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MASTER

SM-1 (APPR-1)
RESEARCH AND DEVELOPMENT PROGRAM

INTERIM REPORT ON CORE MEASUREMENTS

TASK No. VII

ALCO

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APAE MEMO NO. 178

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(APPR-1)

RESEARCH AND DEVELOPMENT PROGRAM

(INTERIM REPORT ON)

CORE MEASUREMENTS

TASK NO. VII

Army Package Power Reactor

Contract AT(30-3)-326

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ABSTRACT

Physics experiments were performed on the SM-1 (formerly APPR-1) core to evaluate temperature and pressure coefficients, transient xenon, neutron source requirements, safety margin, and core reactivity as a function of core life.

The temperature coefficient was measured as $-3.5 \pm .13$ ¢/°F at 443°F several times throughout life and no change with life time is thus far indicated. The hot to cold reactivity change (440°F to 70°F) was 6.70 dollars.

The pressure coefficient was $1.05 \pm .05$¢ per 100 psi at 115°F.

Reactivity value for equilibrium xenon was found to be 3.32 dollars and peak xenon reactivity was 4.63 dollars.

The 15 curie Po Be source and the beryllium photoneutron source have proved adequate for safe startup .

The safety margin with "80% rod insertion" was found to depend strongly upon the rod configuration.

The core reactivity has decreased approximately 5.8 dollars up to 9.1 MWYR leaving an estimated 5.6 dollars to be used. The core life is expected to be 15 MWYR.

All measurements have indicated satisfactory performance of the (SM-1) core.

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1.0 INTRODUCTION

The Army Package Power Reactor at Fort Belvoir, Virginia was designed, constructed and is being operated by Alco Products, Inc. under contract with the Army Reactors Branch of the AEC. The SM-1 (formerly APPR-1) is a prototype of a reactor designed to meet requirements and site conditions of a remote military base. The SM-1 (formerly APPR-1) first went critical on April 8, 1957.

1.1 SM-1 (formerly APPR-1) Core

The SM-1 is an enriched uranium, water-moderated reactor employing stainless steel plate-type fuel elements. The core contains 22.5 kilograms of U^{235} and 19.5 grams of B^{10} as a burnable poison. The core is composed of 45 fuel and control rod elements which approximate a cylinder 22 inches in height and diameter. The core cross-section is shown in Figure 1.1. The reactor has 7 MTR-type control rods and is normally operated with five of the rods positioned to form a bank. The five rod bank consists of rods 1, 2, 3, 4 and C. Rods A and B are normally fully withdrawn during operation. Control rod locations are given in Figure 1.1. The control rod position relative to the stationary elements is given in Figure 1.2. The axial control rod position is measured from the bottom of the fuel in the stationary elements to the top of the active fuel in a control rod element.

1.2 Task VII Description

The experiments performed under Task VII of the SM-1 research and development program will provide a basis for evaluating the nuclear performance of the SM-1 core. These experiments are designed to measure:

a) Temperature Coefficient
b) Pressure Coefficient
c) Core Reactivity
d) Xenon Transients
e) Shutdown Count-rate
f) Safety Margin

1.3 Purpose of Report

This is an interim report to make the results of core measurements through 9.1 MWYR of reactor operation available. Some of the data may be extrapolated and applied directly to other cores and some may be used to normalize calculational models; however, this data is to be considered only preliminary. A final report covering the entire core life of the first SM-1 core will be issued in early 1960.

2.0 EXPERIMENTAL TECHNIQUE

The detailed procedure for core measurements is given in Appendix A. Copies of the data sheets that were developed to simplify the data reduction are also included. The general approach for obtaining data, and some of the problems encountered will be presented in the following sections.

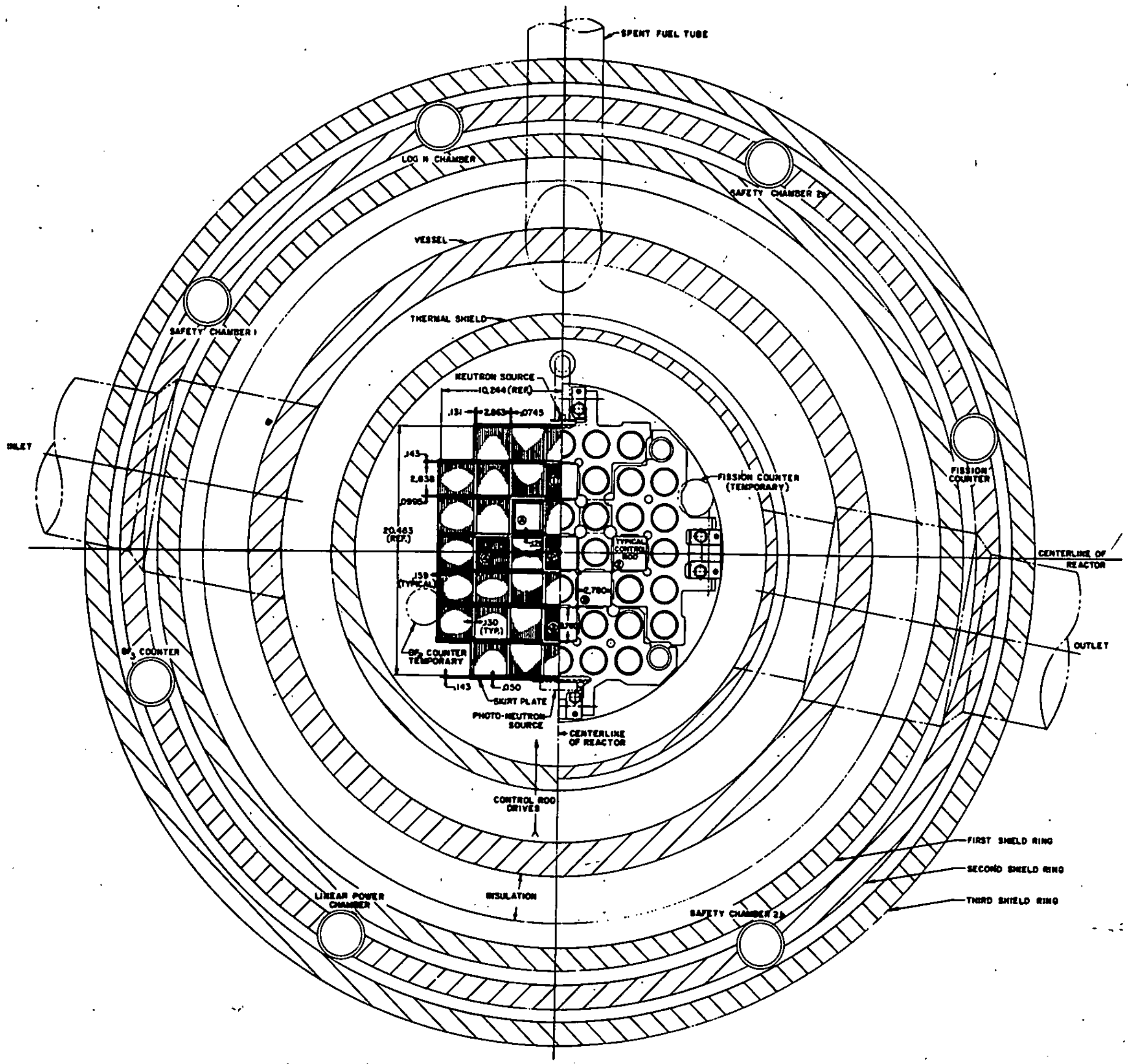

Fig. 1.1-1 Reactor Core Cross-Section

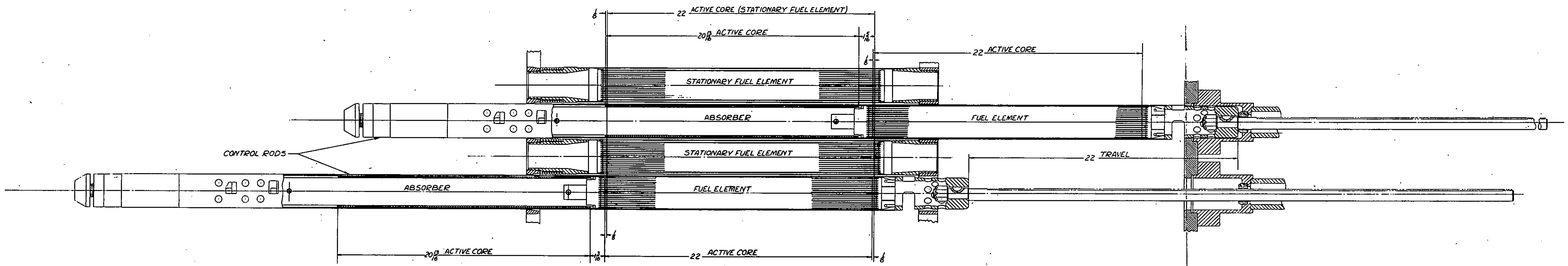

Fig. 1.1-2 Control Rod Positions

2.1 General Approach

The physics measurements were obtained at intervals of approximately 2 MWYRs of core energy release. It was found that data was best obtained after the reactor was shutdown from operating conditions. The reactor was continuously operated at full power for approximately 50 hours to approach equilibrium conditions. The power level was then reduced to approximately 1% of full power and the operating temperature was maintained. The reactivity worth of the xenon transient was followed with the five rod bank and the central control rod alternately. The calibrated central control rod movement was recorded during the xenon transient and the transient was thus evaluated in terms of reactivity. The reactivity worth of the five rod bank was determined from the reactivity worth of the xenon transient and the bank movement.

The average power level was further reduced and the temperature was allowed to decrease after the xenon decayed. Temperature coefficient data was recorded and rod calibrations as a function of temperature were performed throughout the decreasing temperature.

2.2 Problems of Power Reactor Core Measurements

Experimental procedures were developed which avoided or overcame the following difficulties:

1) The core must supply appreciable power to heat the primary system; the xenon thus built up complicates xenon transient and temperature coefficient measurements at startup.

2) Temperature corrections must be applied to all measurements due to the large negative temperature coefficient.

3) The reactor must operate at approximately 1% of full power to maintain the operating temperature (440°F). Therefore, any change in power level as encountered during rod calibrations will induce a temperature change and the resulting reactivity change. Thus, control rods are not calibrated from a simple exponential power rise.

4) Control rod position indication has a probable error of ±0.03 inches.

2.3 Data Reduction

The experimental data was recorded on sheets identical to those included in Appendix A. The methods of data reduction are described in the following sections.

2.3.1 Temperature Coefficient

The temperature coefficient was derived from the following three measurements:

$\partial \rho / \partial x$ - Rod A calibration, cents per inch.

$\partial x / \partial t$ - The change of rod A position with time during the temperature change, inches per minute.

$\partial T / \partial t$ - The change of temperature with time, °F per minute.

The measurements yield the temperature coefficient when combined as follows:

$$\frac{\partial \rho}{\partial T} = \frac{\partial \rho}{\partial x} \cdot \frac{\partial x}{\partial t} \cdot \frac{1}{\frac{\partial T}{\partial t}}$$

where:

$\partial \rho / \partial T$ = The temperature coefficient (cents per °F.)

Rod A was calibrated as a function of axial position, $\partial \rho / \partial x$, at temperatures of 120°F and 440°F. Values at intermediate temperatures were obtained by linear interpolation. The rate of change of rod A position with time, $\partial x / \partial t$, was determined from the position of rod A necessary to maintain criticality as the reactor cooled down. The correction of rod A position due to the pressure change (pressure coefficient) was small and was therefore neglected.

A program (1) was written for the IBM-650 to calculate temperature coefficient. The program uses rod A calibration, rate of change of rod A position and rate of temperature change as input and gives temperature coefficient as a function of temperature as output.

2.3.2 Pressure Coefficient

The integral pressure coefficient was determined by increasing the primary system pressure rapidly and measuring the resultant reactor period. The reactivity of the period was divided by the pressure increase to obtain the pressure coefficient in cents per 100 psi.

The differential pressure coefficient was obtained from rod A position as a function of pressure. Using the rod A calibration the pressure coefficient was determined as a function of pressure in 200 psi increments.

Temperature corrections were not applied to these measurements because of poor temperature data. The corrections may be of the order of 5 - 10%.

2.3.3 Five Rod Bank Position as a Function of Lifetime

All the rod bank position data could not be obtained at the desired reactor conditions, therefore, certain corrections had to be applied. Temperature and pressure corrections were applied as determined from the pressure and temperature coefficients and the rod bank calibration. Xenon corrections were also applied, as determined from the xenon reactivity and the rod bank calibration, to obtain the five rod bank position for the "no xenon" condition. An estimated 12 cents of reactivity is due to the xenon which is present 70 hours after shutdown.

The known uncertainties in bank position are, 1) ± 0.03 inches due to a temperature uncertainty of ± 2°F at 440°F and 2) a probable error of ± 0.03 inches due to the rod position indicator.

2.3.4 Rod Calibrations

Rod calibrations were performed by inserting the rod approximately 0.4 inches from the critical position and evaluating the resulting period in terms of reactivity. The development of a nomograph which directly evaluates the period from the log N trace in terms of reactivity simplified the data reduction considerably. Corrections of 5 - 10% were necessary in most cases due to temperature change and in some cases due to xenon.

2.3.4.1 Rod C Calibration During Transient Xenon, 440°F

Rod C was calibrated from 10 to 19 inches for approximately 36 hours following peak xenon concentration in the core. The reactivity was determined from the slope of the log N trace. Criticality for each calibration run was achieved at low power which resulted in a coolant temperature drop. The rate of change of temperature with time was measured at low power and found to be essentially constant. It was thus possible to convert the change in temperature to a change in reactivity by applying the temperature coefficient. The reactivity introduced by temperature decay was 0.86 cents per minute. The operating temperature was maintained between calibration runs by operating at a higher power level. The xenon decayed from peak concentration throughout the calibration. The rate of change of reactivity due to xenon decay varied with time, but had a peak value of 0.23 cents per minute approximately 20 hours after reduction from full power.

