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MH-IA CORE 4 PHYSICS REPORT

Steven A. Helms, et al

**Army Engineer Reactors Group
Fort Belvoir, Virginia**

16 May 1973

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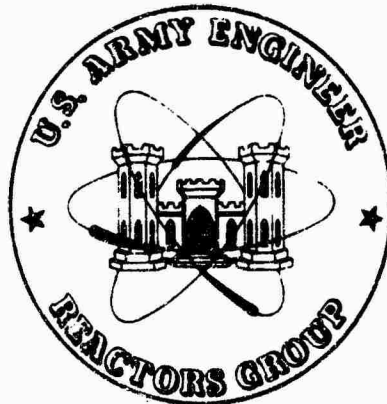
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MH-1A CORE 4 PHYSICS REPORT

STEVEN A. HELMS
HAROLD D. HOLLIS

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ABSTRACT

This report contains the results of core physics testing on MH-1A Core 4. These tests were conducted during Feb 1973, immediately prior to power operation.

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MH-1A CORE 4 PHYSICS REPORT

I. INTRODUCTION

Core physics measurements were performed on the refueled MH-1A core in February 1973. The results are analyzed herein. Those parameters which are important in understanding core behavior (such as the temperature and power coefficients of reactivity, rod worths, xenon build-up, and critical bank position) are derived from the data. Comparisons are made with expected values of these quantities.

A. Approach to Criticality

Initial approach to criticality after the third refueling of the MH-1A was conducted on 4 February 1973. Table I gives the data for the approach to criticality and Figure 1 gives the inverse multiplication curve. The measured critical bank was 10.45 inches at a temperature of 145°F and a pressure of 340 psig.

The measured critical bank position of 10.45 inches compares favorably with the predicted value of 9.6" at 100°F (Ref. # 1).

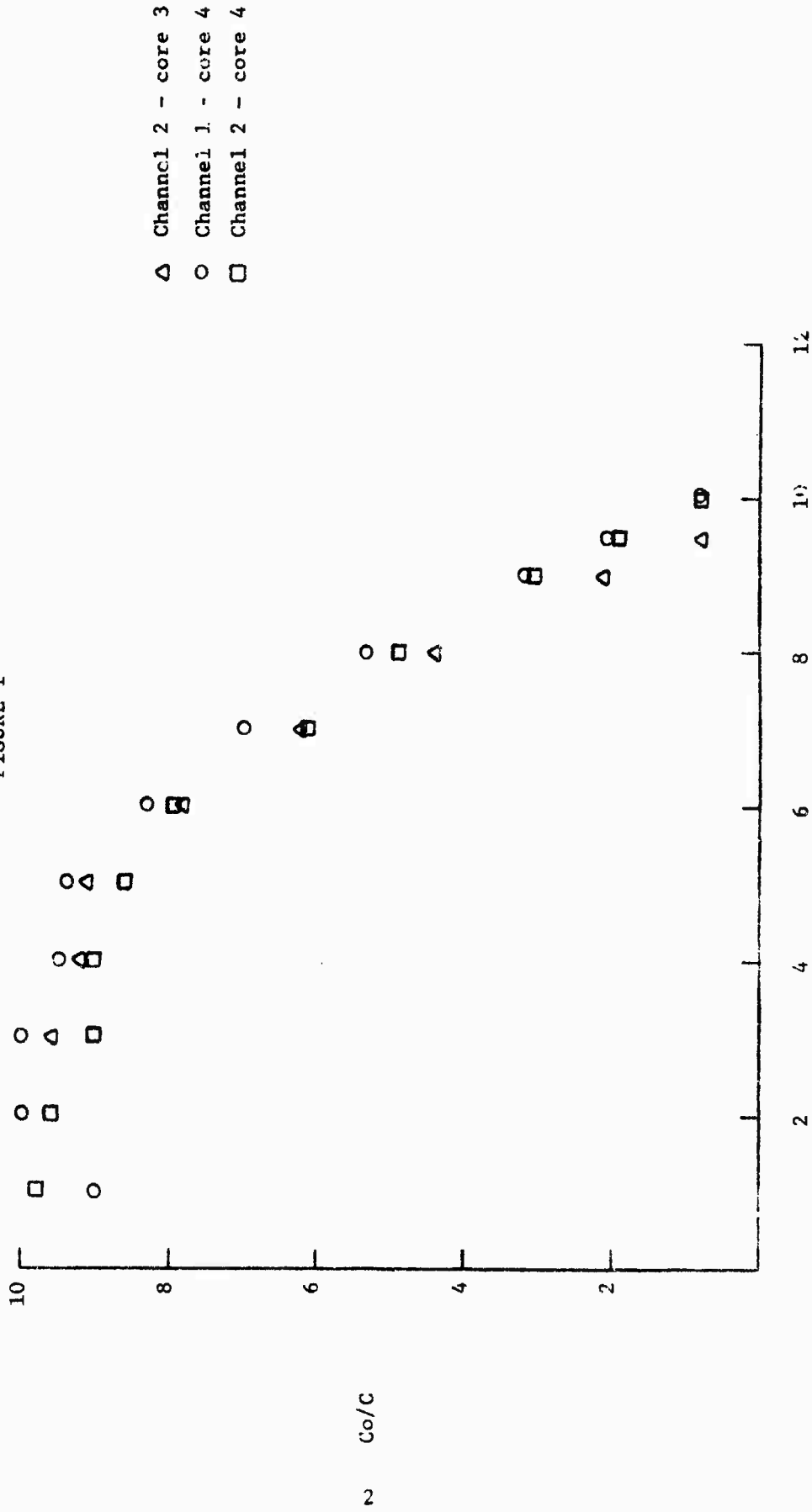
TABLE I
Initial Approach to Criticality

12-Rod Bank Position (Inches)	Source Range Channel 1 (cps)	Source Range Channel 2 (cps)
0.00	21.5	5.1
1.00	23.9	5.2
2.00	20.4	5.3
3.00	21.2	5.7
4.00	22.6	5.7
5.00	23.0	6.0
6.00	25.8	6.4
7.00	30.7	8.3
8.00	40.3	10.4
9.00	68.1	16.7
9.5	104.0	26.8
10.0	258.0	62.5

1/M STARTUP MH-1A Core 4

4 Feb 73

FIGURE 1



INCHES WITHDRAWN

B. Stuck Rod Shutdown Margin

Signal from the forward intermediate range detector (Figure 2) was fed to the reactivity computer for this test and the following tests. This is the same detector position used in Core 2 and 3 physics testing. The critical eleven rod bank for the outer rod stuck full out was higher than that for an inner rod. The shutdown margin measurements for a stuck inner rod (#1) and an outer rod (#5) indicate that an inner rod resulted in a greater margin than did the outer rod. This phenomenon is attributed to spatial effects and was observed in the previous core physics tests (Ref. #1, #2).

