 .34	3-37 2.70	1-28 3.77	A-12 4.65	← Rod No. ← % Deviation

SECTION 7 - MODERATOR TEMPERATURE COEFFICIENT ARO AND REGULATING BANKS IN

The moderator temperature coefficient (MTC) was determined at essentially the all rods out configuration and the configuration with the regulating groups inserted. The MTC was determined by observing reactivity changes on the reactivity computer while cooling or heating the primary coolant system. From the reactivity and temperature changes, an isothermal temperature coefficient (ITC) was determined from which the MTC was extracted using the relationship ITC = MTC + doppler. The doppler coefficient used can be found in Reference 1 and has a value of -1.553×10^{-5} $\Delta\rho/^{o}F$. The MTC determined for the ARO case was extrapolated to full power using the technique given in Reference 5. Results from the MTC measurements are given in Table 6 and as can be seen, review and acceptance criterion were not exceeded.

TABLE 6

Results of MTC Measurements

Rod Position	Measured	Predicted	Measured Value Extrapolated to Full Power
ARO	$9.39 \times 10^{-6} \Delta\rho/^{o}F$	$1.4 \times 10^{-5} \Delta\rho/^{o}F$	$-1.98 \pm 1 \times 10^{-5} \Delta\rho/^{o}F$
Reg groups in	$-6.8 \times 10^{-5} \Delta\rho/^{o}F$	$-7.6 \times 10^{-5} \Delta\rho/^{o}F$	

Review Criterion - Measured value within $5 \times 10^{-5} \Delta\rho/^{o}F$ of the predicted value.

Acceptance Criterion - Measured value between $5 \times 10^{-5} \Delta\rho/^{o}F$ and $-35 \times 10^{-5} \Delta\rho/^{o}F$ when extrapolated to full power

SECTION 8 - RECIPROCAL SOLUBLE BORON WORTH

The reciprocal soluble boron worth was determined through the acquisition of a boron concentration with the regulating groups inserted and with all rods out (ARO). With these two boron end points and the reactivity difference between the end points the reciprocal boron worth is determined. Results of the reciprocal soluble boron worth are given in Table 7. Review and acceptance criterion were not exceeded.

TABLE 7

Reciprocal Soluble Boron Worth

Measured	Predicted	Difference
91.7ppm/%Δρ	97.2ppm/%Δρ	5.5ppm/%Δρ

Review Criterion - Within 15ppm/%Δρ of the predicted value.

Acceptance Criterion - Less than 125ppm/%Δρ.

SECTION 9 - MODERATOR TEMPERATURE COEFFICIENT AT POWER

The moderator temperature coefficient (MTC) at power was determined in a similar manner to that obtained at zero power. The primary coolant system temperature was dropped, keeping core power constant and reactivity changes were obtained by the change in the central rod position (see discussion in Section 5). A doppler coefficient of $-1.252 \times 10^{-3} \% \Delta\rho/^{\circ}F$ was used from Reference 2 to extract the MTC from the isothermal temperature coefficient. Results of MTC measurement at power are given in Table 8. Review and acceptance criteria were not exceeded.

TABLE 8

Results of MTC Measurement at Power

Measured	Predicted	Difference
-6.27×10^{-5} $\Delta\rho/^{\circ}F$	-9.1×10^{-5} $\Delta\rho/^{\circ}F$	$2.83 \times 10^{-5} \Delta\rho/^{\circ}F$

Review Criterion - Measured value within $5 \times 10^{-5} \Delta\rho/^{\circ}F$ from the predicted value.

Acceptance Criterion - Value between $5 \times 10^{-5} \Delta\rho/^{\circ}F$ and $-35 \times 10^{-5} \Delta\rho/^{\circ}F$ when extrapolated to full power.

SECTION 10 - POWER COEFFICIENT

The power coefficient is obtained by dropping core power and measuring a reactivity change from the change in central rod position (see discussion in Section 5). Because of the temperature decalibration of the nuclear drawers, power readings were obtained from the turbine setter. Slight corrections were made to the power coefficient calculated as just described to account for temperature deviations in Tavg and Tref; the predicted power coefficient assumes Tavg equal to Tref. Results from the power coefficient test are given in Table 9. Review and acceptance criteria were not exceeded.

TABLE 9

Power Coefficient Results

Measured	Predicted	Difference
$-.96 \times 10^{-2} \%\Delta\rho/\%P$	$-1.156 \times 10^{-2} \%\Delta\rho/\%P$	$1.96 \times 10^{-5} \Delta\rho/\%P$

Review Criterion - Measured value within $\pm 3 \times 10^{-5} \Delta\rho/\%$ power of the predicted value.

Acceptance Criterion - Measured value within $\pm 6 \times 10^{-5} \Delta\rho/\%$ power of the predicted value.

SECTION 11 - POWER DISTRIBUTION

Information pertaining to the power distribution was obtained from the computer routine INCA which uses incore detector readings to evaluate power distribution parameters. The INCA routine is routinely run and the computer run chosen for this report was one at 92% power and 138.5 MWD/MTU burnup. INCA calculated information or information derived from the INCA results consisted of power distributions, quadrant tilt, assembly power and assembly power RMS deviation. Predicted information used in assembly power and assembly power RMS deviation was obtained from Reference 1. It should be noted that predicted information was at 100% power and 150 MWD/MTU burnup. Acceptance criterion for power distributions based on Technical Specification limits were met.

Quadrant Tilt

The INCA calculated quadrant tilt of .16% is well below the review criterion of 3%. Quadrant tilt did not have an acceptance criterion.