2.3.4.2 Rod C Calibration as a Function of the Four Rod Bank Position

Rod C was calibrated at 120°F and 440°F from 0 to 22 inches at positions spaced approximately 2 inches apart. Criticality was maintained for each rod C position by moving the four rod bank, composed of rods 1, 2, 3 and 4. Reactivity was evaluated from the slope of the log N trace. A temperature correction of 0.86 cents per minute was made for the 440° calibration as described in Section 2.3.4.1. The temperature correction was not significant at the 120°F calibration due to a lower value of temperature coefficient and a smaller coolant temperature change with time.

2.3.4.3 Rod A Calibration as a Function of the Five Rod Bank Position

Rod A was calibrated at 120°F and 440°F from 0 to 22 inches at positions spaced approximately 2 inches apart. Criticality was maintained for each rod A position by moving the five rod bank, composed of rod 1, 2, 3, 4 and C. Data was reduced by the method described in Section 2.3.4.2.

2.3.4.4 Five Rod Bank Calibration

The five rod bank cannot be calibrated directly because of its large reactivity value. Calibration points for the bank were obtained from the integrated reactivity values of the other calibrated rods. The calibration of rod A provides a bank position corresponding to the fully inserted rod A position and another bank position corresponding to the fully withdrawn rod A position. The integral worth of rod A from the fully inserted to the fully withdrawn position was divided by the corresponding bank motion to obtain a bank calibration point in terms of cents per inch. Calibration points were obtained at 440°F and 120°F at several times during core life.

Other calibration points for the five rod bank were obtained from the reactivity worth of transient xenon. The reactivity worth of transient xenon was previously evaluated by maintaining criticality with a calibrated rod during the xenon buildup and decay after a reduction in reactor power. The xenon reactivity worth was then plotted as a function of time after reduction from full power. The position of the five rod bank during the xenon buildup and decay was also plotted as a function of time after reduction from full power. Thereby, the motion of the five rod bank was related to reactivity and the five rod bank was calibrated in terms of cents per inch.

2.3.5 Start-up Count Rate and Power Level

Simultaneous readings on the log N and the counter channels were taken during the neutron flux decay after the reactor was scrammed. The ratio of log N to counter readings was developed from an overlap between the two instruments. The log N reading was known for full power (10 MW) the count rate was known for reactor shutdown to source level. The ratio between log N and counter readings made it possible to interpret the count rate at source level in terms of power.

2.3.6 Start-up Count Rate and Core Reactivity

Criticality was achieved with the five rod bank and rod A. Rod A was inserted stepwise and subcritical count rates were recorded. Rod A was previously calibrated, so that its position could be evaluated in terms of reactivity. Since the reactor was close to a critical condition reactivity was evaluated in terms of $1-K_{eff}$. This was plotted as a function of count rate on logrithmic coordinates. The best line with a slope of minus one was drawn through the plotted points. This slope was based on the assumption that:

$$\text{Source Multiplication, } M = \frac{1}{1-K_{eff}}$$

or: Count Rate, C, is proportional to $\frac{1}{1-K_{eff}}$

or

$$C = \frac{a}{1-K_{eff}}$$

therefore:

$$\ln M = -\ln (1-K_{eff}) + \ln a$$

which has a slope of minus one on logrithmic coordinates. The count rate associated with other subcritical rod configurations was evaluated in terms of $1-K_{eff}$ from the curve.

2.3.7 Axial Flux Distribution as a Function of Core Life

An approximate axial flux distribution was determined from the control rod calibration curve. The calibration curve was used to determine the rod worth in cents/inch at intervals over the rod length. The square root of rod worth was normalized to an average worth of unity and then plotted as a function of position along the rod indicating the approximate relative axial flux distribution.

2.3.8 Stuck Rod Conditions

Stuck rod measurements were obtained for six rod configurations (see data sheet 5). For each, six control rods were positioned as defined and the remaining control rod was moved to determine if a critical position were possible. If a critical rod position was found it was recorded. If a critical position was not found, an additional rod was withdrawn to a critical position. The rod was then calibrated and the reactivity associated with the rod motion was determined.

2.3.9 Reactivity Introduced by Xenon

The reactivity introduced by xenon from initial start-up to the equilibrium condition was evaluated from the five rod bank worth. The five rod bank position (temperature corrected to 440°F) was plotted as a function of time after reactor start-up. The reactivity worth of the xenon was evaluated from the bank position and the bank calibration, and was plotted as a function of time after start-up.

The value of xenon reactivity from equilibrium to peak xenon concentration in the core was obtained. Criticality was maintained during the xenon transient using rod C. Rod C was calibrated and the integral worth of rod C from its position at equilibrium xenon to its position at peak xenon yielded the reactivity value of xenon from equilibrium to peak concentration in the core.

2.3.10 Core Lifetime

The five rod bank position as a function of energy release was recorded at conditions as near as possible to full power equilibrium conditions. Corrections and uncertainties in bank position measurements have been given in Section 2.4.3.

Energy release in this report is expressed in terms of megawatt years. The temperature difference across the core is integrated with time and recorded as °F days. Assuming the specific heat of water to be constant within the range of temperatures encountered at operating conditions and assuming a constant coolant flow rate and temperature difference at full power, °F days were converted to MWYR by the factor 693.28°F days per MWYR. Uncertainties in recording °F days are estimated to be about ± 10%.

2.4 Interpretation of Data

Some of the less obvious sources of serious error in the data and possible misinterpretations are presented in the following sections.

2.4.1 Temperature and Pressure Coefficients

The data indicated that the temperature coefficient is proportional to the rate of change in the density of water. However, there is some disagreement among the references [2,4,5] of the water density as a function of temperature. An accurate prediction of the temperature coefficient at higher temperatures is dependent upon the resolution of this disagreement. Data on the compressibility of water is more consistent and pressure coefficient calculations are based on data from reference [5].

2.4.2 Rod Calibrations

Rod calibrations are necessarily a function of core lifetime, bank position, xenon concentration in the core and coolant temperature; only the xenon concentration is clearly separable from the other variables. Many rod calibrations were performed with practically no xenon in the core. However, even with this condition, rod calibrations are still a function of three variables: lifetime, bank position, and temperature. Additional data as the core continues to burn out will allow some further separation of the variables and further analysis of the data.

2.4.3 Reactivity Values

The values of reactivity in this report are given in dollars or cents. Dollars are converted to ΔK or ρ by multiplying dollars by $\beta_{eff} = .0073$, provided that K_{eff} is close to unity and that reactivity values are near one dollar.

It is difficult to interpret a large sum of reactivity changes. The sum may be described as an integral over a specified path and the integration is not independent of path. If the reactivity is considered as the sum of fractional changes in K, K may be obtained in the following manner: (K refers to $K_{effective}$).

let: $$I = \sum_{1}^{K} \frac{\Delta K}{K}$$

or: $$I = \int_{1}^{K} \frac{dK}{K}$$

$$I = \ln K$$

therefore:

$$K = e^{I}$$

and

$$\rho = \frac{K-1}{K}$$

$$\rho = \frac{e^{I}-1}{e^{I}}$$

or

$$\rho = 1 - e^{-I}$$

3.0 EXPERIMENTAL RESULTS

The methods of experimental procedure, data reduction and interpretation have been described in the preceding sections. The results of the experimental measurements which include temperature and pressure coefficients, five rod bank positions, control rod calibrations, start-up count rate, stuck rod conditions, reactivity introduced by xenon, axial flux distribution and core lifetime will be discussed in the following sections.

3.1 Temperature and Pressure Coefficients

The plot of temperature coefficients as a function of temperature is shown in Figure 3.1-1. The curve was drawn from data points taken at the beginning of life (2), after 7.2 and 9.1 MWYR of energy release. The small deviation in the data points as a function or core life indicated there is yet no significant change in temperature coefficient value with core life. The temperature coefficient is $-3.5 \pm .13$ cents/°F at 440°F. The reactivity change indicated by the integral of the curve from 70°F to 440°F is \$6.63.

The position of the five rod bank (rods A and B at 19 inches) was recorded as a function of temperature several times during core life. The plot of bank position as a function of temperature is shown in Figure 3.1-2. The motion of the five rod bank associated with the reactivity change from 70°F to 440°F was evaluated in terms of reactivity by the bank calibration. In this way the reactivity change was evaluated as \$6.70 $\pm$ .30.

The plot of pressure coefficient as a function of pressure is shown by Figure 3.1-3. The measurement was made by maintaining criticality with a calibrated rod while changing the pressure. Integral measurements were made by quickly increasing the pressure and measuring the resulting period. The experimental results are shown in Table 3.1-1.

