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APAE-8

REACTORS—POWER

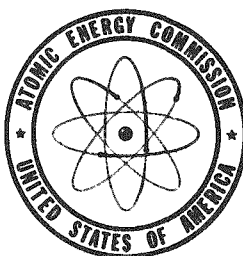
UNITED STATES ATOMIC ENERGY COMMISSION

ARMY PACKAGE POWER REACTOR ZERO
POWER EXPERIMENTS (ZPE-1)

By
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February 8, 1957

Alco Products, Inc.
Schenectady, New York



Technical Information Service Extension, Oak Ridge, Tenn.

Date Declassified: August 14, 1957.

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Since nontechnical and nonessential prefatory material has been deleted, the first page of the report is page 7.

APAE 8

ARMY PACKAGE POWER REACTOR

ZERO POWER EXPERIMENTS

ZPE-1

Contract No. AT(11-1)-318

Issued February 8 , 1957

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ABSTRACT

This report contains the complete results of the Army Package Power Reactor Zero Power Experiments performed on the APPR-1 core at the Alco Criticality Facility.

The fully loaded cold clean core, containing 22,480.1 grams of U^{235} , has an excess K of approximately 16%. The temperature coefficient at 170°F is approximately $-0.67 \times 10^{-4} \Delta K/^{\circ}\text{F}$.

The presence of fine structure in neutron flux measurements and control rod calibrations is evident and further study of these effects from an academic point of view seems justified.

Peak to average flux in the core is as much as 4 to 1 in the tip of the center control rod fuel element. However, flux suppressors placed in the water hole in this region are effective in reducing this value to approximately 3 to 1.

ACKNOWLEDGMENT

We note with appreciation the assistance of Capt. Earl E. Daly, SFC Wm. B. Clark, SFC Ronald S. Poplar, SP2 Robert T. Shakour, M/Sgt Lyndal E. Lasater, of the U.S. Army Reactors Branch in setting up a large part of the circuitry for control and nuclear instrumentation at Alco's Criticality Facility.

We also wish to thank Mr. Dunlap Scott of Oak Ridge National Laboratory for his suggestions and recommendations of foil counting procedures that enabled us to process the large number of activations reported here.

The cooperation of Capt. James Smith of the Schenectady Operations Office has been essential to our operation on a rather tight schedule.

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INTRODUCTION

Alco Products Criticality Facility located in Schenectady, N. Y. initiated operations on the Army Package Power Reactor Zero Power Experiments during the fourth week of August, 1956.

The initial results of these experiments were published in AP Memo No. 61, "Results and Analysis of the APPR-1 Zero Power Experiments, Part I". However, due to the presence of some technical difficulties (See Chapter 5 below) during the initial phases of the experiment, it seemed desirable to repeat some runs. The data herein presented are considered precise, within the errors indicated, and are a complete representation of those experiments undertaken.

The primary purpose of this report is the presentation of data in a form suitable for analytical studies and does not purport to render any detailed analysis.

CHAPTER I SYSTEM DESCRIPTION

1.1 Alco Criticality Facility

The facility, designed originally to expedite the test program for the APPR-1, is described in detail in APAE No. 5⁽¹⁾, and facility operating procedures are described in APAE No. 5 Supplement I⁽²⁾.

Figure 1 shows a plan view of the facility consisting of a reactor room 40 feet long, 30 feet wide, and 30 feet high provided with walls of reinforced concrete. The Control Room, Fig. 2, The Counter Room, Fig. 3, and offices are contained in a concrete block extension on one side of the reactor room.

Approximately in the center of the reactor room is an opening 14-1/2 feet by 19-1/2 feet of which a section 9 feet by 14-1/2 feet is covered with a removable slab. The reactor tank was supported at floor level by columns extending upward from the basement floor. A 3500 gallon water storage tank was installed in the basement under the removable slab.

1.2 APPR-1 Assembly.

The reactor tank, Fig. 4 had a volume of 2500 gallons and was equipped with a source drive, 5 curie Po-Be source, two 15 KVA immersion heaters, an agitator to provide uniform temperature distribution and instrument tubes to contain the ionization chambers. A cut-away view of the reactor tank, Fig. 5, shows the correspondence of the core support and control rod drives to one another and the reactor tank.

A six inch dump line was provided for rapid moderator removal.

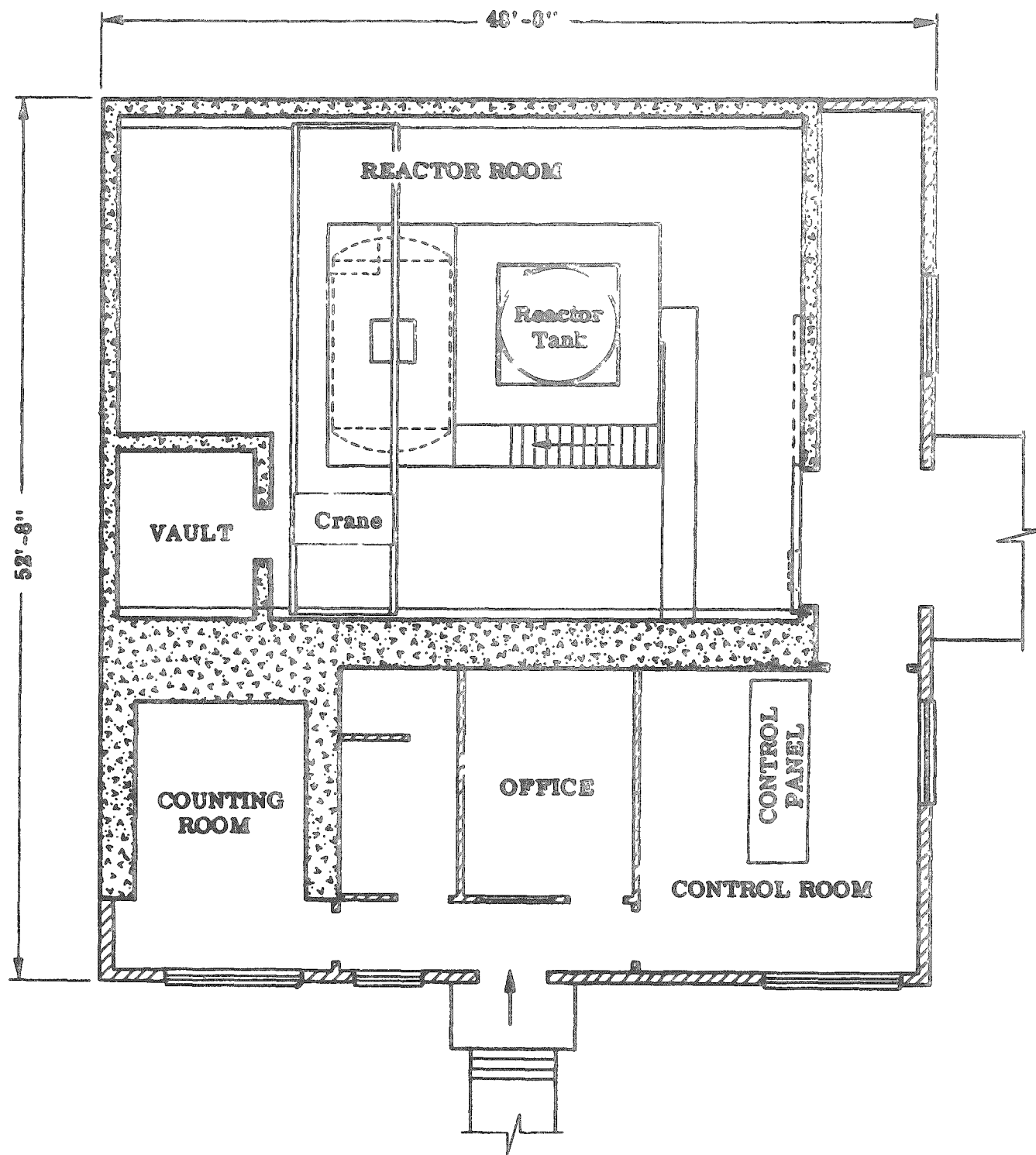


Figure 1
PLAN VIEW OF BUILDING

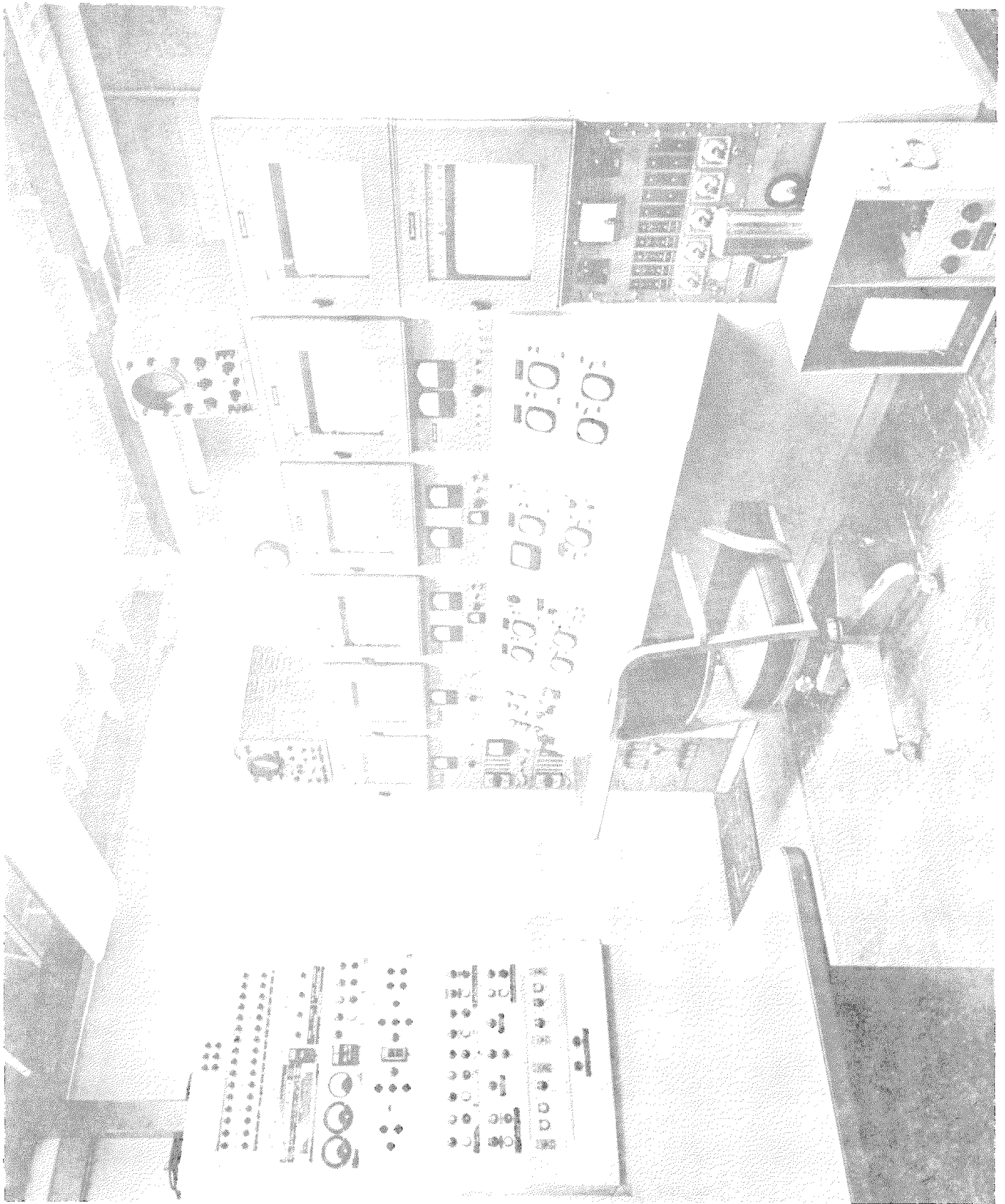


Figure 2
CONTROL ROOM

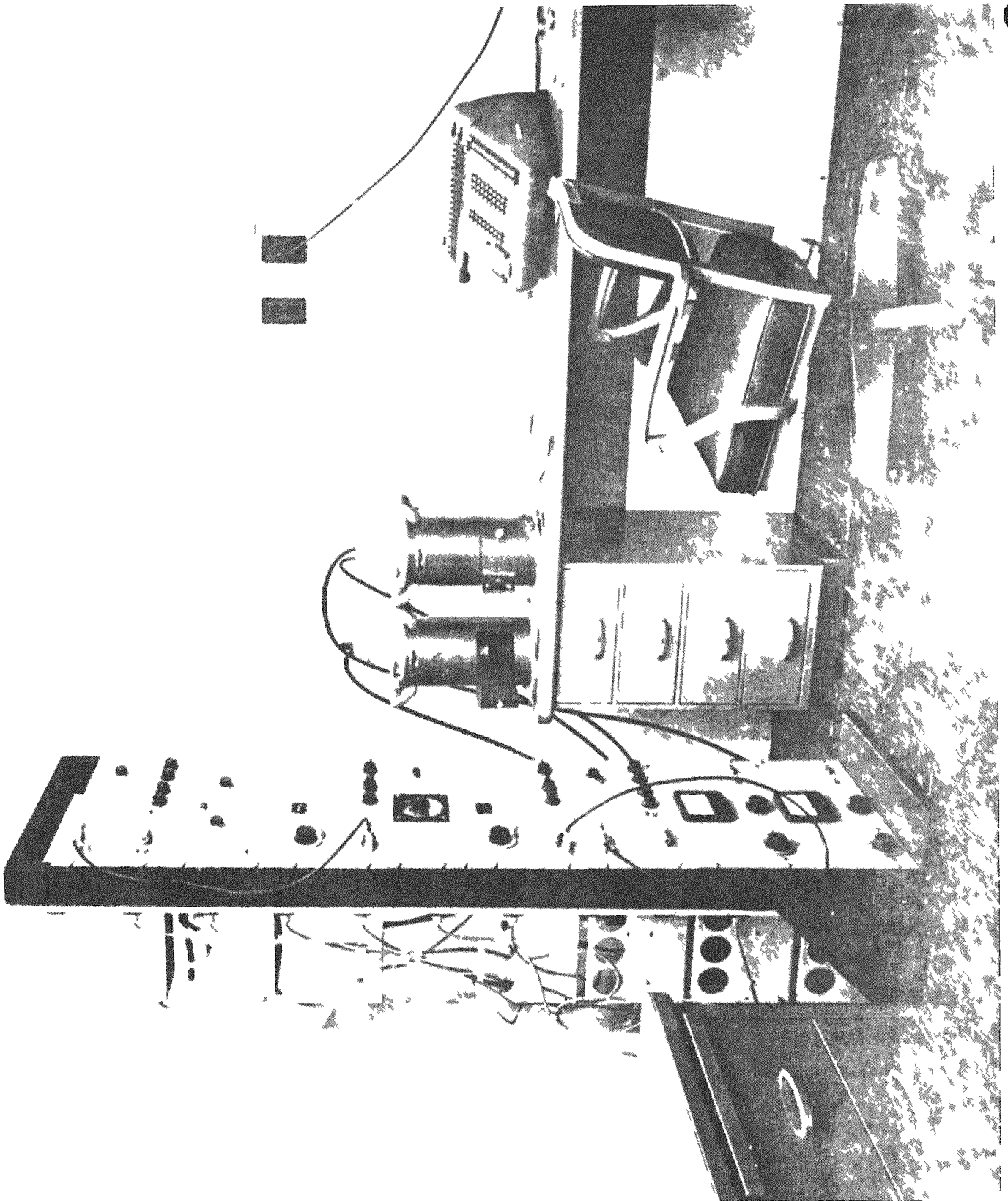


Figure 3
COUNTER ROOM

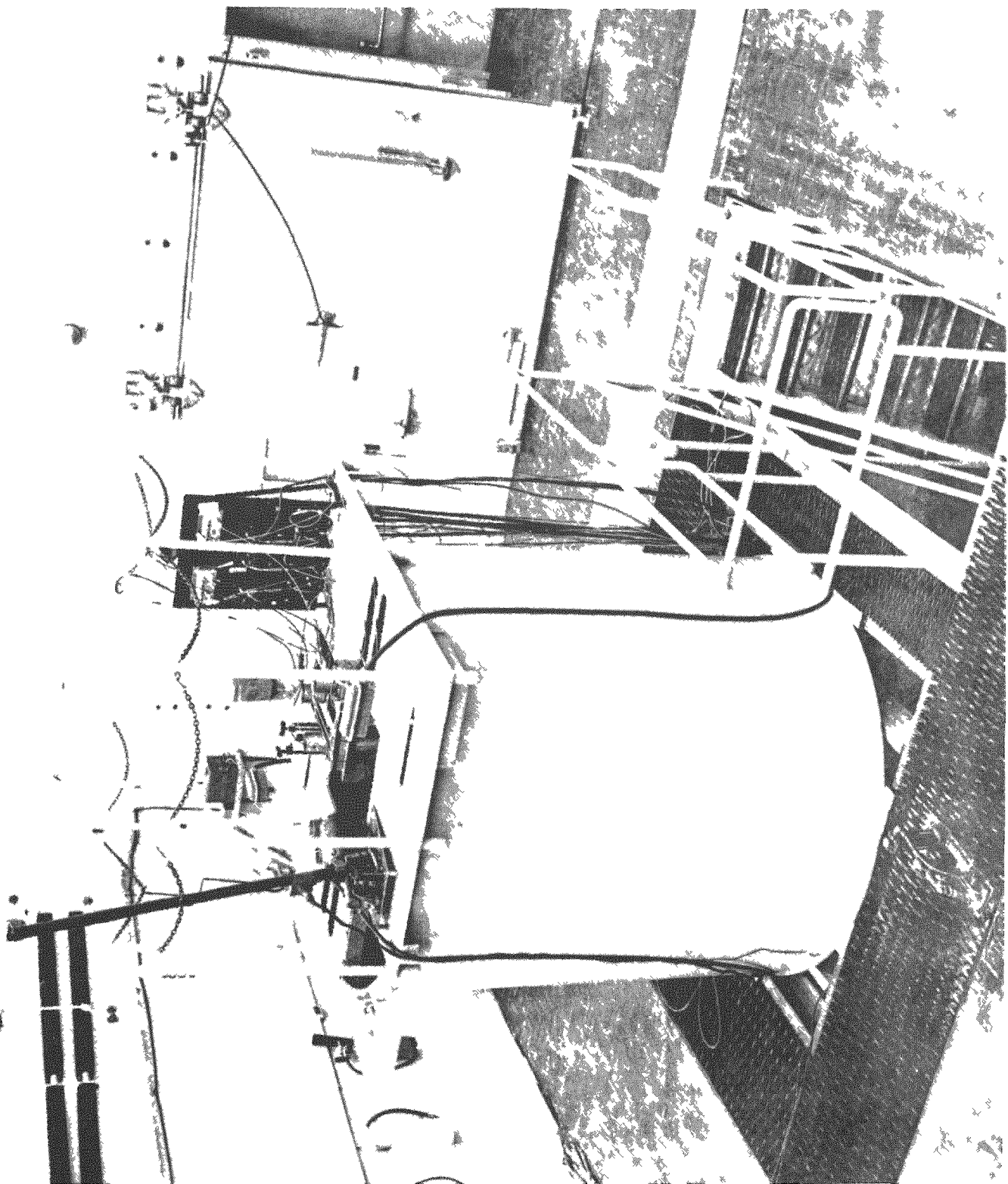


Figure 4
REACTOR TANK ASSEMBLY



Figure 5
REACTOR AND REACTOR TANK

1.2.1 APPR-1 Core

The actual APPR-1 core support was used for these experiments. Figure 6 is a photograph of the core support installed in the reactor tank and flanked by instrument tubes. Two of the hinged doors are in a raised position to allow for access to the fuel elements. It can be seen that one stationary element and one control rod have been removed. Figure 7 shows the reactor core cross section including dimensions.

1.2.2 APPR-1 Control Rods

Figure 8 is a photograph of the APPR-1 control rod basket, fuel element, boron absorber section and cap. There are a total of seven such control rod assemblies, however, during these experiments only five of those rods were motor driven. As a consequence the eccentric rods, designated A and B, were positioned manually prior to each experiment.

The design of the control rod cap prohibits the accidental inversion of fuel element and absorber sections.

Figure 5 shows clearly the engagement of the control rod rack with the drive shaft.

Figure 9 is a photograph showing the magnetic clutches, synchro motors, and limit switches associated with the rod drives. The drive motors are not shown. Initial experimental results indicated the necessity for rewiring the synchro motors from a four wire to five wire system. Since this was a field change, a rather untidy bundle of wires resulted as seen in Fig. 9.

1.2.3 APPR-1 Fuel Elements

The APPR-1 stationary fuel elements are pictured in Fig. 10 and 11 and consist of 18 parallel plates each 0.030 inches thick. Each element contains