The results of the stuck rod shutdown measurement for Core 3 are listed in Table II. Similar data from Core 2 and 3 are shown in Table III and IV, respectively.

TABLE II

Stuck Rod Shutdown Margin Measurements - Core 4

Control Rod # 1	Position (inches)	11-Rod Bank (inches)	Shutdown Check (\$)	Prim Temp (°F)	Prim Pres (psig)
1	35.79	8.95	5.45	150	340
5	35.98	9.28	4.00	148	335
12	35.98	9.18	4.90	148	335

TABLE III

Stuck Rod Shutdown Margin Measurements - Core 3

Control Rod #1	Position (inches)	11-Rod Bank (inches)	Shutdown Check (\$)	Prim Temp (°F)	Prim Pres (psig)
1	35.78	7.88	-4.10	147	345
4	36.00	7.65	-3.50	149	340
5	36.00	8.38	-3.00	145	340
12	36.00	6.26	-3.60	147	350

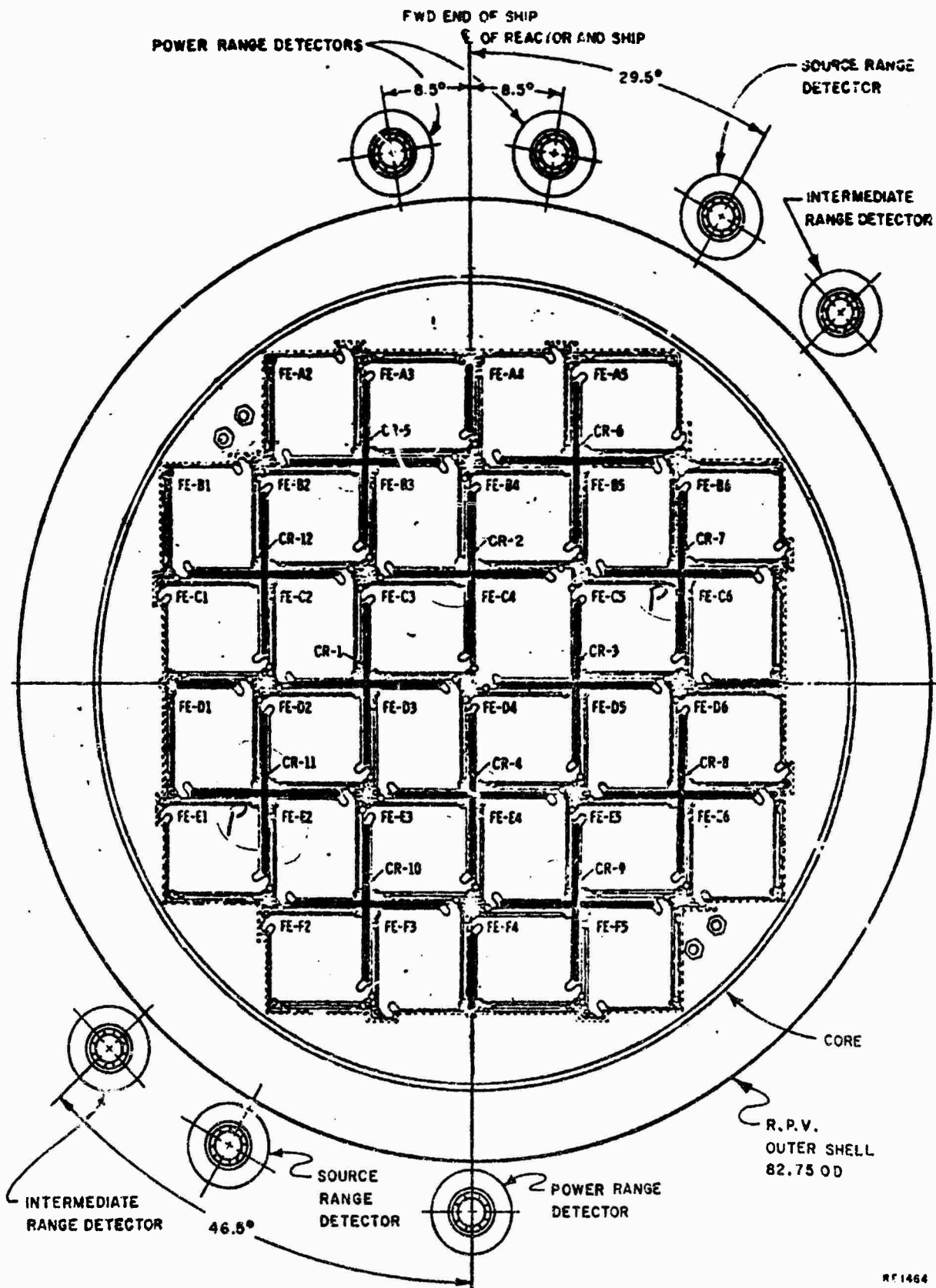


FIGURE 2. CORE - DETECTOR ORIENTATION

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TABLE IV

Stuck Rod Shutdown Margin Measurements - Core 2
(from Reference #2)

Control Rod #1	Position (inches)	11-Rod Bank (inches)	Shutdown Check \$	Prim Temp (°F)	Prim Pres (psig)
2	35.84	9.89	- - -	152	319
1	35.73	9.89	-4.00	150	330
8	35.89	10.18	- - -	145	345
5	36.10	10.10	-2.60	147	340
12	35.96	10.00	-3.60	147	320