Assembly Power

Predicted assembly power, measured assembly power and percent difference between the two are given in Figure 8. As can be seen, the criterion listed below have not been exceeded.

Review Criterion - Measured value within $\pm$ 10% of prediction if assembly power >9 MWt.

- Measured value within $\pm$ 15% of prediction if assembly power $\leq$9 MWt.

Acceptance Criterion - None

Assembly Power RMS Deviation

The assembly power RMS deviation calculated from the assembly powers displayed in Figure 8 equaled 1.82. This number does not exceed the criterion listed below.

Review Criterion - RMS deviation is less than 5%.

Acceptance Criterion - None

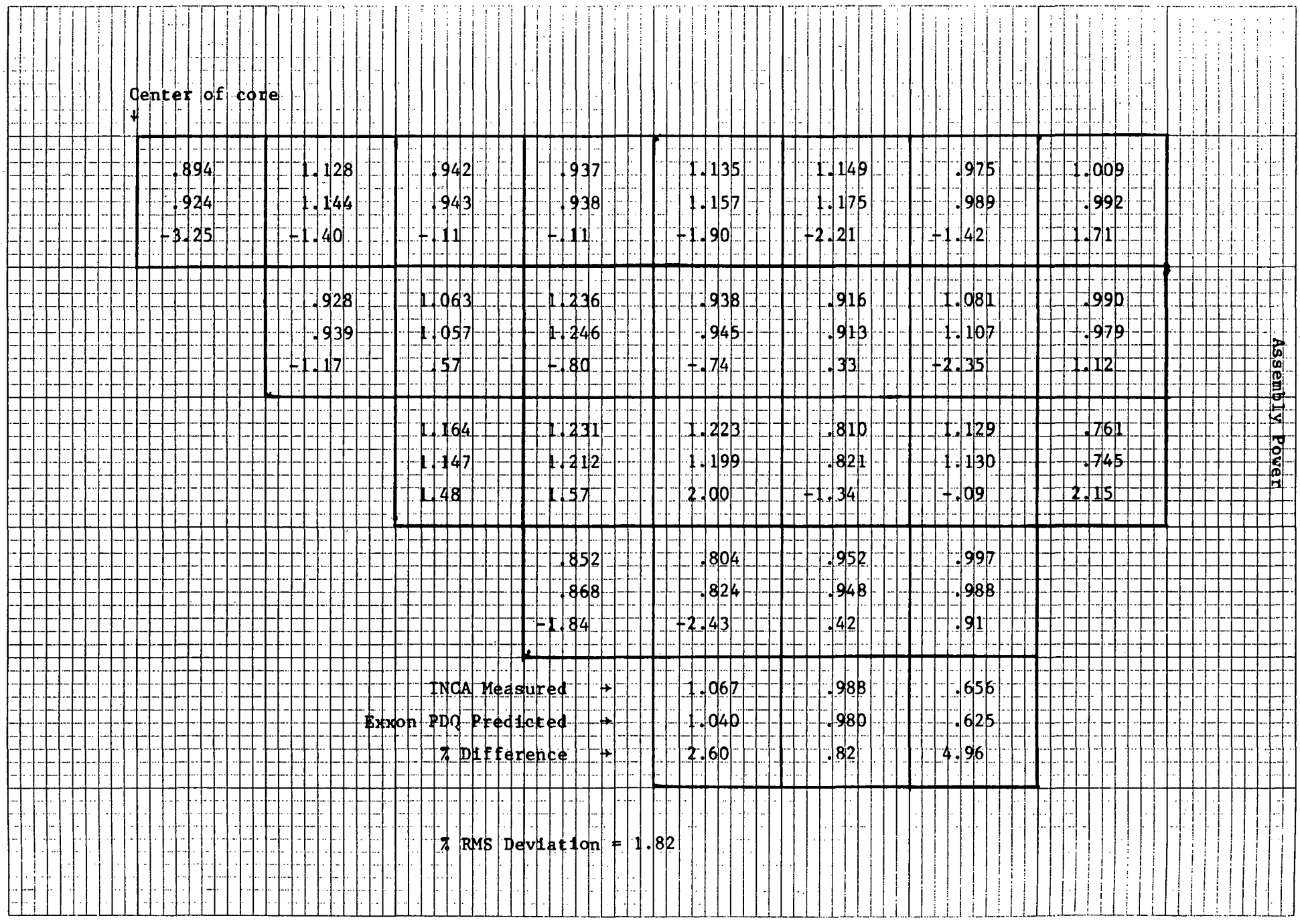


FIGURE 8

Assembly Power

SECTION 12 - CONCLUSION

Low power and power physics testing was conducted at the start of core 4 with the last test finished on June 4, 1980. The testing determined and compared to calculated results various core parameters such as:

1. Boron Concentration
2. Rod Worths
3. Reciprocal Boron Worth
4. Moderator Temperature Coefficient
5. Power Coefficient

In all cases, review and acceptance criterion were not exceeded.

REFERENCES

1. Palisades Cycle 4 Start-up Predictions and Nuclear Data for Operations, XN-NF-79-94, Exxon Nuclear Company, November 1979.

2. Palisades Cycle 4 Reload Fuel Licensing Data Submittal, XN-NF-79-48 Rev 1, Exxon Nuclear Company, September 1979.

3. Letter from Consumers Power, DPHoffman to Director Nuclear Reactor Regulation, Palisades Plant - Physics Test Program, October 31, 1979.

4. Letter from KGGrummer, Exxon Nuclear Company, to BDWebb, Consumers Power entitled Palisades Cycle 4 Start-up Data, Supplementary Information, November 30, 1979.

5. Palisades Plant Technical Specifications, Section 3.12.