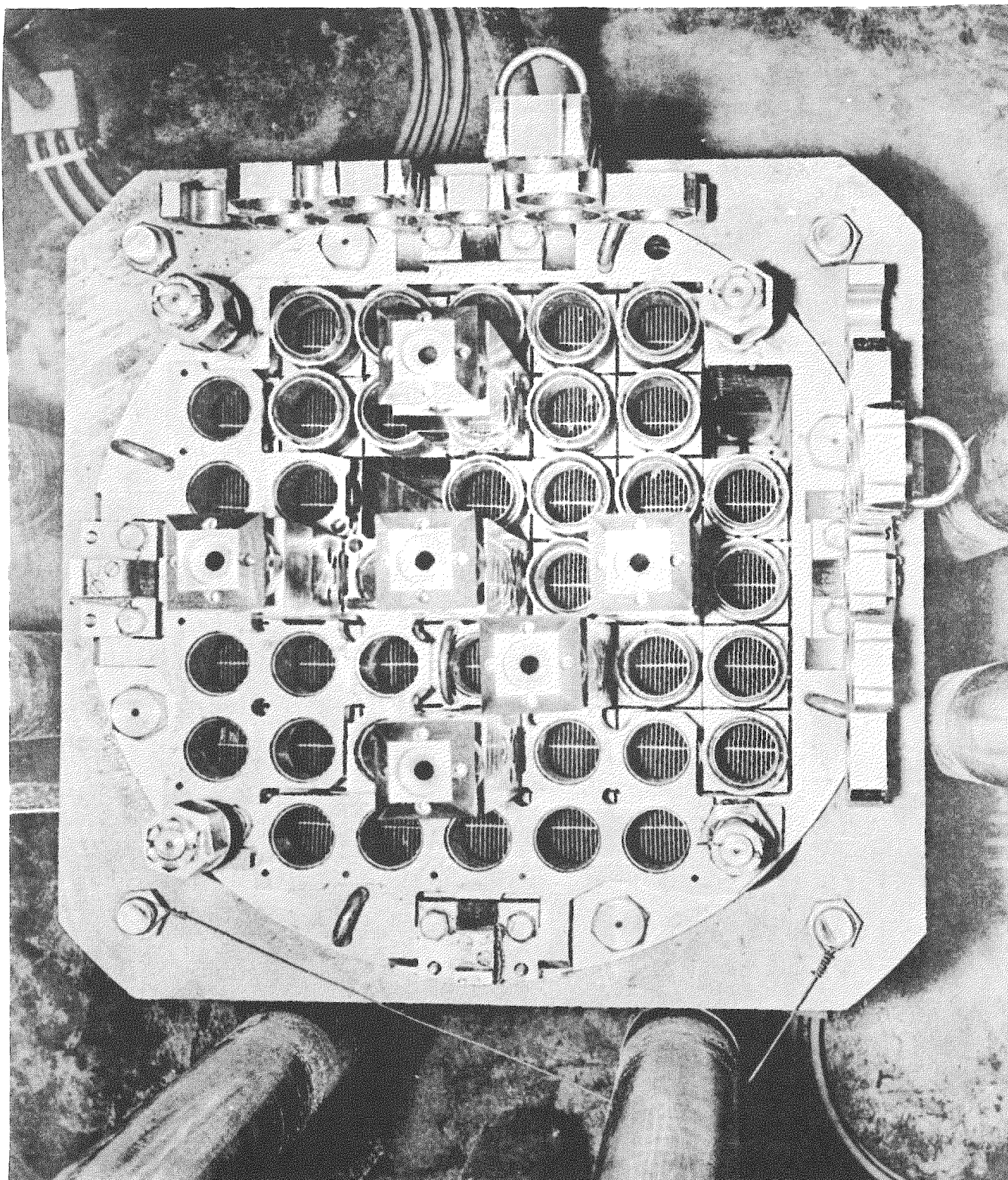


Figure 6
APPR-1 CORE

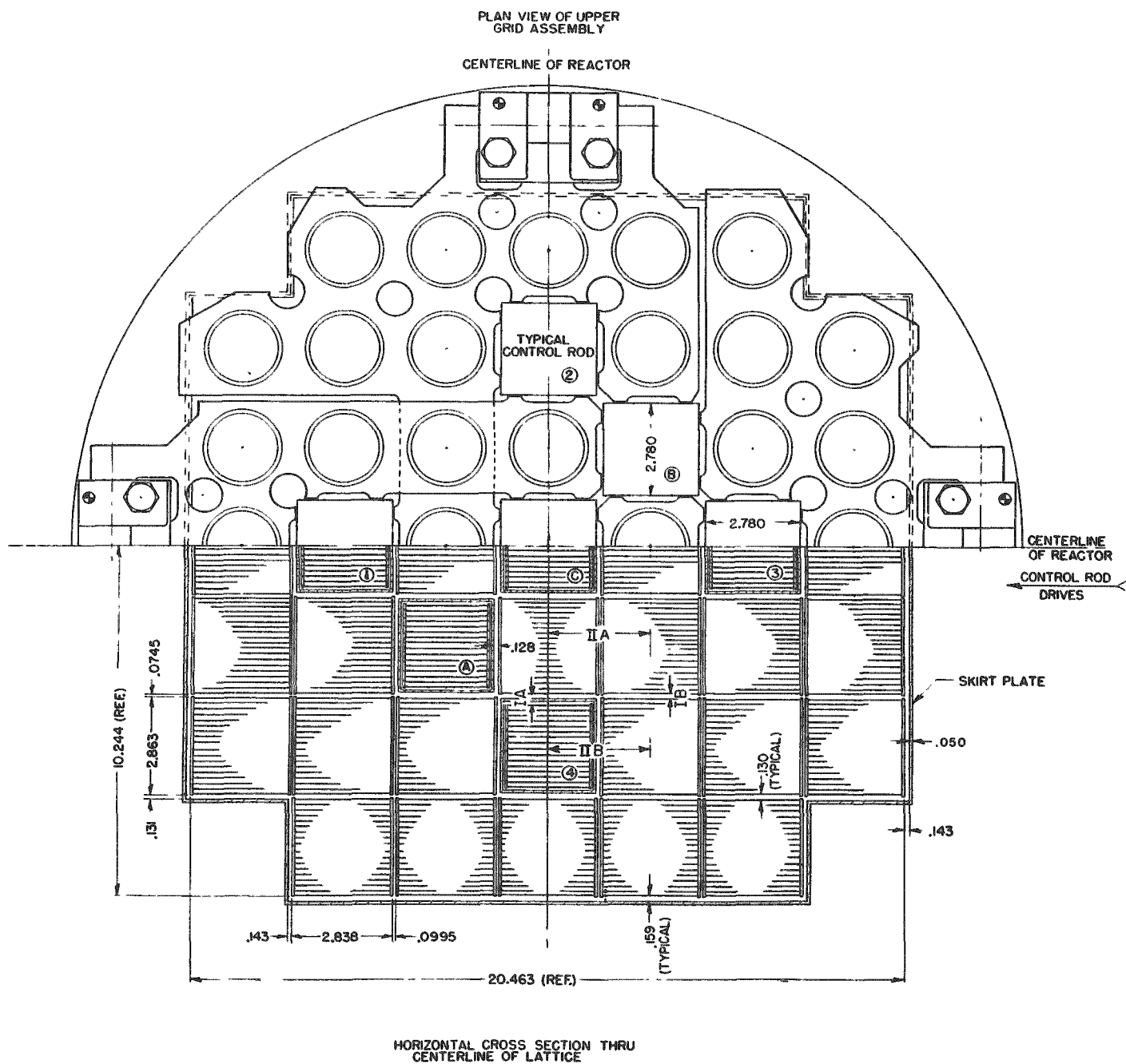


Figure 7
REACTOR CORE CROSS SECTION



Figure 8
CONTROL ROD ASSEMBLY

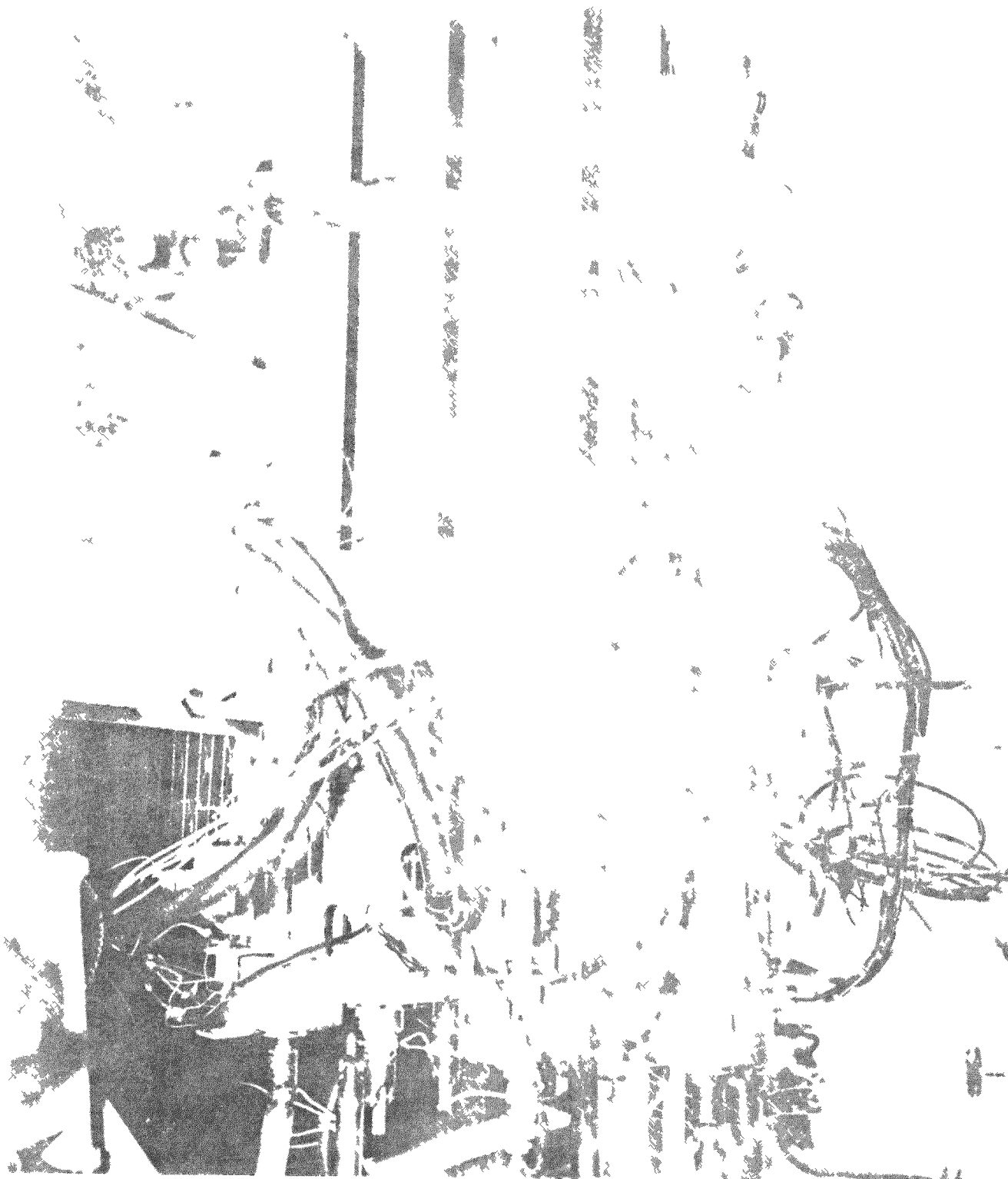


Figure 9
CONTROL ROD DRIVES

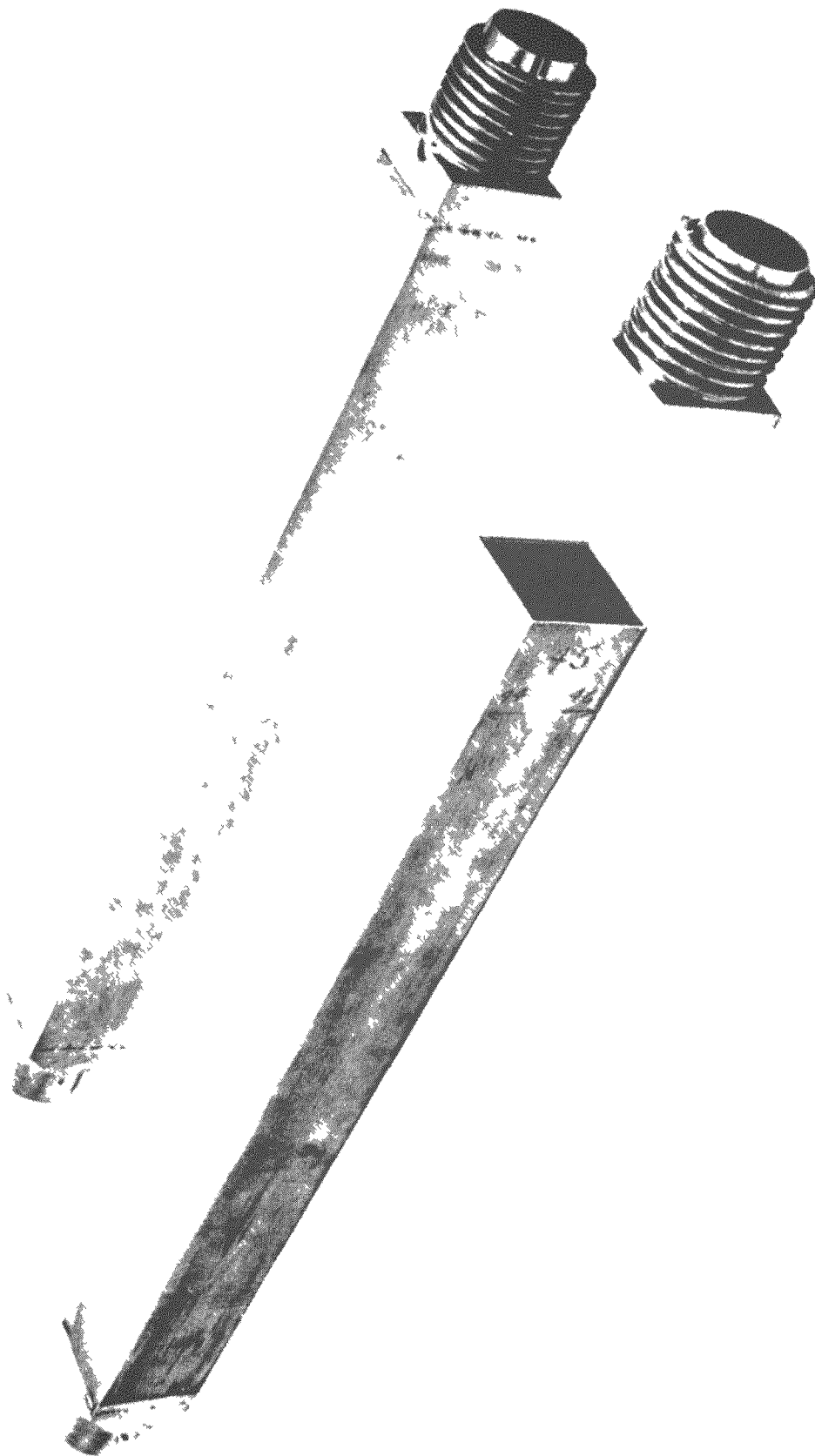


Figure 10
STATIONARY FUEL ELEMENT

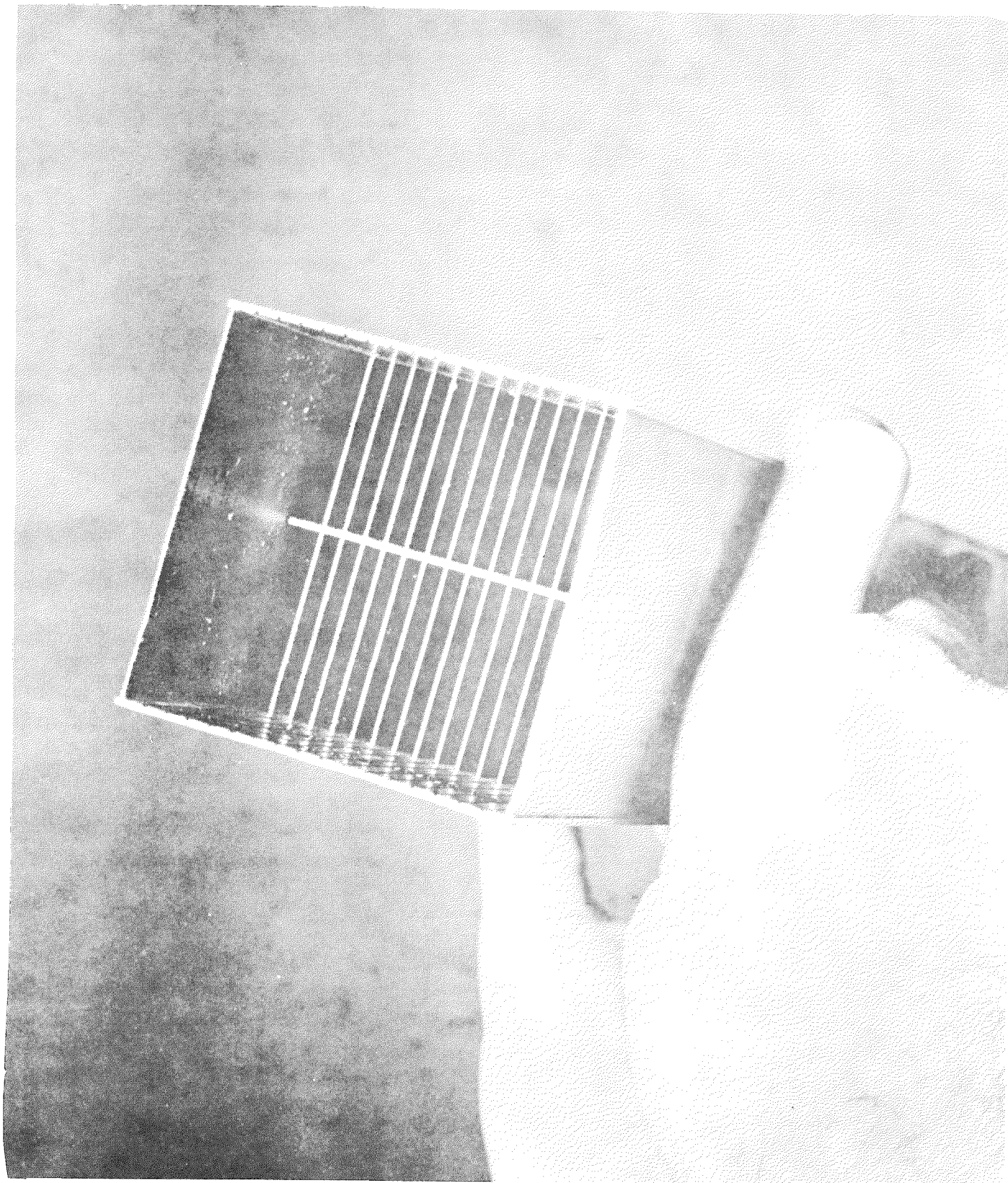


Figure 11
STATIONARY FUEL ELEMENT
WITH PLATES EXPOSED

on the average 514.6 grams of U^{235} and 0.483 grams of B^{10} in a matrix of stainless steel. Each plate is clad with 0.005 inches of stainless steel.

The APPR-1 control rod fuel elements consist of 16 parallel plates each 0.030 inches thick. Each control rod fuel element contains on the average 417.8 grams of U^{235} and 0.392 grams of B^{10} in a matrix of stainless steel. Each plate is clad with 0.005 inches of stainless steel.

The fuel plates are supported by two grooved stainless steel side plates. Total quantities of material in the core are listed in Appendix A.

For purposes of performing certain neutron flux measurements, two stationary fuel elements were provided with removable end boxes as seen in Fig. 10 and 11. A more complete description of the APPR-1 may be found elsewhere. ⁽³⁾

1.2.4 The analysis of the water used as moderator in these experiments is presented in Appendix B.

1.3 Nomenclature.

In order that there be a minimum of misinterpretation of the terminology in this report, several terms are defined or explained here prior to the actual presentation of the data.

Active Core - That region defined by the upper and lower average limits of the U^{235} distributions in the stationary fuel elements.

Bank Position - The average withdrawal measured from the bottom of the active core of four or more control rods. Five rod bank position as used in this report refers to the position of rods 1, 2, C, 3 and 4 with rods A and B fully withdrawn.

Cadmium Fraction - The ratio of bare gold activity minus cadmium covered gold activity to bare gold activity. The cadmium used was 0.020 inches thick for which the cadmium cut-off energy is 0.5 ev.

Clean Reactor - The APPR-1 design as specified in Appendix A, including the nominal 21 grams of B^{10} distributed uniformly. The experiments performed by adding additional boron steel strips then define the poisoned core containing the amount of B^{10} contained in the boron steel strips only. The B^{10} added experimentally and reported as "total B^{10} in core" should not be construed as including that B^{10} fabricated into the fuel elements.

Core Lattice Designations - as shown in Fig. 12

Reactivity - Reactivity as used in this report refers to the quantity ΔK in dollars and cents. One may convert to ΔK in absolute units by multiplying dollars by $\beta = 0.0073$.

Rod Position - A rod's position is defined as the distance withdrawn from its deepest insertion (i. e., the nominal alignment of the bottom of the active core with the top limit of U^{235} distribution in the control rod fuel element) measured in inches.

Rod Withdrawal - Refers to the withdrawal of the boron section of the control rod from the active core and the consequent simultaneous insertion of fuel.

1.4 System Calibrations

The following pertinent system characteristics are reported as estimated during the course of the experiments.

1.4.1 Control rod drive speed - 3 inches per minute equivalent to approximately \$0.10 per second maximum on the five rod bank.

CORE LATTICE DESIGNATIONS

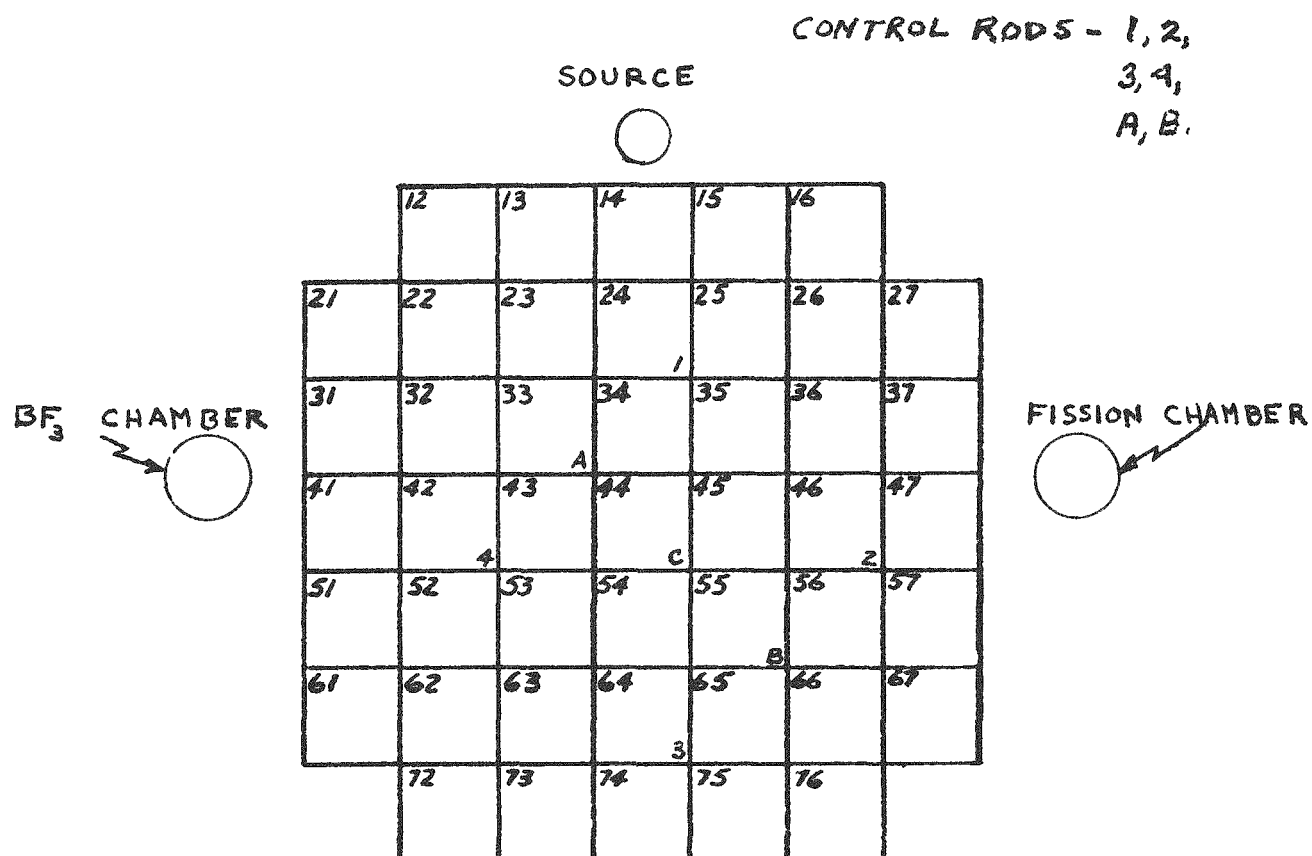


FIG. 12

1.4.2 Moderator feed rate is approximately 35 to 40 gallons per minute maximum. This corresponds to a level increase in the core of one inch per minute.

1.4.3 Moderator dump rate is approximately 50 gallons per second.

1.4.4 Minimum time to reduce reactivity following an instantaneous increase in neutron level is approximately 190 milliseconds.

1.4.5 Unless otherwise indicated, all data were taken at 68°F. Normal moderator temperature variations were within $\pm 5^\circ\text{F}$. This error interval corresponds to approximately ± 0.03 inches on the center rod. See Chapter 6.

1.4.6 The error in determining the manual setting of rods A and B is $\pm 1/8$ inches. The true position of all control rods relative to the bottom of the active core is in error by approximately $+ 1/16$, $- 3/16$ inches due to uncertainties in the limit of U^{235} distribution in the fuel plates.

CHAPTER 2 INITIAL CRITICALITY

The orientation of the Po-Be neutron source and the BF_3 and fission chambers is shown in Fig. 12.

Five control rods partially withdrawn provided the "safety" feature during the initial loadings.

2.1 Loading Sequence

The seven control rod fuel elements comprised the first fuel addition to the system following the source count rate determination by the start-up chambers.

Additional fuel elements were added to the system one at a time in the numbered sequence appearing in Fig. 13. Each source multiplication measurement was taken with all seven rods completely withdrawn. See Fig. 14.

Criticality was attained with 17 fuel elements distributed as shown in Fig. 13 and numbered from 1 to 17. The control rod positions for this critical loading are shown in Table 1.

TABLE 1
ROD WITHDRAWAL FOR INITIAL CRITICALITY

(All Rods Full Out - 22 Inches - Except as Indicated)

Case	Rod Partially Withdrawn	Inches Withdrawn
1	C	17.00
2	3	10.14
3	3 and 4	14.88 and 15.08 respectively

SEQUENCE OF INITIAL LOADING

8
514.62

SHADED AREA INDICATES INITIAL CRITICAL LOADING
 ← INDICATES ORDER OF LOADING
 ← INDICATES GRAMS OF U-235 IN ELEMENT

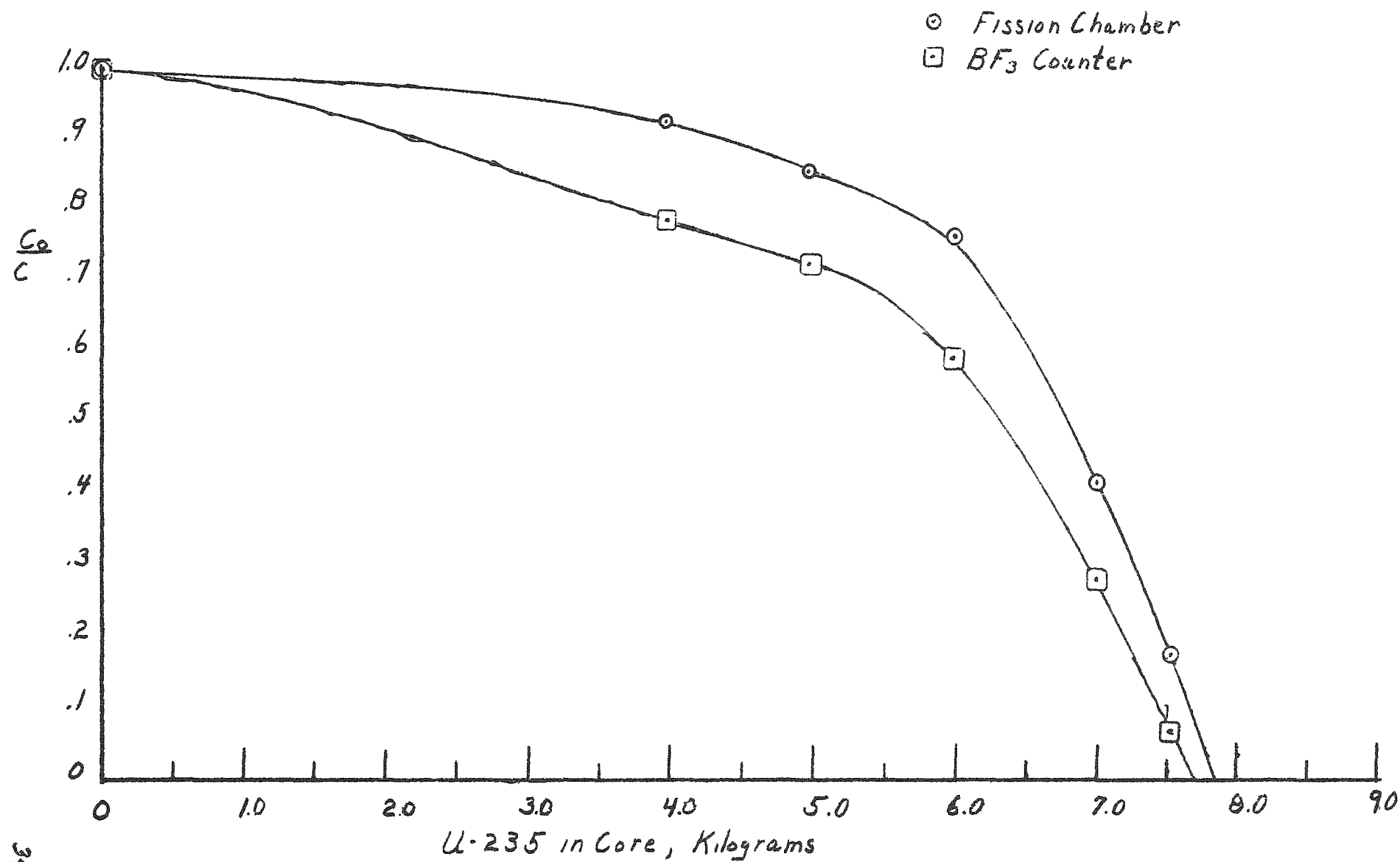
○ SOURCE

	44 514.50	30 514.56	26 514.47	31 514.42	45 514.61	
42 514.61	22 514.63	14 514.65	4 417.76	15 514.68	24 514.54	40 514.54
36 514.62	16 514.75	2 417.76	8 514.62	11 514.73	17 514.90	32 514.44
29 514.50	7 417.76	9 514.68	1 417.76	10 514.93	6 417.76	27 514.44
37 514.62	18 514.84	13 514.62	12 514.85	3 417.76	19 514.78	33 514.62
43 514.53	25 514.42	20 514.59	5 417.76	21 514.68	23 514.84	41 514.62
	38 514.58	34 514.62	28 514.43	35 514.62	39 514.59	

FIGURE 13

INITIAL CRITICAL LOADING : 17 ELEMENTS ; 8,071.73 GRAMS
 FINAL LOADING : 45 ELEMENTS ; 22,480.1 GRAMS

FIGURE 14
INVERSE MULTIPLICATION vs FUEL LOADING



The core contained a total of 8.072 Kg of U^{235} and 7.50 grams of B^{10} .

2.2 Full Loading

Additional fuel elements were added to the system and the subsequent changes in control rod positions were noted. Figure 15 shows control rod bank as a function of fuel elements contained in the system.

The critical position of the 5 rod bank with A and B fully withdrawn and a full 45 element loading was 3.7 inches withdrawn.

2.3 Critical Water Height

The critical water height for the fully loaded core with all rods completely withdrawn was 9 inches measured from the bottom of the active core.

FIGURE 13

POSITION OF 5 ROD BANK VS NUMBER OF ELEMENTS

POSITION OF 5 ROD BANK, INCHES WITHDRAWN

RODS A+B FULL OUT

RODS A+B FULL IN

RODS A+B HALF IN

NUMBER OF ELEMENTS

CHAPTER 3

CRITICAL CONTROL ROD PATTERNS

A series of experiments were performed to determine what combinations of control rods could conceivably remain fully withdrawn following a scram at operating temperatures and yet result in subcritical systems at room temperature.

Figures 16, 17 and 18 present sufficient data to allow immediate criticality interpretation of any combination of fully withdrawn control rods at 68°F. In each case presented the reactor was brought critical by withdrawing an additional rod and period measurements were made on this rod at its critical position.

In some cases two rods can be fully withdrawn, while in other cases only one rod can be fully withdrawn.

FIGURE 16
CORE SCHEMATIC
SHOWING CRITICAL
ROD CONDITIONS

KEY

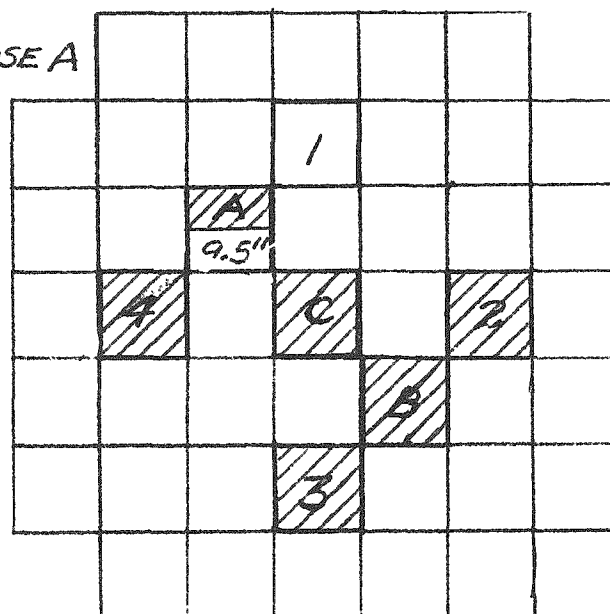
1 ROD 1 FULLY WITHDRAWN

2 ROD 2 WITHDRAWN 4.56"
4.56

3 ROD 3 FULLY INSERTED

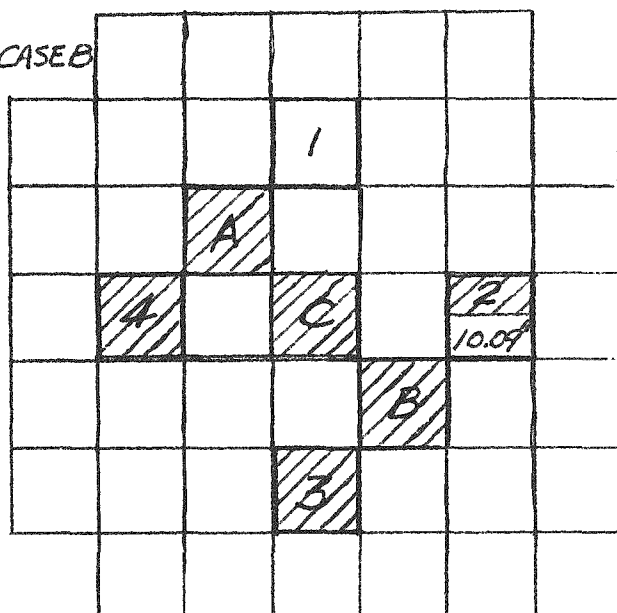
8

CASE A



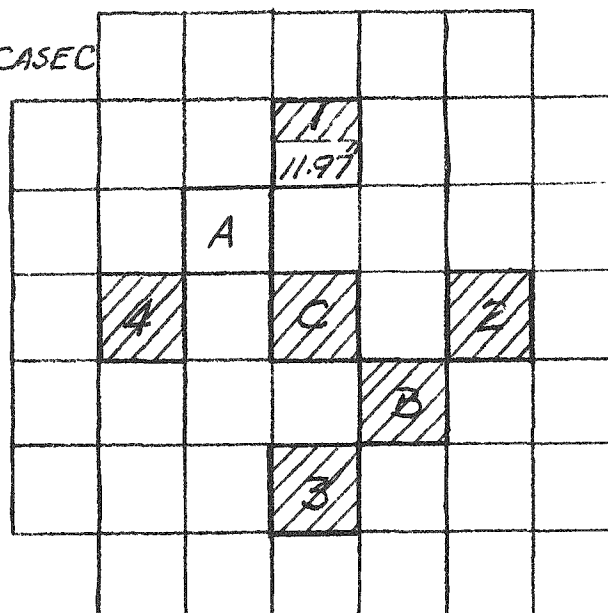
WORTH OF ROD A AT 9.5" =
UNKNOWN

CASE B

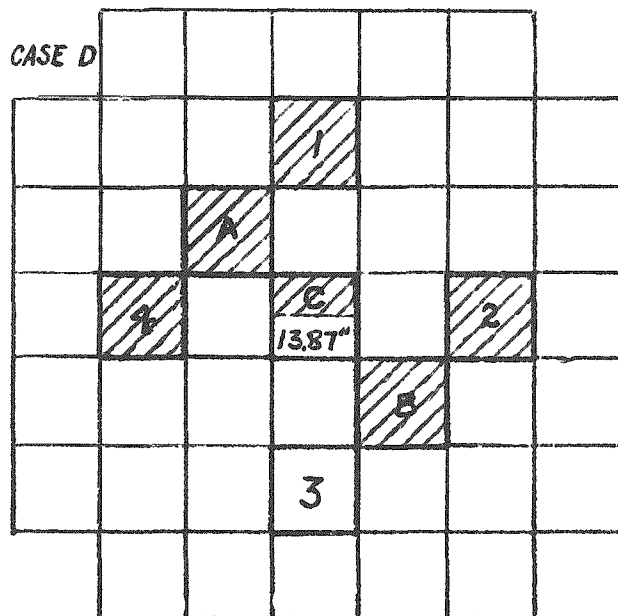


WORTH OF ROD 2 AT 10.09" =
40.0 CENTS PER INCH

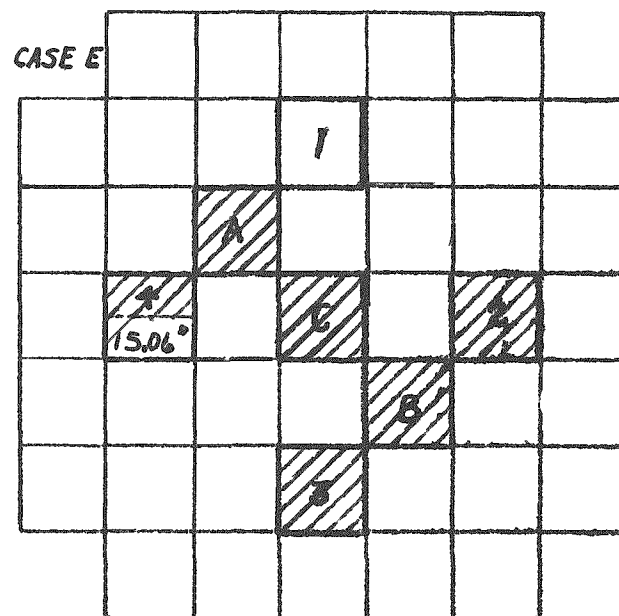
CASE C



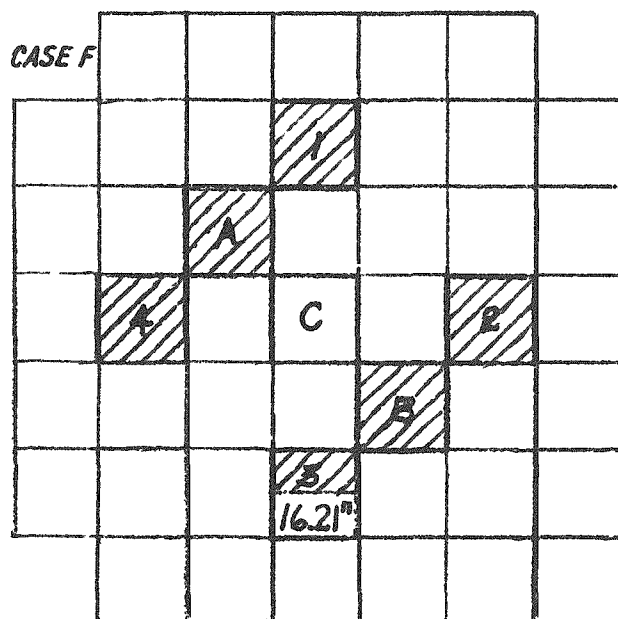
WORTH OF ROD 1 AT 11.97" =
56.9 CENTS PER INCH



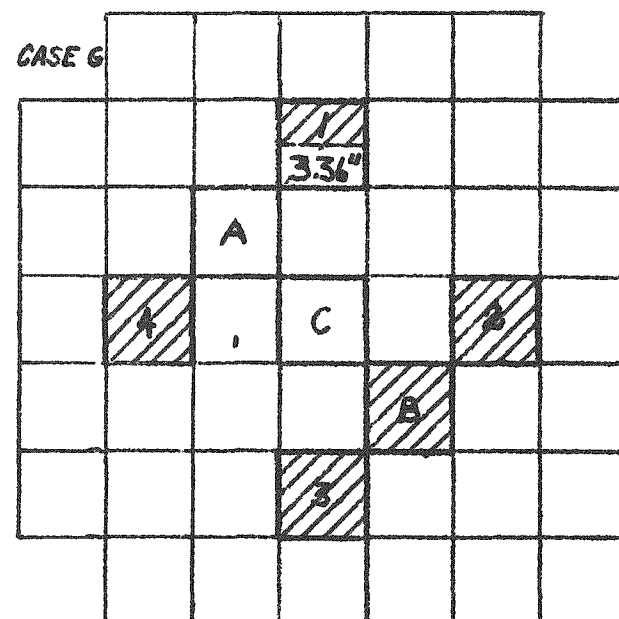
WORTH OF ROD C AT 13.87"
23.1 CENTS PER INCH



WORTH OF ROD 4 AT 15.06"
24.0 CENTS PER INCH



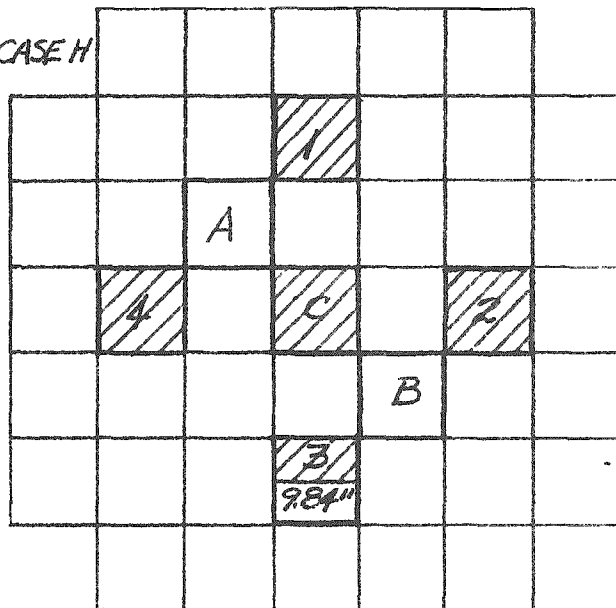
WORTH OF ROD 3 AT 16.21"
27.3 CENTS PER INCH



WORTH OF ROD 1 AT 3.36"
34.6 CENTS PER INCH

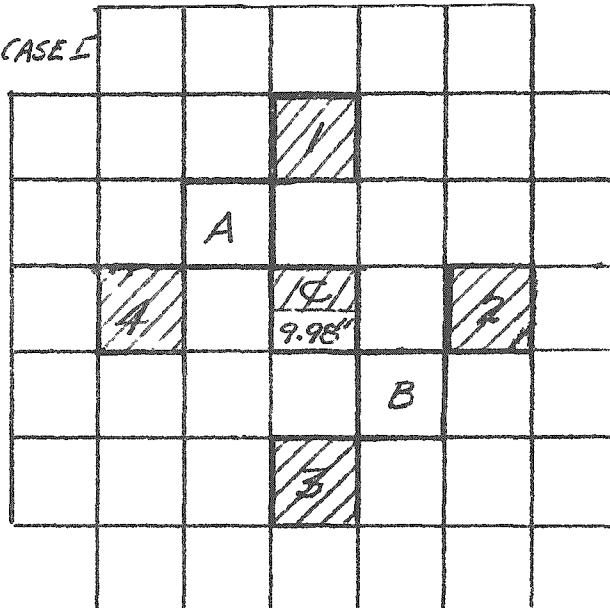
FIGURE 17
CORE SCHEMATIC SHOWING CRITICAL ROD CONDITIONS

CASE H



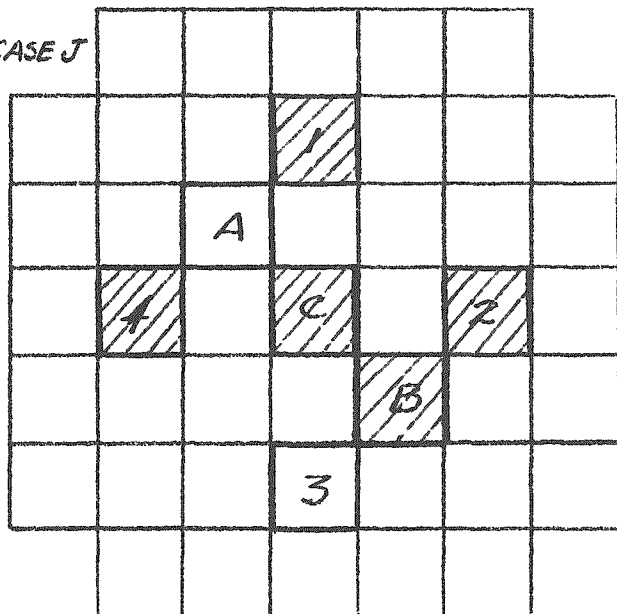
WORTH OF ROD 3 AT 9.84" =
50.0 CENTS PER INCH

CASE I



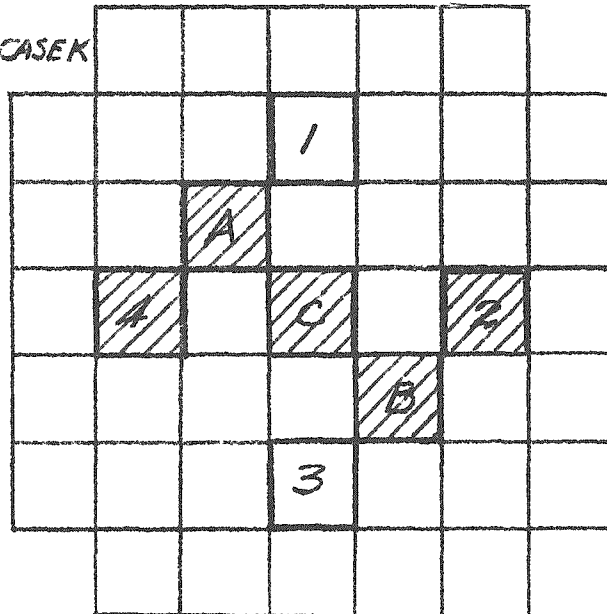
WORTH OF ROD C AT 9.98" =
50.6 CENTS PER INCH

CASE J



THIS SYSTEM IS SUBCRITICAL

CASE K



THIS SYSTEM IS SUBCRITICAL

FIGURE 18
CORE SCHEMATIC SHOWING CRITICAL ROD CONDITIONS

CHAPTER 4

UNIFORM POISON ADDITIONS

4.1 Purpose and Technique

These experiments were performed to provide a basis for the evaluation of the excess K in the cold, clean APPR-1 core. By adding known amounts of poison, Σ_p , uniformly, the excess K of the core was reduced resulting in the withdrawal of the five rod bank to maintain criticality.