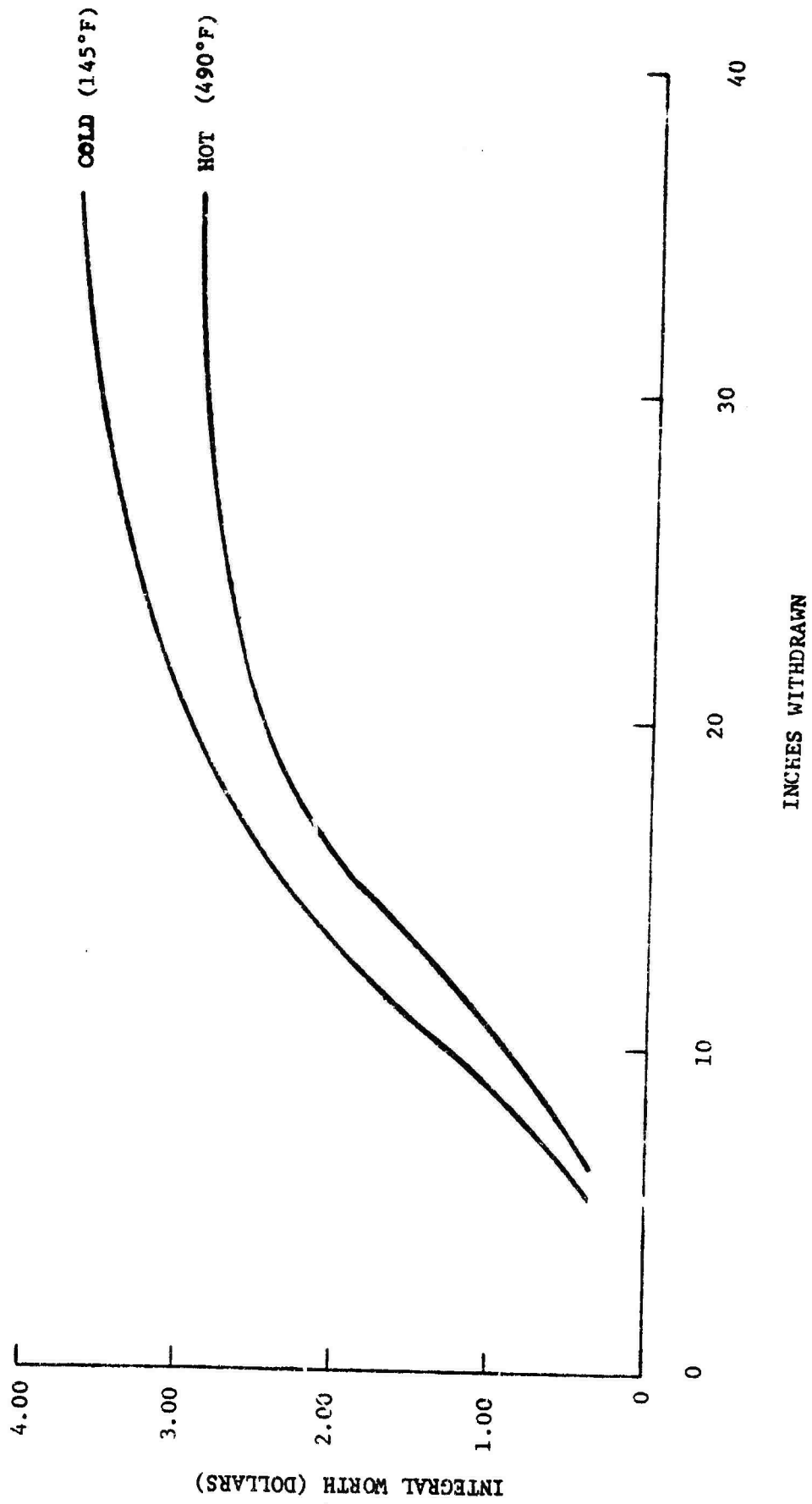
C. Control Rod Calibrations

The calibrations of control rods #1, #5, and #12 were performed on 5 February 1973. Each rod was calibrated singly against the 11-rod bank of the remaining rods. The rod being calibrated was withdrawn an amount sufficient to produce a desired positive reactivity insertion. The magnitude of the insertion was then read from the reactivity computer. After the reading was completed, the 11-rod bank was moved so as to make the reactor slightly subcritical, and the negative reactivity inserted was determined by the computer. This process was repeated until the rod being calibrated was fully withdrawn.

The integral worth curves are shown in Figures 3, 4, and 5. Table V compares the fully withdrawn integral worths for rods #1, #4, #5, and #12 for this core and its predecessors. Since the cores investigated for each of the tests are different, it is difficult to draw any conclusions or comparisons between actual numerical values.