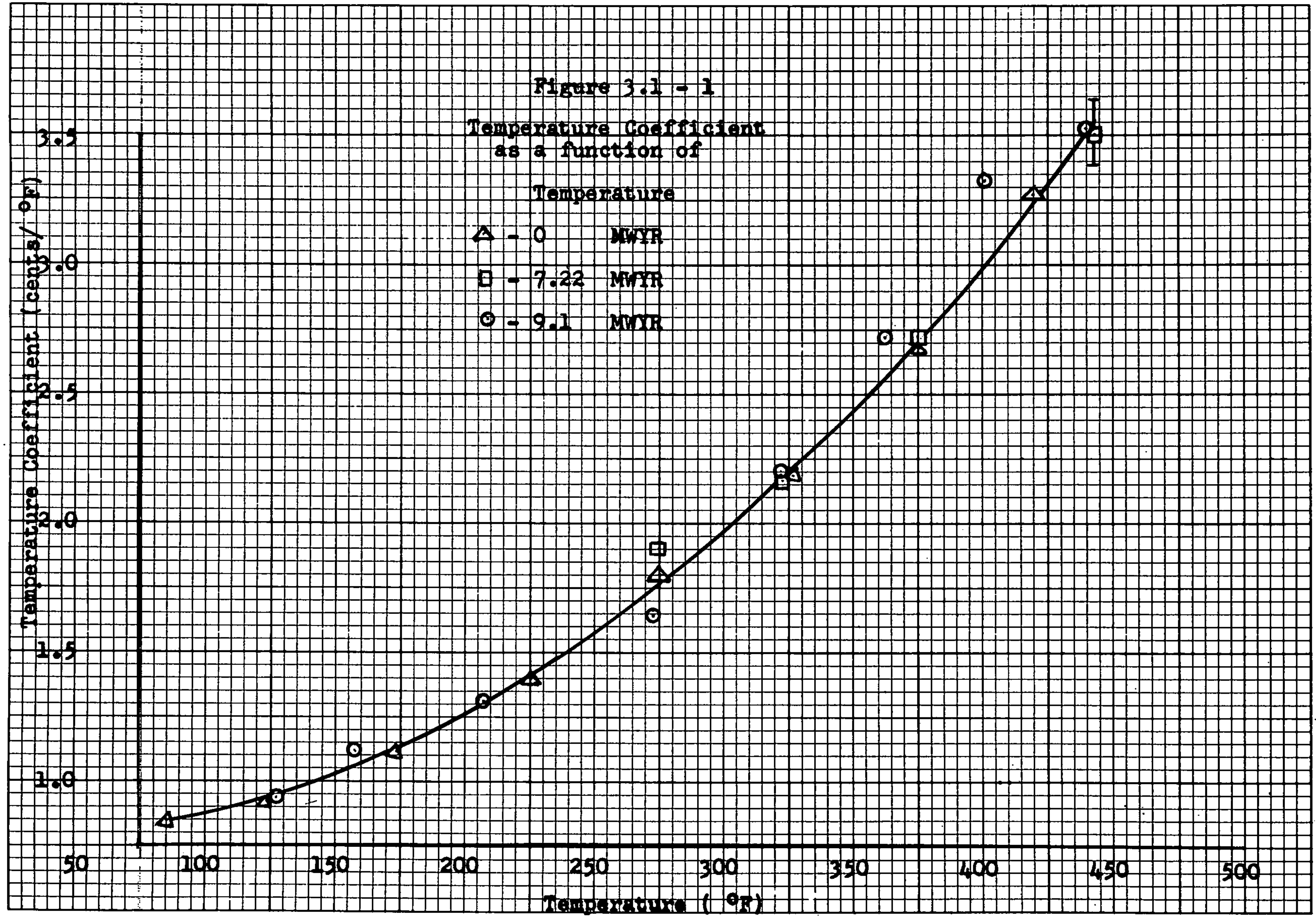

Figure 3.1 - 1

Temperature Coefficient as a function of Temperature

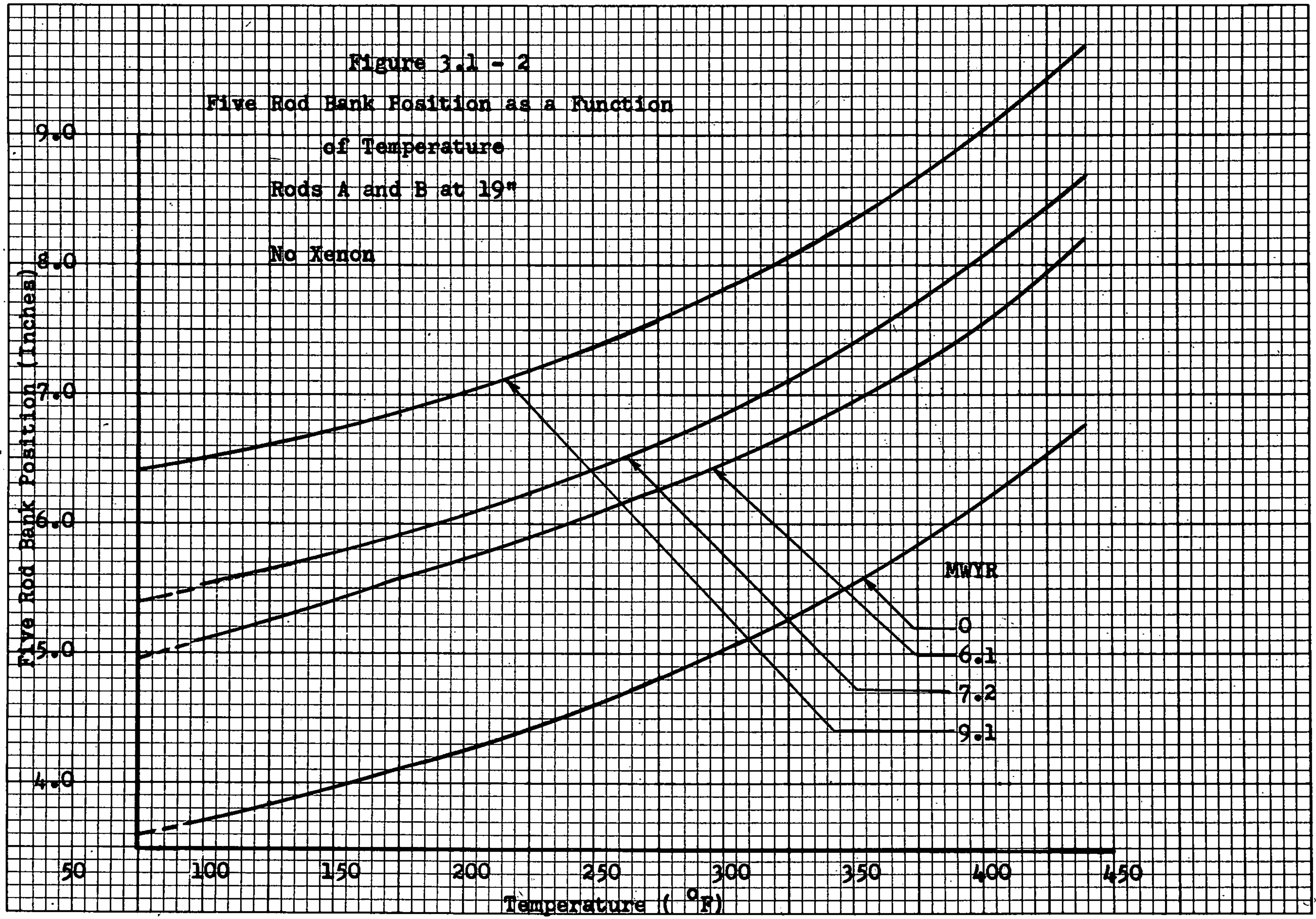
Figure 3.1 - 2
Five Rod Bank Position as a Function
of Temperature
Rods A and B at 19"
No Xenon
9.0
8.0
7.0
6.0
5.0
4.0
Five Rod Bank Position (Inches)
50
100
150
200
250
300
350
400
450
Temperature (°F)
MWYR
0
6.1
7.2
9.1

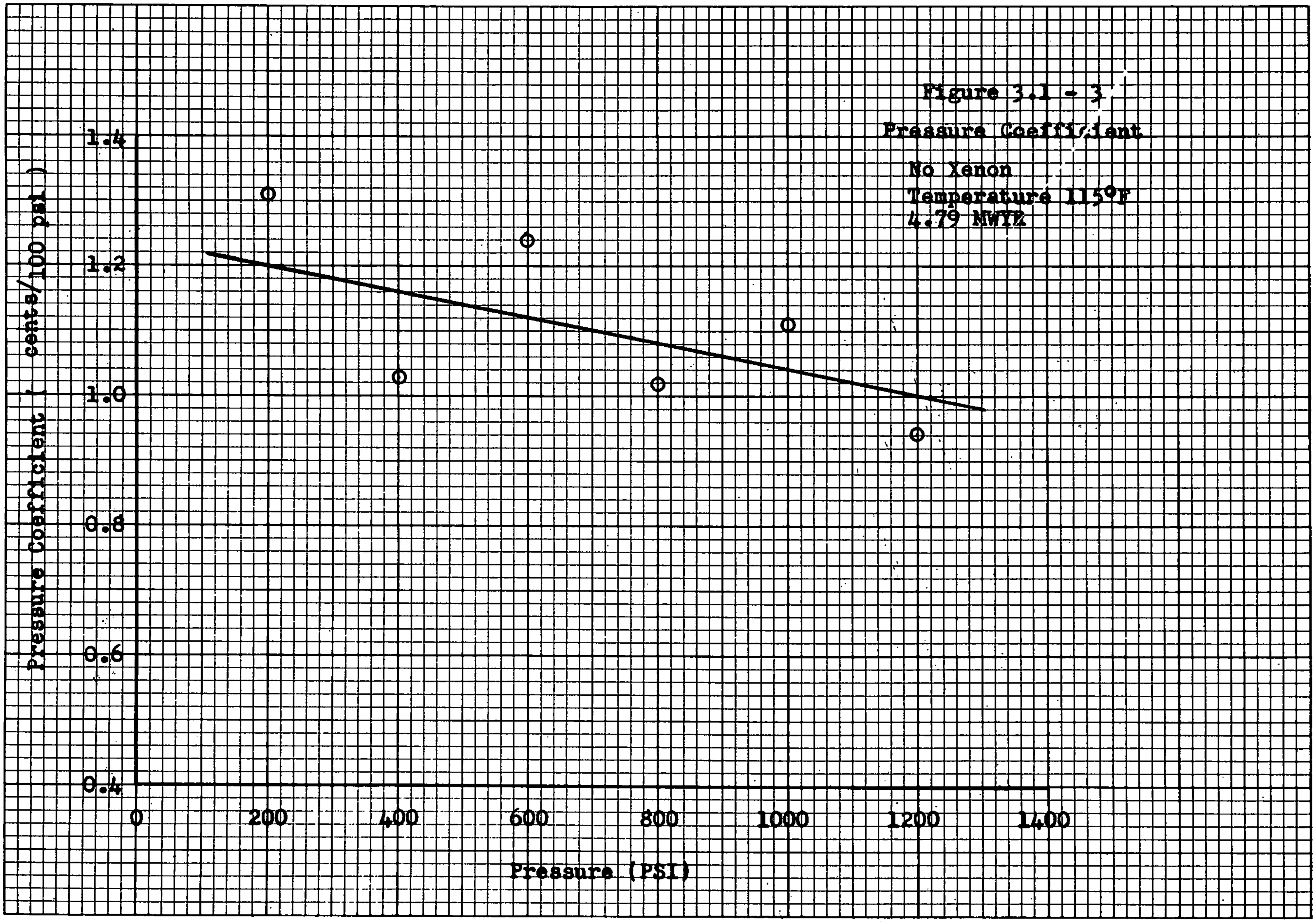

Figure 3.1 - 3

Pressure Coefficient

No Xenon
Temperature 115°F
4.79 MWYR

Computations were made using data (3) on the compressibility of water as a function of temperature. These computations determined the relationship between pressure and temperature based on the density of water.

TABLE 3.1-1

Pressure Coefficient

Pressure psi	No Xenon 115°F 4.79 MWYR Pressure Coefficient cents per 100 psi
200	1.31
400	1.03
600	1.24
800	1.02
1000	1.11
1200	0.94
Average	1.11
Integral Run 2	1.08
Integral Run 1	.98

Pressure coefficient = 1.05 ± .05 cents/100 psi

The pressure-temperature relationship used with the known values for the temperature coefficient yielded values for pressure coefficient. The calculation assumes the temperature coefficient to be caused entirely by the change in density of the moderator. The measured value for the pressure coefficient at 115°F was 1.05 ± .05 cents/100 psi. The computed pressure coefficient values were 1.15 cents per 100 psi at 104°F, and 2.9 cents/100 psi at 440°F. The computations were based on a pressure of 100 atmospheres. The agreement between measured and computed values is within the probable errors in measurements and data on water compressibility.

3.2 Five Rod Bank Position

The reactor is normally operated with the five control rods as a bank and the remaining two rods fully withdrawn as safety rods. The position of the five rod bank is a variable dependent upon temperature, core lifetime, and xenon concentration in the core.

3.2.1 Bank Position as a Function of Core Lifetime

The position of the five rod bank with equilibrium xenon present at 440°F, with peak xenon present at 440°F and with no xenon at 440°F and 70°F are shown as a function of core lifetime in Figure 3.2-1. The bank position data which was recorded during the time the reactor was shutdown for the physics measurements is given in Table 3.2-1. The bank position data recorded at equilibrium operating conditions is given in Table 3.2-2.

3.2.2 Bank Position as a Function of Xenon

The position of the five rod bank as a function time during the xenon buildup and decay is shown in Figure 3.2-2. Measurements were made at both 7.2 and 9.1 MWYR of core energy release. The buildup to equilibrium xenon concentration is shown for the 7.2 MWYR measurement. The initial xenon concentration shown by the data is the result of heating the system to operating temperature with reactor power.

To buildup xenon, the reactor was operated at full power for 51 hours; the power was then reduced to approximately 100 kilowatts which allowed the xenon concentration to increase. The bank position was not changed from the time of power reduction until peak xenon was attained. The reactivity worth of the xenon built up from equilibrium xenon to peak xenon was measured by maintaining criticality with rod C and recording the rod motion. The bank motion to maintain criticality was recorded during the decay of the peak xenon concentration.

The measurements indicate that peak xenon concentration occurs approximately 8 hours after the power is reduced (to essentially zero) and that 18.8 hours after the power is reduced the value of reactivity introduced by xenon is the same as the equilibrium value.

3.3 Rod Calibrations

Rod calibrations are fundamental to all core measurements; they are the basis for core reactivity evaluations. The calibrations of rod C, rod A and the five rod bank were done at several conditions of temperature, xenon concentration and core life time.

3.3.1 Calibration of Rod C

The calibrations of control rod C were performed after the reactor was shutdown and between the time peak xenon built up and the time it decayed. The rod worth was determined by withdrawing the rod slightly and measuring the resultant reactor period. The object in calibrating control rod C during the decay of peak xenon is that the core reactivity is changing with time. Since the four rod bank (rods 1, 2, 3 and 4) was not moved during the calibration, as the core reactivity increased rod C could be inserted allowing it to be calibrated at a new position.

TABLE 3.2-1

EQUILIBRIUM BANK POSITIONS

Temperature - 440°F 2°F

DATE	°F DAYS	MWYR	FIVE ROD BANK POSITION INCHES
June 14, 1957	269	0.388	8.41*
June 28, 1957	544	0.785	8.54*
Aug. 8, 1957	695	1.003	8.51**
Aug. 23, 1957	974	1.405	8.50**
Sept 23, 1957	1122	1.619	8.52**
Oct. 27, 1957	1533	2.212	8.63**
Nov. 28, 1957	1916	2.765	8.73**
Dec. 22, 1957	2191	3.162	8.82**
Jan. 8, 1958	2421	3.494	8.97**
Feb. 3, 1958	2636	3.802	9.00**
Feb. 19, 1958	2883	4.158	9.07**
Mar. 2, 1958	3082	4.44	9.21**
Mar. 20, 1958	3319	4.79	9.32
Apr. 21, 1958	3748	5.41	9.60**
May 5, 1958	4000	5.77	9.77**
May 21, 1958	4265	6.15	10.00**
July 24, 1958		7.22	10.54
Sept 7, 1958		8.10	11.18
Oct. 20, 1958		8.95	11.46
Nov. 1, 1958		9.10	11.71

* Rods A and B at 20.00 inches

** Rods A and B at 19.00 inches

TABLE 3.2-2

BANK POSITION AS A FUNCTION OF ENERGY RELEASE

Data				Corrected Values			
MWYR	Temp.	Press.	Bank Position	No Xenon 100 PSI; 70°F A&B, 19in.	No Xenon 1200 PSI; 440°F A&B 19 in.	Peak Xenon 1200 PSI; 440°F A&B 19 in.	Eq. Xenon 1200 PSI; 440°F A&B 19 in.
0	93	560	3.72	3.686			
	440	1240	6.67		6.670		
4.79	118	280	4.94	4.804			
6.15	117.8	1256	5.27	5.171			
	442	1198	8.388 A = 12"		8.21		
7.2	118.3	200	5.637	5.500			
	440.0	1200	8.71 68 hrs.		8.65		
	440.6	1200	11.417			11.41	
	440	1200	10.59				10.59
9.1	114	240	6.500	6.39			
	441	1200	9.757 63 hrs.		9.67		
	444.7	1210	12.691			12.59	
	441.2	1200	11.689				11.66

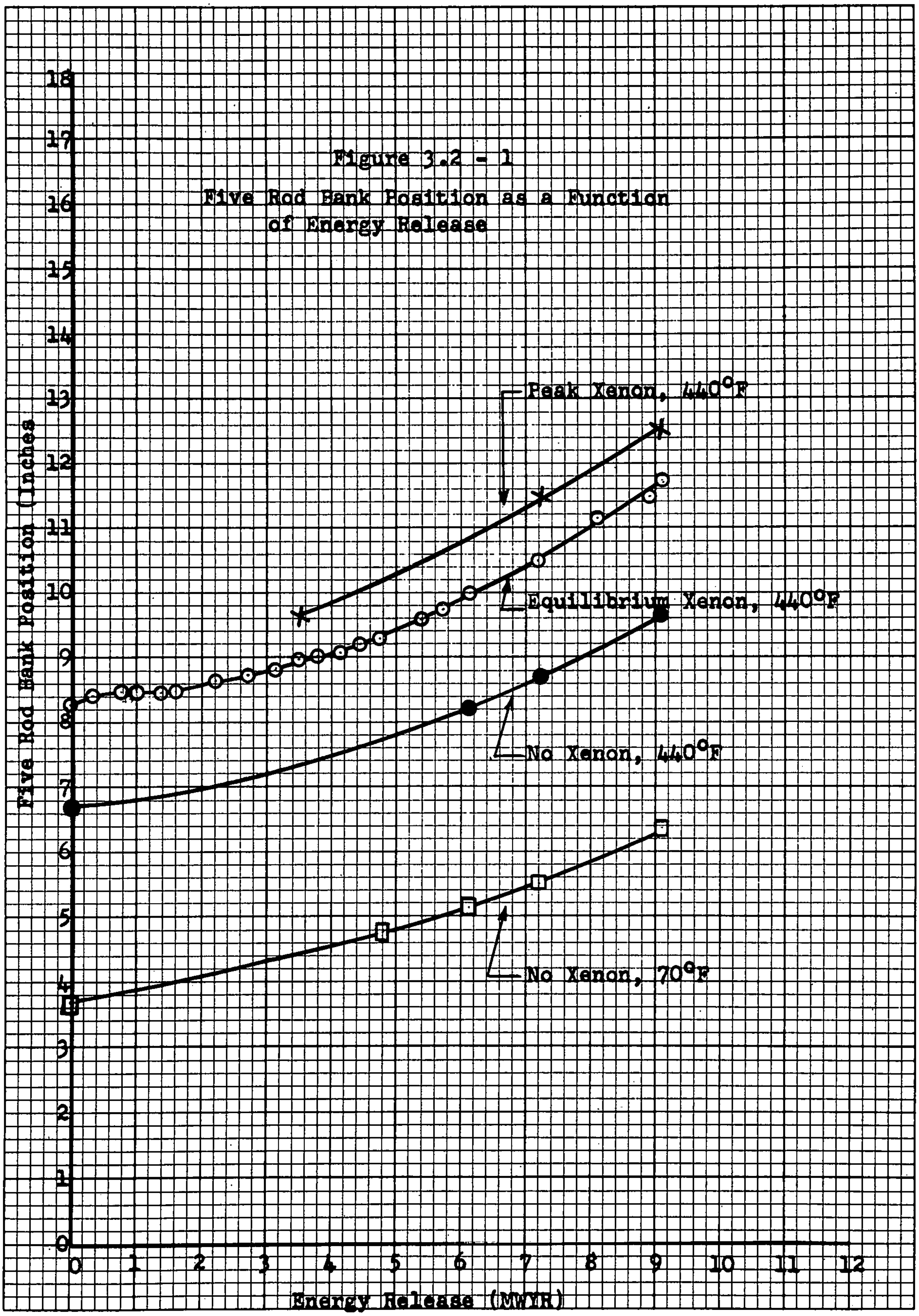
Figure 3.2 - 1
Five Rod Bank Position as a Function
of Energy Release
Peak Xenon, 440°F
Equilibrium Xenon, 440°F
No Xenon, 440°F
No Xenon, 70°F
Five Rod Bank Position (Inches
Energy Release (MWYR)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