The poison was added in the form of borated stainless steel strips containing 1.01 weight percent natural boron. The strips were 23 inches long by 0.5 inches wide and 0.02 inches thick having an average weight of 28.375 grams. The total B^{10} added to the core with one such strip per element (45 strips) was 2.241 grams. A tabulation of the specifications of these strips is presented in Appendix C. One should consider the effect of the other materials in these strips in terms of equivalent Boron-10 poisoning in order to properly estimate the total poison added. Since these strips were 23 inches long and the active core was 22 inches long, one must consider the effect of one-half inch of strip length protruding into the reflector region at each end of the core. Unfortunately there is no experimental data on the reactivity worth of these strips in the reflector region only. Therefore one must estimate this effect by means of the flux distributions reported in Chapter 7, the known Σ_p in the reflector, and the adjoint functions in the core and reflector regions before comparison can be made with the total core excess K determined by rod bank calibrations (Chapter 5).

4.2 Bank vs. Boron Loading for 45 Element Poisoning

Each strip was provided with plastic tape spacers positioning them at the center of the water gap between the fuel plates. Loadings were made of 1 or 2 strips per element per run. For each loading the 5 and 7 rod bank positions were determined, Fig. 19 and Table 2. The rod calibrations made at various boron loadings are reported in Chapter 5 with a discussion of associated errors.

The error in reproducing bank positions was ± 0.02 inches. Since the error in absolute position was assumed constant over the full rod travel, the relative rod positions were subject principally to the ± 0.02 inches error.

Extensive flux measurements were made in the core loaded with 4 strips per element. With this quantity of poison in the core the 5 rod bank position was approximately that calculated for the deepest penetration of the rods into the core during the lifetime of the APPR-1 (4). (See Chapter 7).

4.3 Data for Center 25 Element Poisoning

The effect of distributing poison in the center 25 fuel elements of the reactor was determined. Runs were made with 3, 4 and 5 strips in each of these elements. Criticality was established with the 5 rod bank and also with the center rod or an eccentric rod when certain rods of those remaining were fully withdrawn. Period measurements were made to determine the approximate worth of the final few inches of Rod 1.

Table 3 contains a summary of the data for this experiment.

TABLE 2
BANK VS. BORON LOADING FOR 45 ELEMENT POISONING

<u>Poison Strips Per Element</u>	<u>B-10, Gms Added to Core</u>	<u>5 Rod Bank, Inches Withdrawn</u>	<u>7 Rod Bank, Inches Withdrawn</u>
0	0	3.70	5.34
1	2.24	4.42	5.85
2	4.48	5.05	6.32
3	6.72	5.65	6.80
4	8.96	6.30	7.38
5	11.21	6.98	7.93
6	13.45	7.62	8.53
7	15.69	8.33	9.17
8	17.93	9.13	9.97
9	20.17	9.99	10.76
11	24.65	12.03	12.82
13	29.13	14.57	15.16

FIGURE 18
BORON CONTENT VS BANK POSITION

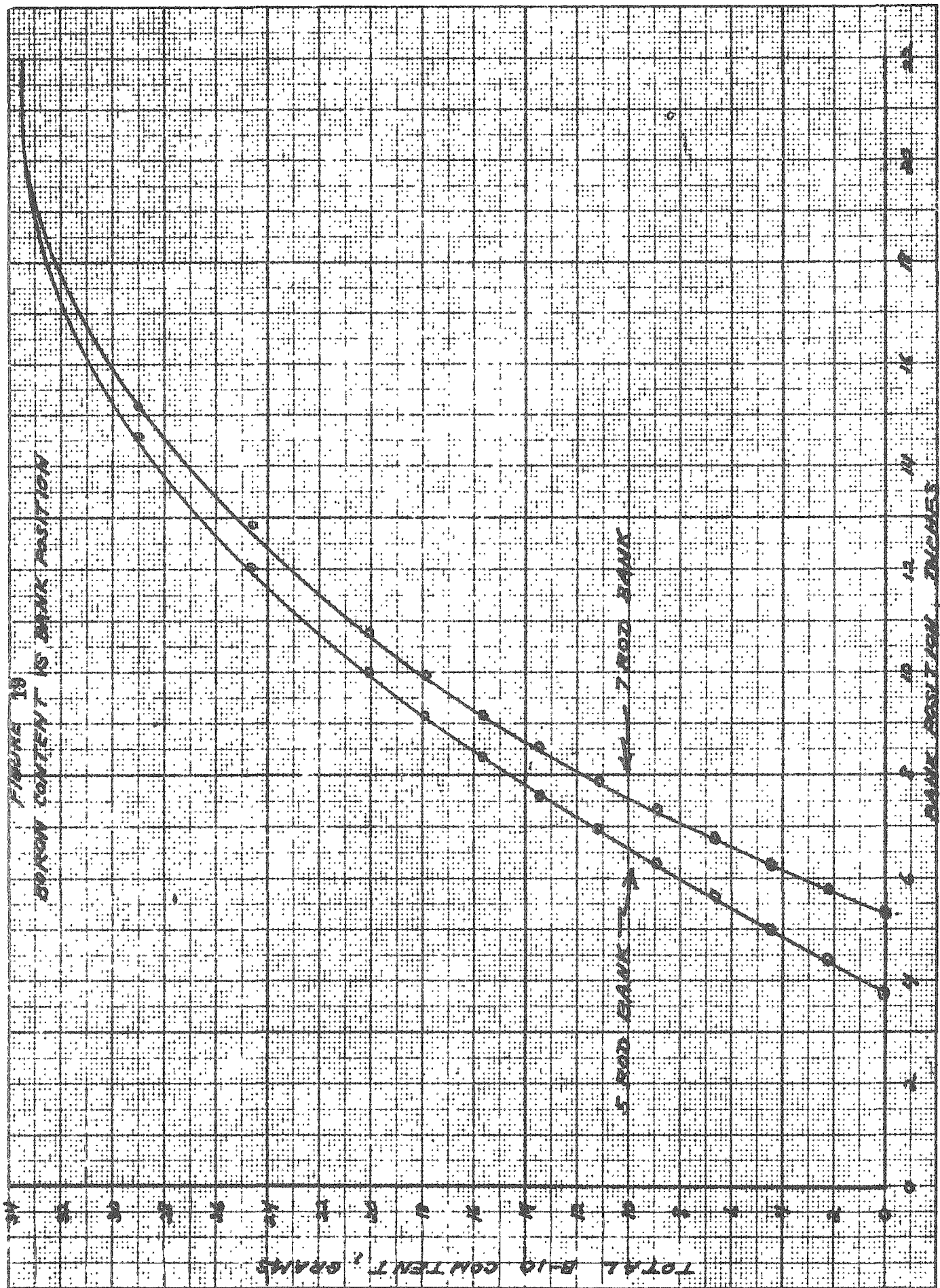


TABLE 3
SUMMARY OF POISON ADDITIONS TO CENTER 25 FUEL ELEMENTS

Run	Boron-10 Added Grams	CONTROL ROD POSITIONS, INCHES WITHDRAWN						
		1	2	C	3	4	A	B
1 - 1	6.225	22.00	0.00	5.58	0.00	0.00	22.00	22.00
1 - 2	6.225	8.08	0.00	22.00	0.00	0.00	22.00	22.00
1 - 3	6.225	6.32	6.33	6.23	6.31	6.36	22.00	22.00
1 - 4	6.225	22.00	0.00	9.72	0.00	0.00	22.00	0.00
2 - 1	4.980	19.53	0.00	0.00	0.00	0.00	22.00	22.00
2 - 2	4.980	5.80	5.84	5.73	5.85	5.84	22.00	22.00
2 - 3	4.980	5.85	0.00	22.01	0.00	0.00	22.00	22.00
2 - 4	4.980	22.00	0.00	6.47	0.00	0.00	22.00	0.00
3 - 1	3.750	5.16	5.20	5.00	5.16	5.22	22.00	22.00
3 - 2	3.750	0.28	0.24	17.70	0.24	0.20	22.00	22.00
3 - 3	3.750	19.66	0.24	0.10	0.24	0.19	22.00	0.00

Note: In run 2-1 Period established by moving Rod 1 full out determined worth to be about \$0.06

In run 3-3 Period established by moving Rod 1 full out determined worth to be about \$0.04

CHAPTER 5 CONTROL ROD CALIBRATIONS

5.1 Discussion

All the control rod calibrations performed during the course of these experiments made use of standard period technique and the in-hour equation with $\beta = 0.0073$. Considerable difficulty was encountered in making these measurements. The initial calibrations, previously reported in AP-61⁽⁴⁾, are subject to considerable question due to the uncertainty in control rod positions which resulted from an interaction between the synchomotor position indicators.

This interaction was eliminated and the calibrations were retaken for several Boron-10 poison loadings and a repeat run of the temperature coefficient, Chapter 6, was also made. The extent of the uncertainty due to this interaction was on the order of ± 0.2 inches. It is considered, therefore, that the 5 rod bank rod positions as originally reported ⁽⁴⁾ are adequate for gross effect interpretations since the error tends to cancel out in averaging bank positions.

However, it now appears from the data reported in Chapter 6, that a fine structure exists in the worth curves and that reproducibility of rod worth is sensitive to the relative positions of the calibrated rod and the 4 rod bank, particularly so in the region of equi-withdrawal of all five rods. Superimposed upon these effects, a sizable statistical uncertainty exists due to the large rod worth and consequent small rod motion required for suitable periods.

5.2 Precision of Data

The data herein reported is considered reliable within the error intervals reported for each point. Whenever an interval is not reported, one may consider the interval to lie within the circle about the point.

The individual rod positions are reproducible to ± 0.02 inches.

5.3 Position of Rod C and 3 vs. the 4 Rod Bank

The data for the remaining sections of this chapter are to be found in Tables 4, 5 and 6.

The critical positions of rod C and rod 3 as a function of the 4 rod bank with rods A and B at 22 inches withdrawal is represented by Figs. 20 and 21, respectively. The Boron-10 added in strip form to compensate for bank motion is noted for each curve.

5.4 Calibrations of Rod C

Figures 22 and 23 represent the reactivity worths of rod C in cents per inch as a function of its withdrawal. The 4 rod bank position is altered to compensate for this withdrawal. Curves are presented for four cases of Boron-10 poisoning.

Curve I, Fig. 22, illustrates some poor reproducibility at small bank withdrawals. A fine calibration at a later date in this region may prove interesting.

Figure 24 represents the integral rod C worth in cents as a function of its position.

5.5 Calibrations of Rod 3

Figures 25 and 26 represent the reactivity worths of rod 3 in cents per inch as a function of its withdrawal. The 4 rod bank position is altered to compensate for this withdrawal. Curves are presented for four cases of Boron-10 poisoning.

As in Section 5.4 some poor reproducibility is apparent at small bank withdrawals, Curve I. The poor agreement of several points on Curve II, Fig. 25, would seem contrary to our argument, however, excellent reproducibility elsewhere would seem to indicate other sources for error in these points.

Figure 27 represents the integral rod 3 worth in cents as a function of its position.

5.6 Five Rod Bank Calibration vs. Bank Position

Figure 28 is a plot of the 5 rod bank reactivity worth in cents per inch as a function of its withdrawal. The probable errors associated with period measurements on the bank are naturally quite large, though the point reproducibility appears excellent.

Figure 29 represents the integral 5 rod bank worth in cents as a function of bank position. Figure 30 is a similar plot, however, with the abscissa in terms of grams of Boron-10 added to the core. From Fig. 29 one may estimate the excess K to be 16.6%. Figure 30 shows the amount of Boron-10 that must be added to override this excess K .

TABLE 4
CALIBRATION OF CONTROL ROD C

Case	Boron-10 Added to Core Grams	Critical Position of Rods 1, 2, 3, 4 in inches (A&B at 22.00 inches)	Critical Position of Rod C Inches	Super Critical Position of Rod C Inches	Rod C Worth ¢/in.
I	0	4.59	0.00	0.68	19.4
	0	4.22	2.00	2.40	38.0
	0	3.68	3.19	3.49	46.5
	0	3.58	4.01	4.30	52.8
	0	2.77	6.01	6.24	53.7
	0	2.72	6.01	6.27	56.2
	0	1.70	8.02	8.26	58.0
	0	1.63	8.01	8.28	55.0
	0	0.33	9.50	9.76	56.0
	0	0.02	9.79	10.04	57.3
II	8.964	8.19	0.00	0.74	19.7
	8.964	7.80	2.10	2.48	39.8
	8.964	7.13	4.10	4.35	62.5
	8.964	6.35	6.10	6.33	63.5
	8.964	5.66	8.10	8.48	51.3
	8.964	5.10	10.10	10.47	41.1
	8.964	4.64	12.10	12.63	32.9
	8.964	4.07	15.10	15.97	20.9

TABLE 4 (CONT'D)
CALIBRATION OF CONTROL ROD C

<u>Case</u>	<u>Boron-10 Added to Core Grams</u>	<u>Critical Position of Rods 1, 2, 3, 4 in inches (A&B at 22.00 inches)</u>	<u>Critical Position of Rod C Inches</u>	<u>Super Critical Position of Rod C Inches</u>	<u>Rod C Worth ¢/in.</u>
III	17.928	12.90	0.22	1.23	15.0
	17.928	12.20	2.98	3.40	35.6
	17.928	10.61	5.98	6.24	61.2
	17.928	9.06	9.04	9.39	48.2
	17.928	8.23	11.98	12.64	27.0
	17.928	7.81	14.98	16.23	13.0
	17.928	7.60	17.98	19.98	2.6
IV	26.892	20.53	6.91	7.27	45.2
	26.892	17.60	8.00	8.32	50.3
	26.892	15.00	9.99	10.32	49.0
	26.892	13.02	12.97	13.54	27.2
	26.892	12.26	15.99	17.58	10.3

TABLE 5
CALIBRATION OF CONTROL ROD 3

<u>Case</u>	<u>Boron-10 Added to Core Grams</u>	<u>Critical Position of Rods 1, 2, C, 4 in inches (A&B at 22.00 inches)</u>	<u>Critical Position of Rod 3 Inches</u>	<u>Super Critical Position of Rod 3 Inches</u>	<u>Rod 3 Worth ¢/in.</u>
I	0	4.18	0.04	1.03	12.5
	0	4.00	2.02	2.48	23.5
	0	3.68	2.91	3.40	30.0
	0	3.72	3.71	4.18	36.4
	0	3.62	4.02	4.31	42.4
	0	3.60	4.00	4.34	38.7
	0	3.00	6.02	6.32	52.3
	0	2.98	6.00	6.28	48.9
	0	1.91	8.01	8.22	61.0
	0	1.91	8.00	8.23	54.3
	0	0.33	9.40	9.63	59.6
	0	0.00	9.59	9.81	61.4
II	8.964	4.09	16.20	17.06	22.1
	8.964	4.67	13.52	14.09	28.8
	8.964	5.10	11.53	11.94	35.2
	8.964	5.13	11.38	11.87	34.3
	8.964	5.65	9.11	9.46	40.6
	8.964	5.69	8.89	9.30	37.6
	8.964	6.37	5.82	6.13	43.0
	8.964	6.38	5.76	6.13	42.8
	8.964	6.70	4.02	4.44	34.1

TABLE 5 (CONT'D)
CALIBRATION OF CONTROL ROD 3

<u>Case</u>	<u>Boron-10 Added to Core Grams</u>	<u>Critical Position of Rods 1, 2, C, 4 in inches (A&B at 22.00 inches)</u>	<u>Critical Position of Rod 3 Inches</u>	<u>Super Critical Position of Rod 3 Inches</u>	<u>Rod 3 Worth ¢/in.</u>
III	17.928	8.17	15.02	16.40	12.6
	17.928	8.52	12.02	12.76	21.2
	17.928	9.07	9.09	9.63	29.9
	17.928	9.77	6.02	6.53	32.8
	17.928	10.34	3.02	3.84	20.8
	17.928	10.58	0.53	2.14	10.8
IV	26.892	12.56	16.00	17.69	7.4
	26.892	13.03	12.99	13.81	16.9
	26.892	13.84	10.02	10.48	26.3
	26.892	14.95	7.02	7.59	24.2
	26.892	16.38	0.70	2.62	7.2

TABLE 6
CALIBRATION OF 5 ROD BANK

<u>Case</u>	<u>Boron-10 Added to Core Grams</u>	<u>Critical Position of Rods 1, 2, C, 3, 4 in inches (A&B at 22.00 inches)</u>	<u>Super Critical Position of Rods 1, 2, C, 3, 4 in inches</u>	<u>Bank Worth ¢/in.</u>
I	0	3.68	3.75	235
	0	3.66	3.74	225
	0	3.72	3.80	233
II	8.964	6.26	6.31	251
III	17.928	9.07	9.17	184
	17.928	9.06	9.14	193
IV	26.892	13.03	13.15	123
	26.892	13.03	13.10	119

Figure 20

**CRITICAL POSITION OF FOUR ROD BANK
VS CONTROL ROD C**

CURVE:

- I - 0 BORON STRIPS PER ELEMENT
0.00 GRAMS TOTAL B¹⁰ IN CORE
- II - 4 BORON STRIPS PER ELEMENT
8.964 GRAMS TOTAL B¹⁰ IN CORE
- III - 8 BORON STRIPS PER ELEMENT
17.928 GRAMS TOTAL B¹⁰ IN CORE
- IV - 12 BORON STRIPS PER ELEMENT
26.892 GRAMS TOTAL B¹⁰ IN CORE

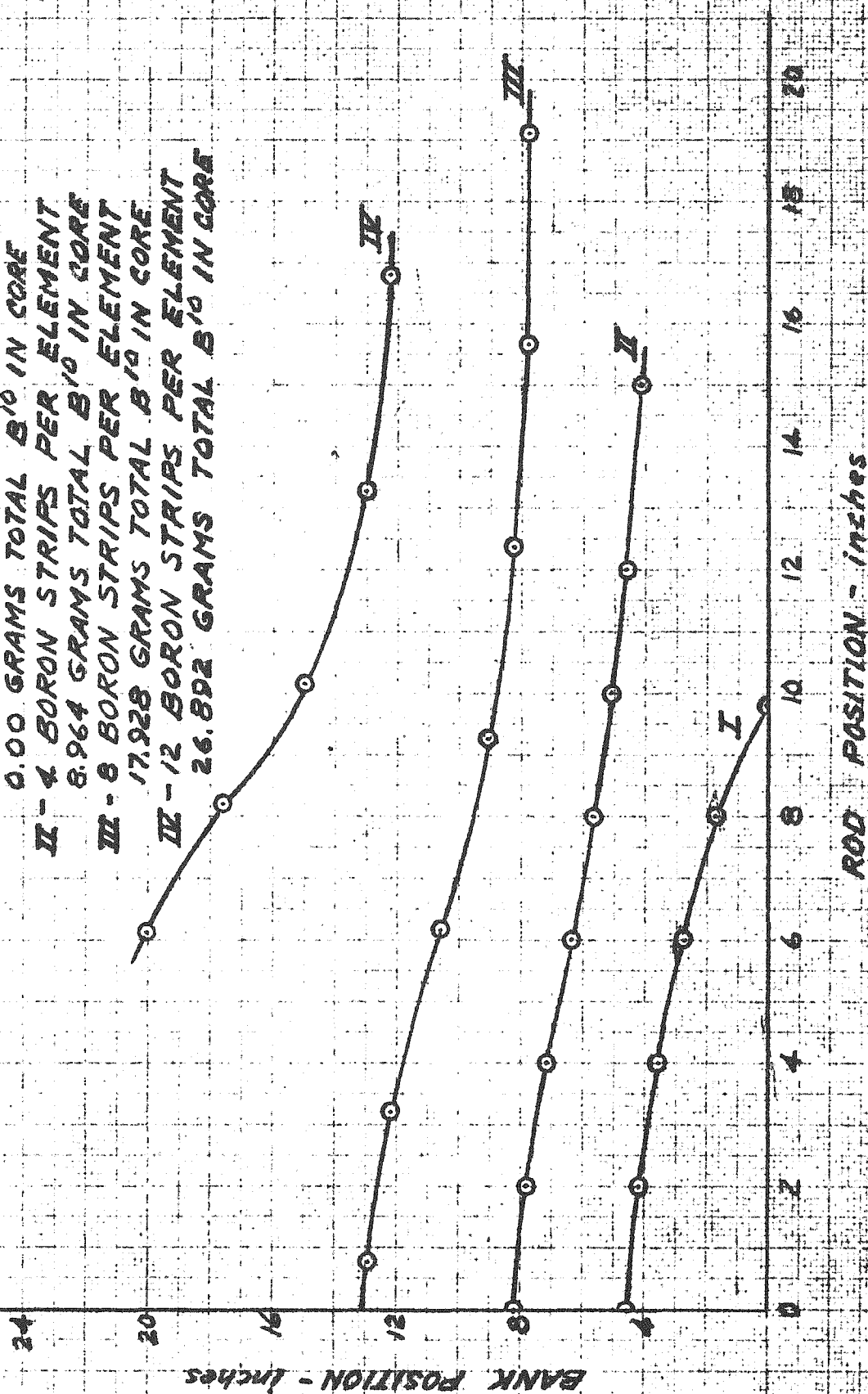


Figure 21

CRITICAL POSITION OF FOUR ROD BANK VS CONTROL ROD A CURVE:

- I - 0 BORON STRIPS PER ELEMENT
0.00 GRAMS TOTAL B¹⁰ IN CORE
- II - 4 BORON STRIPS PER ELEMENT
8.964 GRAMS TOTAL B¹⁰ IN CORE
- III - 8 BORON STRIPS PER ELEMENT
17.928 GRAMS TOTAL B¹⁰ IN CORE
- IV - 12 BORON STRIPS PER ELEMENT
26.892 GRAMS TOTAL B¹⁰ IN CORE

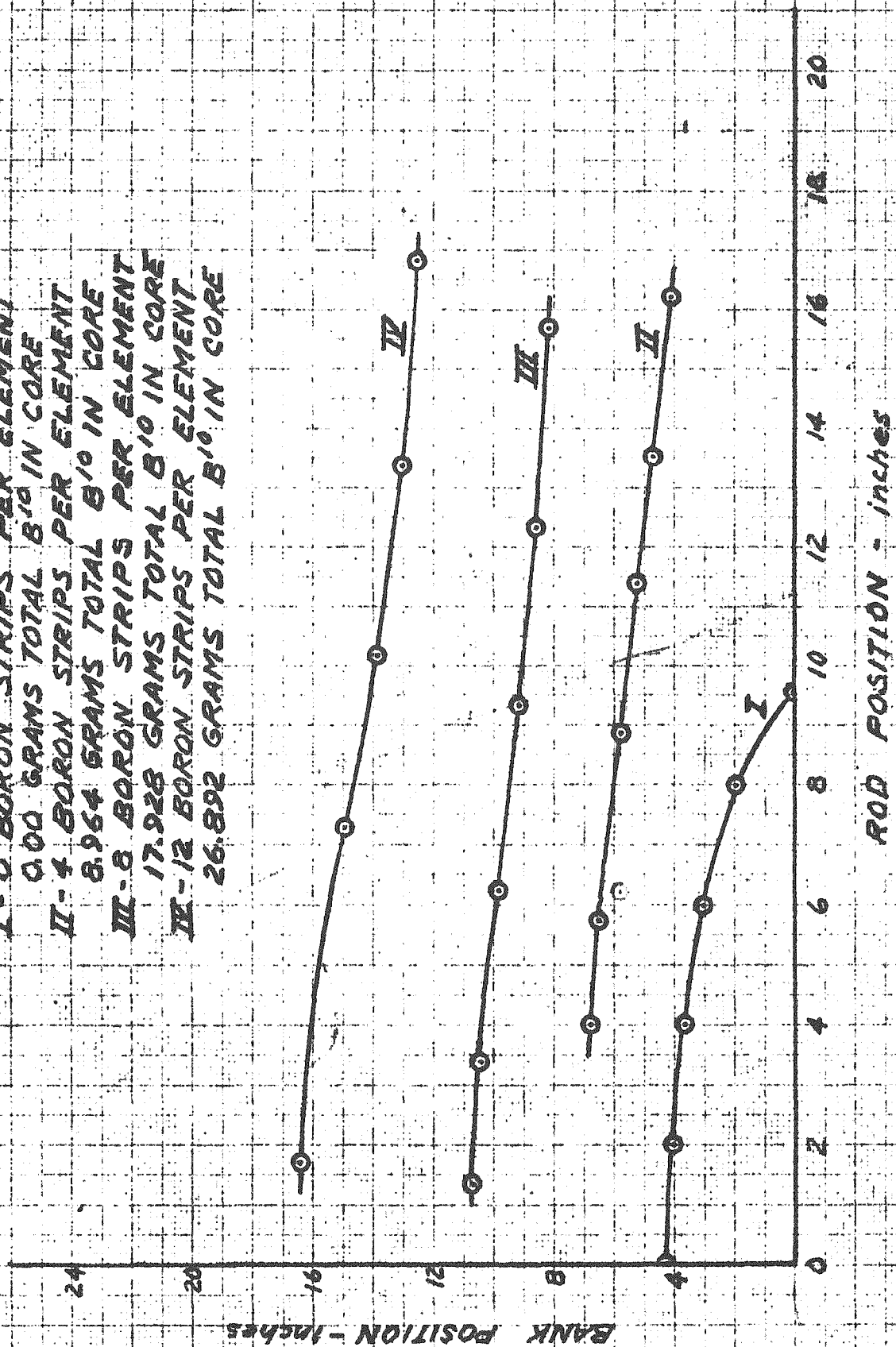


Figure 22

CALIBRATION OF CONTROL ROD C

CURVE:

I - 0 BORON STRIPS PER ELEMENT
0.00 GRAMS TOTAL B¹⁰ IN CORE

II - 4 BORON STRIPS PER ELEMENT
8.964 GRAMS TOTAL B¹⁰ IN CORE

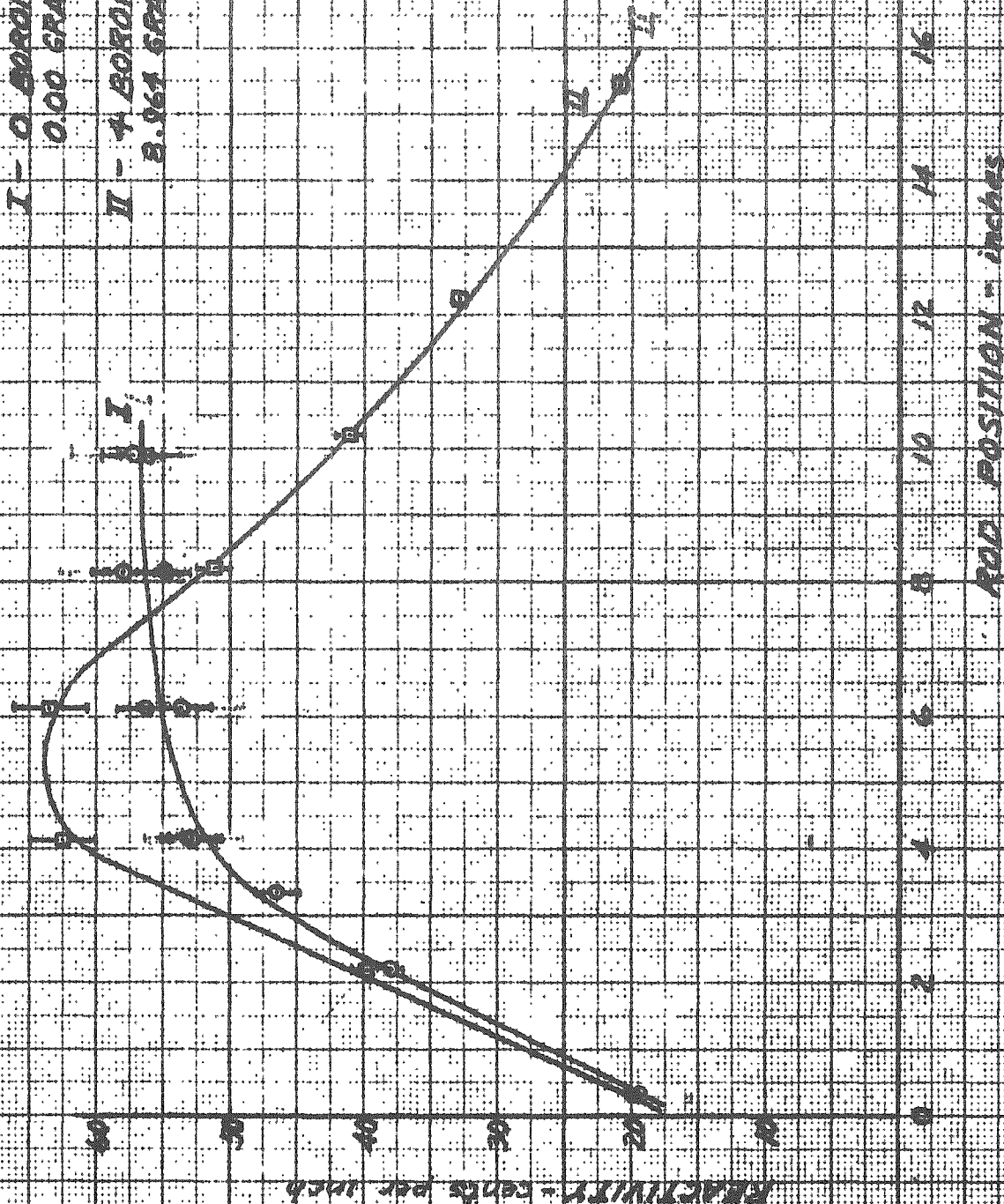


Figure 23

CALIBRATION OF CONTROL ROD C

CURVE:

III - 8 BORON STRIPS PER ELEMENT
17.928 GRAMS TOTAL B¹⁰ IN CORE

IV - 12 BORON STRIPS PER ELEMENT
26.892 GRAMS TOTAL B¹⁰ IN CORE

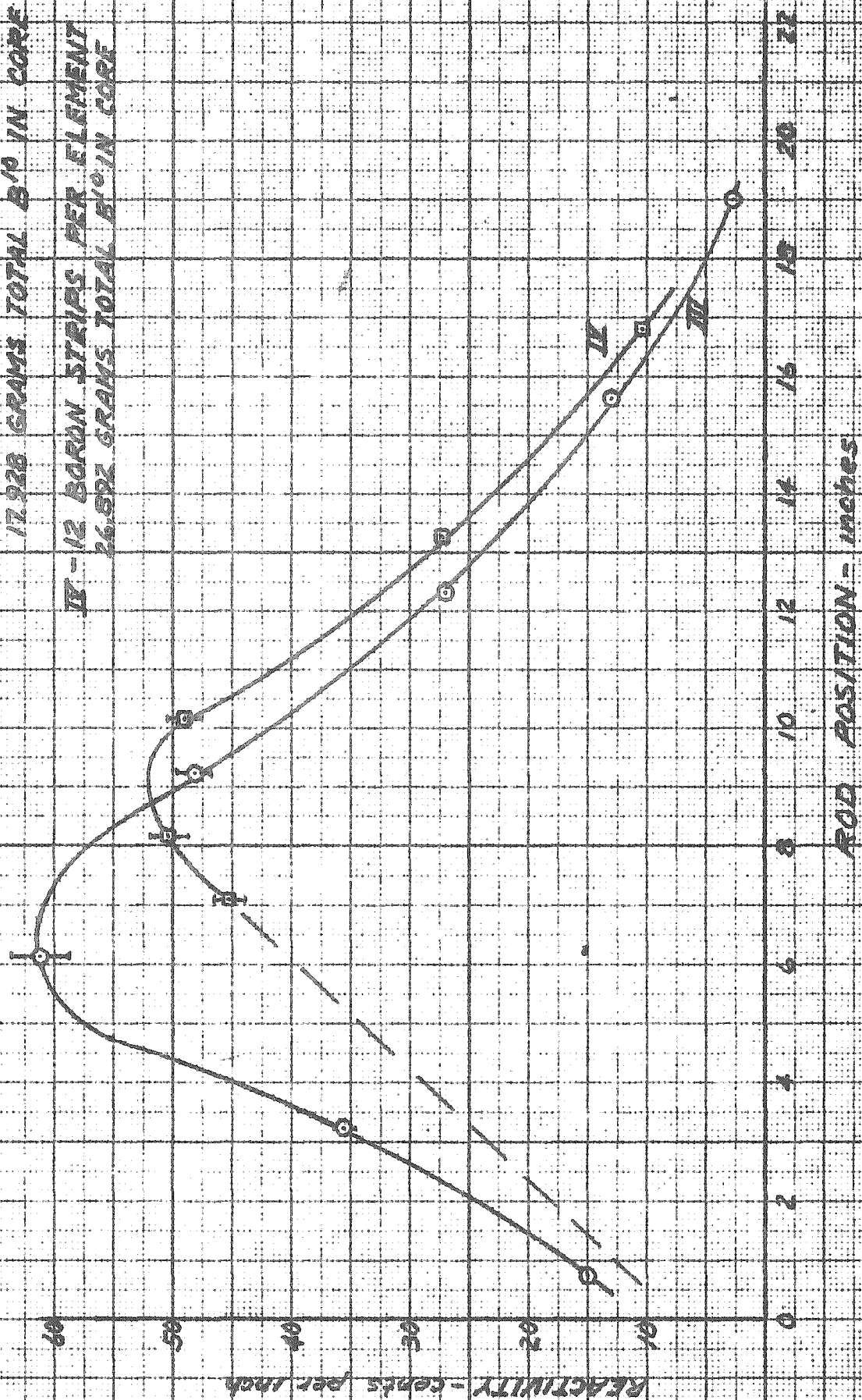


Figure 24

INTEGRAL ROD VALUE VS ROD WITHDRAWAL - RODC

CURVE:

- I - 0 BORON STRIPS PER ELEMENT
- II - 0.000 GRAMS TOTAL B¹⁰ IN CORE
- III - 4 BORON STRIPS PER ELEMENT
- IV - 8 BORON STRIPS PER ELEMENT
- V - 17.928 GRAMS TOTAL B¹⁰ IN CORE
- VI - 12 BORON STRIPS PER ELEMENT
- VII - 26.892 GRAMS TOTAL B¹⁰ IN CORE