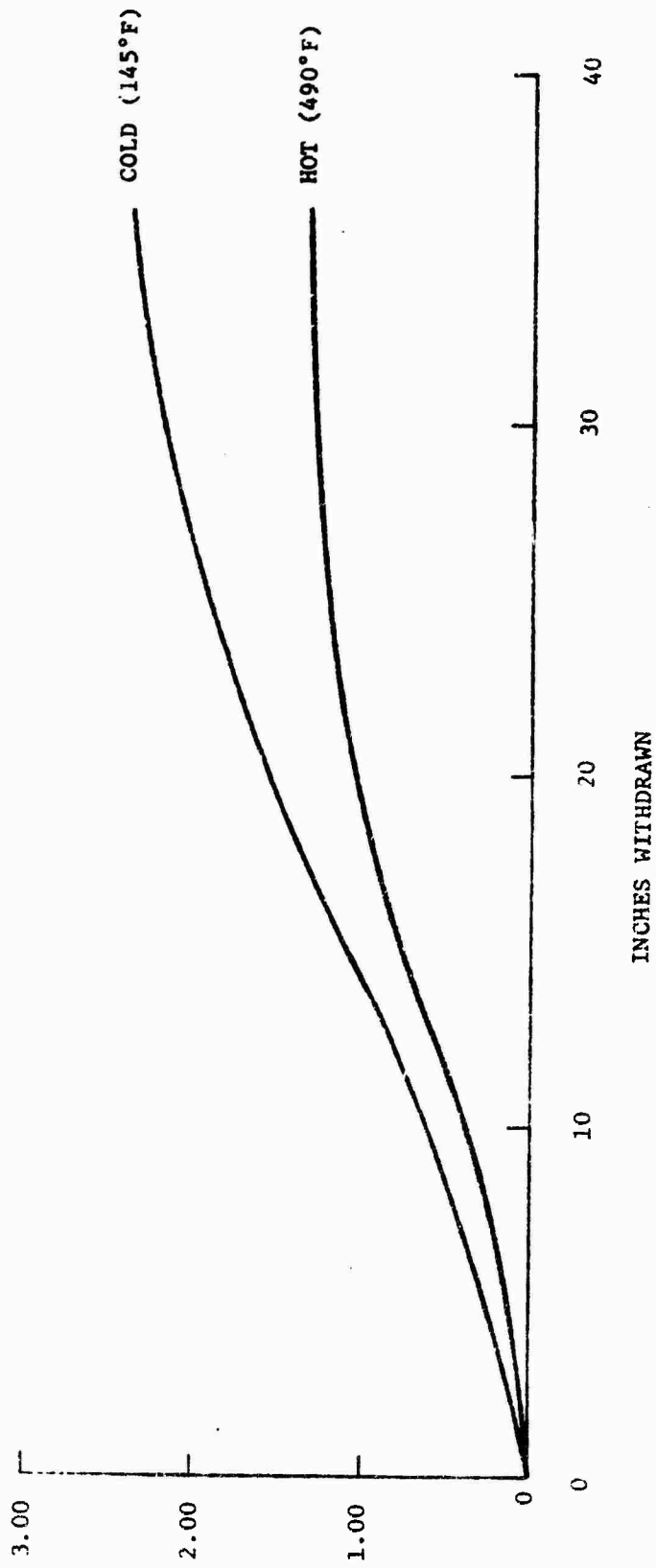
INTEGRAL ROD WORTH CURVES - ROD #1

FIGURE 3



INTEGRAL ROD WORTH CURVES - ROD #5

FIGURE 4



INTEGRAL ROD WORTH CURVES -- ROD #12

FIGURE 5

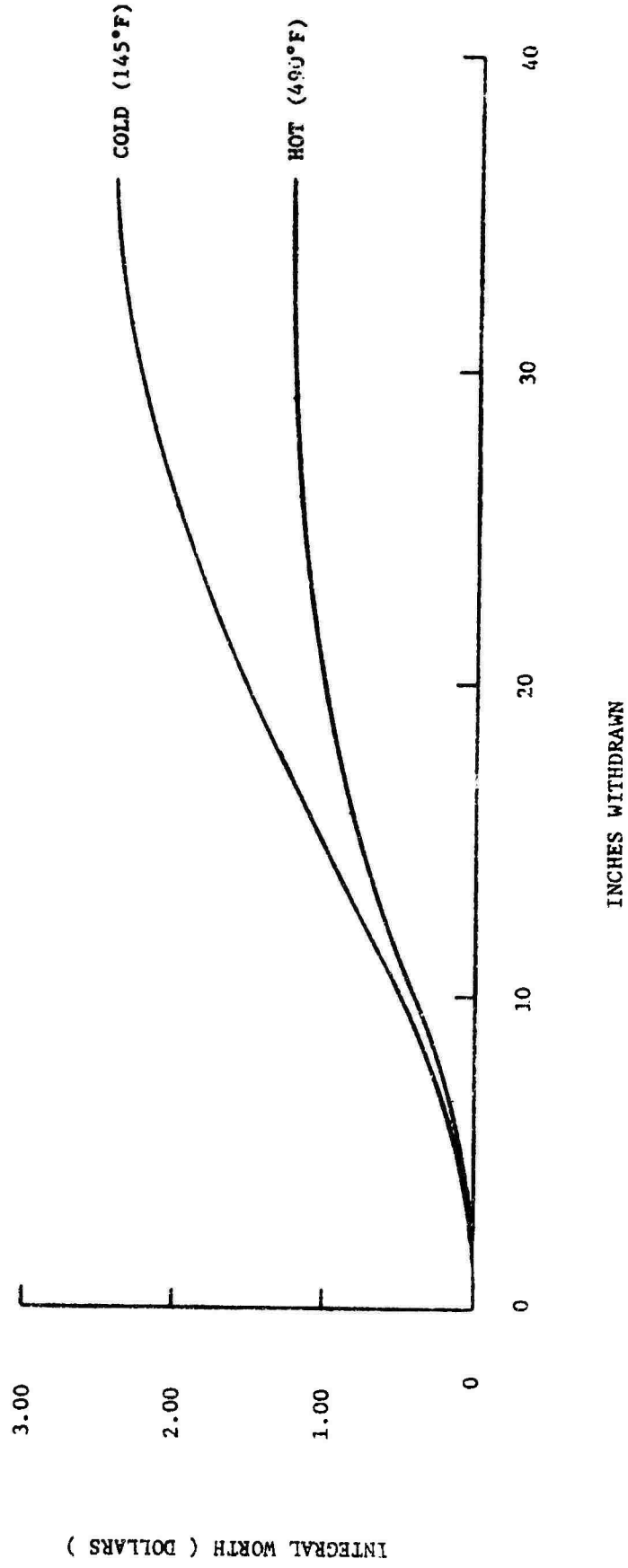


TABLE V

Fully Withdrawn Integral Rod Worths

	Rod # 1	Rod # 4	Rod # 5	Rod # 12
Feb 1973****	\$2.92 (490°F)		\$1.32 (490°F)	\$1.19 (490°F)
June 1971***	3.21 (493°F)	3.25 (492°F)		1.38 (491°F)
Nov 1969 **	2.84 (484°F)			1.53 (489°F)
Oct 1968 *	1.92 (479°F)		1.15 (470°F)	2.42 (148°F)
Feb 1973 ****	3.72 (147°F)			
June 1971 ***	4.23 (145°F)	4.44 (145°F)	2.36 (147°F)	2.91 (146°F)
Nov 1969 **	3.18 (147°F)			2.33 (147°F)
Oct 1968 *	3.70 (101°F)		2.78 (101°F)	

* Core 1 ** Core 2 *** Core 3 **** Core 4

D. Temperature Coefficient of Reactivity

The temperature coefficient measurement was performed on 5 February 1973. The data are plotted in Figures 6 and 7. Tables VI and VII summarize data from this and previous cores.