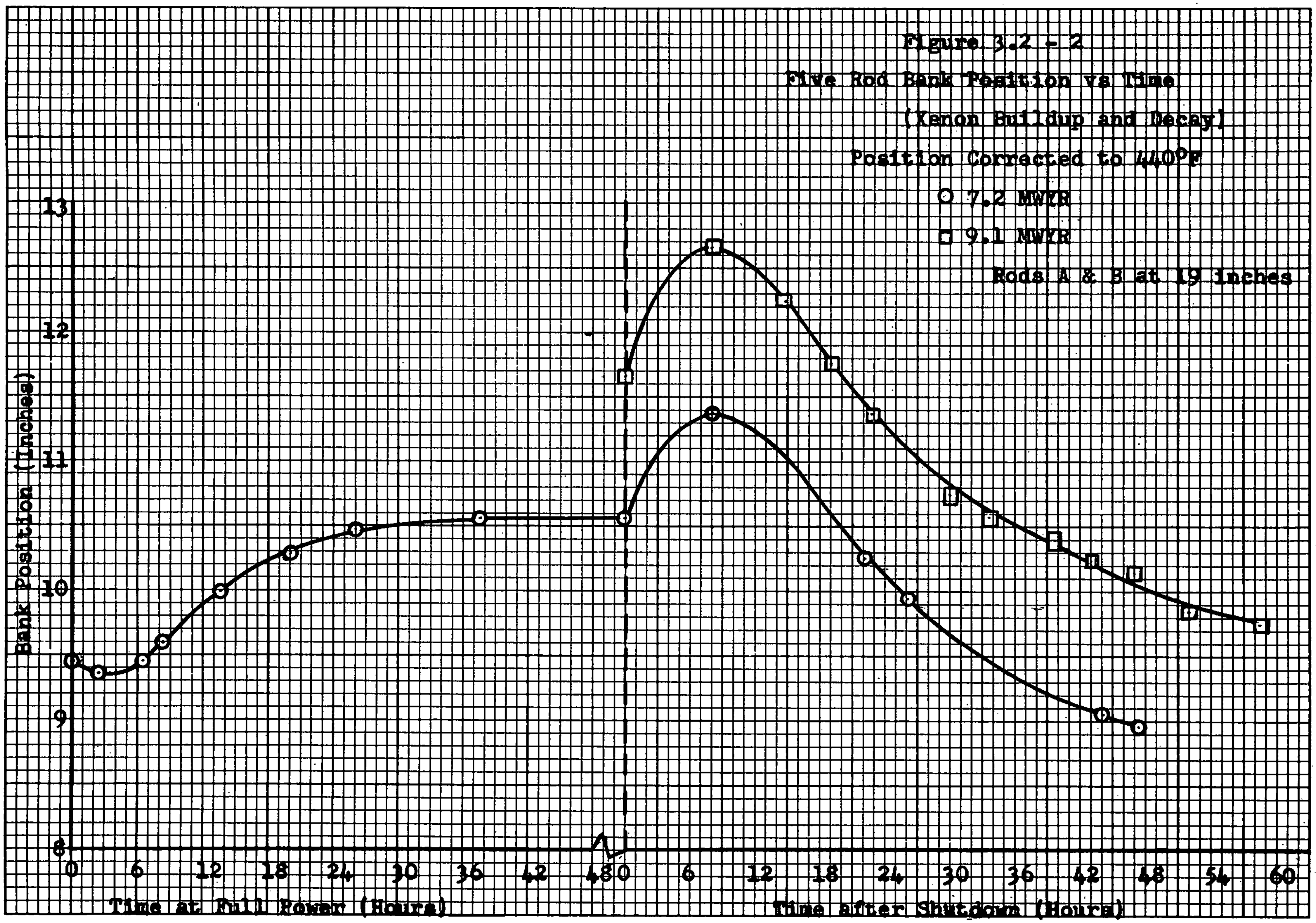
Figure 3.2 - 2
Five Rod Bank Position vs Time
(Xenon Buildup and Decay)
Position Corrected to 440°F
7.2 MWYR
9.1 MWYR
Rods A & B at 19 inches
Bank Position (Inches)
8
9
10
11
12
13
0
6
12
18
24
30
36
42
48
0
6
12
18
24
30
36
42
48
54
60
Time at Full Power (Hours)
Time after Shutdown (Hours)

The results of the measurements are plotted as rod worth as a function of rod position in Figure 3.3-1. Curves of measurements taken at a core energy release of 0, (4), 6.1, 7.2 and 9.1 MWYR are included. In each case the calibration curve is the best polynomial fit to at least 50 data points. The root mean square deviation in each case is less than 8%.

The increase in the differential rod worth, cents/in. during the core life time is principally due to the motion of the four rod bank as a function of lifetime.

3.3.2 Calibration of Rod A

The calibration of rod A at different average bank positions, core temperatures and core lifetimes is shown in Figure 3.3-2. The shift in rod worth with axial position is due principally to changes in the five rod bank position.

There is a difference in the area under the rod worth curves for 120°F and 440°F. This difference in area or integral rod worth implies that the rod worth is temperature dependent; however, more data is needed to substantiate such a statement.

A comparison between calibrations at different temperatures at the same five rod bank positions may be performed as additional calibrations are made during core lifetime.

3.3.3 Calibration of the Five Rod Bank

The calibration of the five rod bank as a function of position is shown in Figure 3.3-3. The calibration points through which the curve was drawn were obtained at different times during core life and at various core conditions. These are listed below:

1) Rod A calibration at 120°F and 440°F at 6.1, 7.2 and 9.1 MWYR
2) Xenon reactivity worth at 440°F and 7.2 MWYR
3) Rod C Calibration at 9.1 MWYR
4) Rod C as a function of temperature from 90°F to 440°F at 0 MWYR
5) Subcritical conditions at 100°F and 7.2 MWYR

3.4 Start-up Neutron Count Rate

Initially the reactor core was provided with a 15 curie Po-Be source and a 0.5 x 3 x 3 in. beryllium plate photoneutron source as shown in Figure 1.1. After about two MWYR of reactor operation there is sufficient quantity of fission product gamma activity built up to make the photoneutron source significant with respect to the Po-Be source.

Source multiplication experiments were performed to establish the adequacy of these neutron sources. By adequate is meant the ability of the nuclear instruments to "see" the sources during startup.

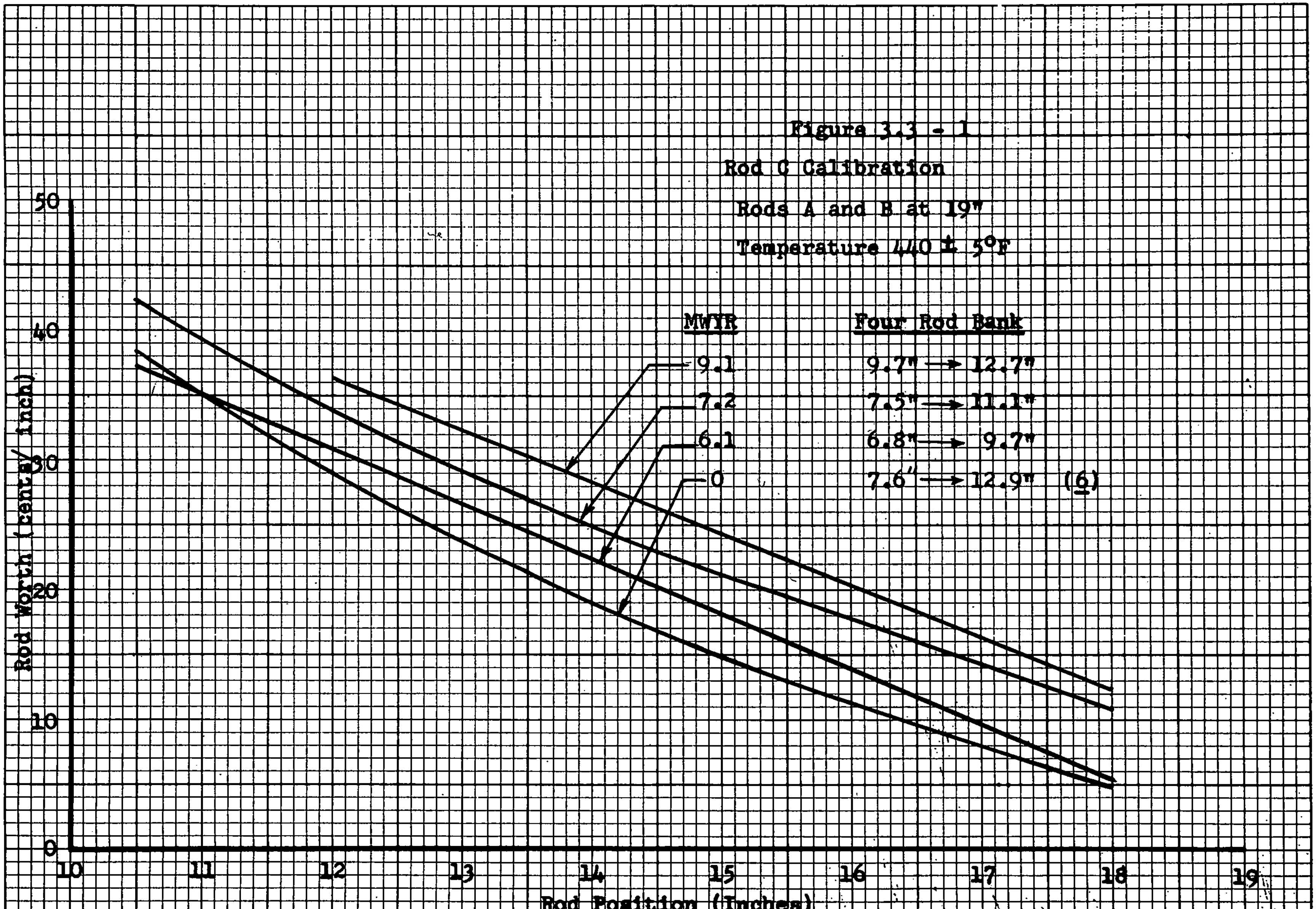

Figure 3.3 - 1
Rod C Calibration
Rods A and B at 19"
Temperature 440 ± 5°F
MWYR
Four Rod Bank
9.1
9.7" → 12.7"
7.2
7.5" → 11.1"
6.1
6.8" → 9.7"
0
7.6" → 12.9" (6)
Rod Worth (cents/ inch)
0
10
20
30
40
50
10
11
12
13
14
15
16
17
18
19
Rod Position (Inches)