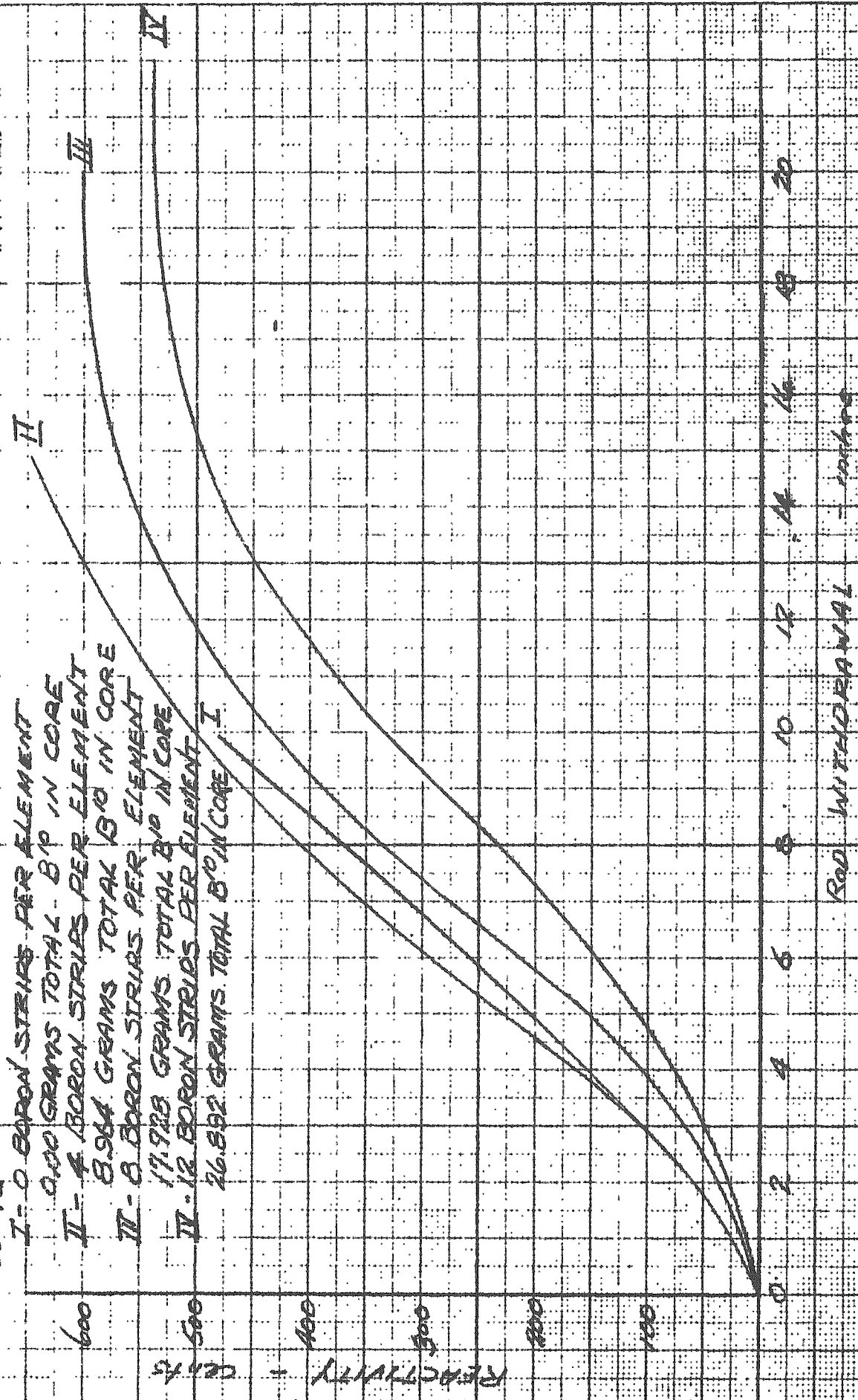


Figure 25

CALIBRATION OF CONTROL ROD 3
CURVE

I - 0 BORON STRIPS PER ELEMENT
0.00 GRAMS TOTAL B¹⁰ IN CORE

II - 4 BORON STRIPS PER ELEMENT
3.964 GRAMS TOTAL B¹⁰ IN CORE

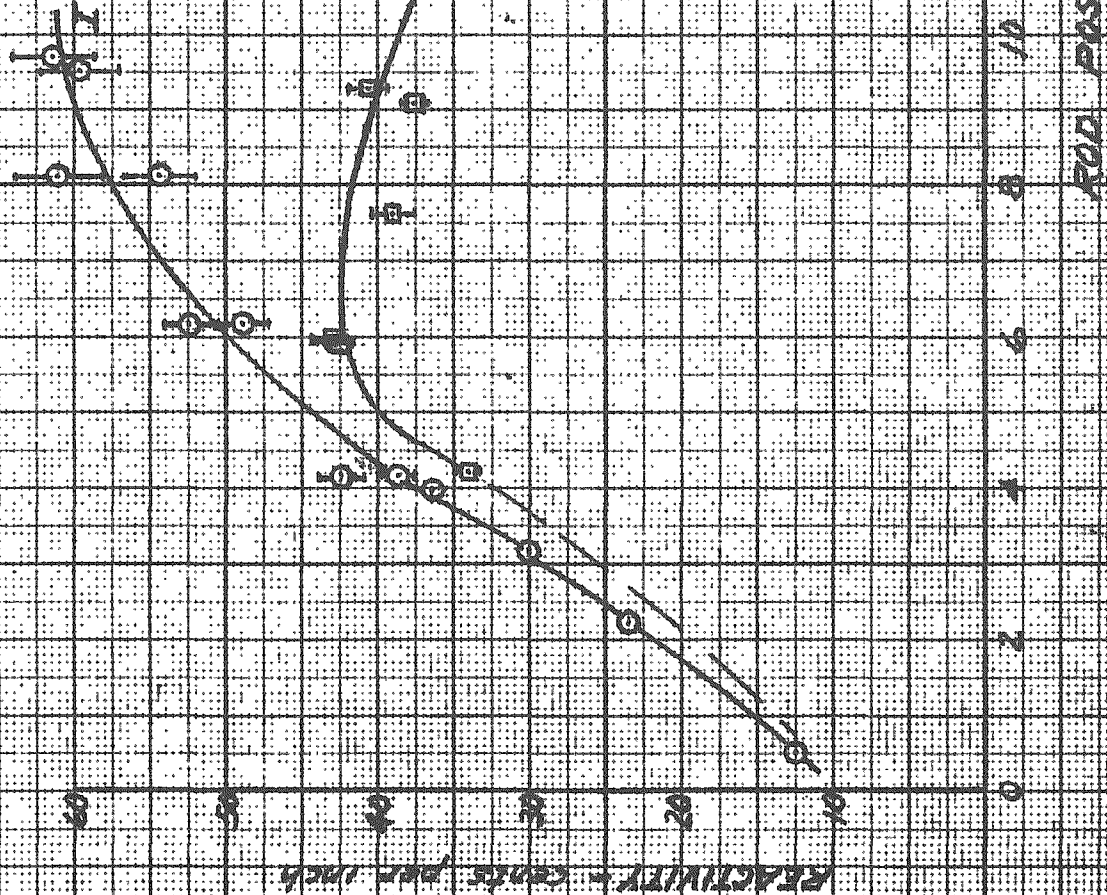


Figure 20

CALIBRATION OF CONTROL ROD 3

CURVE:

III - 8 BORON STRIPS PER ELEMENT
17.928 GRAMS TOTAL B¹⁰ IN CORE

IV - 12 BORON STRIPS PER ELEMENT
26.892 GRAMS TOTAL B¹⁰ IN CORE

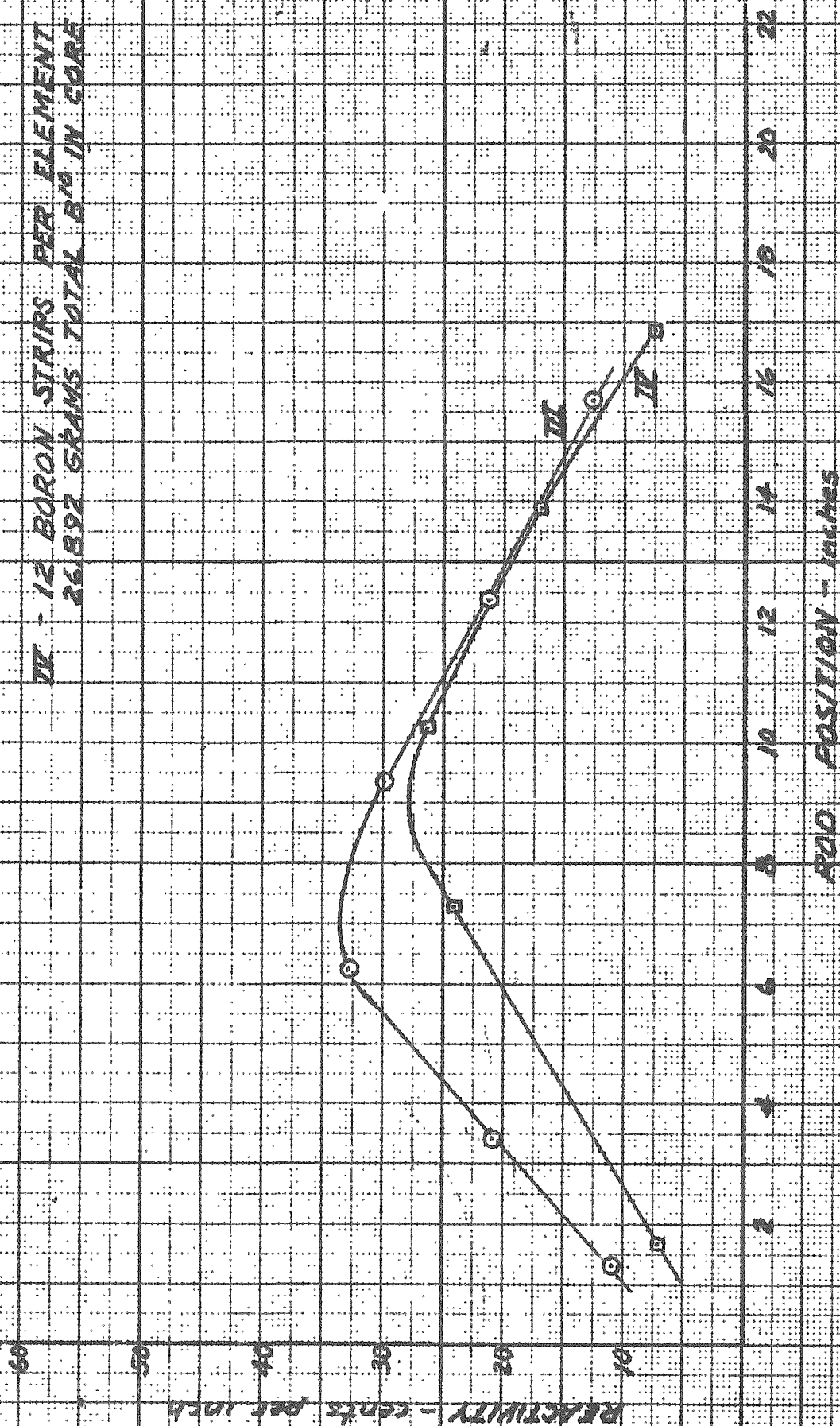


Figure 27

INTEGRAL ROD VALUE VS. ROD WITHDRAWAL - ROD 3

CURVE:

I - 0 BORON STRIPS PER ELEMENT

0.00 GRAMS TOTAL B¹⁰ IN CORE

II - 4 BORON STRIPS PER ELEMENT

8.964 GRAMS TOTAL B¹⁰ IN CORE

III - 8 BORON STRIPS PER ELEMENT

17.928 GRAMS TOTAL B¹⁰ IN CORE

IV - 12 BORON STRIPS PER ELEMENT

26.892 GRAMS TOTAL B¹⁰ IN CORE

REACTIVITY - CENTS

ROD WITHDRAWAL - INCHES

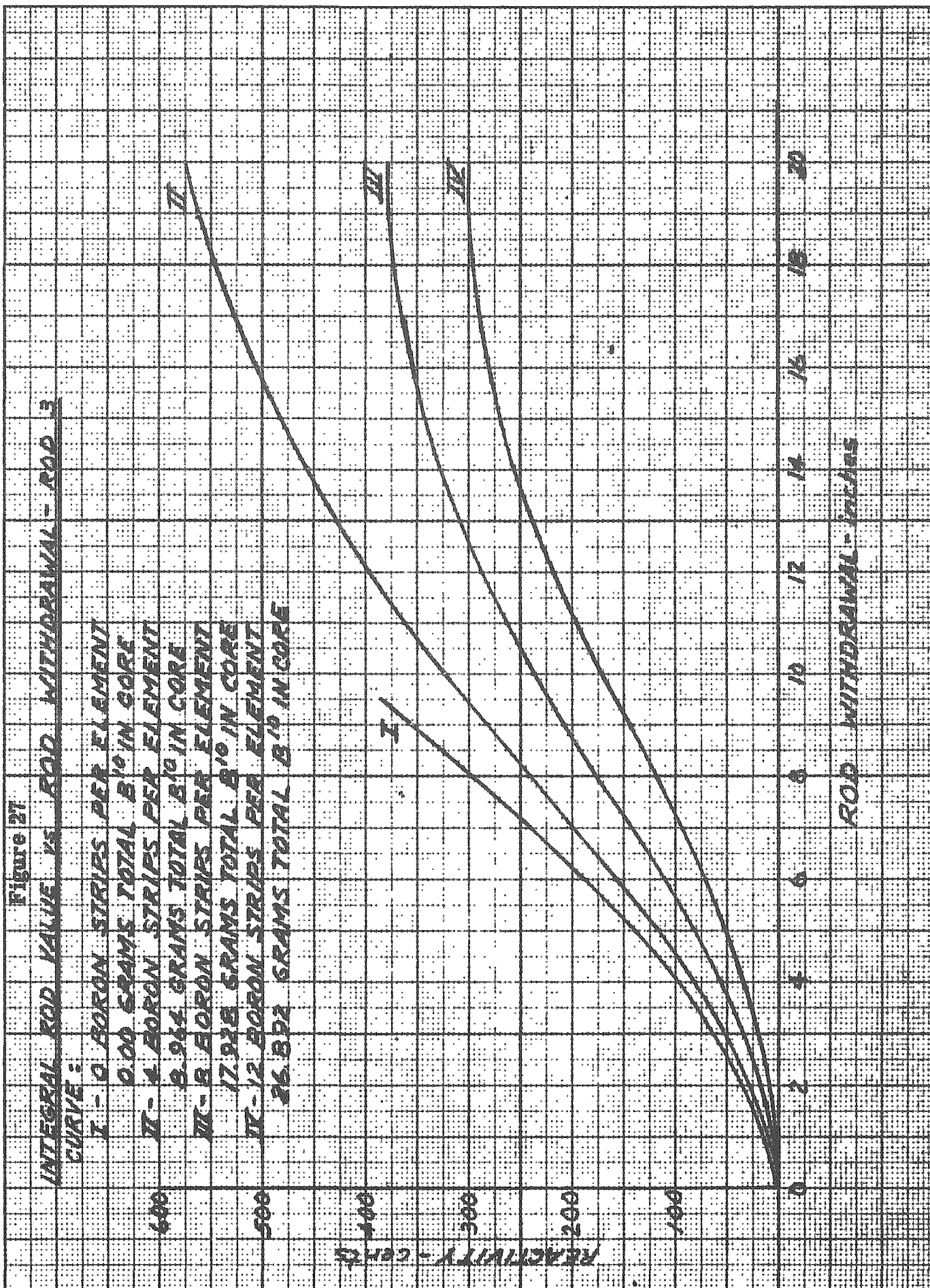


Figure 28
CALIBRATION OF FIVE ROD BANK

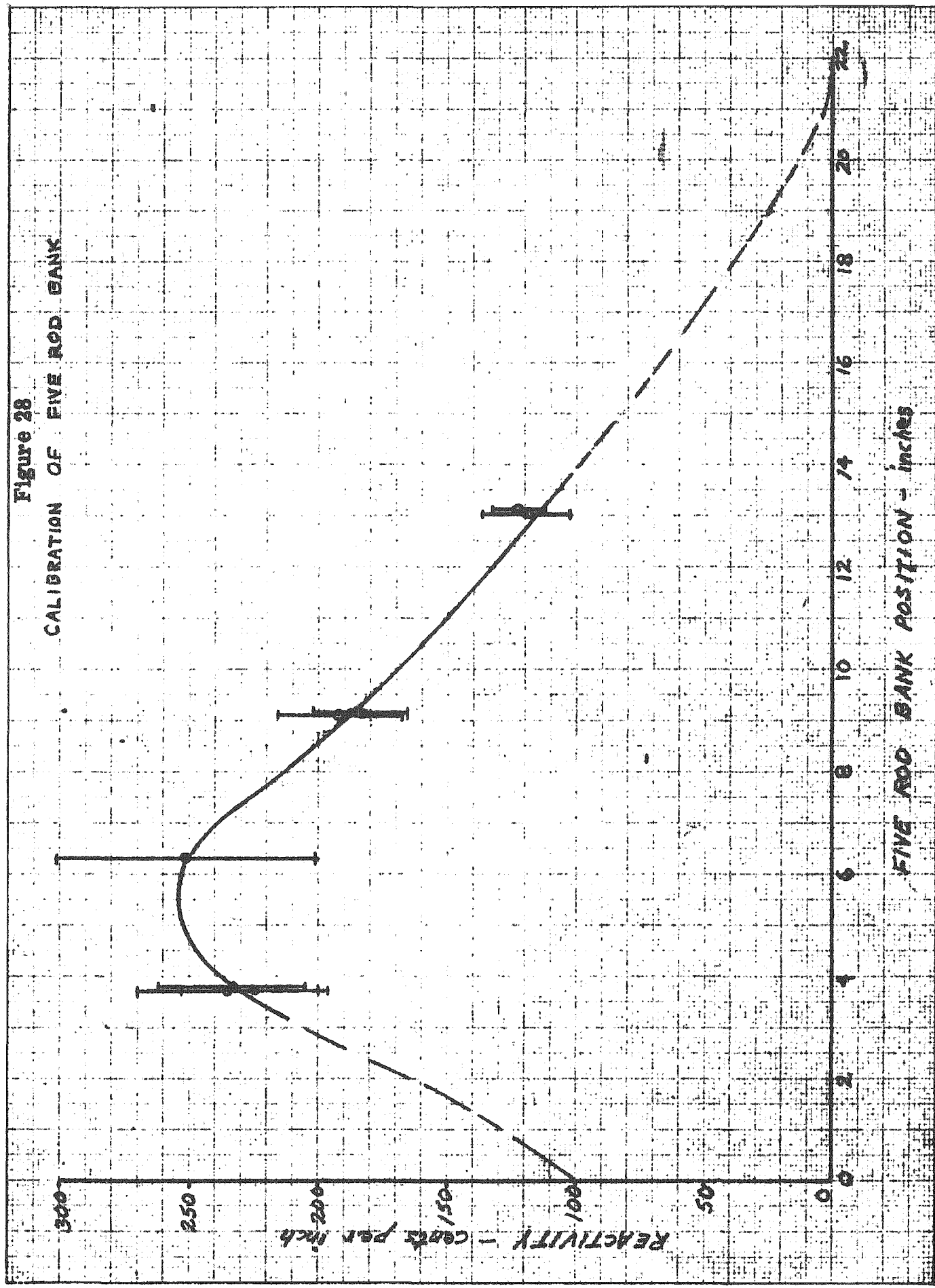


Figure 20

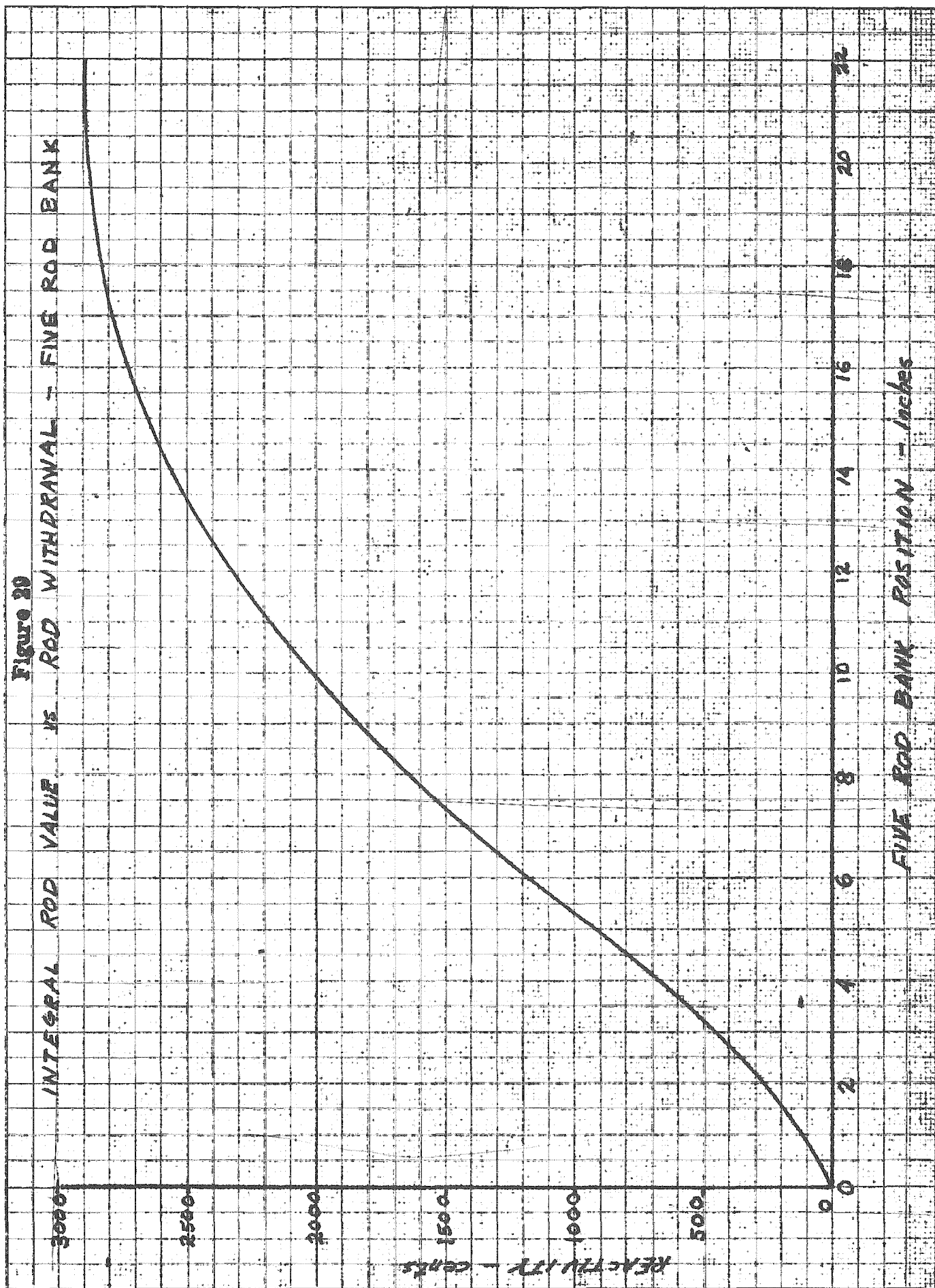


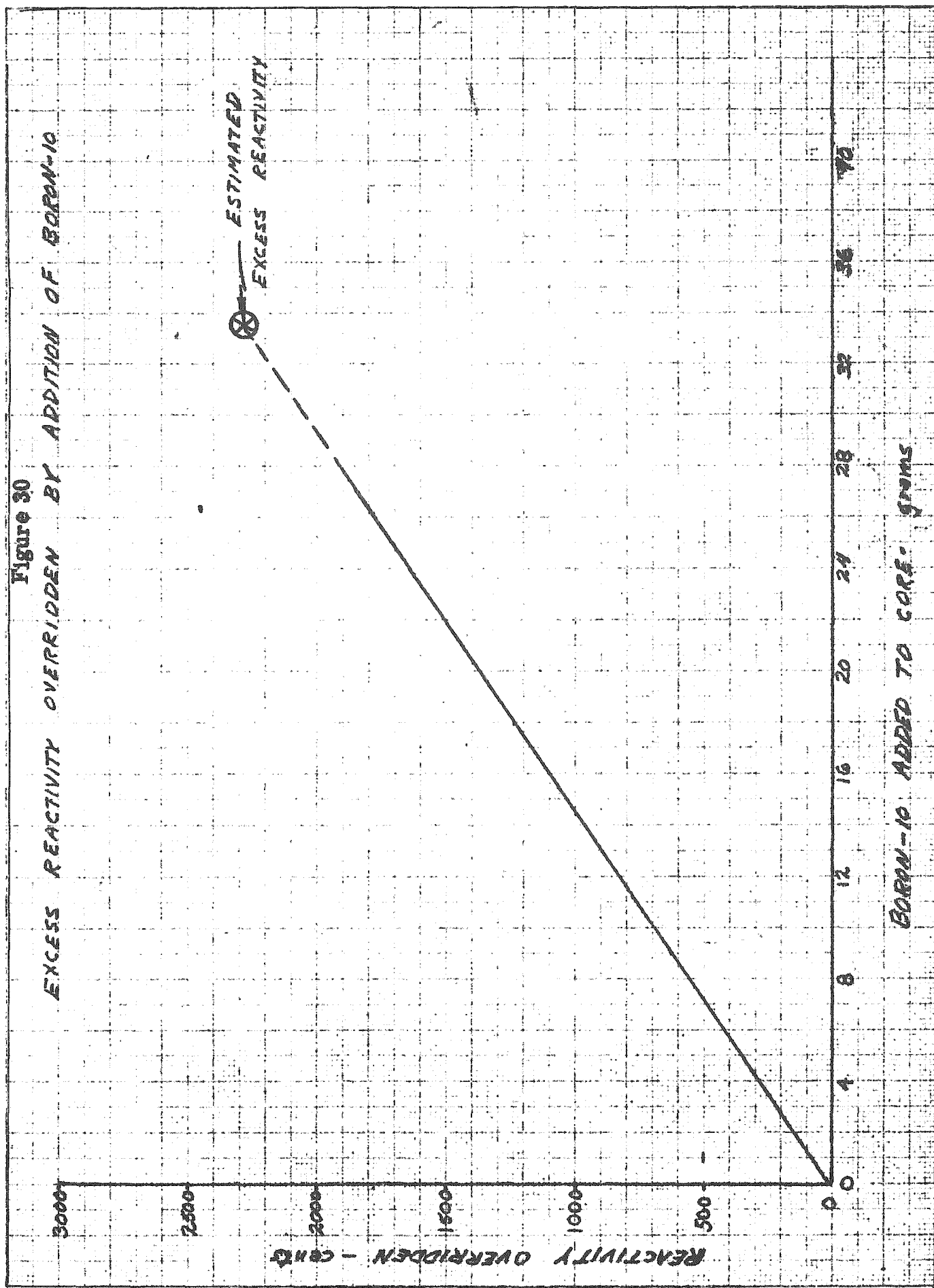
Figure 30

EXCESS REACTIVITY OVERRIDDEN BY ADDITION OF BORON-10

ESTIMATED
EXCESS REACTIVITY

BORON-10 ADDED TO CORE - GRAMS

REACTIVITY OVERRIDDEN - CENTS



CHAPTER 6

TEMPERATURE COEFFICIENT

The data presented in this chapter results from a rerun of an experiment previously reported (4). Although the temperature range extends only from 68°F to 170°F, the improvement in the data assures a somewhat more confident extrapolation.

6.1 Experimental Technique

The water in the reactor tank was heated by two 15 KVA immersion type heaters located at the bottom of the reactor tank and approximately two feet from the active core. An agitator was employed to stir the water and insure a uniform temperature throughout the reactor.

Water temperatures were measured by three iron-constantan thermocouples located symmetrically at the active core midplane adjacent to the core. A Bristol Manual Balance Indicating Potentiometer was used in conjunction with the thermocouples. All three thermocouples yielded consistent temperature readings. The average rate of temperature increase from 70°F to 170°F was 9°F per hour. This rate varied uniformly from 12°F per hour at 70°F to 6°F per hour at 170°F.

The critical position of various control rod configurations was determined, and control rod calibrations were made at approximately 20°F intervals. The temperature coefficient was calculated from the changes in control rod position with temperature and the control rod calibrations.

6.2 Control Rod Positions vs Temperature

The critical positions as a function of temperature were determined for the following cases:

6.2.1 Control Rods 1, 2, 3, 4 and C as a 5 rod bank, A & B fully withdrawn - Fig. 31.

6.2.2. Control Rods 1, 2, 3, & 4 at 3.73 inches withdrawn, Rod C adjusted and A & B fully withdrawn - Fig. 32.

6.2.3 Control Rods 1, 2, 3, & 4 at 3.90 inches withdrawn, Rod C adjusted and A and B fully withdrawn - Fig. 33.

6.2.4 Control Rods 1, 2, 3, and 4 at 4.30 inches withdrawn, Rod C adjusted and A and B fully withdrawn - Fig. 34.

Table 7 includes the data plotted in Figs. 31, 32, 33, and 34.

6.3 Control Rod Calibrations.

Calibrations of the 5 rod bank and rod C at each of the aforementioned (Sec. 6.2) control rod configurations were made by period measurements. The rise in temperature during the calibration is considered negligible.

Tables 7 and 8 present the calibrations for rod C and the 5 rod bank.

The rod worth is plotted as a function of the average rod position for calibration as shown in Figs. 35, 36, 37, and 38. The change in rod worth is primarily a function of its position with respect to the core and the other control rods and not of the temperature.

TABLE 7
 REACTIVITY WORTH OF ROD C AT VARIOUS
 4 ROD BANK
 POSITIONS VS. TEMPERATURE

Temperature of	Position of Rods 1, 2, 3, & 4	Critical Position of Rod C - inch	Super Critical Position of Rod C - inch	Worth of Rod C Cents/inch
68	3.73	3.74	4.06	55.3
80	3.73	3.79		
89	3.73	3.86	4.16	48.3
100	3.73	3.98		
110.5	3.73	4.18	4.51	47.3
120	3.73	4.33		
130	3.73	4.41	4.69	52.2
140	3.73	4.58		
150	3.73	4.71	4.99	55.7
160	3.73	4.80		
165	3.73	4.91	5.17	53.1
168	3.73	5.00		
70	3.90	3.23	3.60	45.2
91	3.90	3.38	3.74	47.0
112.5	3.90	3.72	4.08	50.2
130.6	3.90	3.97	4.28	54.2
151.3	3.90	4.26	4.55	52.4
166.3	3.90	4.51	4.80	51.7
71.5	4.30	1.81	2.36	35.3
91.5	4.30	1.99	2.42	36.1
113	4.30	2.48	2.87	39.4
132.5	4.30	2.77	3.13	45.2
151.6	4.30	3.08	3.41	46.1
167.3	4.30	3.38	3.66	49.7

TABLE 8
REACTIVITY WORTH OF 5 ROD BANK VS. TEMPERATURE

Temperature of	Average Critical Position of 5 Rod Bank - 1 inch	Average Super Critical Position of 5 Rod Bank	Worth of 5 Rod Bank Cents/inch
68	3 730	3.798	204.
95	3.768	3.844	193.
116	3.866	3.942	198.
133	3.926	3.988	230.
153	3.998	4.062	214.
168	4.064	4.128	189.