TABLE VI

Temperature Coefficients - % $\Delta k/k^\circ F$

Experimental/Calculated

Temperature	Core 1	Core 2	Core 3	Core 4
68°F	.003/	.0081/.0033		
200°F			.0126/.0091	.0118/.0112
490°F	.0295	.0245/.027	.0225/.0205	.0250/.0325

TABLE VII

Temperature Defect - % $\Delta k/k$

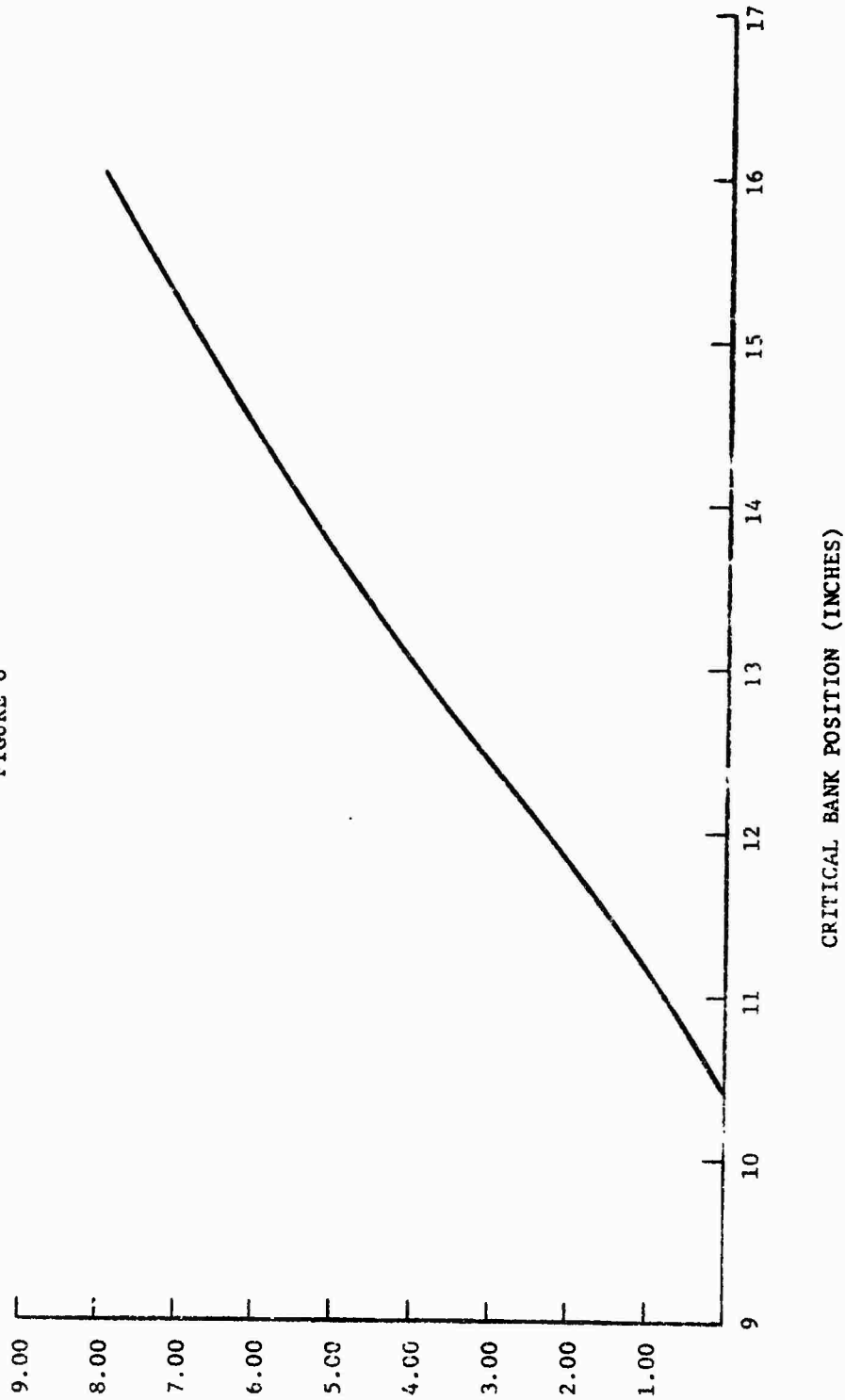
Experimental/Calculated

Core 1	Core 2	Core 3	Core 4
6.4 ¹ /	6.47 ¹ /4.8 ¹	5.84 ³ /5.3 ² (rods in)	5.69 ⁴ /6.30 ²
		5.84 ³ /11.5 ² (rods out)	