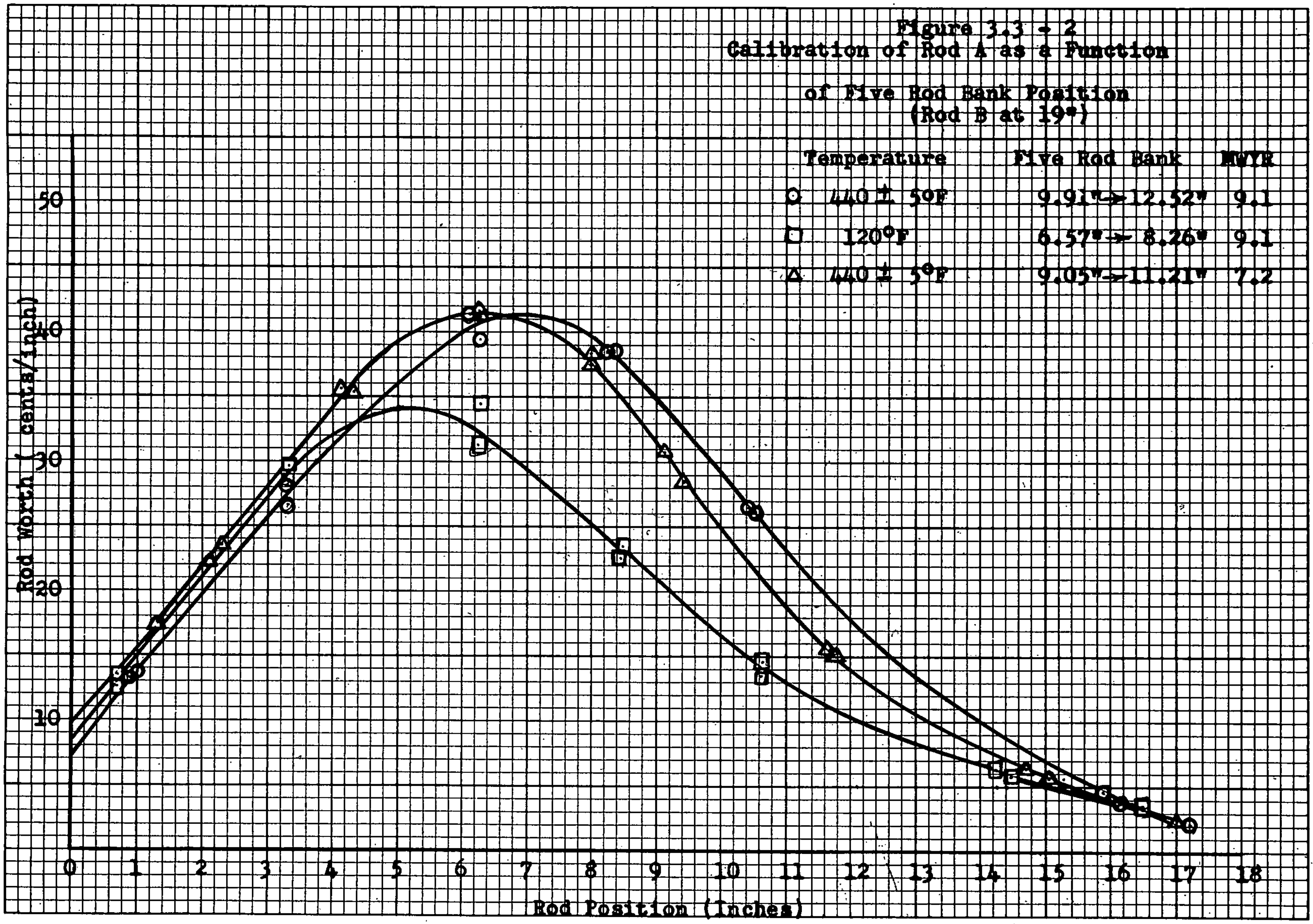
Figure 3.3 - 2
Calibration of Rod A as a Function
of Five Rod Bank Position
(Rod B at 19")
Temperature
Five Rod Bank
MWYR
440 ± 5°F
9.91"→12.52"
9.1
120°F
6.57"→ 8.26"
9.1
440 ± 5°F
9.05"→11.21"
7.2
Rod Worth (cents/inch)
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Rod Position (Inches)

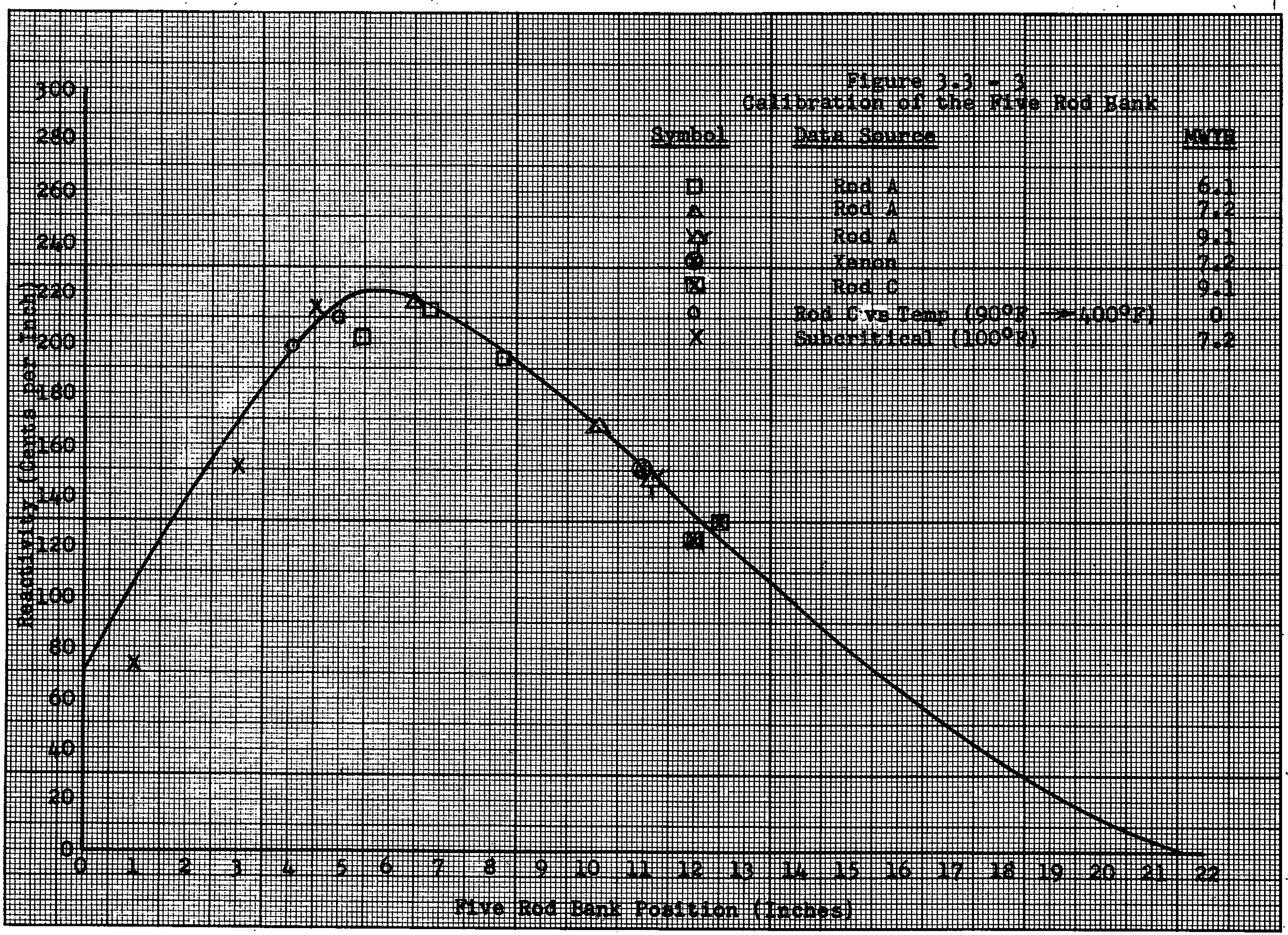

Figure 3.3 - 3
Calibration of the Five Rod Bank

The overall reduction in start-up neutron count rate since the beginning of the core life was found to be less than a factor of two, although the Po-Be source has decayed to one-tenth its initial strength. It is expected that the beryllium source will provide sufficient neutrons for the remainer of the core provided the reactor is not shutdown for extended periods of time.

3.4.1 Startup Count Rate and Power Level

The decay in the power level of the reactor core, after it was completely shutdown by fully inserting all seven control rods, was determined by recording the neutron flux decay. By reading the log N and counter channels simultaneously it was possible to correlate count rate with power level and thus utilize the higher sensitivity of the counter channels to determine the power at levels not within the range of the log N meter. A plot of these readings is shown in Figure 3.4-1 as a function time after shutdown. By using the above method the power generation due to source neutrons was determined after a core energy release of 6.1, 7.2 and 9.1 MWYR. The resulting source power levels were 0.019, 0.013 and 0.105 watts respectively.

The shutdown power levels were measured as a function of time after shutdown to determine if the decay of photoneutrons was reflected in the power level. The measured data was not consistent with the expected rate of decay of gamma intensity above 1.6 Mev (the Be threshold). Further measurements are required to resolve the inconsistancy.

3.4.2 Start-up Count Rate and Core Reactivity

The neutron count rate as a function of 1-K of the core has been determined at 7.2 MWYR of energy release and 156 hours after the reactor was shutdown. The results are shown in Figure 3.4-2. The negative reactivity was introduced by the insertion of rod A.

By utilizing Figure 3.4-2, the sub-critical reactivity associated with a given bank position or complete shutdown can be found from the neutron count rate. For example, with all 7 control rods fully inserted the count rate was 1.4 counts/sec. indicating a negative reactivity of 0.14. When only 5 control rods were inserted the count rate was 3.5 counts/sec. yielding a negative reactivity of 0.058.

The above method was used to obtain some of the calibration data for the 5 rod bank which in included in Figure 3.3-3.

3.5 Stuck Control Rod Conditions

The SM-1 was designed to be shutdown with 80% of the rods inserted. The "80% shutdown" is interpreted as meaning 80% of the available rod motion starting from the fully withdrawn position. Thus, 80% of 7 rods means 5.6 rods can be inserted and 1.4 rods must be withdrawn or all 7 rods can be 20% withdrawn. The 1.4 withdrawn rods can be met by several situations. One rod can be fully withdrawn and another 0.4 withdrawn or any combination of the above which yields a total of 1.4 rods withdrawn.

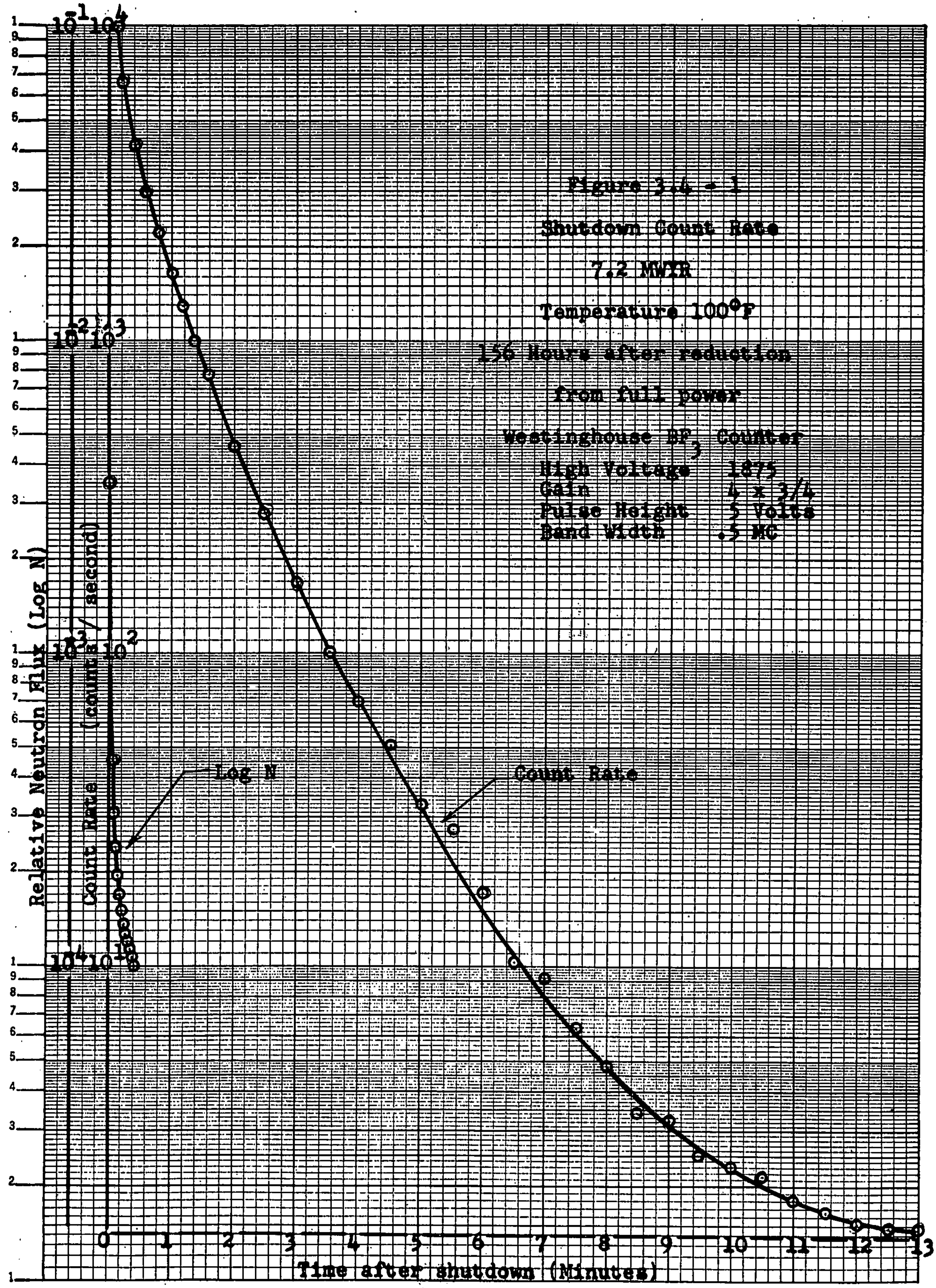
Figure 3.4 - 1
Shutdown Count Rate
7.2 MWYR
Temperature 100°F
156 Hours after reduction
from full power
Westinghouse BF3 Counter
High Voltage 1875
Gain 4 x 3/4
Pulse Height .5 Volts
Band Width .5 MC
Log N
Count Rate
Relative Neutron Flux (Log N)
Count Rate (counts / second)
Time after shutdown (Minutes)