Figure 31
CRITICAL POSITION OF FIVE ROD BANK vs TEMPERATURE

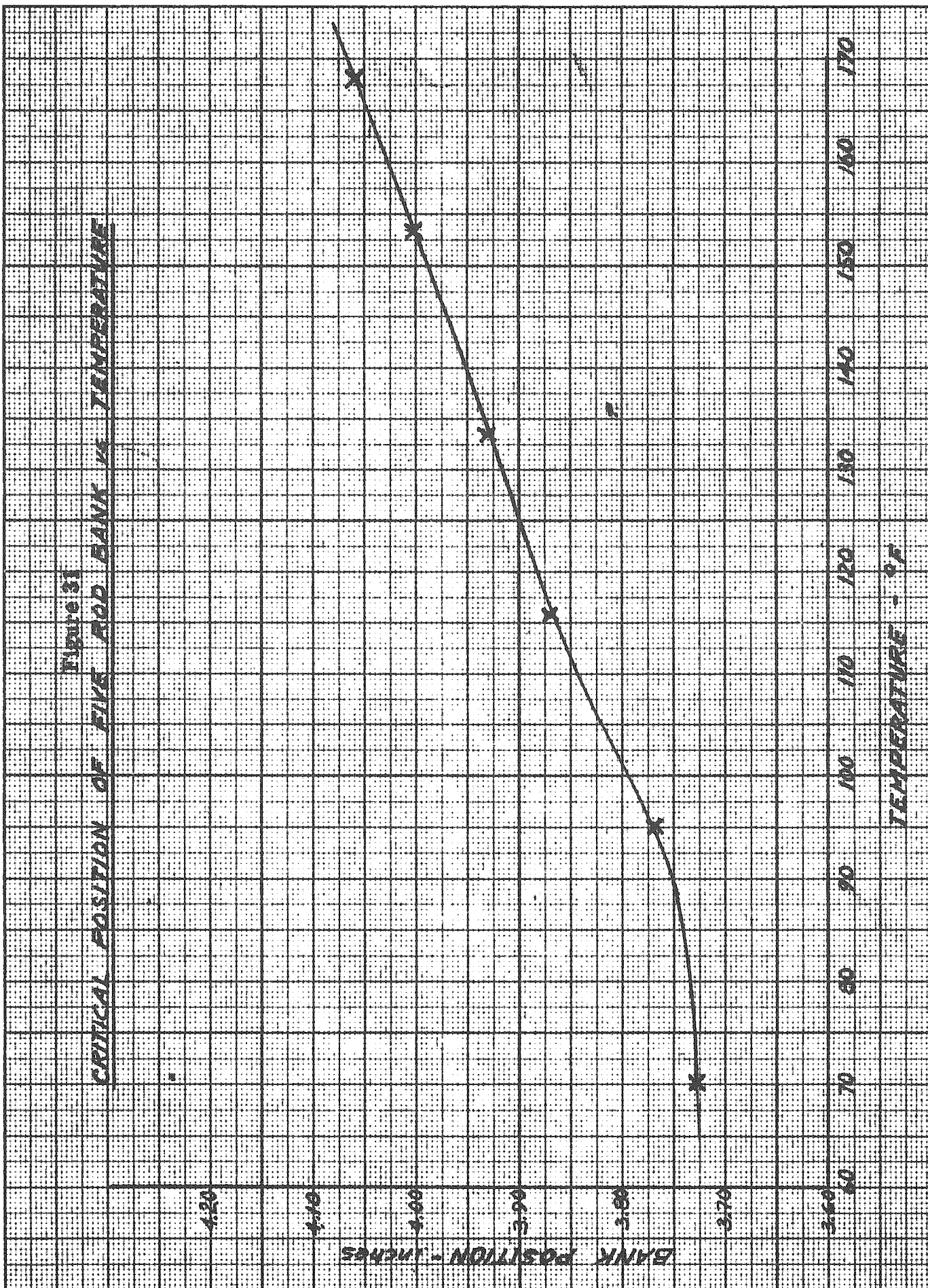


Figure 32

CRITICAL POSITION OF ROD C VS TEMPERATURE
CONTROL RODS 1, 2, 3, 4 AT 373 INCHES

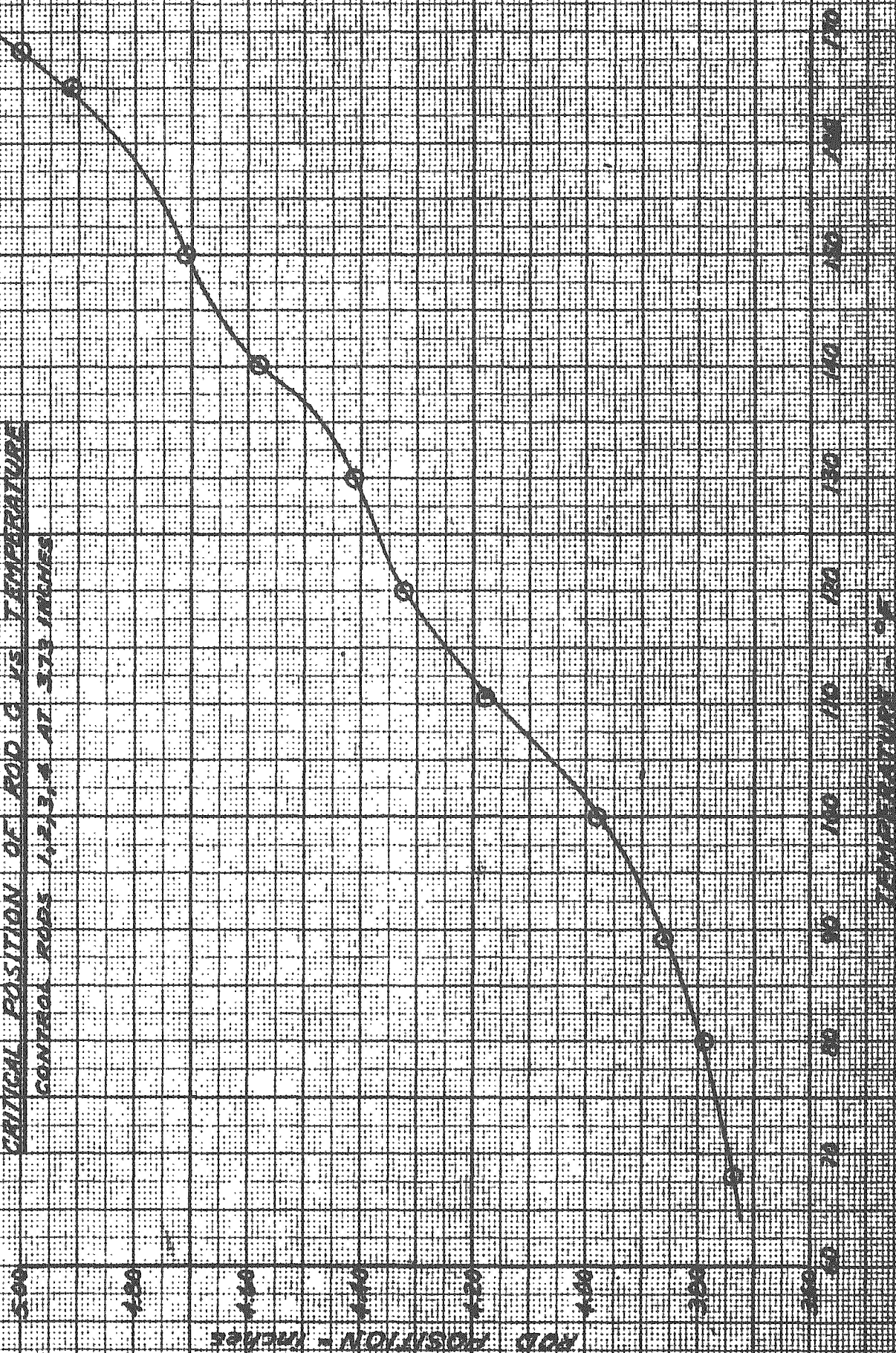


Figure 33

CRITICAL POSITION OF ROD C VS TEMPERATURE

CONTROL RODS 1, 2, 3, 4 AT 3.50 INCHES

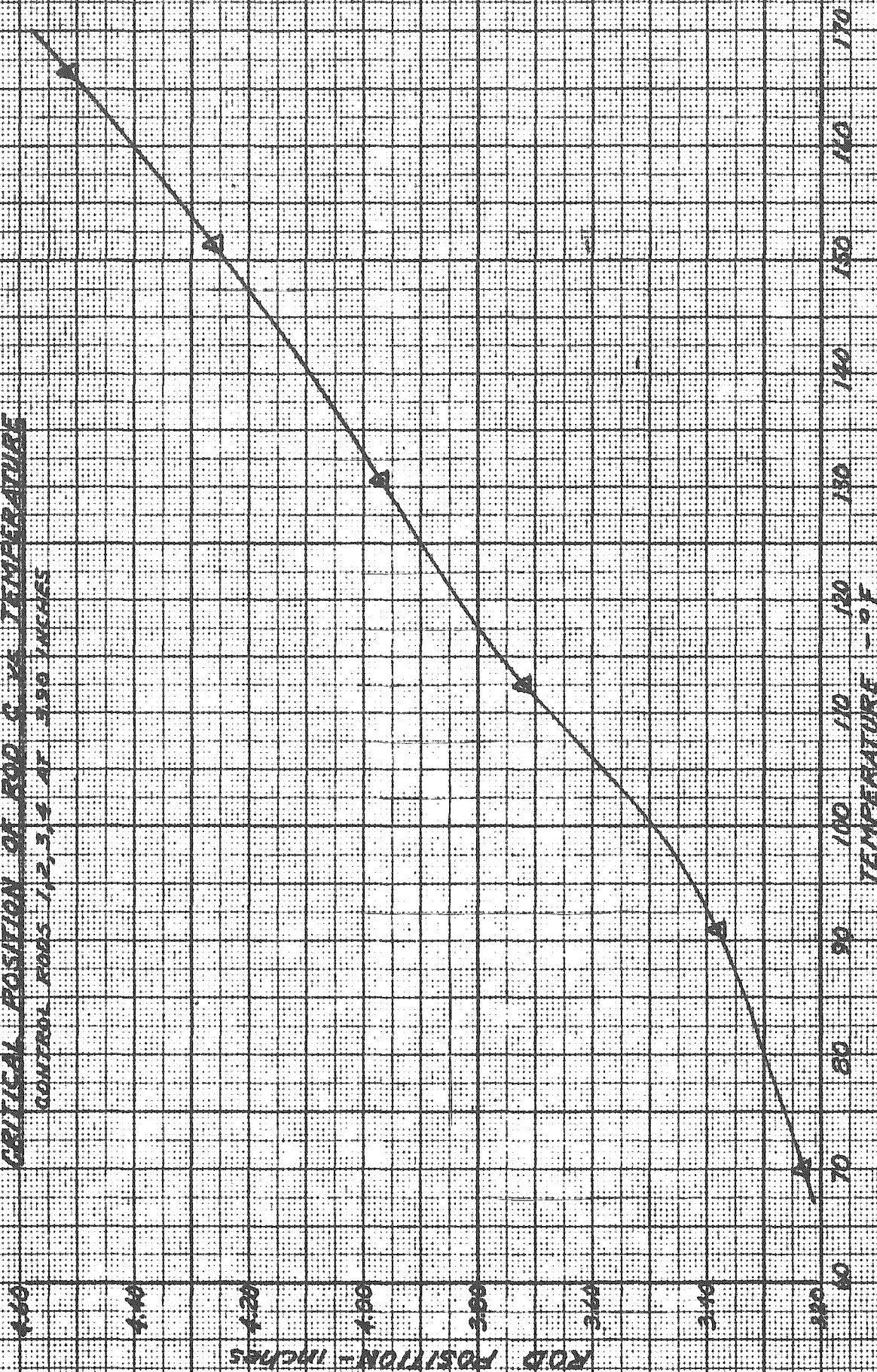


Figure 34

CRITICAL POSITION OF ROD C VS TEMPERATURE

CONTROL RODS 1, 2, 3, 4 AT 4.30 INCHES

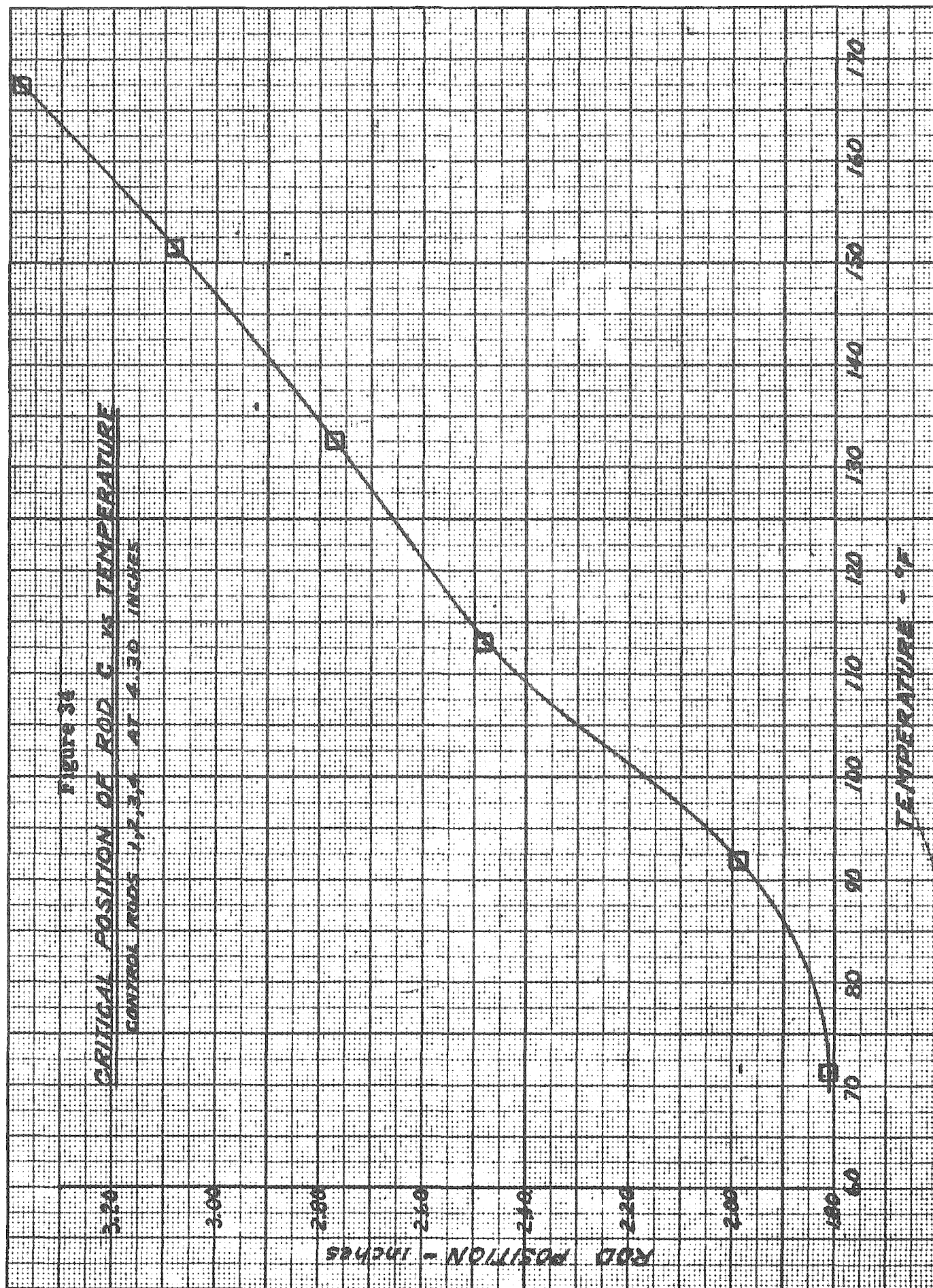


Figure 35
CALIBRATION OF FIVE ROD BANK
VARIABLE TEMPERATURE

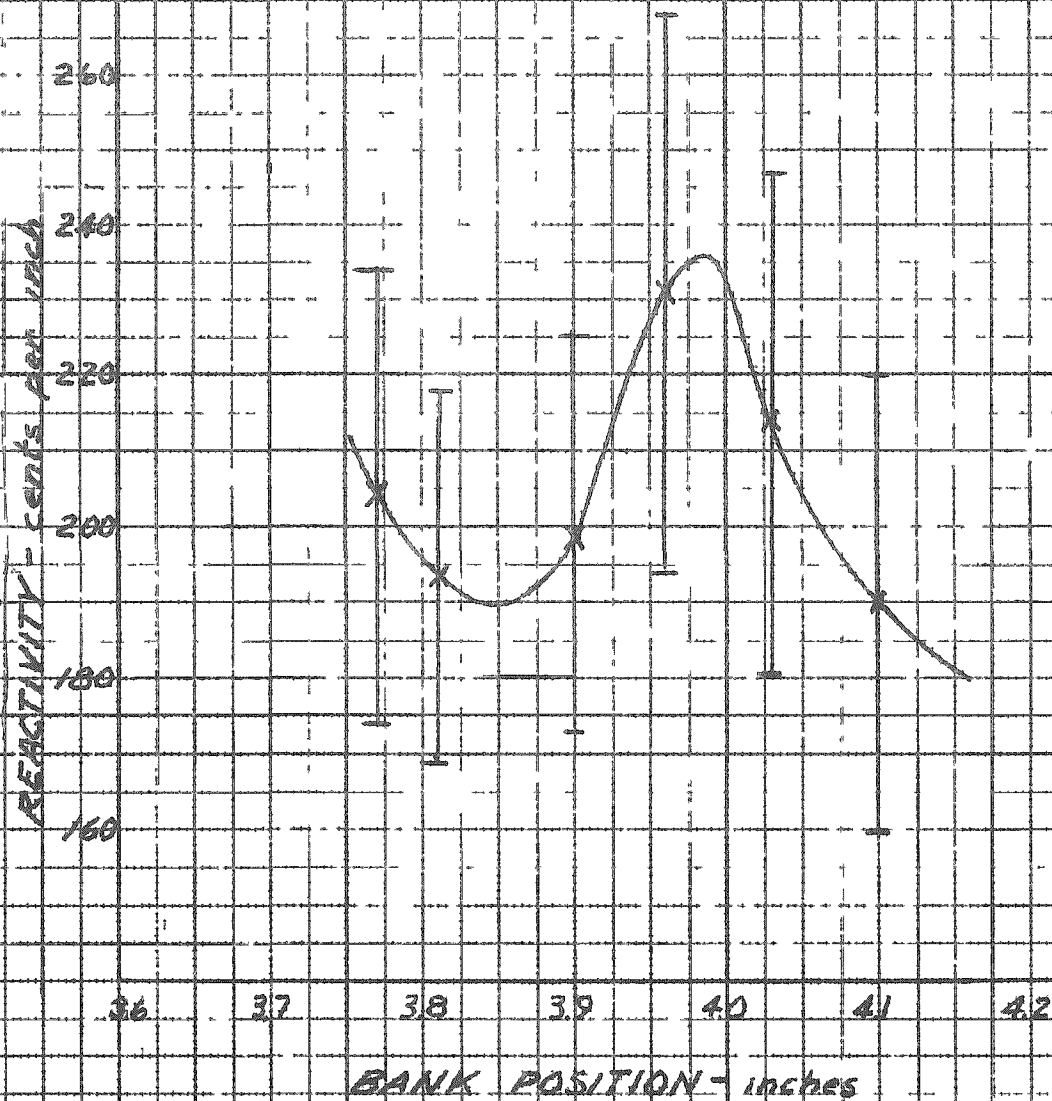


Figure 36

CALIBRATION OF CONTROL ROD C

CONTROL RODS 1,2,3,4 AT 3.75 INCHES
VARIABLE TEMPERATURE

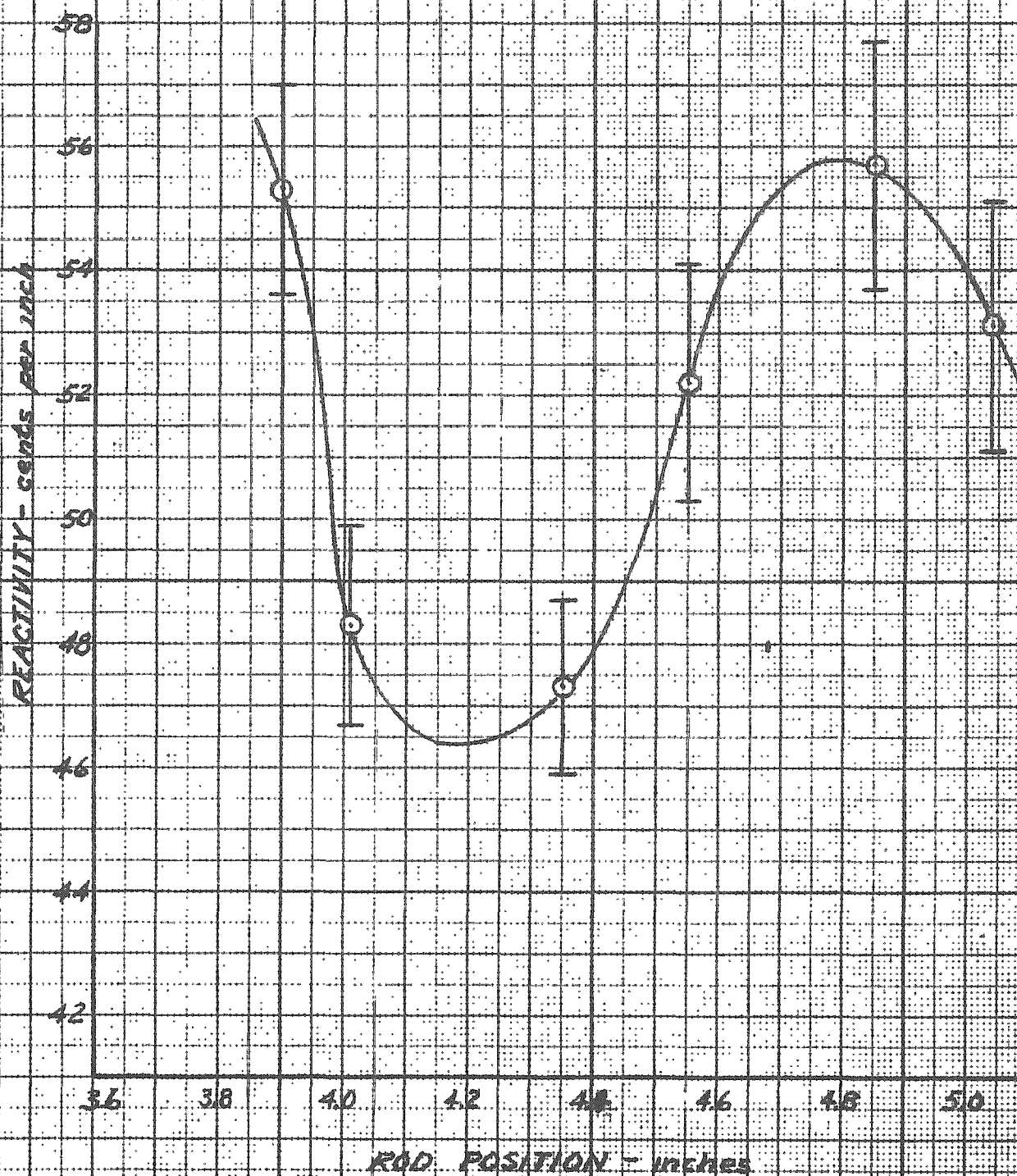


Figure 37

CALIBRATION OF CONTROL ROD C

CONTROL RODS 1,2,3,4 AT 3.00 INCHES
VARIABLE TEMPERATURE

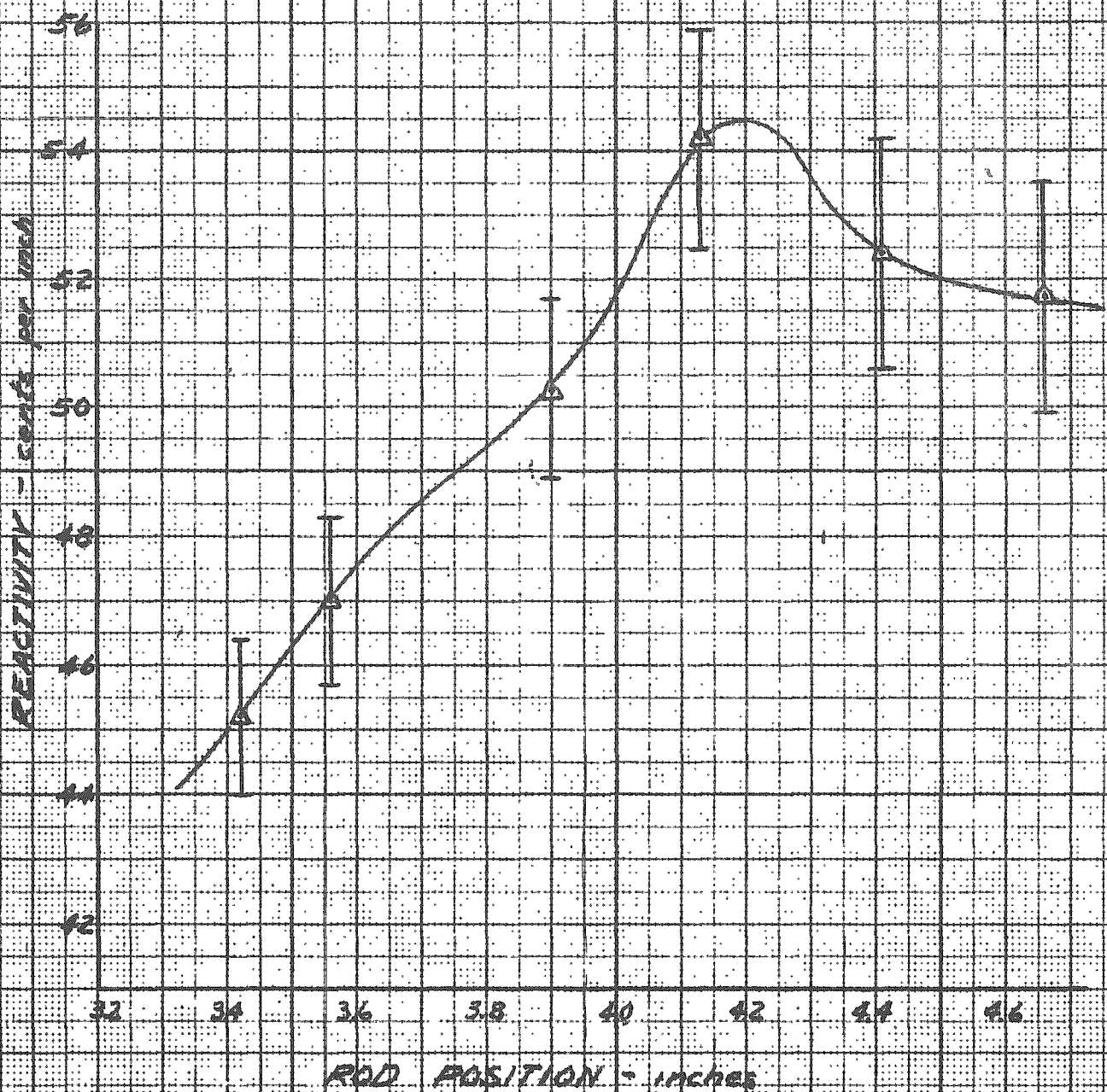
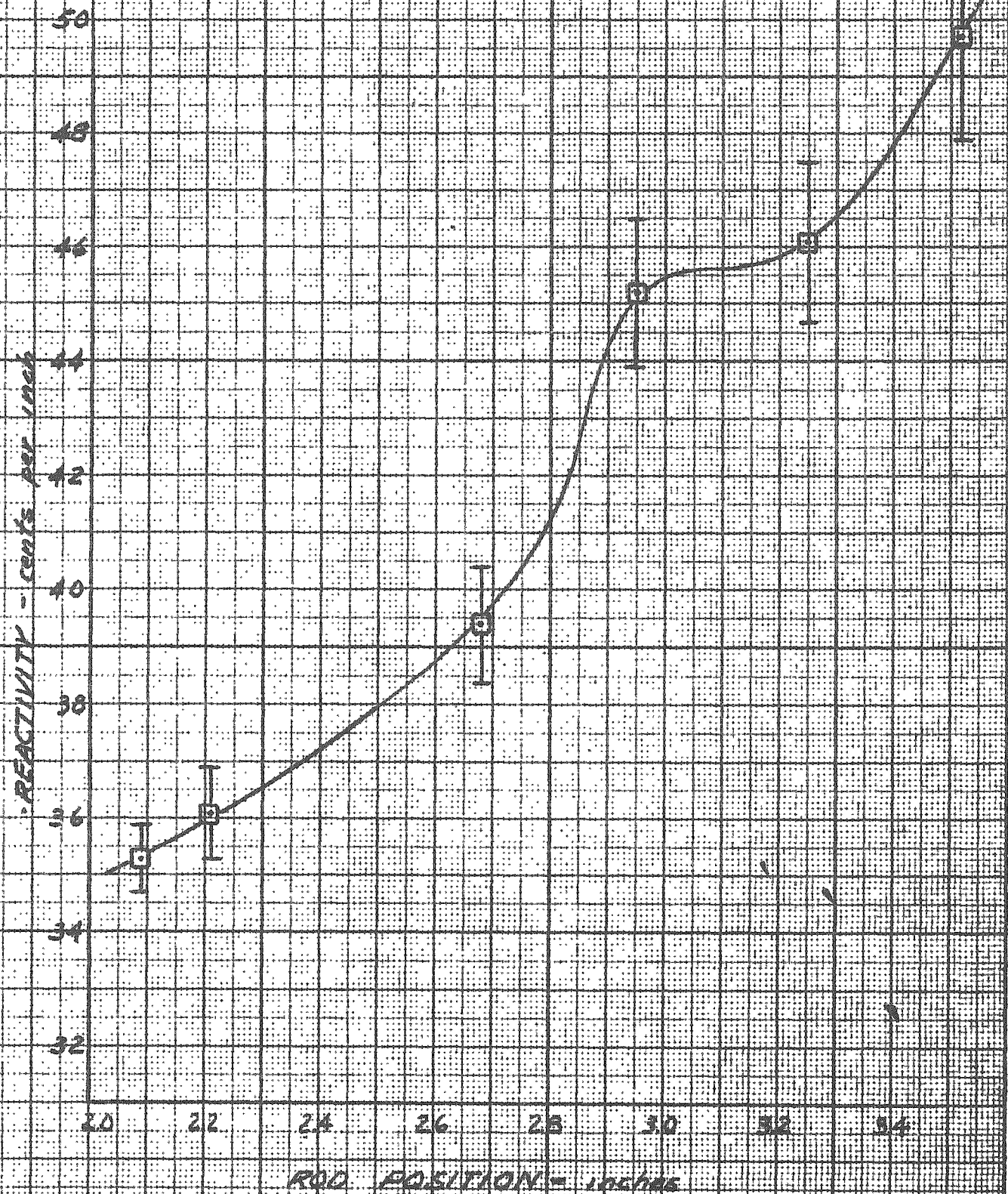


Figure 38

CALIBRATION OF CONTROL ROD C

CONTROL RODS 1,2,3,4 AT 4.30 INCHES
VARIABLE TEMPERATURE



6.4 Temperature Coefficient vs. Temperature.

The temperature coefficient has been calculated from the data by two methods. Method #1 utilized the rod position vs. temperature curves, Figs. 31, 32, 33, and 34, in conjunction with the reactivity corresponding to a measured rod movement, Tables 7 & 8. The temperature intervals corresponding to these measured rod movements were therefore known and one could determine the average temperature coefficient over the temperature intervals directly.

Figure 39 represents the data reduced by this method. The horizontal lines indicate the temperature interval over which the average temperature coefficient was determined.

Method #2 utilized the rod position vs. temperature curves, Figs. 31, 32, 33, and 34, and the rod calibration curves, Figs. 35, 36, 37 and 38. The temperature was then determined using the rod worth corresponding to the average rod position over a 10°F temperature interval. (The data is presented in Fig. 40.) The points were plotted at the midpoint of the temperature interval and the curve was drawn through the average of the points at each temperature. The vertical lines represent the average probable error associated with the data. Both methods involved the assumption that the control rod calibrations are independent of temperature, over each interval.

6.5 Conclusion.

Since Method #1 did not involve the calibration curves, Figs. 35, 36, 37 and 38, the distortion in the temperature coefficient curve is independent of way in which those curves were drawn. Furthermore, since Method #2, using the calibration curves, yields essentially the same temperature coefficient effect, these experiments indicate an unexplained calibration curve fine structure.

Figure 39
TEMPERATURE COEFFICIENT VS
TEMPERATURE

METHOD # 1

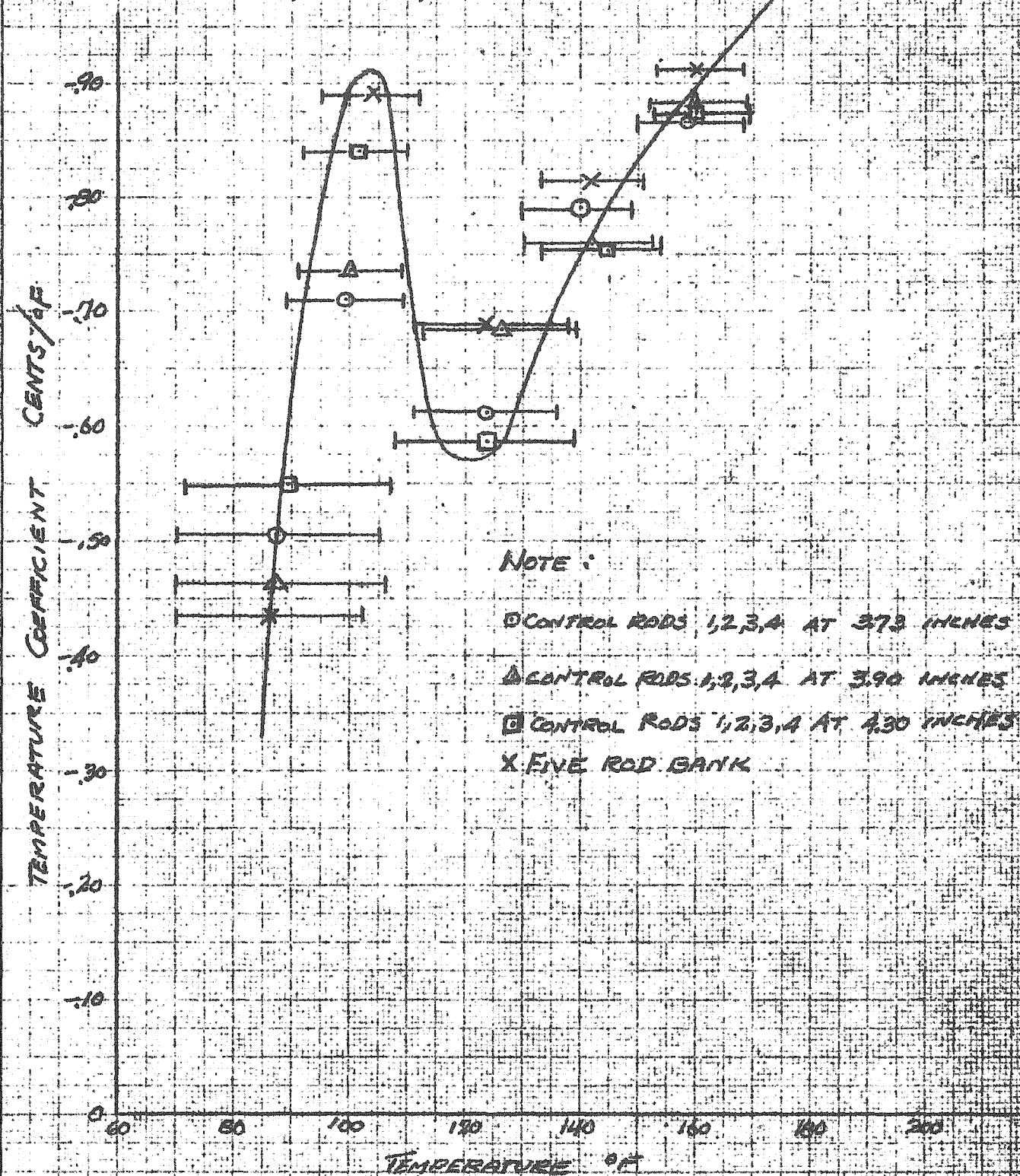
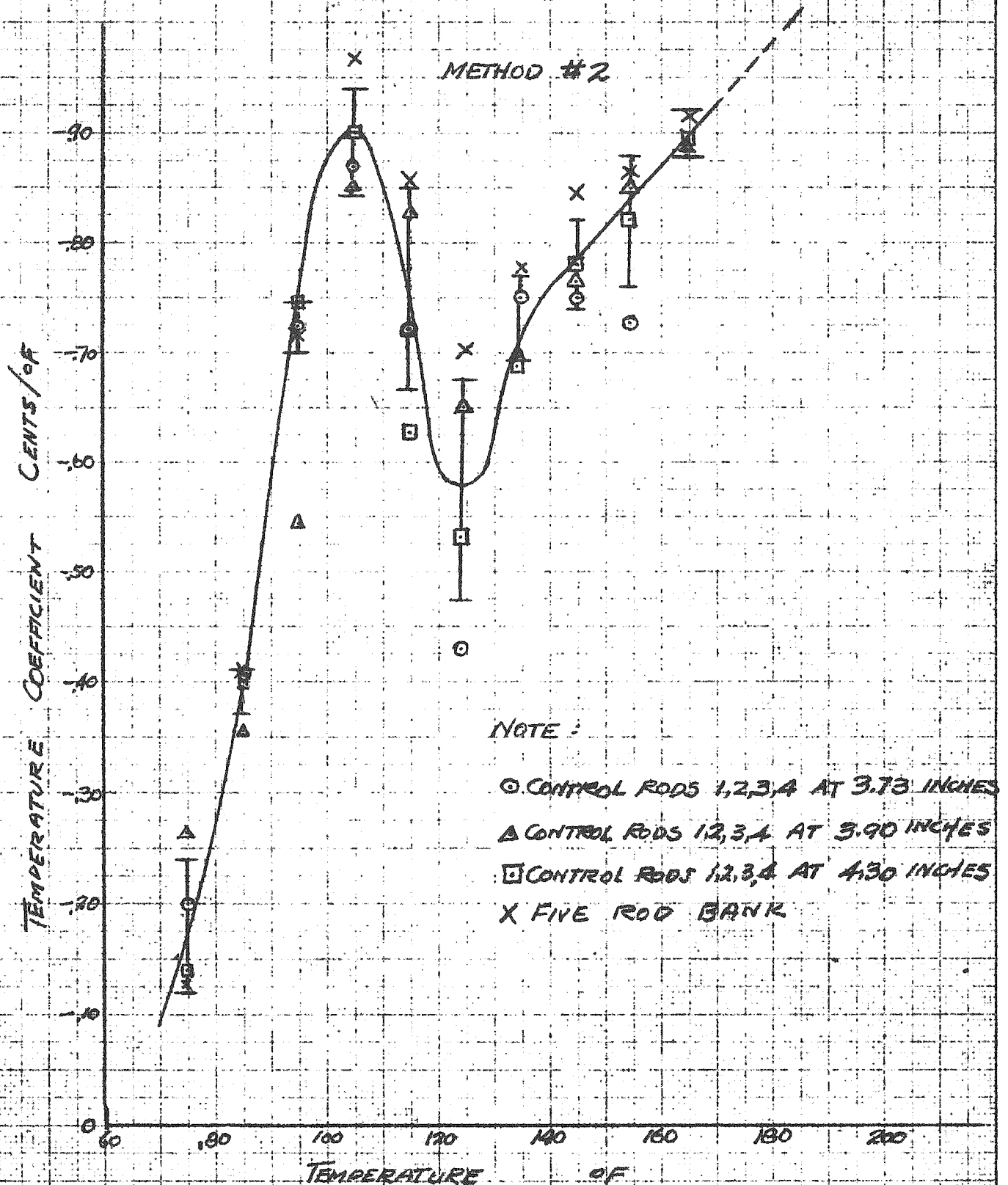


Figure 40

TEMPERATURE COEFFICIENT VS
TEMPERATURE



CHAPTER 7. NEUTRON FLUX MEASUREMENTS

An extensive flux measurement program was carried out during the Zero Power Experiments. One purpose of these measurements was to determine the relative power distribution in the core. This was done in the clean core with the 5 Rod bank at 3.7 inches withdrawn, and in the core poisoned with 4 boron-steel strips per element, with the Bank at 6.30 inches.