(1) 68 - 490°F (2) 100-490°F (3) 147 - 490°F (4) 165 - 490 °F

TEMPERATURE DEFECT VS. BANK POSITION

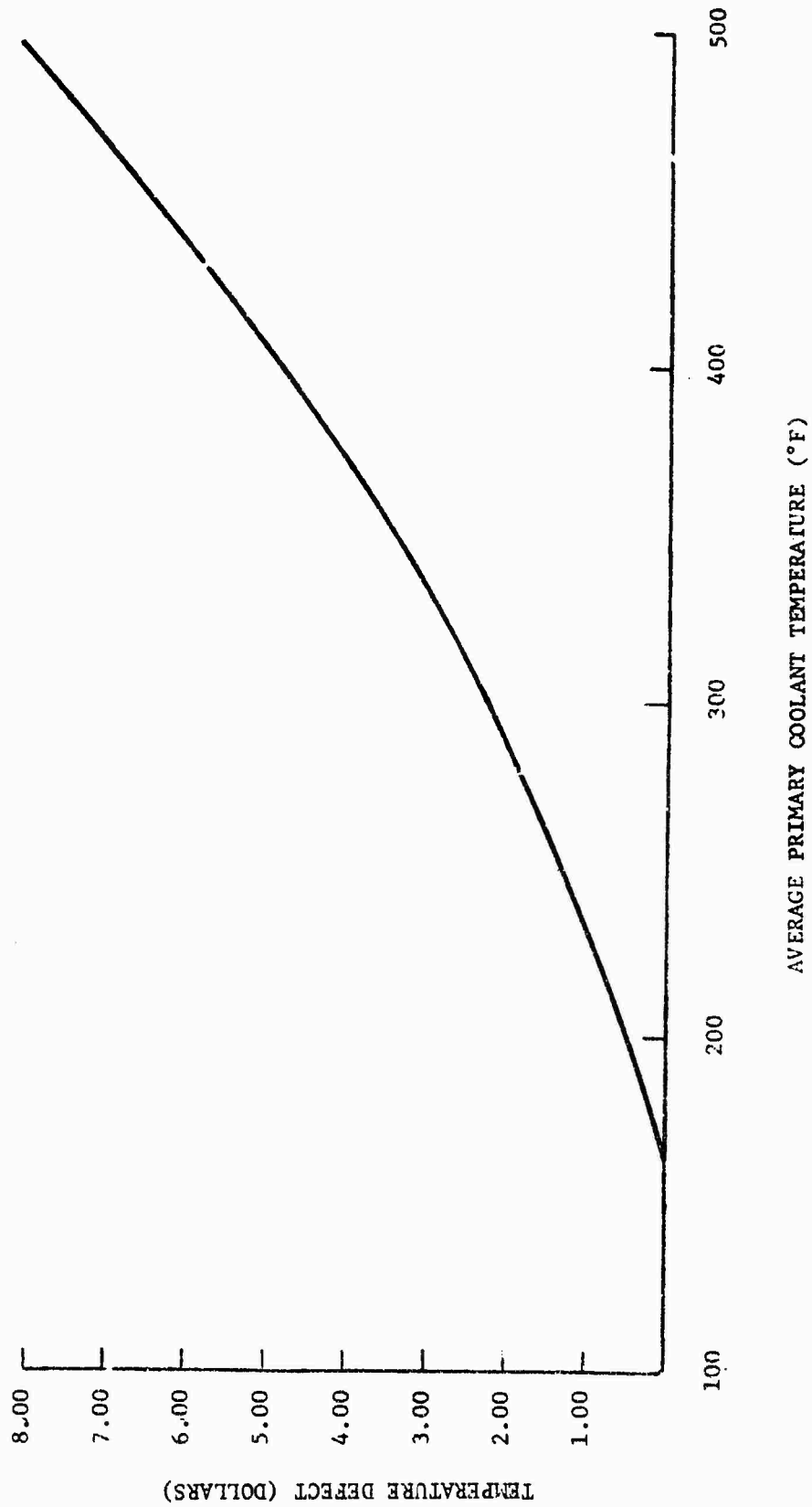
FIGURE 6



TEMPERATURE DEFECT (DOLLARS)

TEMPERATURE DEFECT VS. AVERAGE PRIMARY COOLANT TEMPERATURE

FIGURE 7



E. Power Coefficient Test

The purpose of this test is to determine the reactivity per megawatt that is lost due to doppler. This determination is made by increasing reactor power from low power to as close to full power as possible, in as little time as possible. During the increase in power, no adjustments are made in the control rod bank; thus, the positive reactivity inserted by the reduction in average primary coolant temperature offsets the negative reactivity due to doppler.

The test must be completed as rapidly as possible in order to minimize Xenon effects and is terminated when the turbine throttle pressure becomes so low that turbine damage (due to low quality) becomes a concern.

The test data are recorded in Table VIII and plotted, along with the core 3 data, in Figure 8.

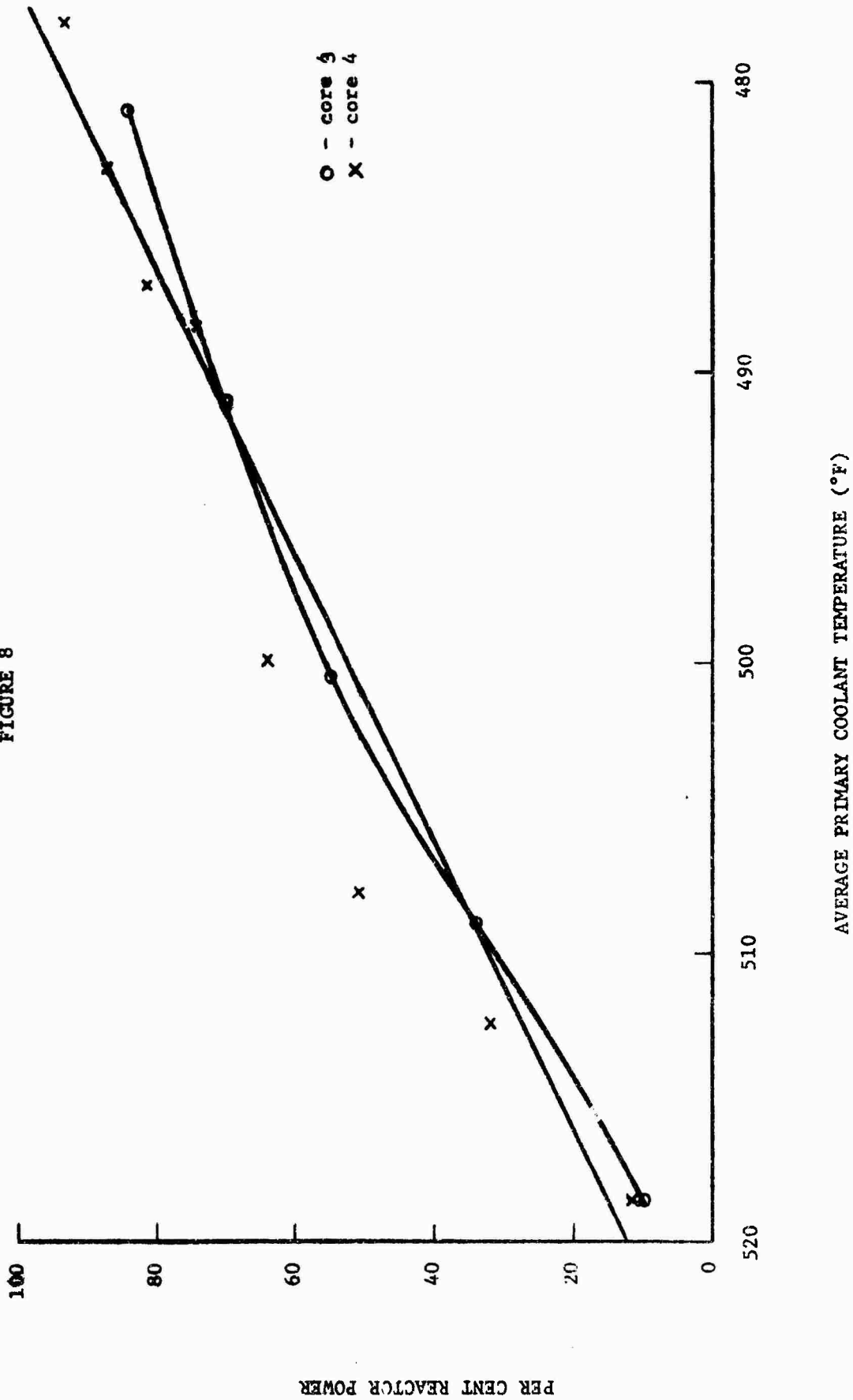
The average primary coolant temperature drops 40.5°F as load is increased from 0% to 84% power. From Figure 7, the temperature defect over the interval is approximately \$1.35; therefore, the power coefficient is calculated to be

$$\frac{\$1.35}{.84 \times 45 \text{ MWT}} = 3.62\text{¢/MWT}$$

It is worthwhile to note that core 3 data represents a smooth curve whereas there is considerable scatter in the core 4 data. For core 3, six data points were taken in 70 minutes compared to eight data points taken in 25 minutes for core 4. The scatter appears to result from failure to let the system stabilize between adjustments in the power level. On the other hand, the inflection in the core 3 data leads one to believe that Xenon influenced the results.