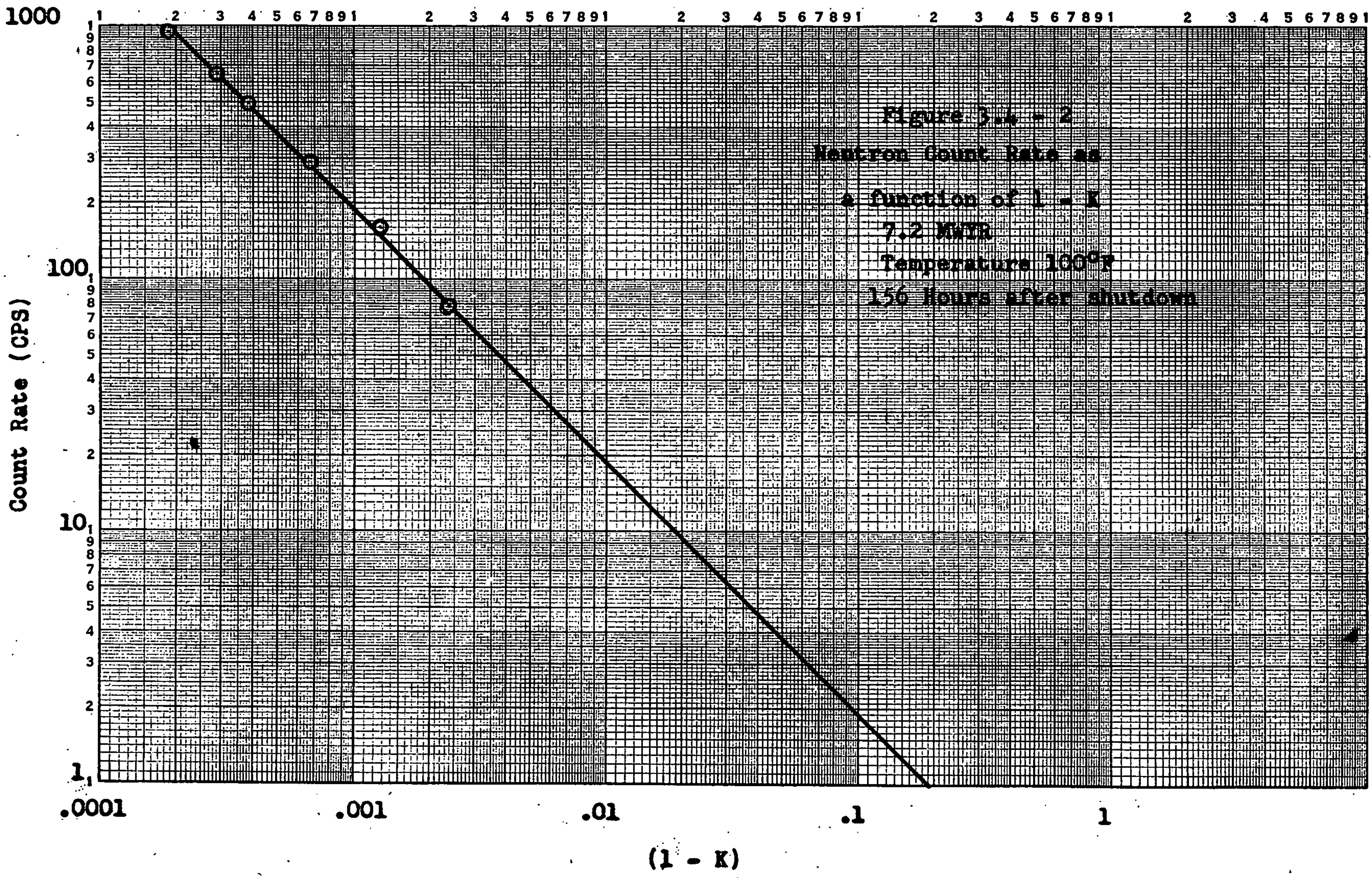

Figure 3.4 - 2
Neutron Count Rate as
a function of 1 - K
7.2 MWYR
Temperature 100°F
156 Hours after shutdown

The worst condition, or that which is the most difficult to meet is the case where one rod is fully withdrawn and another 0.4 withdrawn. The case of 7 rods each inserted 80% of their travel results in the largest safety margin.

3.5.1 Core With 7 Control Rods

Rod worth measurements have been made over the reactor core life for the following cases:

a) Control rod 1 fully out control rod A 8.8 in. withdrawn
b) Control rod 1 fully out control rod A at critical position
c) Control rod 1 fully out control rod 2 8.8 in. withdrawn
d) Control rod 1 fully out control rod 2 at critical position
e) Control rod A fully out control rod 1 8.8 in. withdrawn
f) Control rod A fully out control rod 1 at critical position

These are considered to be the worst cases because the configurations give the least shutdown margin at 68°F.

With five rods fully inserted and one rod fully withdrawn, the critical position at 68°F was measured and is plotted in Figure 3.5-1 as a function of core energy release (MWYR). Also shown on Figure 3.5-1 is the rod position which corresponds to the 80% shutdown criteria. It should be noted that in all of the cases the worth of the rods was more than sufficient to meet the shutdown requirements.

As the core burned out, the safety margin increased due to reduction in core reactivity. It should be noted that had more boron been initially present in the core, the control rod would have had to be inserted as the burnable poison was burned, then after the maximum reactivity of the core was reached the rod would start to be withdrawn. The converse is also true, had no boron been present in the core, the rod would have been withdrawn at a more rapid rate initially.

The negative reactivity of the reactor core for various combinations of the "80% shutdown" has been determined as a function of core energy release and is shown in Figure 3.5-2. The smallest safety margin is obtained when rod 1 is fully withdrawn and rod A is 8.8 in. withdrawn. Regardless, the "80% shutdown" requirement is met in all cases.

3.5.2 Core With 6 Control Rods

A reactor core containing only 5 control rods is of interest with respect to future core designs. Such a design would have a center rod and four rods in a ring. Safety rods A and B would be replaced with fuel elements. If the "80% shutdown" criteria is applied to the reactor, then it would be necessary to shutdown with one rod withdrawn.

Measurements were made to determine,

a) The critical position of rod C (A and B withdrawn)
b) The critical position of rod 3 (A and B withdrawn)

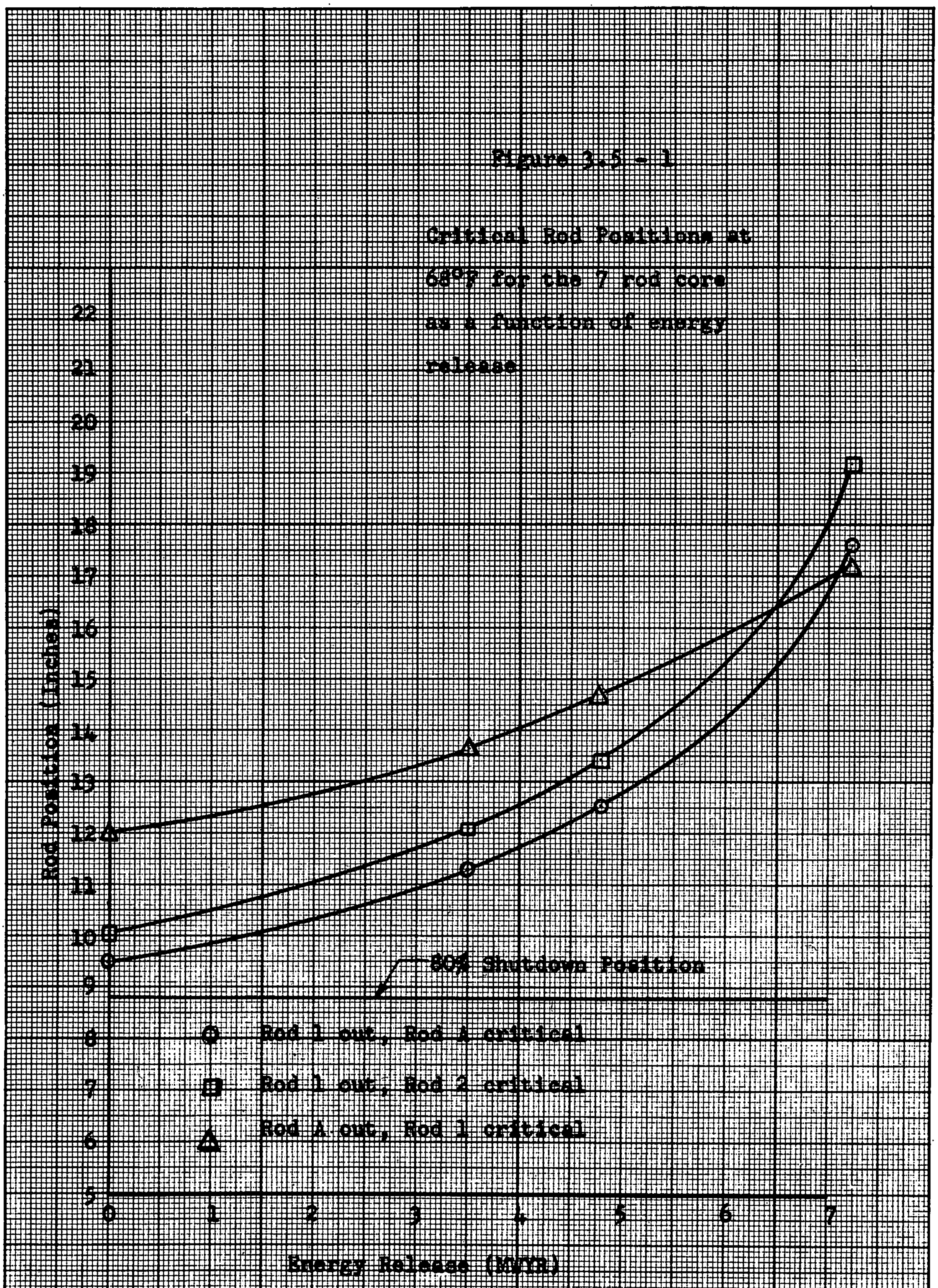
Figure 3.5 - 1
Critical Rod Positions at 68°F for the 7 rod core as a function of energy release
Rod Position (Inches)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
0
1
2
3
4
5
6
7
Energy Release (MWH)
80% Shutdown Position
Rod 1 out, Rod A critical
Rod 1 out, Rod 2 critical
Rod A out, Rod 1 critical

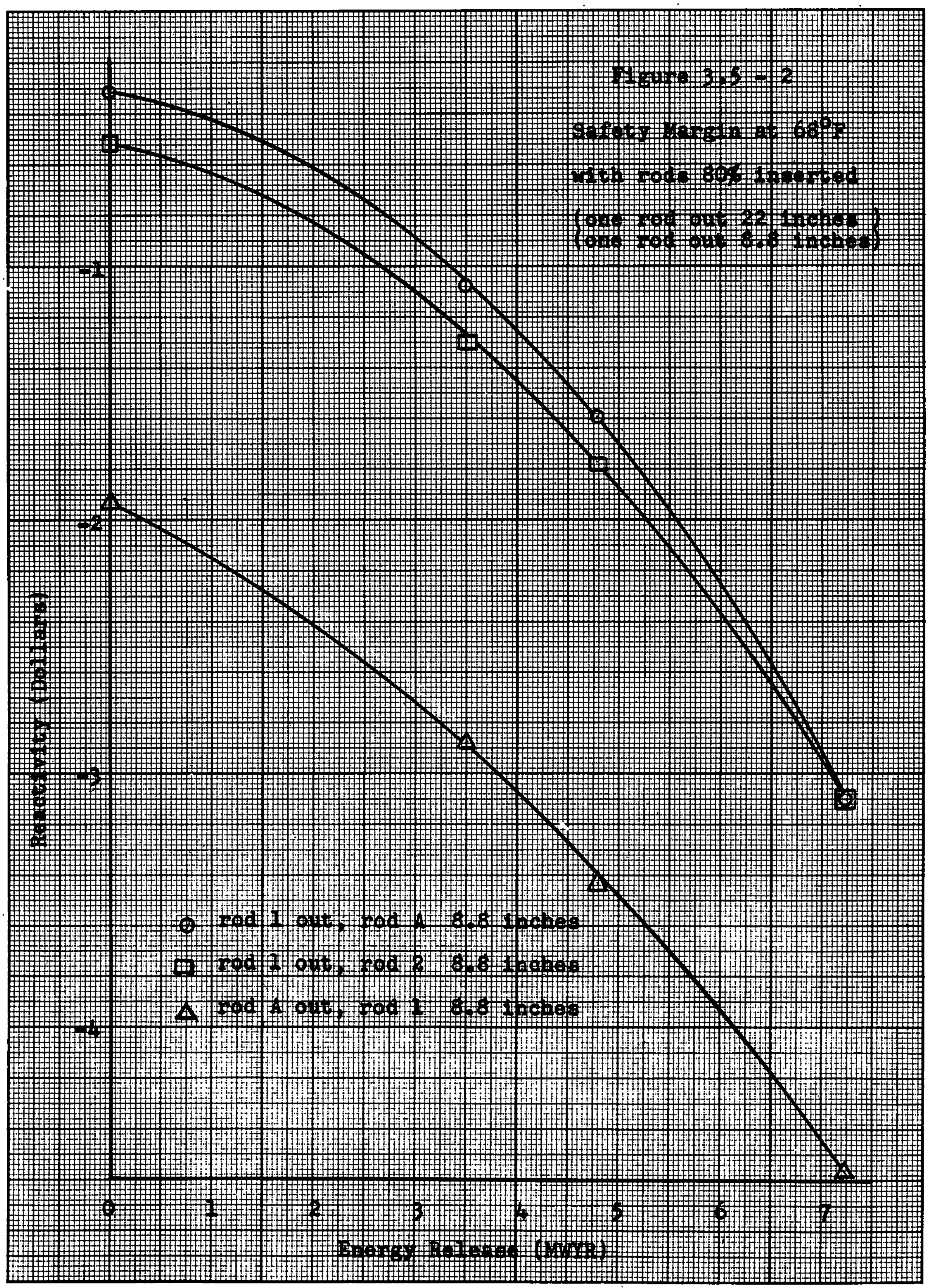

Figure 3.5 - 2
Safety Margin at 68°F
with rods 80% inserted
(one rod out 22 inches)
(one rod out 8.8 inches)
rod 1 out, rod A 8.8 inches
rod 1 out, rod 2 8.8 inches
rod A out, rod 1 8.8 inches
Reactivity (Dollars)
-1
-2
-3
-4
0
1
2
3
4
5
6
7
Energy Release (MWYR)

c) Core reactivity with rods A, B and C withdrawn
d) Core reactivity with rods A, B and 3 withdrawn

as a function of core energy release (MWYR). The results of measurement a) and b) above are shown in Figure 3.5-3 where critical rod position for rod C and rod 3 is plotted versus MWYR. The reactor must release about 7.5 MWYR of energy before the reactivity is reduced enough for the core to be shutdown with rods A, B and C withdrawn. In some configurations, an eccentric control rod is worth more than the center rod and an extrapolation of present data indicates that the core must release about 10 MWYR of energy before the reactivity is reduced enough to be controlled with four rods (rod A, C and 3 withdrawn). When rod 3 is fully withdrawn, essentially half of the reactor core does not have any control rods inserted. This is a more reactive configuration than a core with a ring of four control rods.