Considerable effort was taken to determine fine flux variations in the core. Measurements were made to investigate flux peaking at the element side plate, between fuel plates of an element, in the reflector, and in the water region inside control rod absorber sections.

7.1 Description of Techniques.

All flux measurements were made by activating pure gold foils, 0.002 inches thick and 0.25 inches in diameter. The critical experiments at Oak Ridge ⁽⁵⁾ indicated that flux distributions measured with bare gold are similar to power distributions measured with uranium foils, in core regions away from thermal flux peaks.

Cadmium cover gold activations were made to investigate variations of the thermal flux, and the neutron spectrum in the core. The cadmium covers (shown in Fig. 41) were .020 inches thick.

In general, foils were positioned in the core by taping them to plexiglass stringers (See Fig. 41) and sliding the stringers between the plates of a fuel element. Foils exposed in this manner were spaced about 0.030 inches from the surface of a fuel plate. Other foils were taped to the surface of fuel plates that were accessible, on fuel element side plates and on the surface of control rod absorber sections.



Figure 41
NEUTRON FLUX DETECTORS

Foil activation was measured by counting the integral gamma activity from gold. Counting equipment consisted of 2 similar scintillation detectors each with a regulated power supply, linear amplifier and scaler (See Fig. 42). Use of the pulse height selection feature of the linear amplifiers made it possible to count only photons of 0.411 Mev or higher, thus reducing background somewhat. The nominal 1 microsecond total resolving time of the equipment made dead time corrections unnecessary for the range of activities encountered during the experiments.

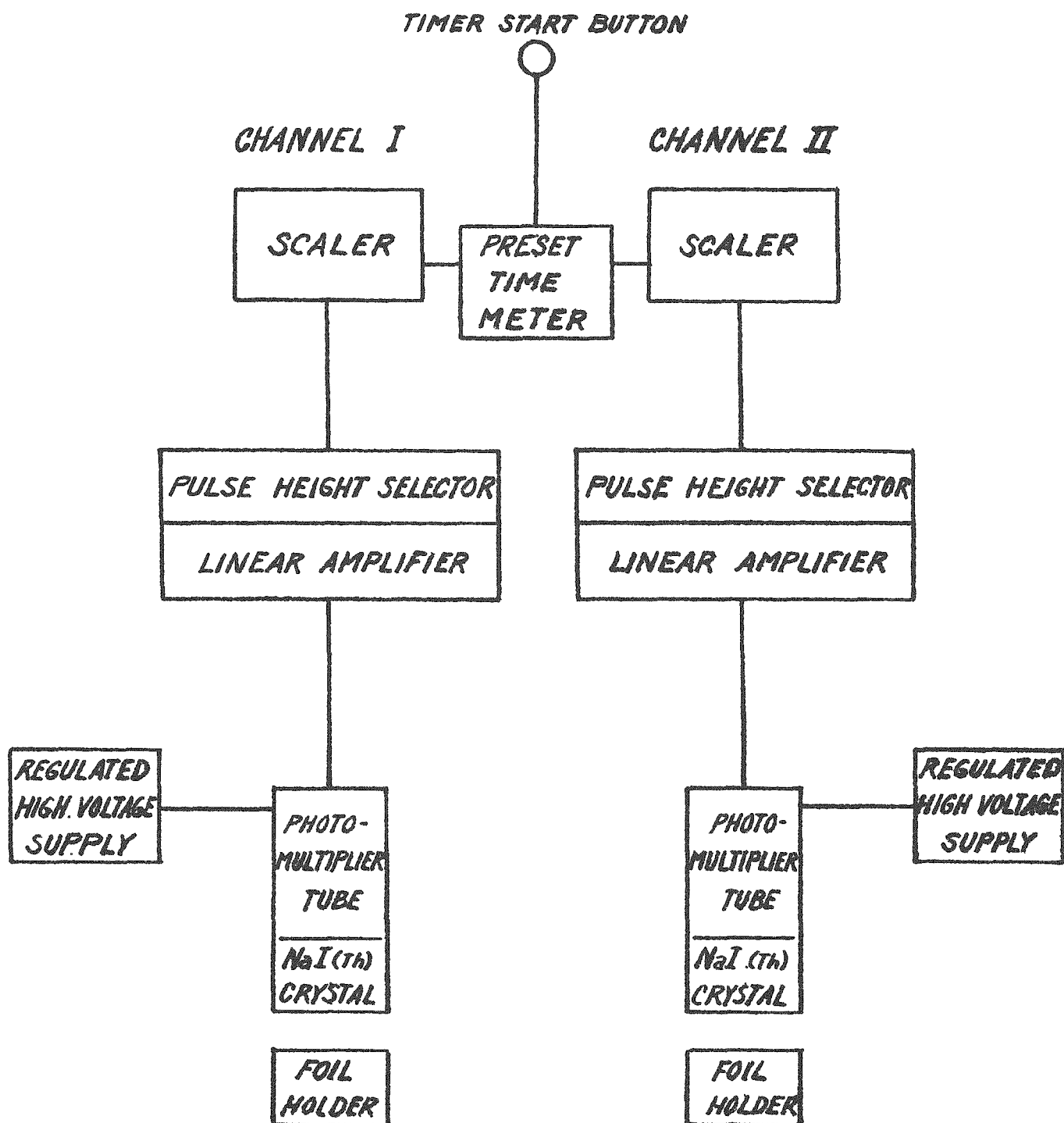
During each foil run, a gold normalizing foil, 0.002 inches thick and 0.75 inches in diameter was exposed at a fixed point in the core. Each foil was counted in one counting channel, while the normalizer was counted for the same length of time in the other channel, and then the foils were switched between counters and recounted. The ratio of the activity of the foil to the normalizing foil was found for each counting, and their average plotted as the relative activity of the foil. Simultaneous counting of the foil and normalizer automatically corrected data for decay, and variation in power during successive runs.

To simplify the interpretation of the data, all points were renormalized at the end of the experiments to an average relative activity in the core equal to unity. This average was found for the 2 core conditions investigated: clean core, 5 rod bank at 3.70 inches, and the poisoned core, 5 rod bank at 6.30 inches. Average relative activity was determined in each case by axial traverses made at the center of each of 8 elements in the core. Fine flux variations in the core, such as peaking at side plates, and depressions adjacent to absorber sections tend to make the center line traverses a representative value of the average flux in an element.

The normal reactor power during foil activation was 6 ± 2 watts. At this power level, foils were activated for 1/2 to 1 hour.

FIGURE 42

COUNTING ROOM EQUIPMENT SCHEMATIC



7.2 Measurements in the Clean Core - 5 Rod Bank at 3.7 inches.

7.21 Bare Gold Gross Mapping.

A complete map of gross core flux was made in the cold clean reactor.

Table 9 and Figs. 43, 44, 45, and 46 describe the data.

For this measurement foils were placed along the center line of all elements in one octant of the core unless otherwise indicated. The average bare gold activity was determined for each element based on a core average of unity. Figure 47 shows the individual element average bare gold activation in terms of a core average of unity.

TABLE 9

VERTICAL TRAVERSE ALONG ELEMENT AXES

Vertical Position (Distance above Bottom of Core in inches)		Relative Activity (Normalized to Average Core Activity = 1)
Element 14		
.5		.836
2.5		.999
4.5		1.109
6.5		1.088
9.5		1.030
14.0		.825
18.0		.531
21.0		.300
Element 24 (control rod 1)		
.5		1.156
2.5		1.561
4.5		4.152
6.5		3.222

TABLE 9 (Cont'd.)

	Vertical Position (Distance above Bottom of Core in inches)	Relative Activity (Normalized to Average Core Activity = 1)
Element 34	.5	1.687
	2.5	1.808
	4.5	1.976
	6.5	1.756
	9.5	1.551
	14.0	1.183
	18.0	.757
	21.0	.427
Element 15	.5	.920
	2.5	.946
	4.5	1.183
	6.5	1.188
	9.5	1.135
	14.0	.909
	18.0	.604
	21.0	.329
Element 25	.5	1.346
	2.5	1.529
	4.5	1.734
	6.5	1.708
	9.5	1.598
	14.0	1.235
	18.0	.820
	21.0	.436
Element 35	.5	1.456
	2.5	1.819
	4.5	2.029
	6.5	1.903
	9.5	1.740
	14.0	1.346
	18.0	.846
	21.0	.484

TABLE 9 (Cont'd.)

	Vertical Position (Distance above Bottom of Core in inches)	Relative Activity (Normalized to Average Core Activity = 1)
Element 16	.5	.615
	2.5	.783
	4.5	.978
	6.5	.993
	9.5	.999
	14.0	.841
	18.0	.583
	21.0	.309
Element 26	.5	1.093
	2.5	1.346
	4.5	1.645
	6.5	1.756
	9.5	1.698
	14.0	1.351
	18.0	.878
	21.0	.478
Element 45	.5	1.503
	2.5	1.798
	4.5	1.887
	6.5	1.724
Element 44 (control rod C)	-6.0	.079
	-5.0	.184
	-4.0	.331
	-3.4	.447
	-1.4	.867
	- .4	1.156
	+ .5	1.424
	1.6	1.682
	2.5	1.892
	4.5	4.972
	6.5	3.663
Element 45 (Side Adjacent to Element 44)	2.5	1.939
	4.5	2.344
	6.5	1.099

TABLE 9 (Cont'd.)

	Vertical Position (Distance above Bottom of Core in inches)	Relative Activity (Normalized to Average Core Activity = 1)
Element 45	2.5	1.761
(Side Adjacent	4.5	2.218
to Element 46)	6.5	1.125
Element 47		
(Side Adjacent	2.5	1.335
to Element 46)	4.5	1.703
	6.5	.772
Element 47	2.5	1.020
(Side Adjacent	4.5	1.261
to Reflector)	6.5	1.325

7.22 Gross Axial Bare and Cadmium Covered Gold Activity in Element 35.

Cadmium covered gold activations were made in the axial direction in element 35. Table 10 and Fig. 48 present this data in comparison with the bare gold activations in element 35.

TABLE 10
VERTICAL TRAVERSE ALONG AXIS OF ELEMENT 35

Vertical Position (Distance above Bottom of Core in inches)	Bare Gold Relative Activity	Cadmium Covered Gold Relative Activity	Cadmium Fraction
.5	1.456	.760	.478
2.5	1.819	1.135	.376
4.5	2.029	1.245	.386
6.5	1.903	1.222	.358
9.5	1.740	1.095	.371
14.0	1.346	.860	.360
18.0	.846	.567	.330
21.0	.484	.288	.405

Figure 43

RELATIVE ACTIVITY vs. POSITION
 CENTER of ELEMENT
 NORMALIZED TO AVERAGE RELATIVE
 ACTIVITY IN CORE = 1
 ROD BANK AT 3.7 inches

RELATIVE ACTIVITY

POSITION ABOVE BOTTOM OF ACTIVE CORE - inches

ELEMENT 35

ELEMENT 25

ELEMENT 15

Figure 44

RELATIVE ACTIVITY VS. POSITION
CENTER OF ELEMENT
NORMALIZED TO AVERAGE RELATIVE
ACTIVITY IN CORE = 1
ROD BANK AT 3.7 inches

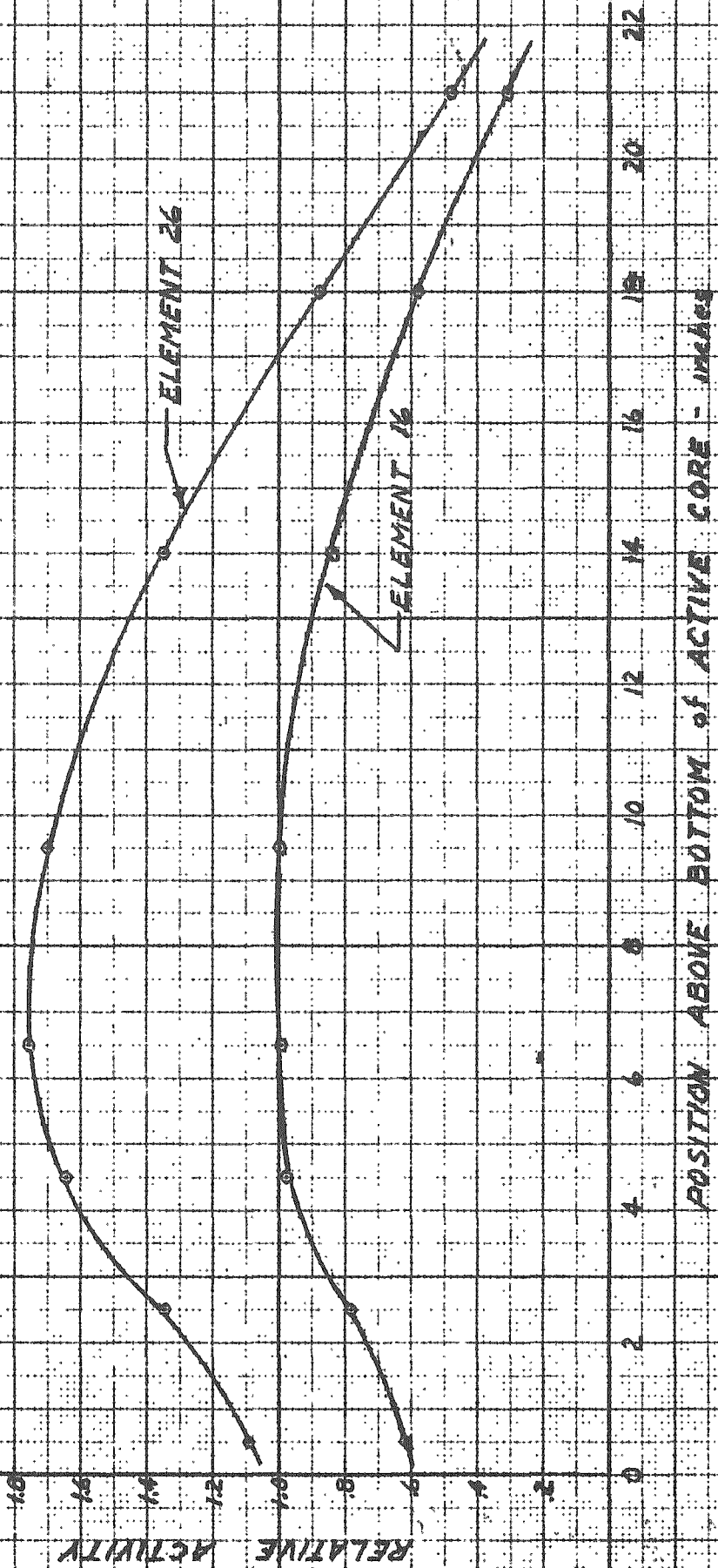


Figure 4b

RELATIVE ACTIVITY VS POSITION

CENTER OF ELEMENT
ROD BANK 37 INCHES
NORMALIZED TO AVERAGE
RELATIVE ACTIVITY IN
CORE = 1

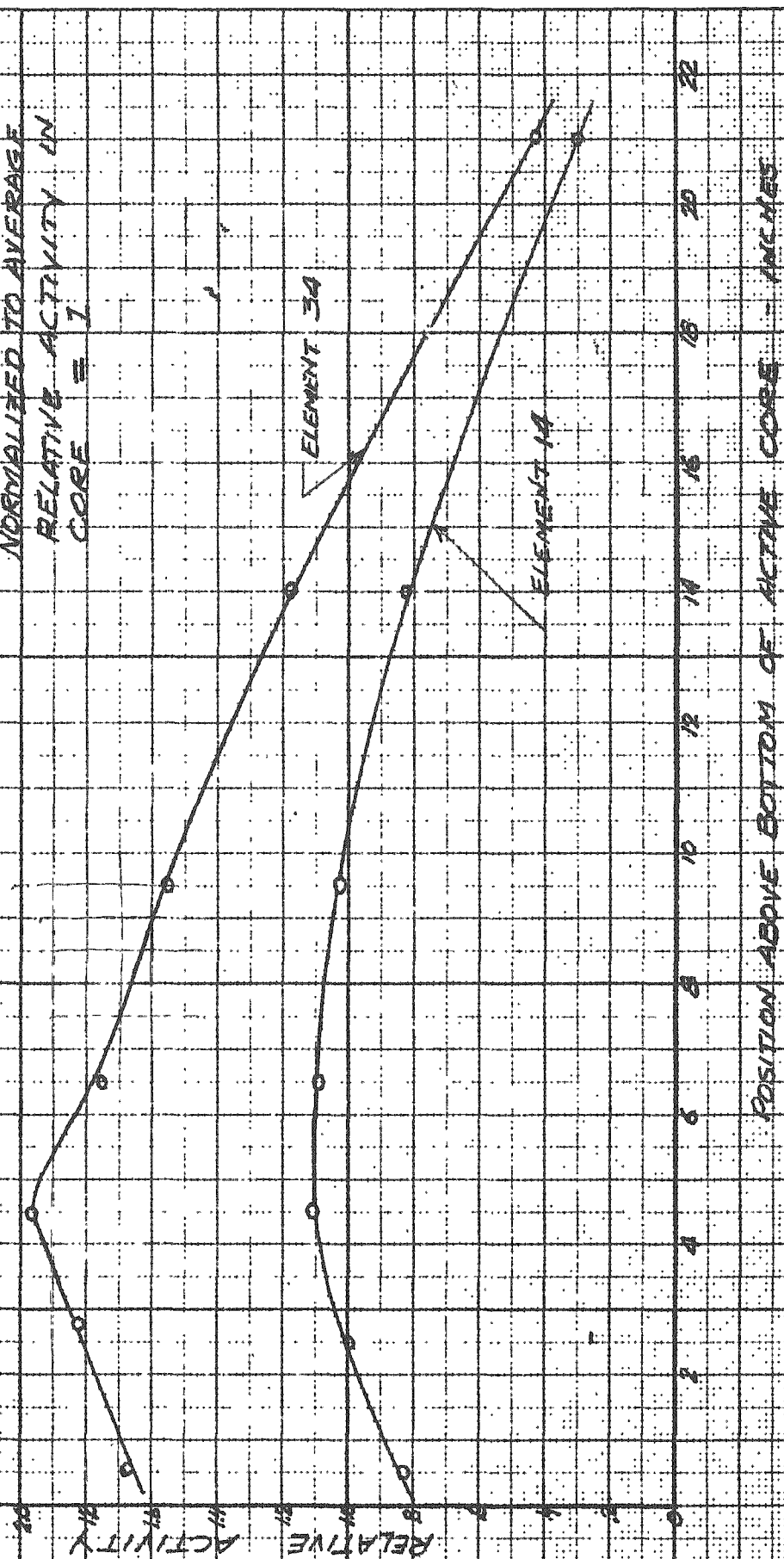


Figure 4B

RELATIVE ACTIVITY VS. POSITION

CENTER OF ELEMENT
NORMALIZED TO AVERAGE
RELATIVE ACTIVITY IN
CORE = 1

ROD BANK AT 3.7 INCHES

ELEMENT 24 (CR #C)

ELEMENT 24 (CR #1)

RELATIVE ACTIVITY

POSITION ABOVE BOTTOM OF ACTIVE CORE - INCHES

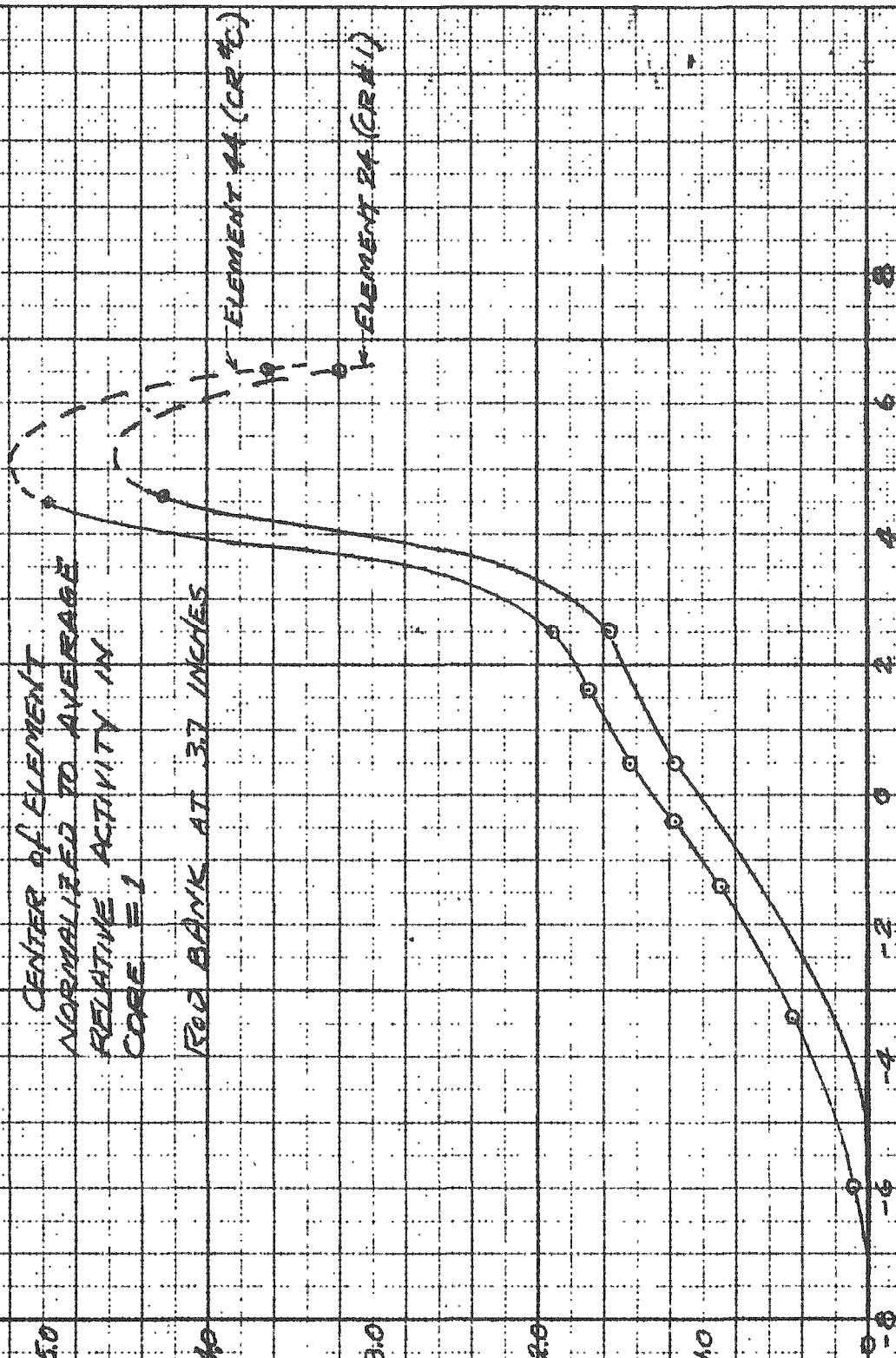


FIGURE 47
AVERAGE ACTIVITY PER ELEMENT
ROD BANK AT 3.7 "

MEASURED WITH BARE GOLD AXIAL TRAVERSES
IN THE CENTER OF ELEMENTS 14, 15, 16, 25, 26,
34, 35 AND CONTROL RODS 1 & C. NORMALIZED
TO AVERAGE REACTOR ACTIVITY = 1 PER ELEMENT.

	12	13	14	15	16	ELEMENT #
	.778	.899	.836	.899	.778	← RELATIVE ACTIVITY
21	.778	1.298	1.277	.352	1.277	1.298
				1		
31	.899	1.277	1.414	1.324	1.414	1.277
			A			.899
41	.836	.352	1.324	.471	1.324	.352
		4		C		.836
51	.899	1.277	1.414	1.324	1.414	1.277
				B		.899
61	.778	1.298	1.277	.352	1.277	1.298
				3		.778
	72	73	74	75	76	
	.778	.899	.836	.899	.778	

Figure 48

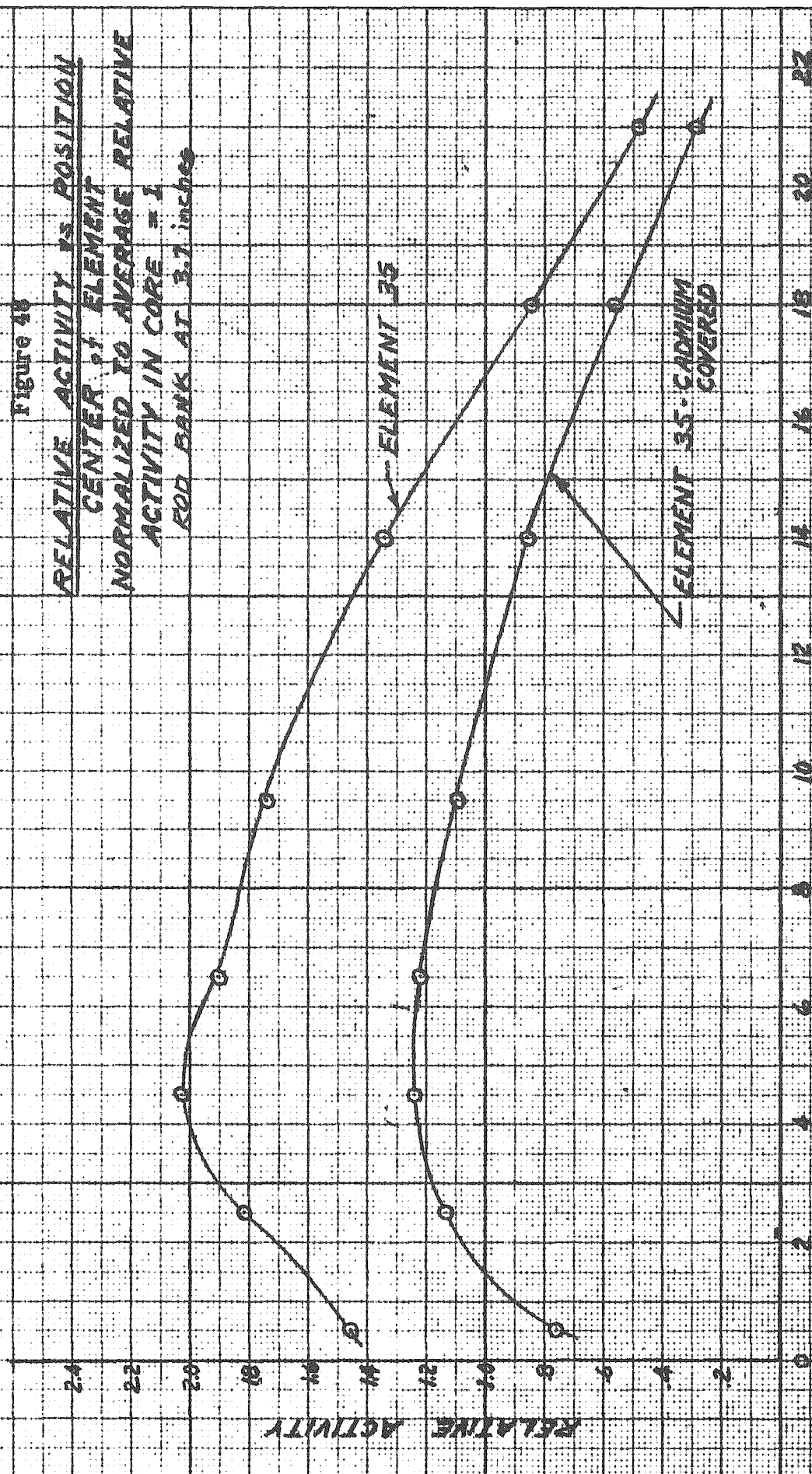
RELATIVE ACTIVITY vs. POSITION
 CENTERED TO ELEMENT
 NORMALIZED TO AVERAGE RELATIVE
 ACTIVITY IN CORE = 1
 ROD BANK AT 3.7 inches

RELATIVE ACTIVITY

POSITION ABOVE BOTTOM OF ACTIVE CORE - inches

ELEMENT 35

ELEMENT 35 - CADMIUM
 COVERED



7.23 Gross Radial Bare and Cadmium Covered Gold Activity

The radial traverses of bare and cadmium covered gold activations were taken at three axial positions. Table 11 and Fig. 49 describe the data taken at 6.5 inches above the bottom of the active core. Table 12 and Fig. 50 describe the data taken at 4.5 inches and Table 13 and Fig. 50 present the data taken at 2.5 inches above the bottom of the active core.

Figure 51 shows the support for the foil activations taken in the reflector.