POWER COEFFICIENT DATA

FIGURE 8



PER CENT REACTOR POWER

AVERAGE PRIMARY COOLANT TEMPERATURE (°F)

TABLE VIII
Power Coefficient Data
Core 4

Time (hrs)	Primary Pressure (psig)	Rod Bank Position (inches)	Average Primary Coolant Temp (°F)	Generator Load (MW)	Average Reactor Power (%)
0049	1368	17.27	518.5	0	10
0052	13600	17.27	512.5	1.8	32
0055	1357	17.27	508	3.6	51
0059	1360	17.27	499.5	5.0	63
0104	1360	17.27	488.5	6.4	74
0109	1380	17.27	487	7.4	81
0111	1370	17.27	483.5	8.6	87
0114	1370	17.27	478	9.8	93

F. Equilibrium Xenon

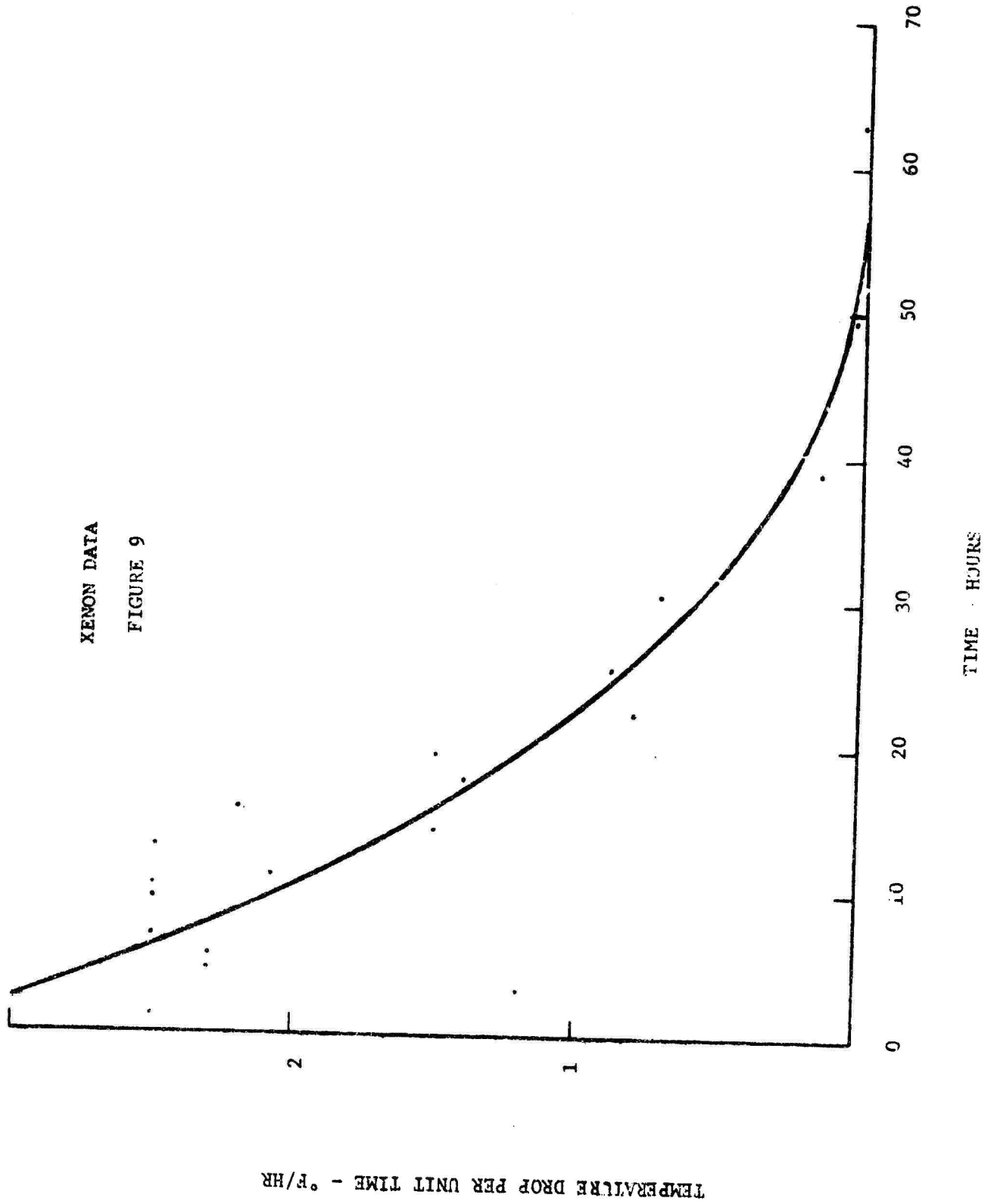
The equilibrium test started at 0215 hours, 7 February and was terminated at 0215 hours on 10 February. The reactor power level was $97 \pm 3\%$.

A summation of the temperature drops during this test results in a total temperature drop of 43.5°F . Using the experimental negative temperature coefficient from Table VI, the Xenon defect would be 1.09%. It is obvious that this value is far below what one would expect (see Table IX). After a closer examination of the raw data it was noted that the time required to increase the average primary coolant temperature, via control rod adjustments, was excessive. In fact the time required to make these adjustments varied between 8 and 110 minutes. Xenon build-up during these adjustments was not observable.

Figure 9 represents an attempt to determine the Xenon defect indirectly. Temperature drop per unit time is plotted against time. Each point on the curve was calculated from the raw data, during the time between control rod

XENON DATA

FIGURE 9



adjustments. The curve is an approximate fit of the data. Numerical integration of this curve yields a total temperature drop of 62.2°F and a Xenon defect of 1.6% $\Delta k/k$.

The calculated and experimental Xenon defect for this and previous cores is recorded in Table IX.

	Core 2	Core 3	Core 4
Calculated	2.1	2.5	1.9
Measured	1.4	2.3	1.6

II . REVIEW OF THE DATA

A. Critical Bank Positions

The critical bank position of 10.45" at 145°F is in good agreement with the 9.6" predicted at 100°F. The hot critical position of 16.02" does not compare favorably with the prediction of 18.2"

B. Stuck Rod Margins

The critical 11-rod bank positions and measured shutdown margins are shown in Table II. Since all shutdown margins are greater than those obtained for core 3 (Table III), the shutdown margin is in excess of the 1% required by the technical specifications.