The excess reactivity of the core at 68°F with rods A, B and C, and rods A, B and 3 withdrawn respectively is shown in Figure 3.5-4 as a function of core energy release. It should be noted that with rod C withdrawn the excess reactivity is zero at 7.5 MWYR.

It must be noted that the SM-1 control rod fuel element has only 16 fuel plates compared to 18 in the stationary fuel element. If a core contained 40 stationary elements and five control rod elements the ractivity associated with the stuck rod condition would be approximately 92 cents greater than that shown in Figure 3.5-4 due to the additional fuel in location now occupied by the fuel element portion of rods A and B.

3.6 Flux Distribution as a Function of Core Lifetime

Perturbation theory indicates that the worth of a thermal absorber is proportional to the product of the thermal neutron regular and adjoint fluxes. Assuming the regular and adjoint fluxes to have the same shape (which is true for a bare reactor) and assuming a control rod to be essentially a thermal absorber, the worth of a control rod is proportional to the square of the local thermal flux.

As an experimental check on the above assumptions the square root of the reactivity worth of rod A, with the bank at 6.4 inches, was plotted versus rod A position as shown in Figure 3.6-1. The neutron flux as determined from bare gold foil activations in the zero power experiments (4) was also plotted in Figure 3.6-1 to serve as a comparison. The bank position for the gold foil traverse was 6.3 inches. Both curves are normalized to an average neutron flux of unity.

From the close agreement between the two curves in Figure 3.6-1 it appears that the square root of the rod worth as a function of position gives a good indication of the overall axial flux distribution. It should be noted that the bare gold foil does not measure only the thermal neutron flux.

By assuming that the rod worth predicts the neutron flux distribution, the relative neutron flux for different bank positions was calculated and is shown in Figure 3.6-2. The shift in the axial location of the peak neutron flux as the bank is withdrawn is shown rather clearly. On this

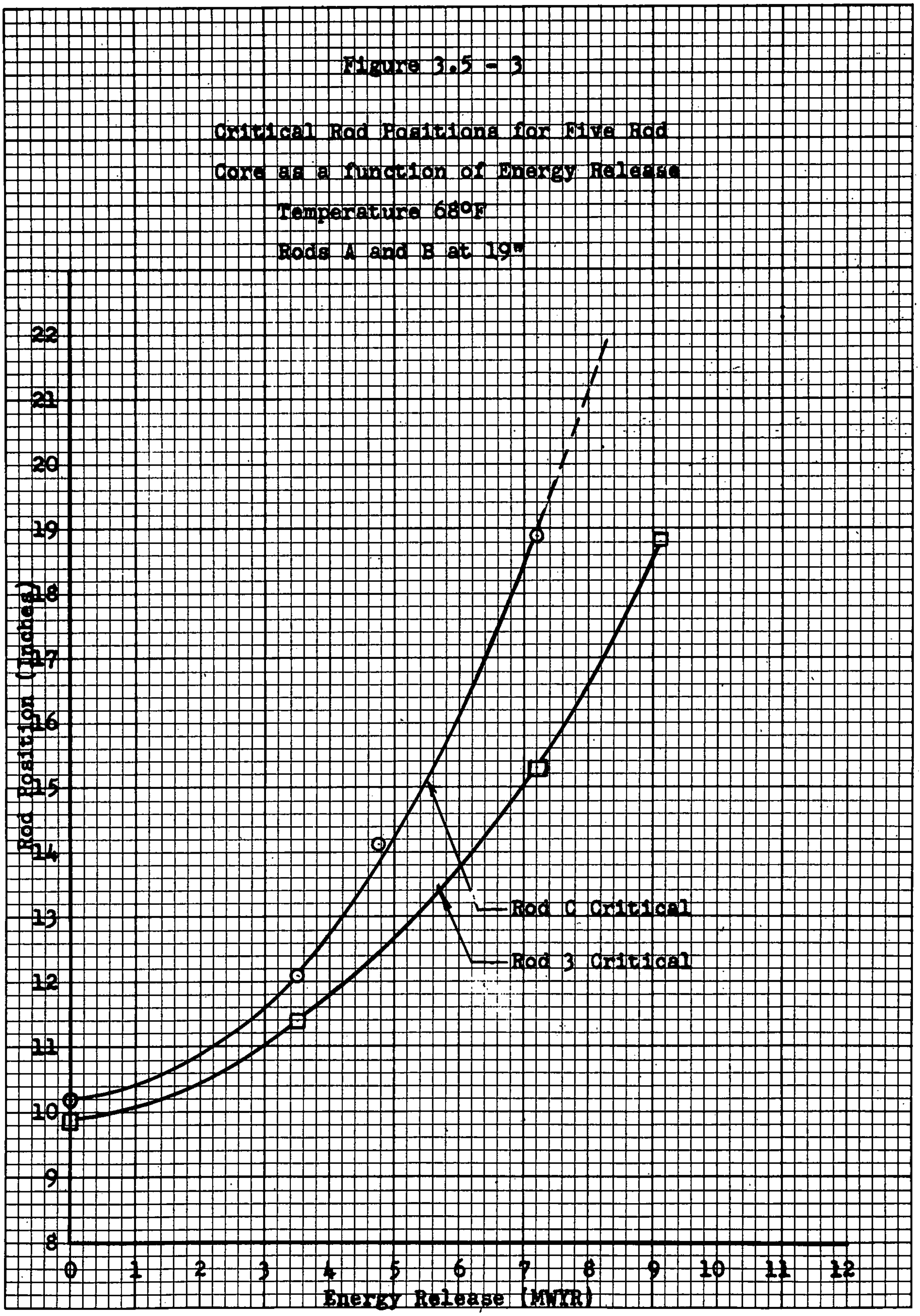
Figure 3.5 - 3
Critical Rod Positions for Five Rod
Core as a function of Energy Release
Temperature 68°F
Rods A and B at 19"
Rod C Critical
Rod 3 Critical
Rod Position (Inches)
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
1
2
3
4
5
6
7
8
9
10
11
12
Energy Release (MWYR)

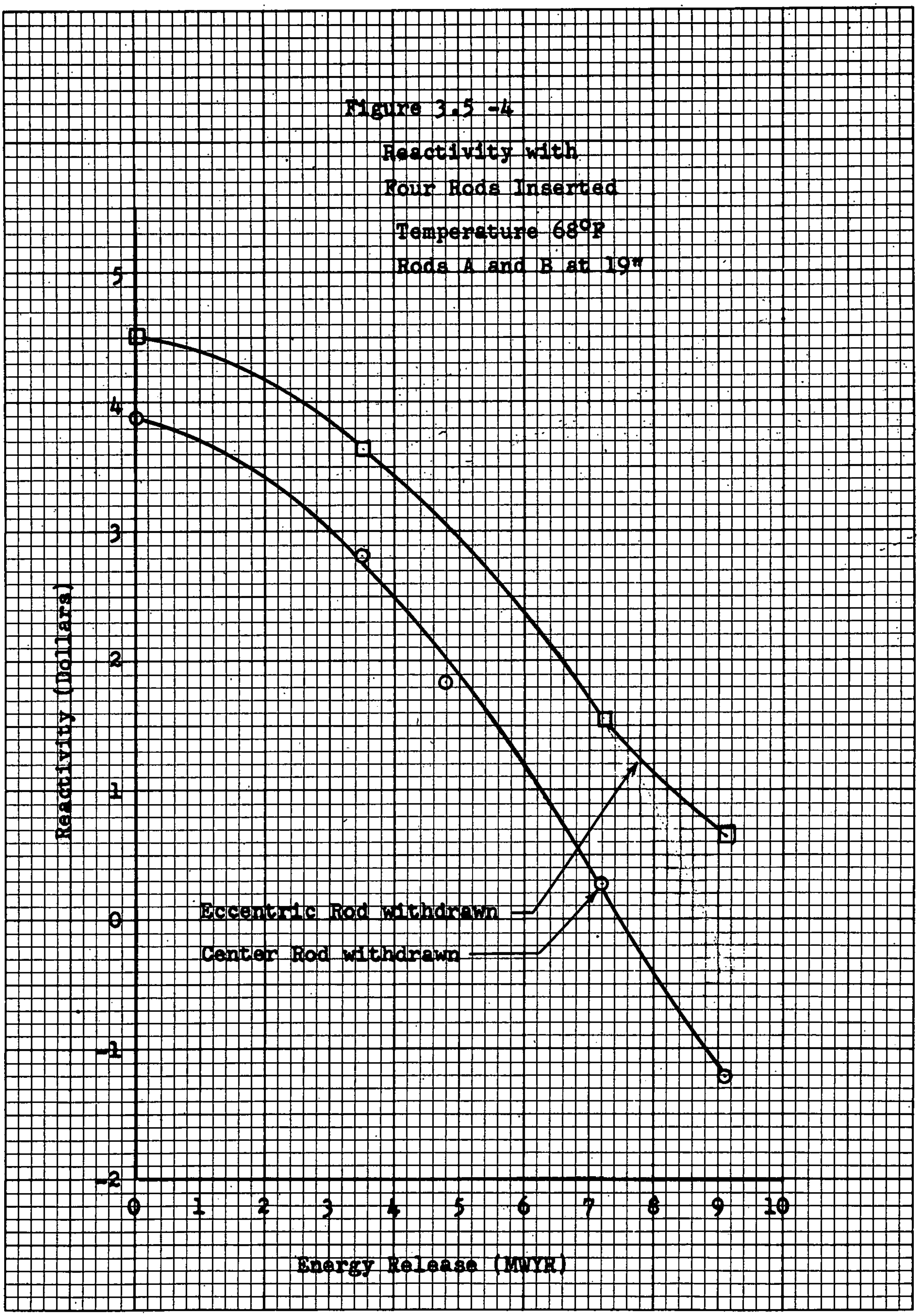
Figure 3.5 -4
Reactivity with
Four Rods Inserted
Temperature 68°F
Rods A and B at 19"
Reactivity (Dollars)
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
10
Eccentric Rod withdrawn
Center Rod withdrawn
Energy Release (MWYR)

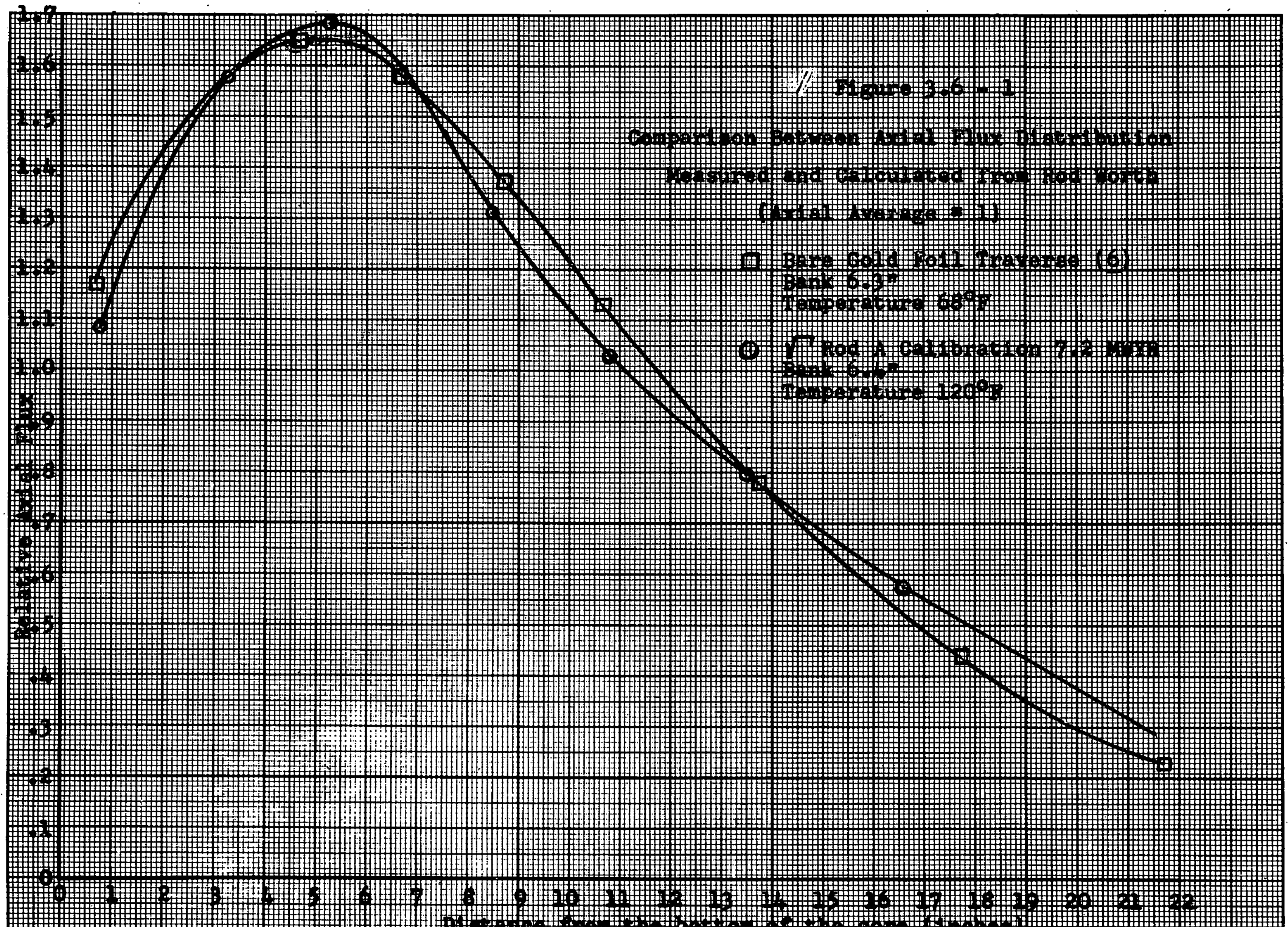
Figure 3.6 - 1
Comparison Between Axial Flux Distribution
Measured and Calculated from Rod Worth
(Axial Average = 1)
Bare Gold Foil Traverse (6)
Bank 6.3"
Temperature 68°F
√ Rod A Calibration 7.2 MWYR
Bank 6.4"
Temperature 120°F
Relative Axial Flux
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Distance from the bottom of the core (inches)