TABLE 11

RADIAL TRAVERSE AT 6.5 INCHES ABOVE THE BOTTOM OF THE ACTIVE CORE

<u>Position</u>	<u>Inches from Center Line</u>	<u>Bare Gold</u>	<u>Cadmium Covered Gold</u>	<u>Cd Fraction</u>
1. Control Rod C, at center of Absorber section in water hole	0	3.67		
2. Element 45, on plate next to Control Rod C	1.50	1.1	.763	.307
3. Element 45, 2 plates away from Control Rod C	1.70	1.40		
4. Element 45, at center of element	2.93	1.72	1.1	.363
5. Element 45, 2 plates away from Control Rod 2	4.1	1.41		
6. Element 45, on plate next to Control Rod 2	4.30	1.12	.795	.294
7. Control Rod 2, at center of Absorber Section in water hole	5.80	3.22		
8. Element 47, on plate next to Control Rod 2	7.25	.77	.558	.279
9. Element 47, at center of element	8.80	1.09	.700	.357

TABLE 11 (Cont'd)
RADIAL TRAVERSE AT 6.5 INCHES ABOVE THE BOTTOM OF THE ACTIVE CORE

	<u>Inches from Center Line</u>	<u>Bare Gold</u>	<u>Cadmium Covered Gold</u>	<u>Cd Fraction</u>
10. Element 47, on outside plate next to reflector	10.15	1.32	.500	.623
11. In reflector	11.3	2.40	.290	.879
12. In reflector	13.3	1.32	.089	.933
13. In reflector	15.3	.495	.030	.939
14. In reflector	17.3	.143	.013	.909
15. In reflector	19.3	.054	.005	.911
16. In reflector	23.3	.008		

TABLE 12
RADIAL TRAVERSE AT 4.5 INCHES ABOVE THE BOTTOM OF THE ACTIVE CORE

<u>Position</u>	<u>Inches from Center Line</u>	<u>Bare Gold</u>
1. Control Rod C, at center of water hole between fuel and absorber	0	4.972
2. Element 45, on plate next to Control Rod C	1.50	2.344
3. Element 45 at center of element	2.93	1.976
4. Element 45, on plate next to Control Rod 2	4.30	2.218
5. Control Rod 2, at center of water hole between fuel & absorber	5.80	4.152
6. Element 47, on plate next to Control Rod 2	7.25	1.703
7. Element 47, at center of element	8.80	1.109
8. Element 47, on plate next to reflector	10.15	1.261

TABLE 13

RADIAL TRAVERSE AT 2.5 INCHES ABOVE THE BOTTOM OF THE ACTIVE CORE

<u>Position</u>	<u>Inches From Center Line</u>	<u>Bare Gold</u>	<u>Cadmium Covered Gold</u>	<u>Cd Fraction</u>
1. Center of Rod C, at center of fuel section	0	1.892		
2. Element 45, on plate next to Control Rod C	1.50	1.939	1.14	.412
3. Element 45, at center of element	2.93	1.808	1.12	.381
4. Element 45, on plate next to Control Rod 2	4.30	1.761	1.06	.398
5. Center of Rod 2, at center of fuel section	5.80	1.561		
6. Element 47, on plate next to Control Rod 2	7.25	1.335	.790	.408
7. Element 47, at center of element	8.80	.999	.640	.359
8. Element 47, on plate next to reflector	10.15	1.020	.426	.582

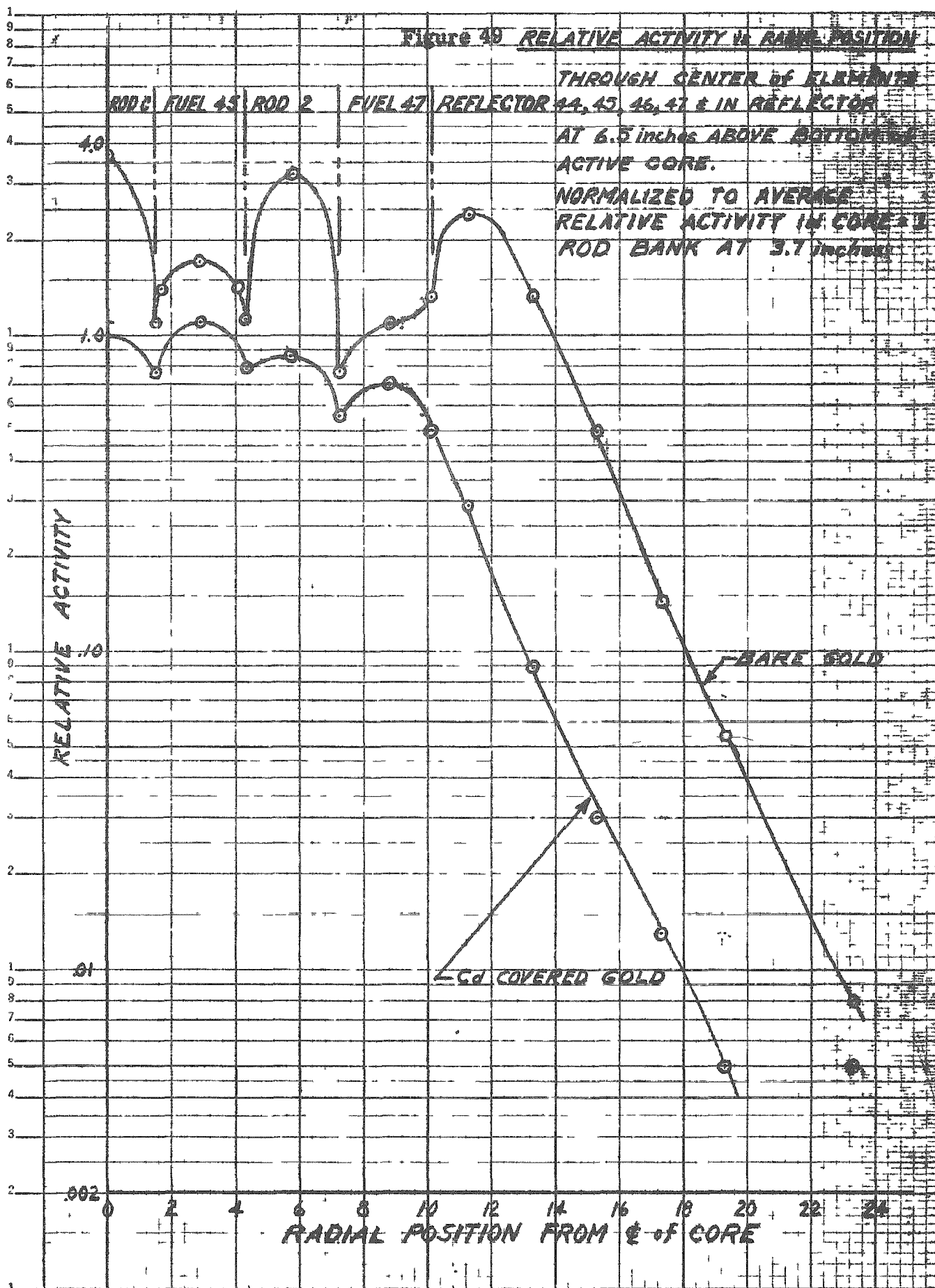
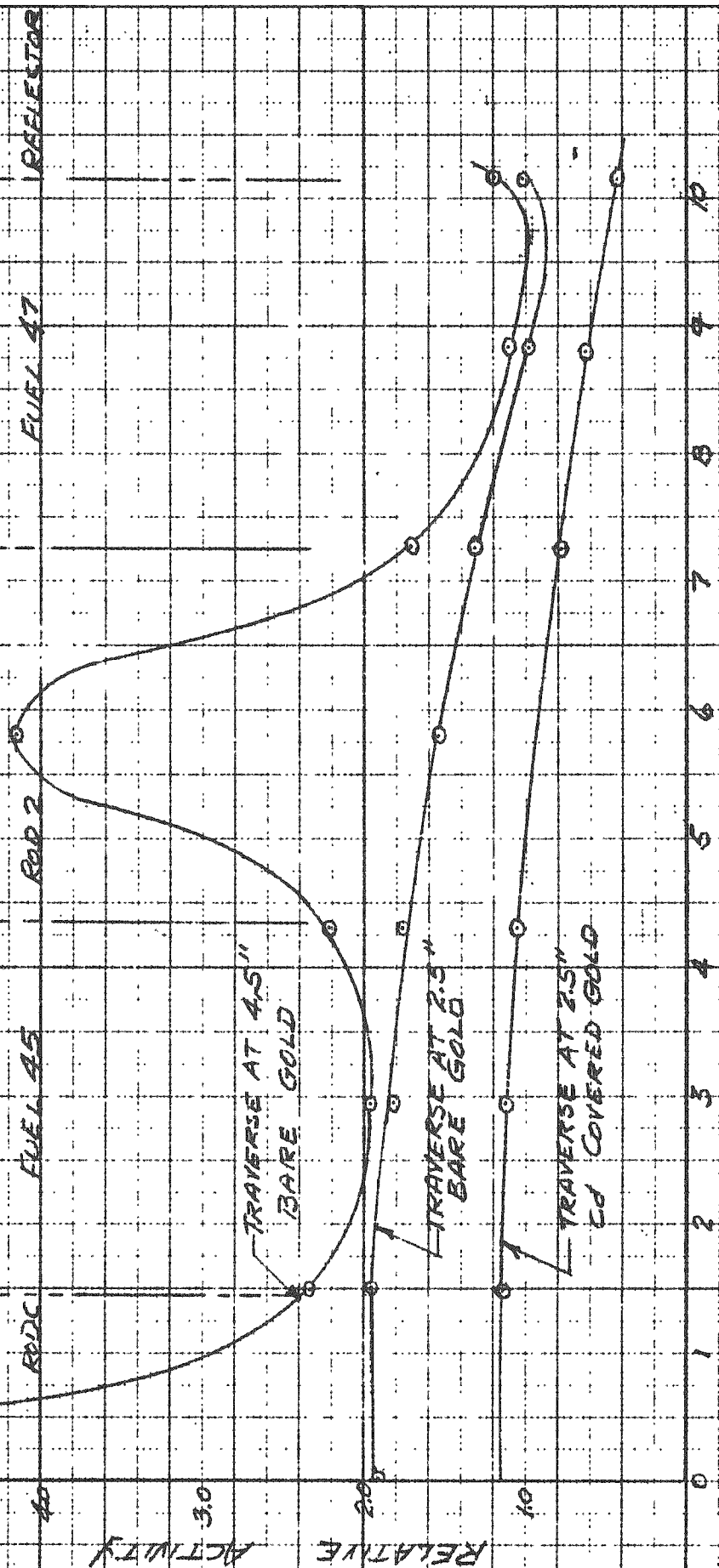


Figure 50

RELATIVE ACTIVITY VS RADIAL POSITION

THROUGH CENTER OF ELEMENTS 44, 45, 46, 47 AT
2.5 & 4.5 INCHES ABOVE BOTTOM OF ACTIVE CORE.
NORMALIZED TO AVERAGE RELATIVE ACTIVITY IN
CORE = 1.
ROD BANK AT 3.7 INCHES



RADIAL POSITION FROM CENTER OF CORE - INCHES

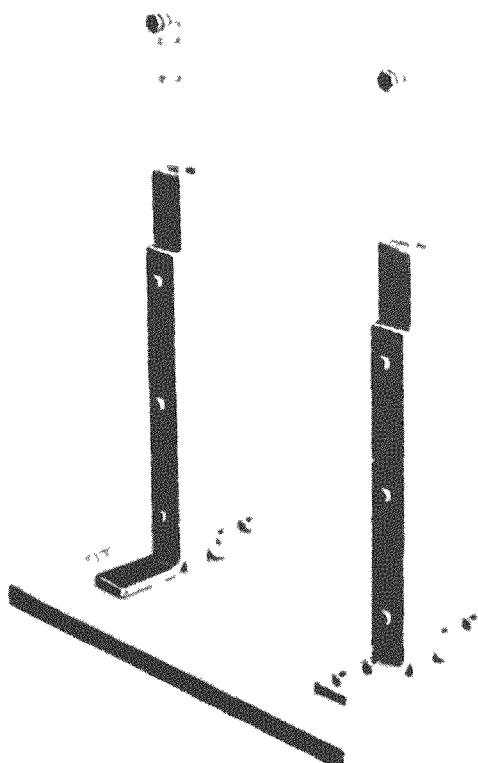


Figure 51
REFLECTOR FOIL SUPPORT

7.24 Fine Structure in Clean Core.

Figure 52 depicts the flux peaking within an individual element. This peaking is due to the absence of meat in the extremities of the fuel plates and is considered independent of control rod effects. Traverses were performed in elements 43 and 45 in a direction parallel to the fuel plates.

The measurement was taken at 2.5 inches from the bottom of the active core. The bare and bare minus Cd covered activities of the foils were normalized separately to unity at the center of the element. The reduced data are presented in Table 14.

Figure 53 depicts flux peaking between two adjacent plates within a fuel element. Bare gold foils were activated at the positions indicated in Table 15 but were displaced axially from 6 to 8 inches above the bottom of the active core. The relative activities were corrected for axial flux distribution. The activities were then normalized to unity at the surface of the fuel plate. The experimental curve of relative bare gold activity is plotted. The curve of bare minus Cd covered activity vs position was derived from the bare gold activity curve by assuming a constant Cd covered activity across the span between the plates.

TABLE 14

FINE STRUCTURE PARALLEL TO THE FUEL PLATES

<u>Distance from Center of Fuel Element Inches</u>	<u>Relative Activity Bare Gold</u>	<u>Relative Activity Bare - Cd. Cov. Gold</u>
0	1.00	1.00
0.30	1.006	1.01
0.60	1.025	1.04
0.90	1.042	1.13
1.20	1.148	1.38
1.42	1.187	1.50

TABLE 15

INTERPLATE TRAVERSE AT 7 INCHES ABOVE CORE BOTTOM - CENTER OF ELEMENT

<u>Position From Center of Water Gap Inches</u>	<u>Bare Gold</u>	<u>Bare-Cd. Cov. Gold</u>
0.000		1.078
0.002	1.0328	1.077
0.015	1.0205	1.073
0.043	1.0164	1.045
0.062	1.004	1.011
0.067	1.000	1.000

Figure 52

**SIDE PLATE PEAKING EFFECT
STATIONARY ELEMENTS
MEASURED ON FUEL PLATE
SURFACE IN ELEMENTS 43 & 45**

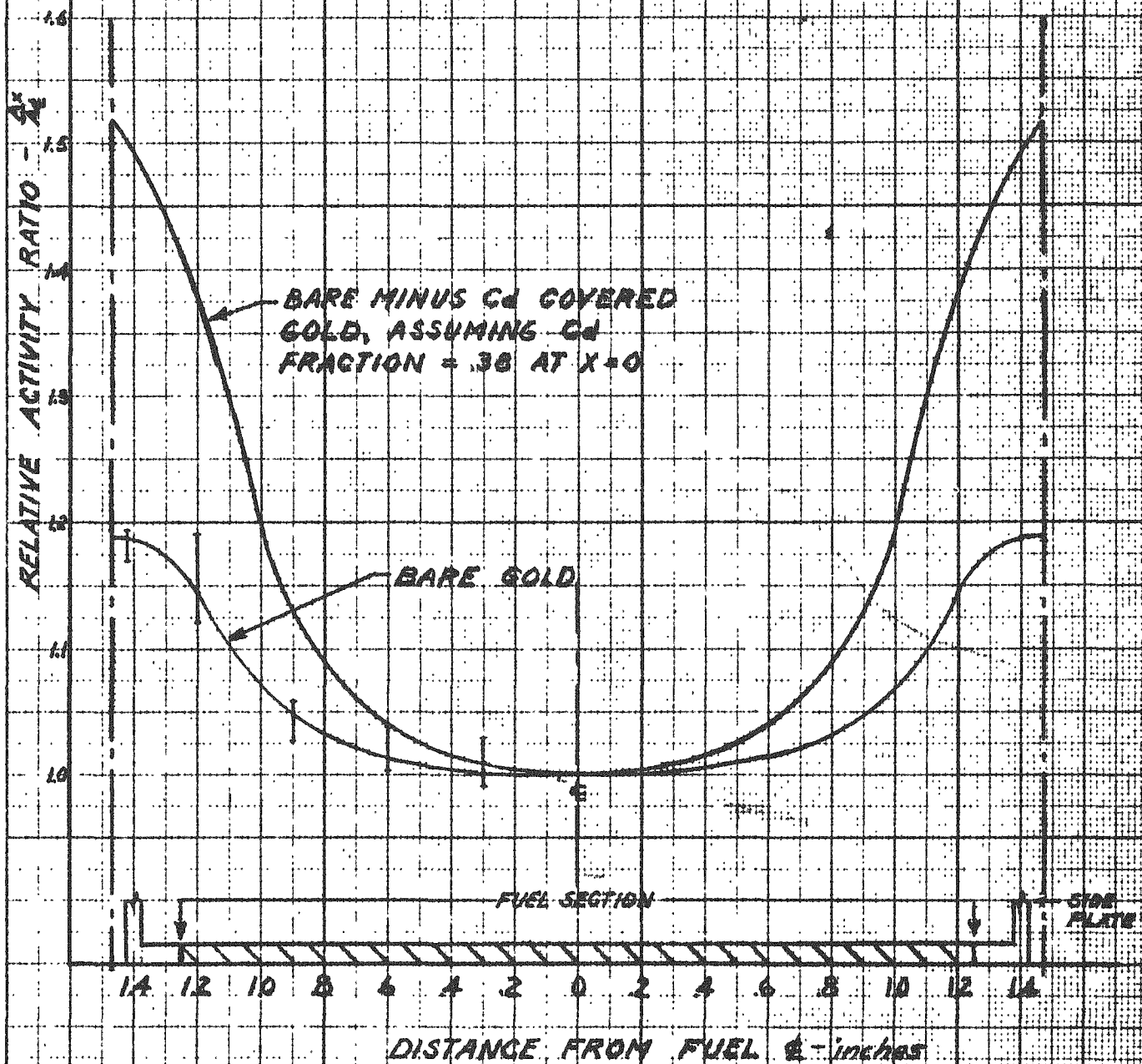
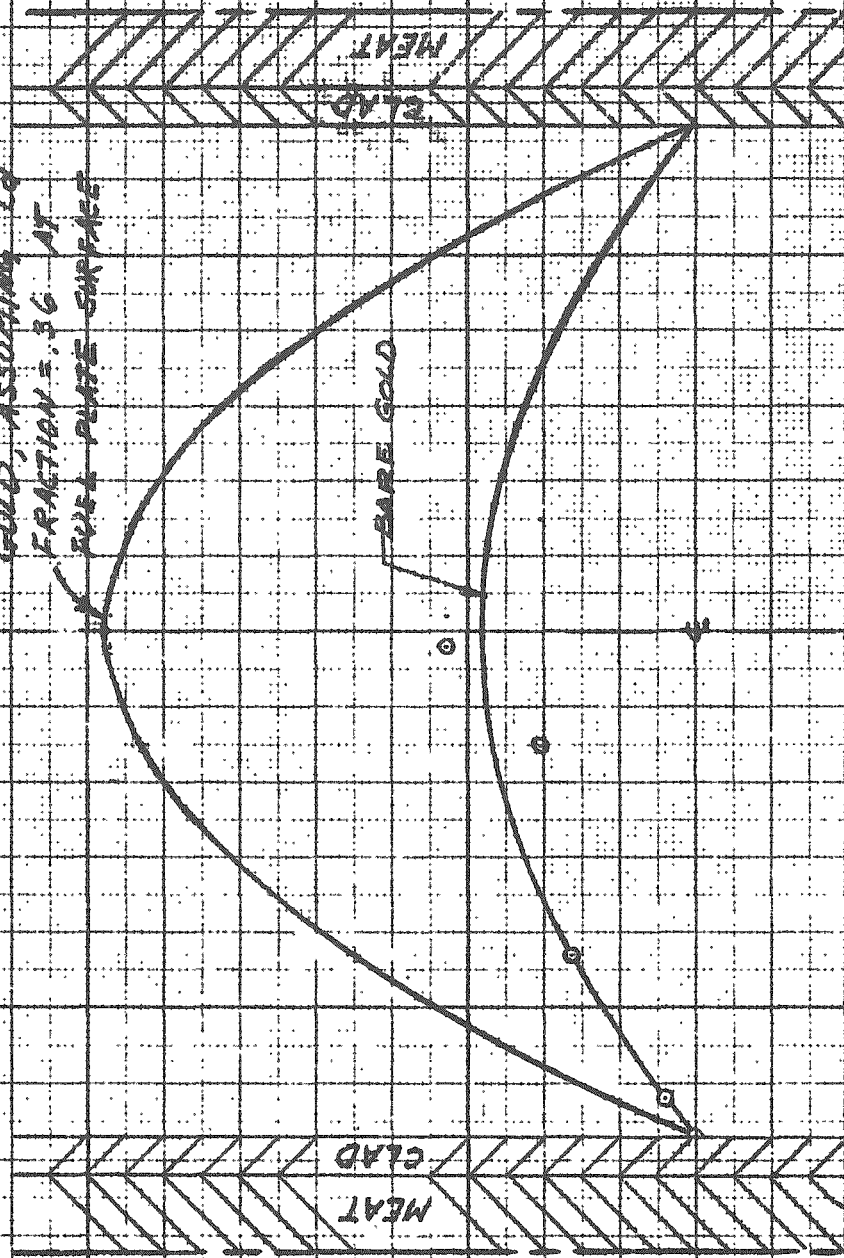


Figure 53

FLUX PEAKING IN WATER GAP BETWEEN FUEL PLATES

BARE MINUS Cd COVERED
GOLD, ASSUMING Cd
FRACTION = .36 AT
FUEL PLATE SURFACE



DISTANCE FROM WATER GAP x - inches

7.3 Measurements in the Poisoned Core - 4 Boron Steel Strips per Element-
5 Rod Bank at 6.30 inches.

The lowest predicted operating position of the 5 rod bank foreseen during the life of the APPR-1 is 6.30 inches withdrawal.

7 3.1 Bare Gold Gross Mapping.

A gross bare gold flux mapping was taken in the core poisoned by 4 boron steel strips per element. The purpose of the mapping is to describe the maximum peak to average flux relationships likely to occur during the APPR-1 life.

For this measurement foils were placed 0.38 inches from each of the two mutually perpendicular axial planes that describe the axis of each element. Table 16 and Figs. 54-57, inclusive, describe the data taken over one octant of the core.

The average bare gold activity was determined for each element based on a core average of unity. Figure 58 shows the individual element average bare gold activation in terms of a core average of unity.

TABLE 16
VERTICAL TRAVERSES ALONG ELEMENT AXES

	<u>Distance from Core Bottom in inches</u>	<u>Relative Activity</u>
Element 15	0.6	.874
	2.6	1.134
	4.6	1.38
	5.6	1.35
	6.6	1.36
	8.6	1.23
	10.6	1.09
	13.6	.801
	17.6	.477
	21.6	.275

TABLE 16 (Cont'd.)

	<u>Distance from Core Bottom in inches</u>	<u>Relative Activity</u>
Element 35	0.6	1.62
	4.6	2.30
	6.6	2.21
	8.6	1.92
	10.6	1.56
	13.6	1.090
	17.6	.632
	21.6	.331
Element 16	0.6	.640
	2.6	.866
	4.6	1.035
	6.6	1.135
	8.6	1.083
	10.6	.967
	13.6	.768
	17.6	.428
Element 26	21.6	.243
	0.6	1.045
	2.6	1.385
	4.6	1.635
	5.6	1.697
	6.6	1.697
	8.6	1.58
	10.6	1.395
	13.6	1.050
	17.6	.626
	21.6	.309

TABLE 16 (Cont'd.)

	<u>Distance from Core Bottom in inches</u>	<u>Relative Activity</u>
Element 44	1.3	.87
	0.3	1.48
	1.3	1.82
	2.3	2.11
	3.3	2.30
	4.3	2.43
	5.3	2.51
	6.3	3.96
	7.3	5.21
	7.6	4.88
	10.3	2.67
Element 24	-1.3	.697
	0.6	1.26
	2.6	1.775
	4.6	1.95
	5.6	2.01
	7.6	4.11
Element 14	.6	0.910
	2.6	1.205
	4.6	1.385
	6.6	1.395
	8.6	1.055
	10.6	.852
	13.6	.637
	17.6	.3645
	21.6	.173
Element 34	-3.6	1.10
	-2.6	1.90
	-1.6	2.78
	-0.6	2.77
	0.6	1.63
	1.6	1.97
	2.6	2.09
	4.6	2.33
	5.6	2.36
	7.6	1.93
	9.6	1.50
	11.6	1.167
	13.6	.980
	15.6	.721

TABLE 16 (Cont'd)

	<u>Distance from Core Bottom in inches</u>	<u>Relative Activity</u>
Element 34 (Cont'd.)	17.6	.548
	18.6	.465
	20.6	.288
	22.6	.414
	23.6	.331
	24.6	.167
	25.6	.092
	26.6	.052

7.32 Bare and Cadmium Covered Gold Activations in Control Rod C Water Hole

A high thermal flux peak was discovered in the region just above the control rod fuel elements. In this region the poison within the control rod absorber section is approximately 1.19 inches above the U^{235} in the control rod fuel element. The extreme peaking in this water hole results in a consequent steep gradient in the upper half inch of fuel.

A series of experiments was performed to determine the effect of flux suppressors in reducing this peak. Since the fuel region in a control rod fuel plate ends approximately one half inch below the end of the plate, the suppressors were designed in the form of combs whose teeth extended $5/32$ inches down between the fuel plates. Boron steel and Haynes Alloy No. 25 were considered as materials. Figures 59 and 60 show the suppressors and relationship to the control rod fuel element.

Figure 54

RELATIVE ACTIVITY VS. POSITION
 CENTER OF ELEMENT
 NORMALIZED TO AVERAGE RELATIVE
 ACTIVITY IN CORE = 1
 ROD BANK AT 6.3 INCHES

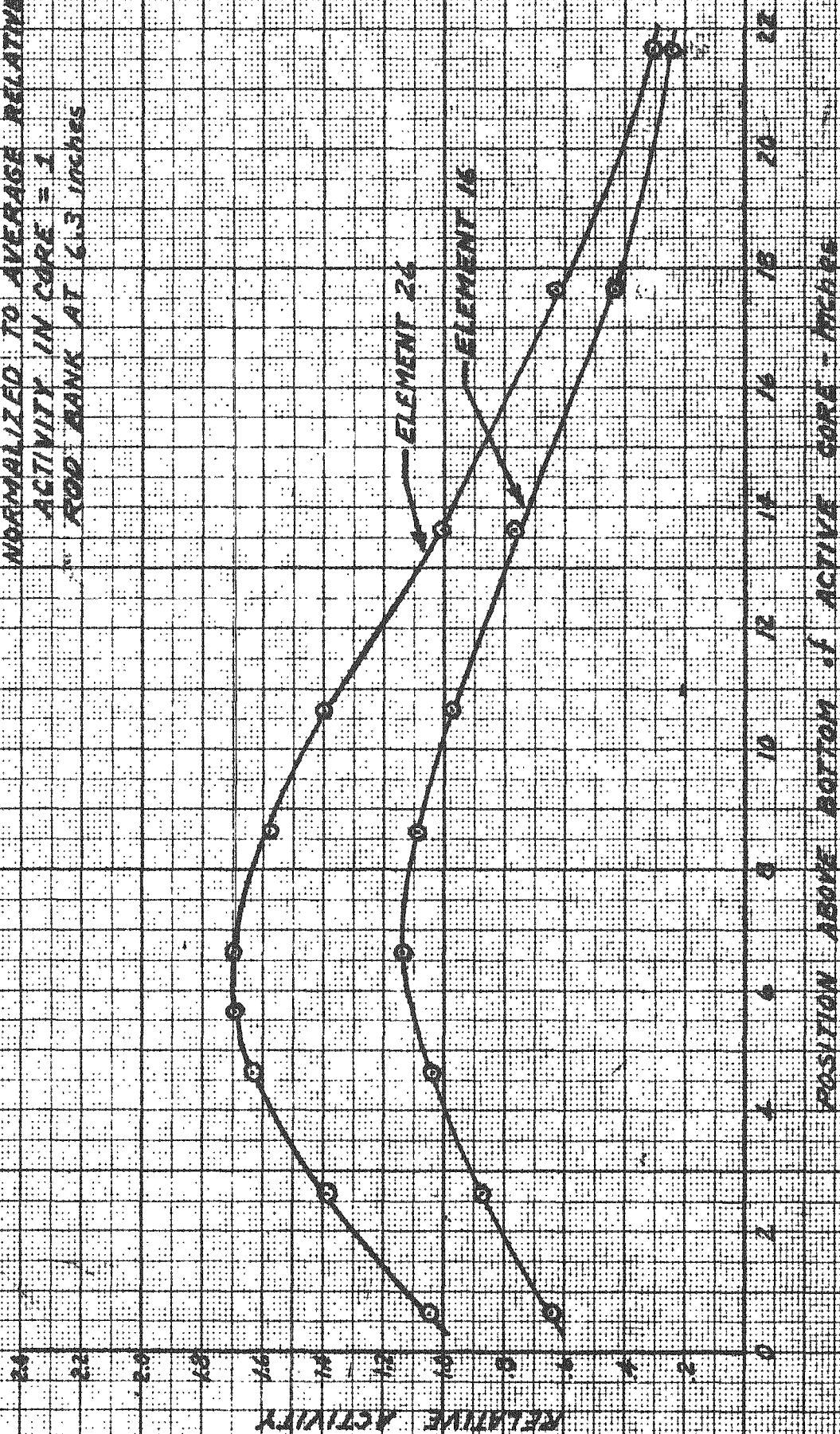


Figure 55

RELATIVE ACTIVITY VS POSITION
CENTER OF ELEMENT
NORMALIZED TO AVERAGE RELATIVE
ACTIVITY IN CORE = 1
ROD BANK AT 6.3 inches

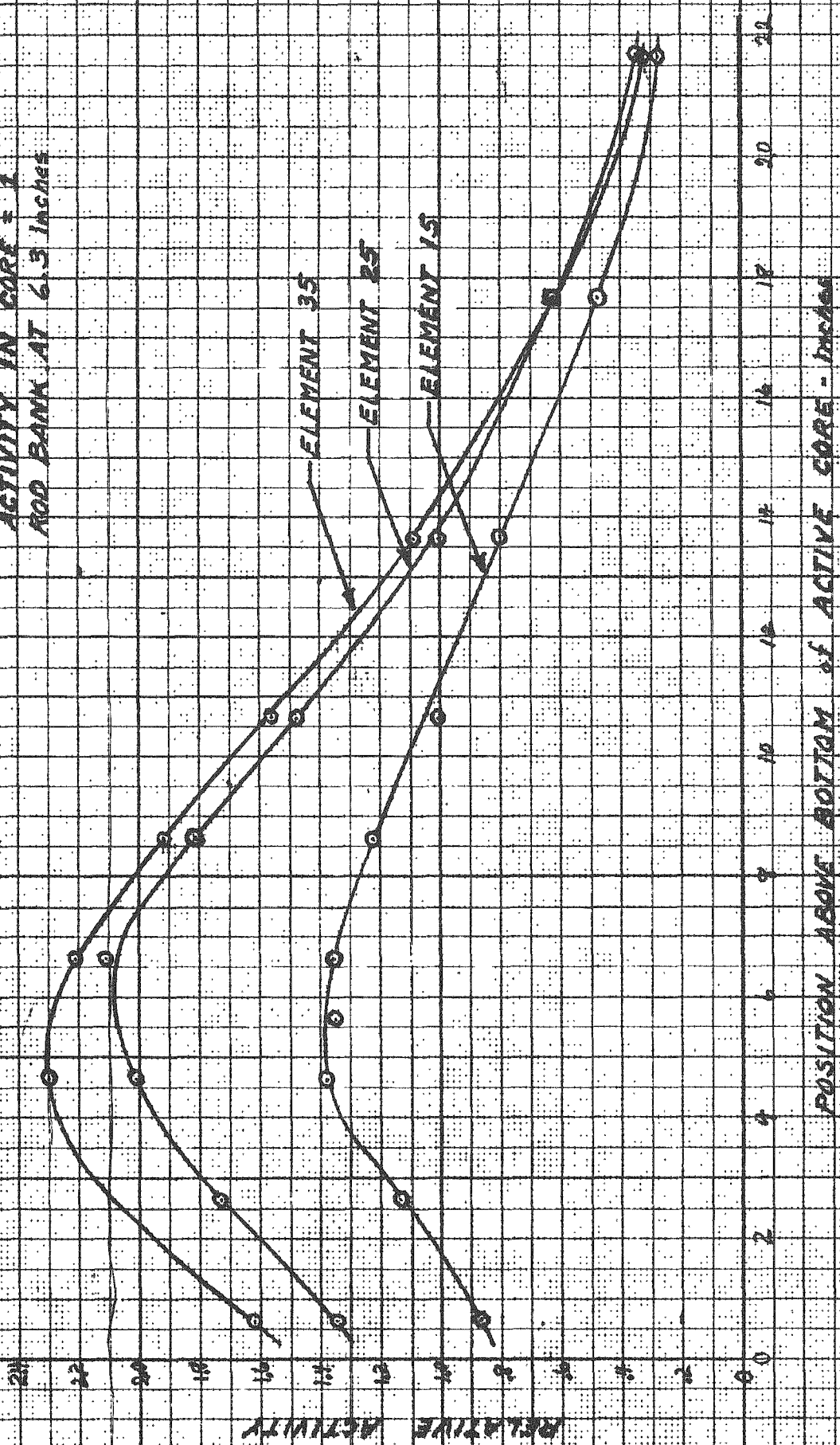


Figure 56

RELATIVE ACTIVITY vs POSITION
 CENTER of ELEMENT
 NORMALIZED TO AVERAGE
 RELATIVE ACTIVITY IN CORE = 1
 ROD BANK AT 6.3 inches



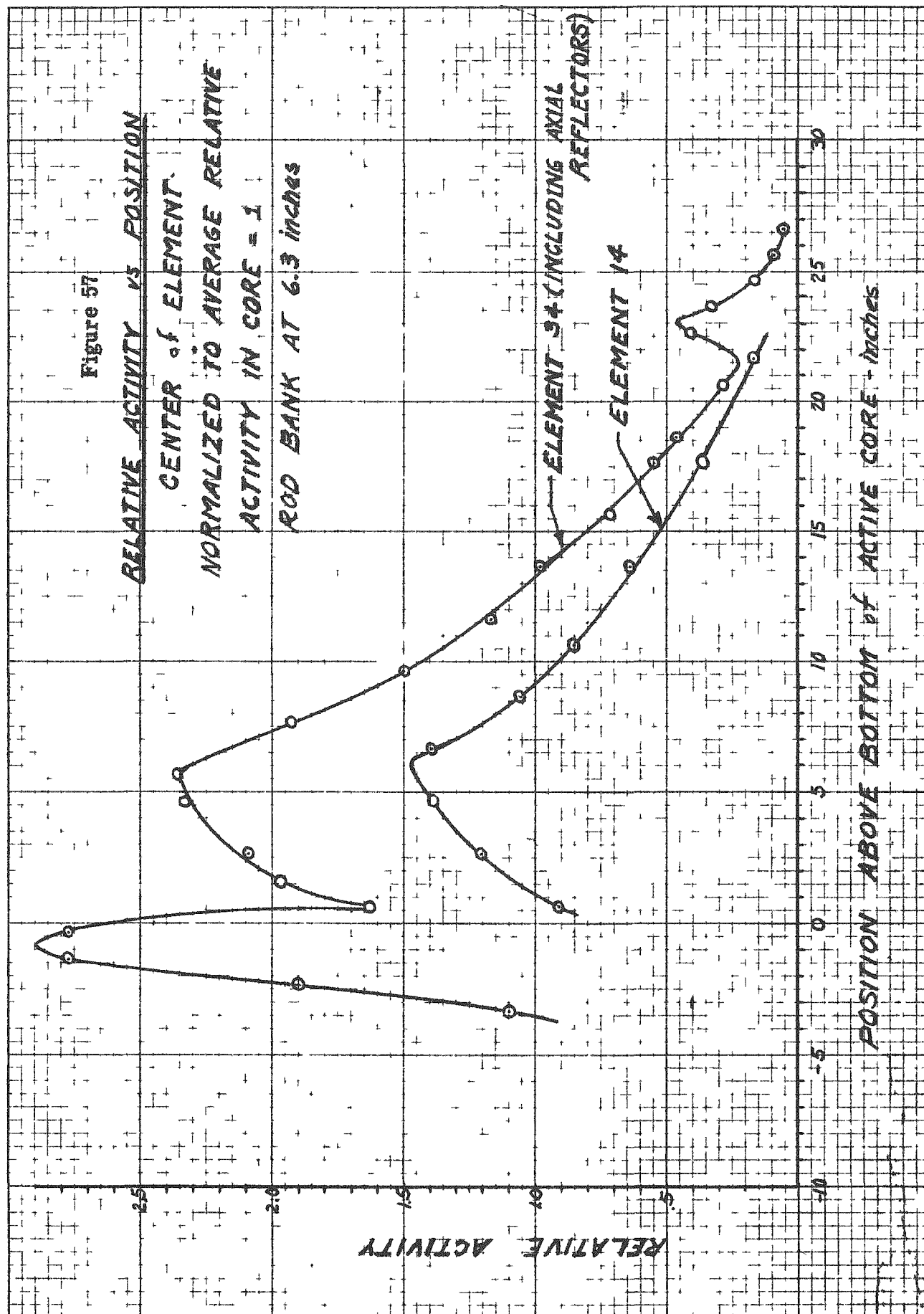


FIGURE 58 AVERAGE ACTIVITY PER ELEMENT

ROD BANK AT 6.3"