The calculated minimum shutdown margin for core 4 is \$2.18. This is conservative compared to the measured values.

C. Differential Bank Worths

The power range rod withdrawal transient is initiated by an uncontrolled withdrawal of the 12-rod bank at the maximum rate of 2 inches per minute. Reference 3 assumed a maximum insertion rate of 5.9×10^{-4} $\Delta k/\text{sec}$ which corresponds to \$2.52 per inch. This value is conservative when compared to \$1.55 per inch one would calculate from Figure 6.

D. Ejected Rod Worth

The integral worth curve for control rod #1 is shown in Figure 3. Graphs of temperature defect and twelve rod bank position vs Tave are shown in Figures 6 and 10, respectively.

The cold peaking factor for core 4 is 5.2 (Ref. 1 & 4). From Figure 7, Ref. 5, it can be shown that the maximum ejected rod worth cannot exceed \$2.35 at 400°F or \$2.47 at 70°F. The ejected worth of control rod # 1 at a critical bank position of 10.5" (150°F) is approximately \$2.30. Thus, no fuel melting will occur during a rod ejection accident if Tave is $\geq 150^\circ\text{F}$ before withdrawing control rods.

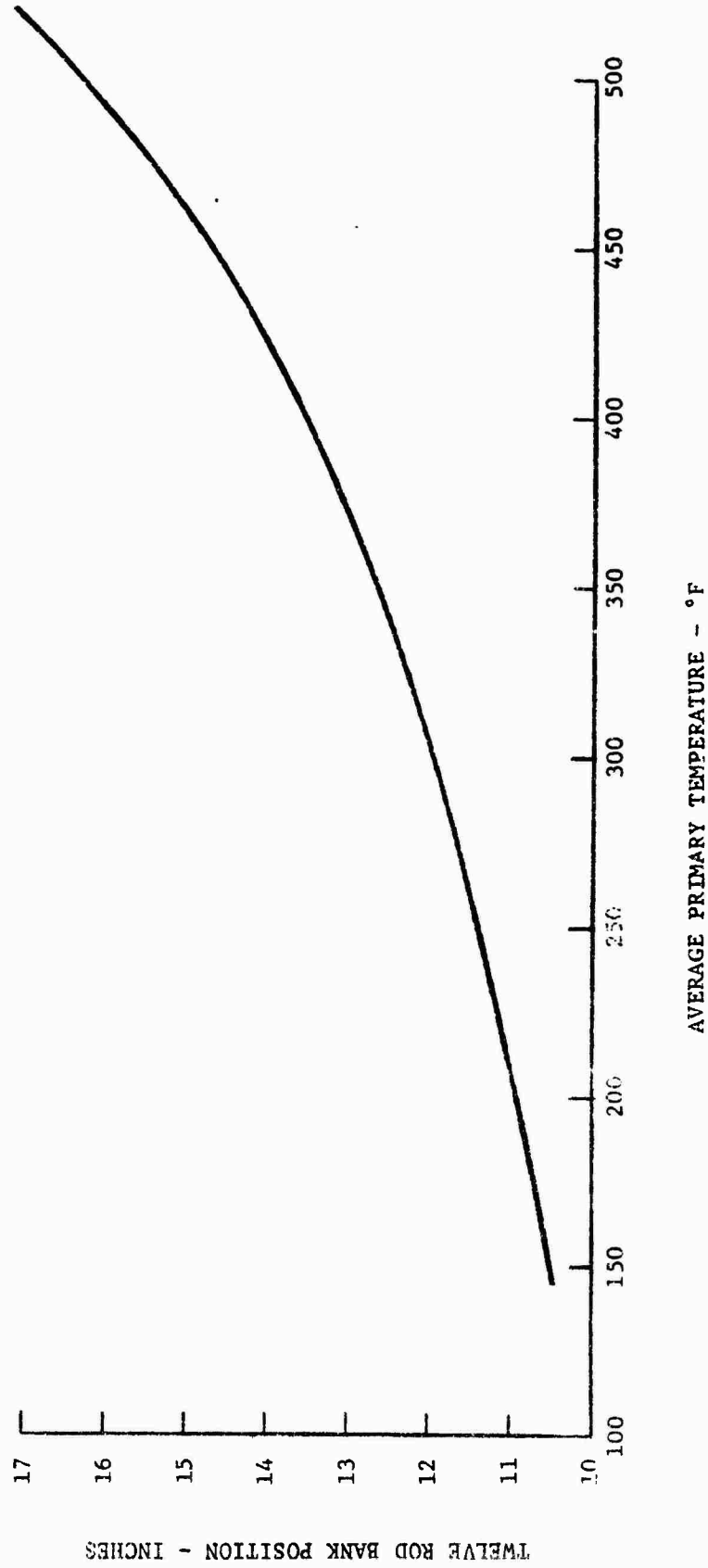
E. Temperature Coefficient

The measured temperature coefficient of $3.56\text{¢}/^\circ\text{F}$ compares with $2.7\text{¢}/^\circ\text{F}$ used in the power range rod withdrawal transient and $3.71\text{¢}/^\circ\text{F}$ used in the main steam line rupture. The measured value is conservative in both cases.

The predicted value of $4.62\text{¢}/^\circ\text{F}$ does not compare favorably with the measured value.

TWELVE ROD BANK POSITION VS. AVERAGE TEMPERATURE

FIGURE 10



F. Power Coefficient

The 3.62¢/MWT compares favorably with the 3.84¢/MWT measured for core 3 (Reference # 2). A power coefficient of 2.91¢/MWT was calculated implicitly in Reference 1 and a conservative 2.14¢/MWT was used in the accident analysis.

IV. CONCLUSIONS AND RECOMMENDATIONS

The core can be operated within the restrictions of the technical specifications.

The discrepancy in the hot critical bank and temperature coefficient calculations is embedded in the TURBO* depletion calculations of three previous shuffle cores. TURBO* has since been replaced by the PDQ-7 core. Any attempt to locate errors in TURBO* would be costly and of little value in the future.

The power coefficient and equilibrium Xenon tests were conducted by the crew after the test engineers had departed. In the future, it is recommended that the test engineers remain in the plant through the first 24 hours of the equilibrium Xenon test.

The reactivity computer output was recorded on a strip chart recorder. This greatly facilitated the interpretation of the data taken during the control rod calibrations, stuck rod margins and temperature coefficient tests. The recorder should be used in future tests.

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