MEASURED WITH BARE GOLD AXIAL TRAVERSES
IN THE CENTER OF ELEMENTS 14, 15, 16, 25, 26,
34, 35 AND CONTROL RODS 1 & C. NORMALIZED
TO AVERAGE ACTIVITY = 1 PER ELEMENT

	12	13	14	15	16	ELEMENT #
	.753	.888	.805	.888	.753	RELATIVE ACTIVITY
21	.753	1.110	1.281	.626	1.281	1.110
31	.888	1.281	1.384	1.291	1.384	1.281
41	.805	.626	1.291	.778	1.291	.626
51	.888	1.281	1.384	1.291	1.384	1.281
61	.753	1.110	1.281	.626	1.281	1.110
72	.753	.888	.805	.888	.753	

RELATIVE ACTIVITY IN CONTROL ROD C

(Measured At 0.6 Inches From the Center of Rod C)

A. No Flux Suppressor

<u>Vertical Position, Inches Above Bottom of Core</u>	<u>Relative Activity Bare Gold</u>	<u>Relative Activity Cd Covered Gold</u>	<u>Cd Fraction</u>
.3	1.48		
1.3	1.82		
2.3	2.11	1.32	.37
3.3	2.30		
4.3	2.43	1.52	.37
5.3	2.51		
6.3	3.96	1.44	.636
7.3	5.21	1.31	.75
7.6	4.88		
10.3	2.67		

B. Suppressor: 5 Combs, Haynes 25, .050" thick

5.3	2.43
6.3	3.21
7.3	2.81

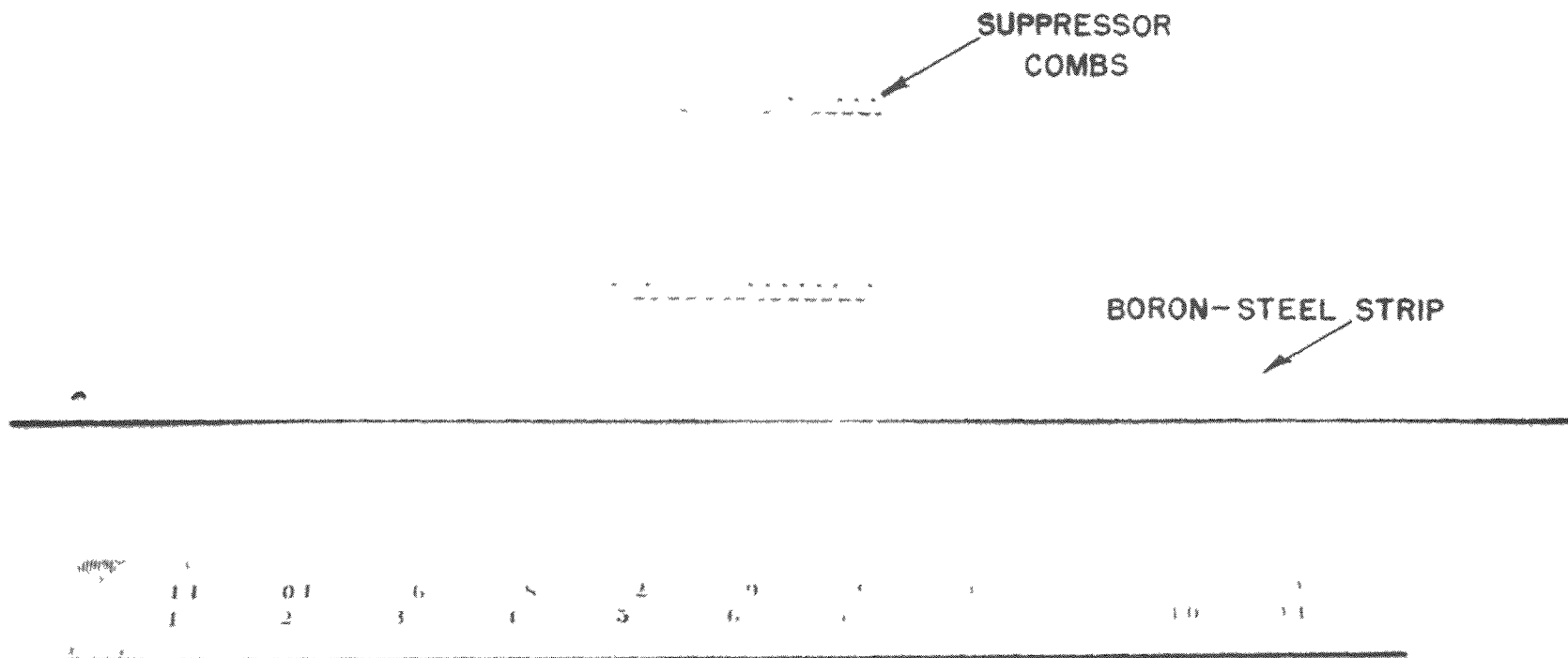
C. Suppressor: 9 Combs, Haynes 25, .050" thick

5.3	2.43
6.3	3.01
7.3	2.15

D. Suppressor: 9 Combs, Boron Steel, 1.01 wt. %B, .040" thick

5.3	2.40
6.3	2.90
7.3	1.95

Figure 59
FLUX SUPPRESSORS



1	1	0	6	8	2	9	6	1	10	11
1	1	2	3	4	5	6	7	8	9	10

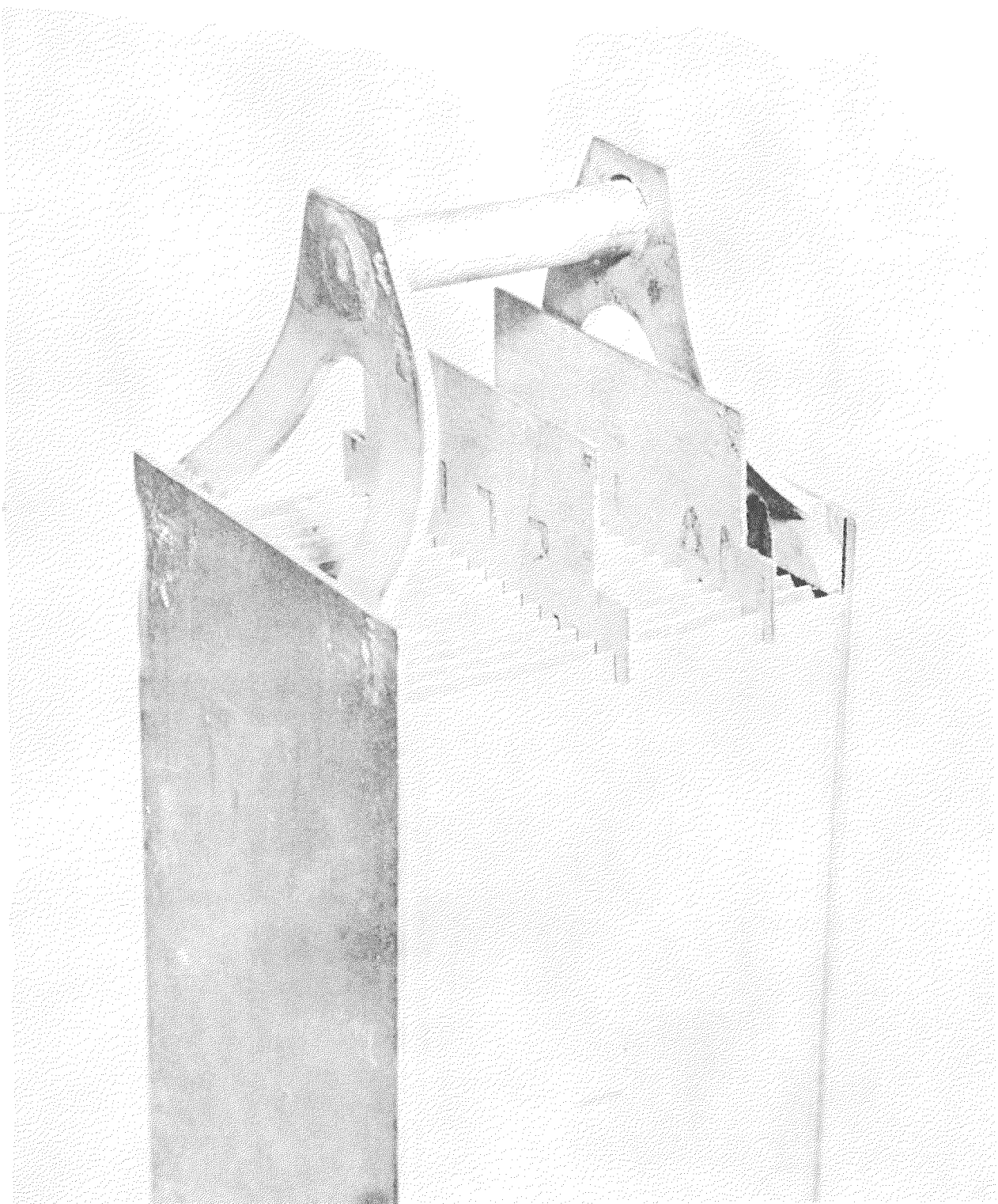


Figure 60
CONTROL ROD FUEL ELEMENT
WITH SUPPRESSORS

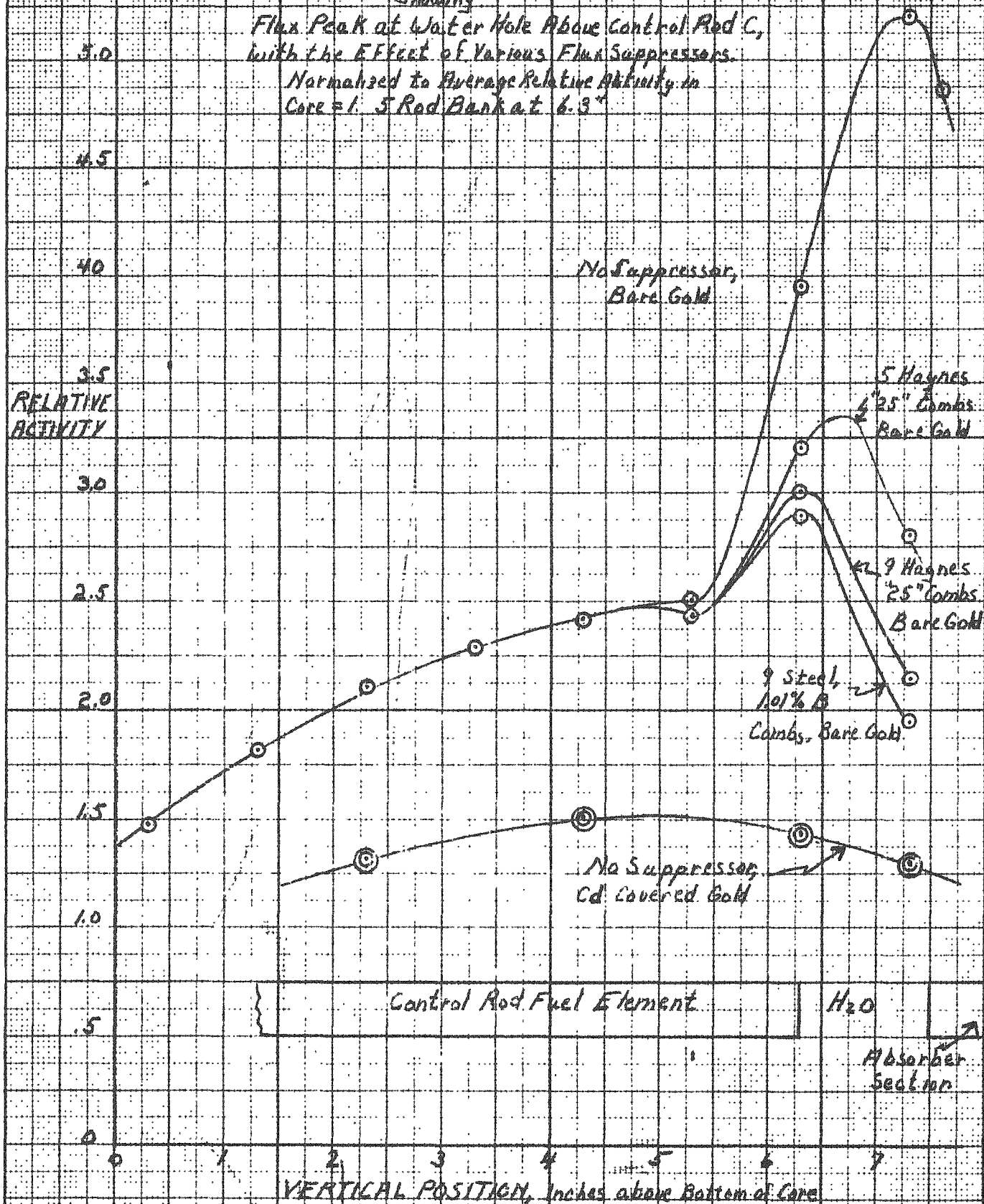
Figure 61

RELATIVE ACTIVITY vs. VERTICAL POSITION

Showing

Flux Peak at Water Hole Above Control Rod C,
with the Effect of Various Flux Suppressors.

Normalized to Average Relative Activity in
Core = 1.5 Rod Bank at 6.3"



7.33 Bare and Cadmium Covered Gold Activation in Control Rod C Absorber Section

The relative activity in and around control rod C absorber section was measured with bare, and cadmium covered gold and normalized to an average bare gold activity in the core of unity. Table 18 and Fig. 62 describe these measurements.

TABLE 18

BARE AND CADMIUM COVERED GOLD ACTIVATIONS IN CONTROL ROD C ABSORBER SECTION

A. Measured on the inside surface of the absorber section.

1. Bare Gold

Vertical Position - Inches

<u>Above Bottom of Core</u>	<u>Above Bottom of Absorber Region</u>	<u>Relative Activity</u>	<u>Bare Gold Relative Activity</u>	<u>Cd Fraction</u>
7.4	-.1	2.54		
7.8	.3	1.32		
9.8	2.3	.96		
11.8	4.3	.82		
13.8	6.3	.69		
15.8	8.3	.53		
17.8	10.3	.39		

2. Cd Covered Gold

7.5	.0	1.03	3.20	.68
9.5	.2	.61	1.02	.40
11.5	4.0	.49	.85	.42
13.5	6.0	.39	.71	.45
15.5	8.0	.30	.56	.46

B. Measured about 1/8" from the inside surface of the absorber section, bare gold.

8.3	.8	3.4		
9.3	1.8	1.75		
10.3	2.8	1.32		
11.3	3.8	1.24		
12.3	4.8	1.12		
13.3	5.8	.94		

C. Measured in Water Hole, about 5/8" from the center of the water region.

1. Bare Gold

Vertical Position, Inches

<u>Above Bottom of Core</u>	<u>Above Bottom of Absorber</u>	<u>Relative Activity</u>	<u>Bare Gold Activity</u>	<u>Cd Fraction</u>
7.3	-.2	5.22		
7.8	.3	4.82		
8.5	1.0	4.02		
9.0	1.5	3.56		
10.0	2.5	2.81		
11.0	3.5	2.34		
12.0	4.5	2.02		
13.0	5.5	1.72		

2. Cd Covered Gold

6.3	-1.2	1.39	3.96	.65
7.3	-.2	1.23	5.22	.76
9.3	1.8	.89	3.34	.73
11.3	3.8	.65	2.25	.71
13.3	5.8	.53	1.65	.68

D. Measured at the center of the absorber section water hold, bare gold

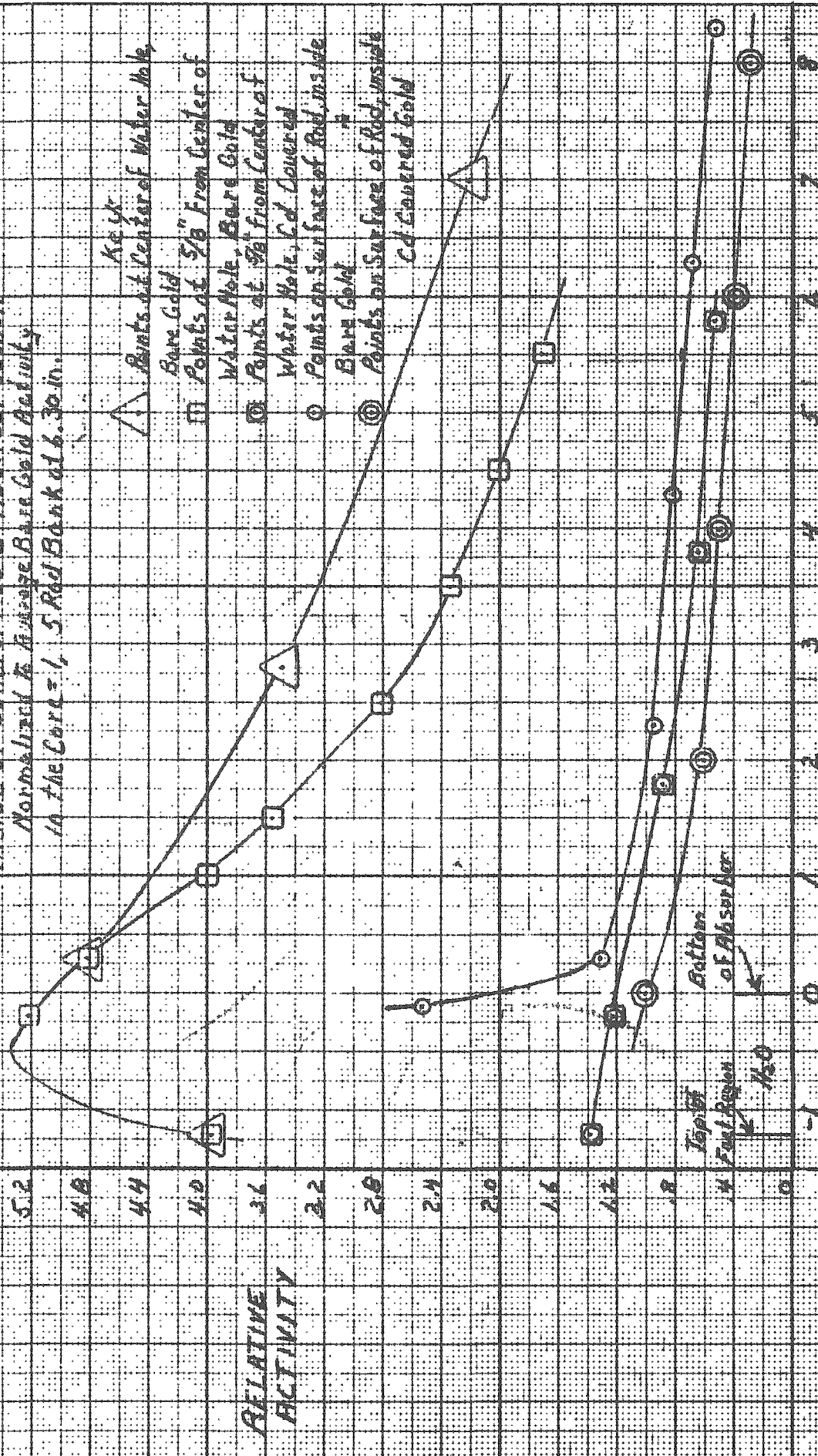
7.8	-.2	4.82
10.3	2.8	3.50
14.5	7.0	2.22

Figure 62

RELATIVE ACTIVITY vs. VERTICAL POSITION

Inside of Control Rod C, Absorber Section
Normalized to Average Bare Gold Activity
in the Core = 1, 5 Rod Bank at 6.30 in.

- Key:
- △ Points at Center of Water Hole, Bare Gold
 - Points at 5/8" from Center of Water Hole, Bare Gold
 - Points at 9/16" from Center of Water Hole, Cd Covered
 - Points on Surface of Rod, inside Bare Gold
 - Points on Surface of Rod, inside Cd Covered Gold



VERTICAL POSITION, in above Absorber

VERTICAL POSITION, in above bottom of Core

Relative activity measurements were made along the outside of the center control rod fuel element and absorber section with bare gold. Values normalized to an average bare gold activity in the core of unity are presented in Table 19 and Fig. 63.

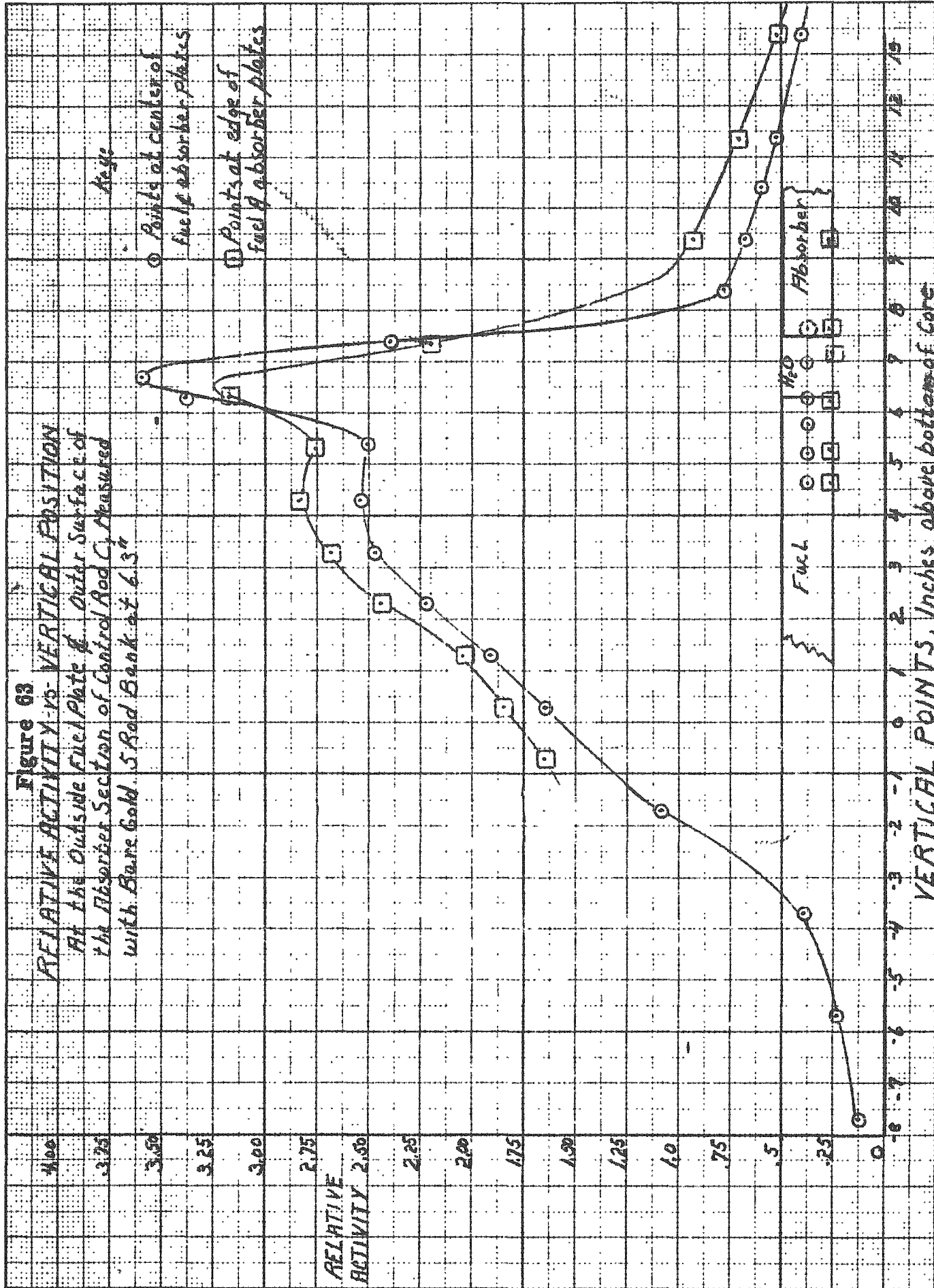
TABLE 19
BARE AND CADMIUM COVERED GOLD ACTIVATIONS
ON CONTROL ROD C SIDE PLATE

A. Measurements at the center of the outside of Control Rod C.

<u>Vertical Position, Inches Above Bottom of Core</u>	<u>Relative Activity</u>
-7.7	.125
-5.7	.244
-3.7	.40
-1.7	1.09
.3	1.65
1.3	1.92
2.3	2.22
3.3	2.47
4.3	2.54
5.3	2.51
6.3	3.39
6.7	3.60
7.4	2.30
8.4	.781
9.4	.68
10.4	.60
11.4	.53
13.4	.41

B. Measurement at the edge of the outside of Control Rod C.

<u>Vertical Position, Inches Above Bottom of Core</u>	<u>Relative Activity</u>
-.7	1.66
.3	1.85
1.3	2.05
2.3	2.44
3.3	2.68
4.3	2.84
5.3	2.76
6.3	3.17
7.4	2.20
9.4	.93
11.4	.71
13.4	.52



CHAPTER 8 POWER LEVEL CALIBRATION

The power level at which the APPR-1 Zero Power Experiments were performed has been determined. This information will be used to perform a preliminary power calibration of the APPR-1 at Ft. Belvoir. This calibration will give some relationship between power level and instrument readings until a more accurate thermal calibration can be accomplished.

The power level was determined by exposing gold foils to a known flux and to the APPR-1 PE flux. By comparing the activities of the foils, one can evaluate the unknown thermal flux. With a knowledge of the cadmium fractions of the gold and fuel involved, the disadvantage factor of the fuel, and the thermal flux, one can calculate the fission rate in the reactor and consequently the power level.

The following expression was developed for calculating the thermal flux in the APPR:

$$\phi_{APPR} = \frac{\phi_{TTR} t_{TTR} CF_{APPR.}}{t_{APPR} CF_{TTR}} \cdot \frac{A_{APPR}}{A_{TTR}}$$

where TTR refers to the Thermal Test Reactor at KAPL

APPR refers to the APPR-1

ϕ = thermal flux (20-mil Cd cutoff = 0.5 ev)

t = time of exposure of foil in seconds (1 hour or less)

CF = cadmium fraction of a 2-mil gold foil

A = Activity or count rate received from the foil at shutdown

$\phi_{TTR} = 3.06 \times 10^7 \text{ n/cm}^2/\text{sec/watt}$

$CF_{TTR} = 0.758$

The count rate from a 2 mil, .0310 gm gold foil exposed in the TTR at 12 watts for 15 minutes was 31,585 CPM at shutdown. The count rate from a 2 mil .0313 gm. gold foil exposed to the average flux in the APPR-1 for 60 minutes at a nominal power of ".2 on Log N" (2×10^{-7} ~~W~~ A) was 3,850 cpm at shutdown.

Thus at a nominal power of ".2 on log N" the average thermal flux was

$$\phi_{TH} = 5.32 \times 10^6 \text{ n/cm}^2/\text{sec}$$

The next step was to calculate the average thermal flux per watt in the clean cold APPR.

$$\text{Thermal flux per watt} = \frac{k}{\frac{d}{CF} \cdot \Sigma_f}$$

$$\text{where } k = 3.15 \times 10^{10} \text{ fissions per watt-sec}$$

$$d = 0.8 \text{ disadvantage factor of fuel}$$

$$CF = 0.8 \text{ Cadmium Fraction of APPR fuel}$$

$$\Sigma_f = \text{Total fission cross-section of core}$$

$$\Sigma_f = 3.15 \times 10^4 \text{ barns}$$

$$\text{Thermal flux per watt} = 1.0 \times 10^6 \text{ n/cm}^2/\text{sec}$$

Thus at an instrument reading of ".2 on log N" the power level was 5.3 watts.

With this evaluation one can show that the reactor in the Alco Critical Facility has not been operated at a power level greater than 15 watts.

The accuracy of this determination is probably not better than $\pm 25\%$. The errors are introduced principally by uncertainties in the disadvantage factor and in the cadmium fractions of fuel and gold.

It must be pointed out that these estimates of power level are valid only at 70°F. There are two large effects which will change the ionization chamber current per unit power level.

1. The flux per watt will increase approximately 30% in going from 70°F to 450°F.
2. The neutron current per watt reaching ionization chambers located outside the pressure vessel will increase approximately a factor of four in going from 70° to 450° due to the increase in migration length.

CHAPTER 9
CONTROL ROD FUEL ELEMENT EVALUATION

The 7 control rod fuel elements differ somewhat in design from the 38 stationary fuel elements. They have a smaller cross-section (See Table 20) and contain fewer plates, in order that they may fit into the supporting basket.

TABLE 20
FUEL ELEMENT CHARACTERISTICS

	<u>Control Rod Element</u>	<u>Stationary Element</u>
No. of Plates	16	18
Aver. U ²³⁵ per element, gms	417.76	515.16
Aver. B ¹⁰ per element, gms	.392	.483
Side Dimension, across plates, in.	2.650	2.863
Side Dimension, parallel to plates, in.	2.650	2.838

The reduction in fuel loading, the increased water space between rod elements and other elements, and the existence of the stainless steel basket produce definite reactivity effects.

9.1 Reactivity Effect of Differences Between Stationary and Control Rod Fuel Elements.

Zero power experiments were performed to determine the reactivity worth of the structural differences between these elements. The measurements were made in the position of element 33, normally occupied by Control Rod A. The zero condition was established with the Rod A fuel section and associated basket fully in the active core (absorber section fully withdrawn).

TABLE 21
REACTIVITY EFFECTS IN POSITION 33

Condition of Rod A	Reactivity change in Cents
1. Normal Rod A + steel basket full withdrawn	0
2. Aluminum basket in place of steel, Rod A fuel in core	+16.
3. No basket. Rod A fuel in core	+29.
4. Stationary fuel element in Rod A position. Rod A - fuel, absorber, and basket removed	+46.

9.2 Reactivity Effect of Control Rod A Components.

The reactivity changes associated with individual components of control rod A were also measured. Again the zero condition was established with the normal control rod A withdrawn.

TABLE 22
REACTIVITY EFFECTS OF CONTROL ROD A COMPONENTS

Condition of Rod A	Reactivity change in Cents
1. Rod A fuel in core (with steel basket)	0
2. Rod A fuel and absorber removed (steel basket in core)	-160.
3. Rod A fuel absorber and basket removed (water hole only)	-145.
4. Rod A fully inserted Absorber in core. (with steel basket)	-350.

9.3 Reactivity Effect of Cadmium-Silver Absorber Sections.

The reactivity changes associated with the replacement of the APPR-1 boron absorber section by cadmium-silver absorber sections of varying thicknesses were determined.

The zero condition for these measurements was established with Rod C (containing its boron absorber section) fully inserted and the reactor critical on Rods 1, 2, 3 and 4.

Rods A and B were fully withdrawn.

The cadmium-silver absorber was approximately 70 wgt % silver and 30 wgt % cadmium.

TABLE 23
REACTIVITY EFFECT OF CADMIUM-SILVER ABSORBER SECTIONS

<u>Condition</u>	<u>Reactivity Change in Cents</u>
1. Boron section in Rod C - fully inserted	0
2. Cd-Ag section 0.1 inches thick - Rod C fully inserted	+9.1
3. Cd-Ag section 0.2 inches thick - Rod C fully inserted	+15.5

The data indicates that the cadmium-silver was less effective than boron when used in the APPR control rod. It also indicates that displacing water from the inside of the absorber section decreases the effectiveness of the control rod.

APPENDIX A
APPR-1 REACTOR DESIGN DATA

Core Dimensional Data

Configuration		7 x 7 array of elements
Equivalent diameter	in	22.24
Active core height	in	22
Radial reflector		H ₂ O
Number of fixed elements		38
Number of control rod elements		7

Core Material Content

Weight

U ²³⁵	kg	22.480
UO ₂	kg	27.346
B-10	gm	21.109
B ₄ C	gm	147.86
SS	kg	208.92
H ₂ O (68°F)	kg	111.08
Total	kg	347.47

Fixed Element

U-235	gm	515.16
B-10	gm	0.483

Control Rod Element

U-235	gm	417.76
B-10	gm	0.392

APPENDIX A (Cont'd.)

Control Rod Absorber Section

B-10	gm	56.4
------	----	------

Volume in Core

UO ₂	cc	2509.
B ₄ C	cc	58.9
SS	cc	26527.
H ₂ O	cc	110,894.
Total	cc	139,989.

Volume Fractions

H ₂ O fixed element position	0.7967
H ₂ O control rod element position	0.7674

APPENDIX B
ZPE-1 WATER ANALYSIS

Total Solids (maximum)	238 ppm
Suspended Solids (maximum)	6.8 ppm
Chlorides (maximum)	10.1 ppm
Iron (maximum)	0.5 ppm
Hardness (maximum)	59.4 ppm
Ph (average)	8.0

APPENDIX C
SPECIFICATIONS OF BORON-STEEL STRIPS

Dimensions

Length	in.	23.0
Width	in.	0.5
Thickness	in.	0.020

Weight

Total	gm	28.375
Boron	gm	0.2866
Boron-10	gm	0.4979

Analysis

Carbon	wgt %	0.09
Manganese	wgt %	0.66
Silicon	wgt %	0.70
Chrome	wgt %	17.88
Nickel	wgt %	10.50
Boron	wgt %	1.01
Iron	wgt %	Balance

1. APAE No. 5, 'Hazards Summary Report on the Zero Power Experiments for the APPR'. J L. Meem, et al.
2. APAE No. 5, Supplement I, "Supplement to Hazards Summary Report on the Zero Power Experiments for the APPR". J. W. Noaks
3. APAE No. 4, 'APPR-1 Description and Supplement'.
4. AP-61, "Results and Analysis of the APPR-1 Zero Power Experiments, Part I". H. W. Giesler, et al.
5. ORNL-2128, "Army Package Power Reactor Critical Experiment". D. V. P. Williams, et al.