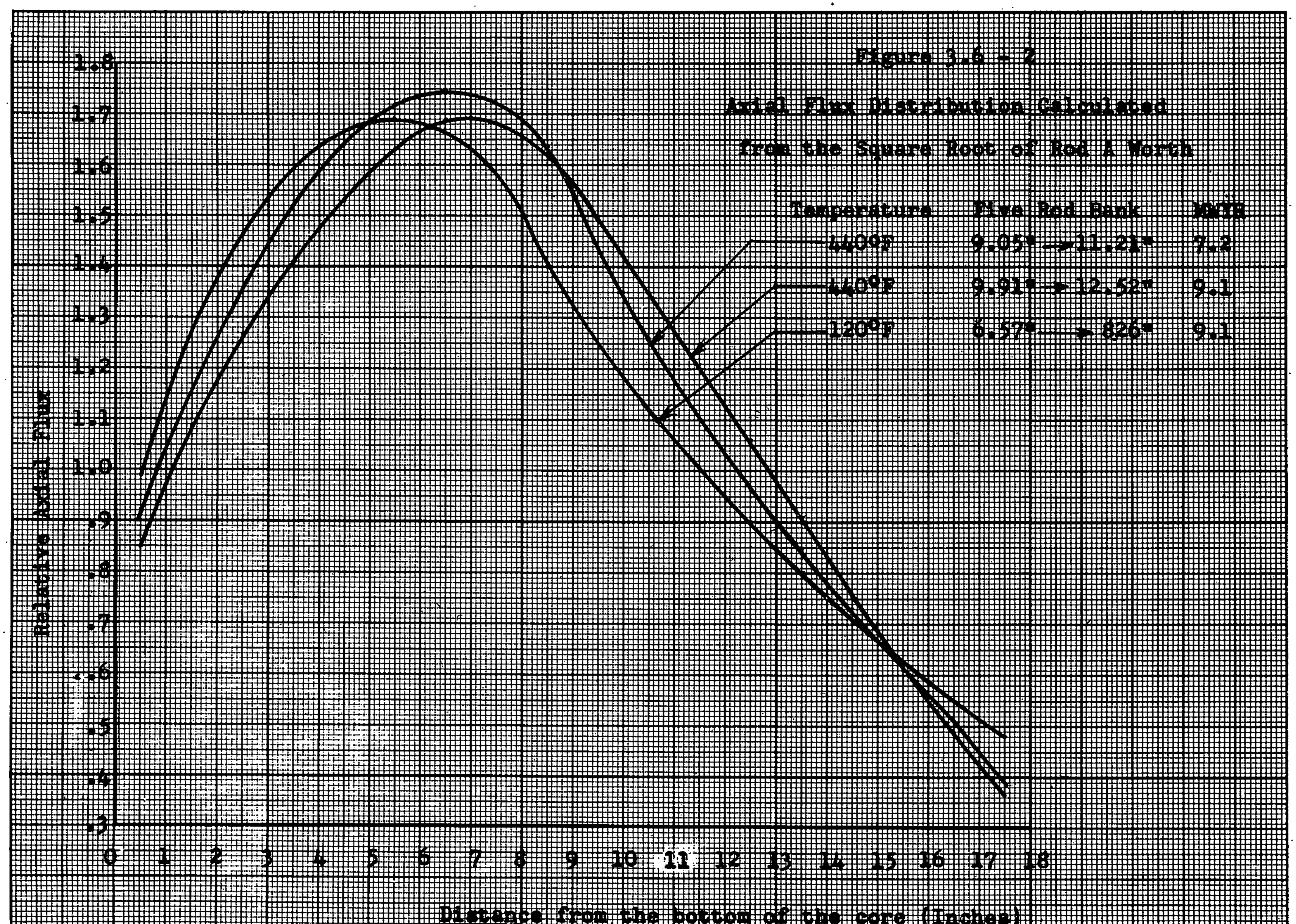

Figure 3.6 - 2

Axial Flux Distribution Calculated from the Square Root of Rod A Worth basis, the rod worth can be used to give an indication of the axial flux distribution as a function of core lifetime.

3.7 Reactivity Introduced by Xenon

The reactivity worth of the xenon built up in the reactor core during operation and after shutdown was determined by recording the motion of the 5 rod bank during the xenon buildup and decay. The motion of the 5 rod bank as shown in Figure 3.2-2 was then converted to reactivity by the 5 rod bank calibration curve shown in Figure 3.3-3.

The resultant reactivity worth of the xenon, as a function of time after reaching full power (10 MW) and also as a function of time after the reactor was shutdown, is given in Figure 3.7-1. The actual sequence of events were:

1) The system was heated to 440°F by reactor power resulting in an initial xenon concentration.

2) The reactor was operated at full power for 51 hours during which time equilibrium xenon was built up.

3) The reactor was shutdown and the xenon concentration built up to a peak and decayed.

The equations for the reactivity worth of the xenon have been derived and are given below:

For start-up,

$$X = 3.32 \left[1-e^{-0.1614t}\right] + 2.52 \left[e^{-0.1614t}-e^{-0.1044t}\right]$$

For shutdown,

$$X = 3.32e^{-0.0752t} - 27.2 \left[e^{-0.1044t}-e^{-0.0752t}\right]$$

3.8 Energy Release as a Function of Calendar Time

The energy release was plotted as a function of calendar time and is shown in Figure 3.8-1. The curve slopes for various load factors are also shown in Figure 3.8-1. It is expected that future schedules, including the time during which the reactor is shutdown for training and research and development, will continue as in the past and the average load factor will be approximately 62%. If the core energy release is about 15 MWYR the end of core life will occur during November 1959.

3.9 Core Lifetime

The 5 rod bank position has been recorded as a function of core energy release and is shown plotted in Figure 3.9-1. It is based on the reactor being at operating temperature (440°F) with equilibrium xenon concentration present.

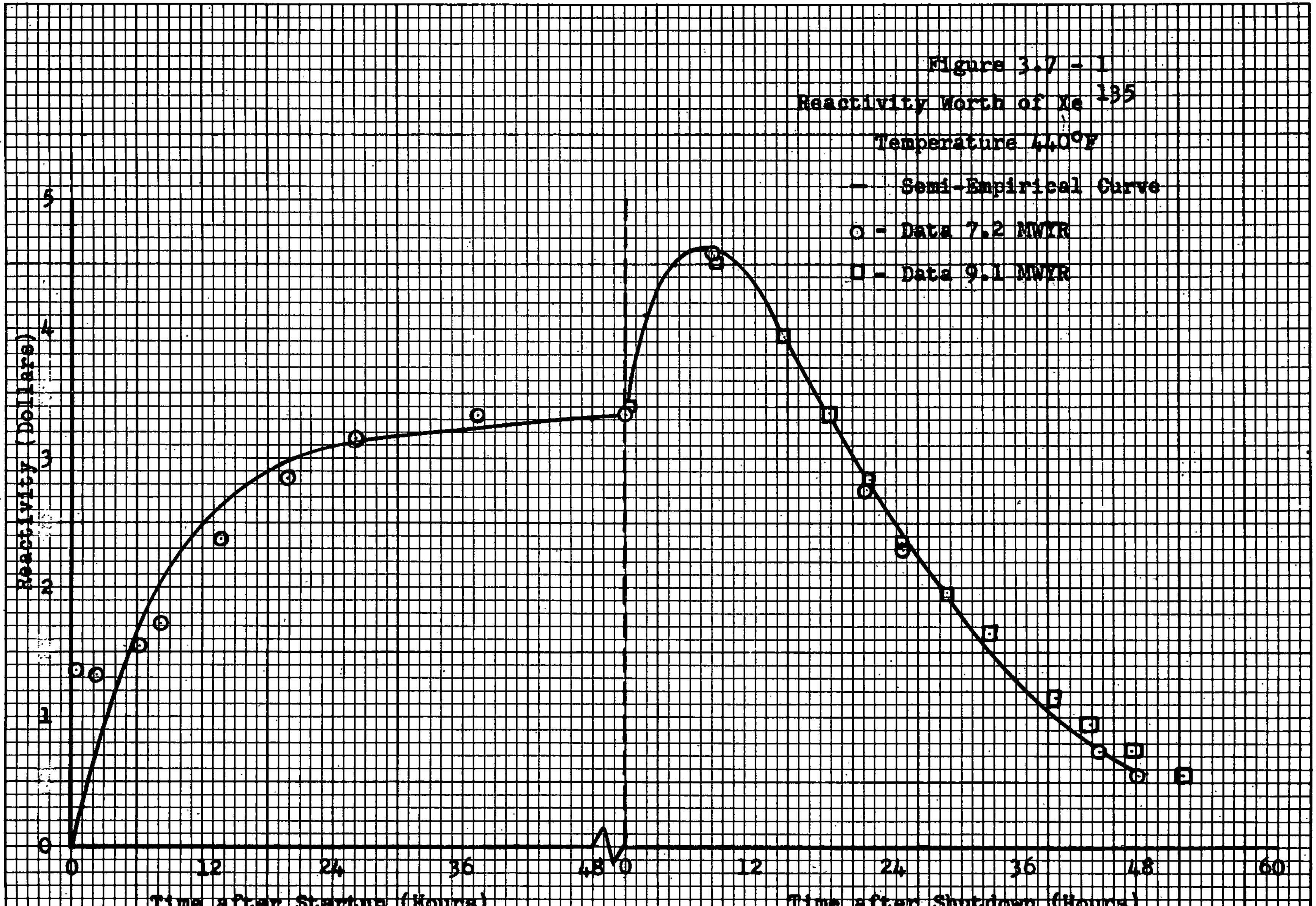

Figure 3.7 - 1

Reactivity Worth of Xe^{135}

Temperature 440°F

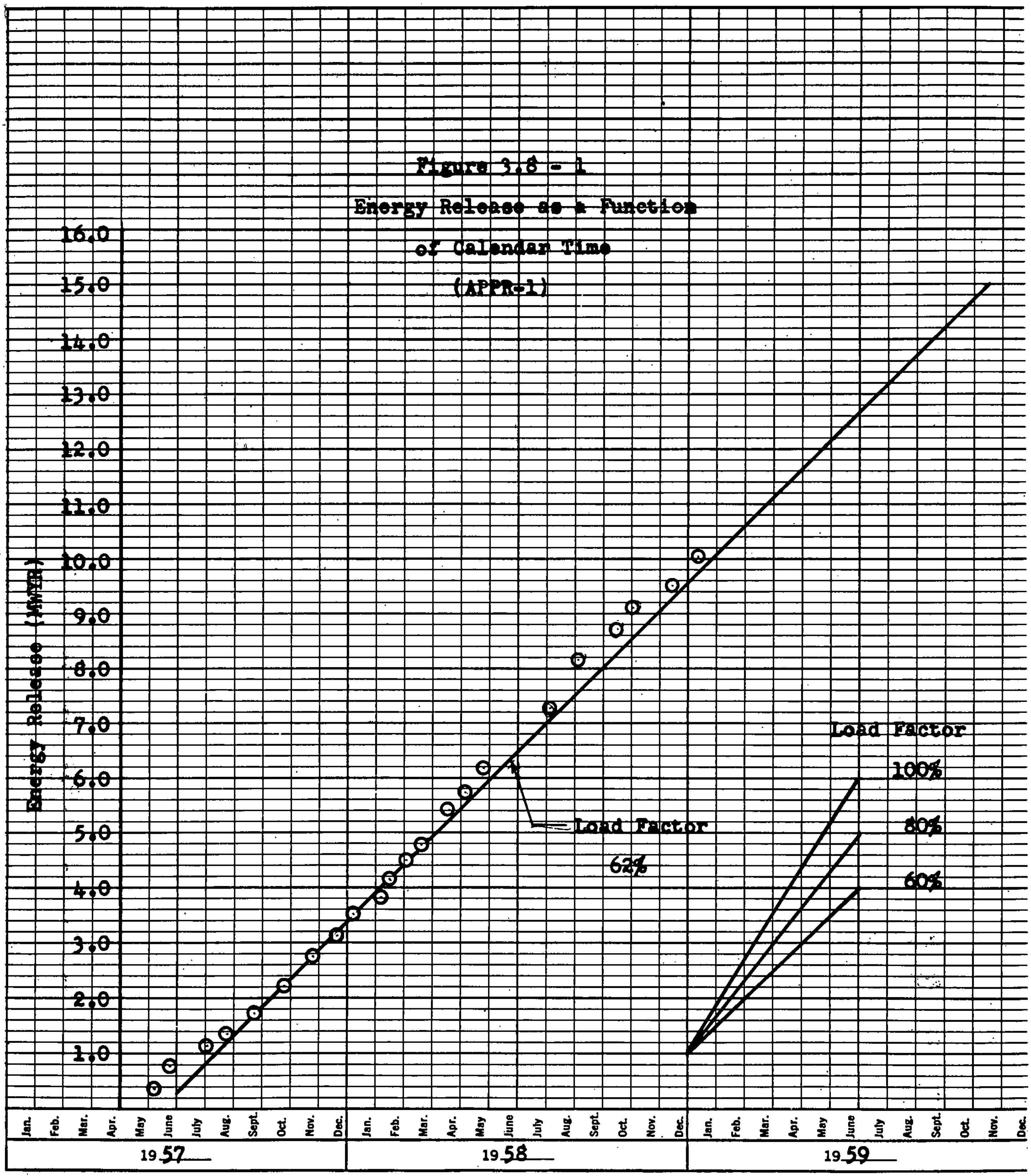
Figure 3.8 - 1
Energy Release as a Function
of Calendar Time
(APPR-1)
Energy Release (MWYR)
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Load Factor
62%
Load Factor
100%
80%
60%
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
1957
1958
1959

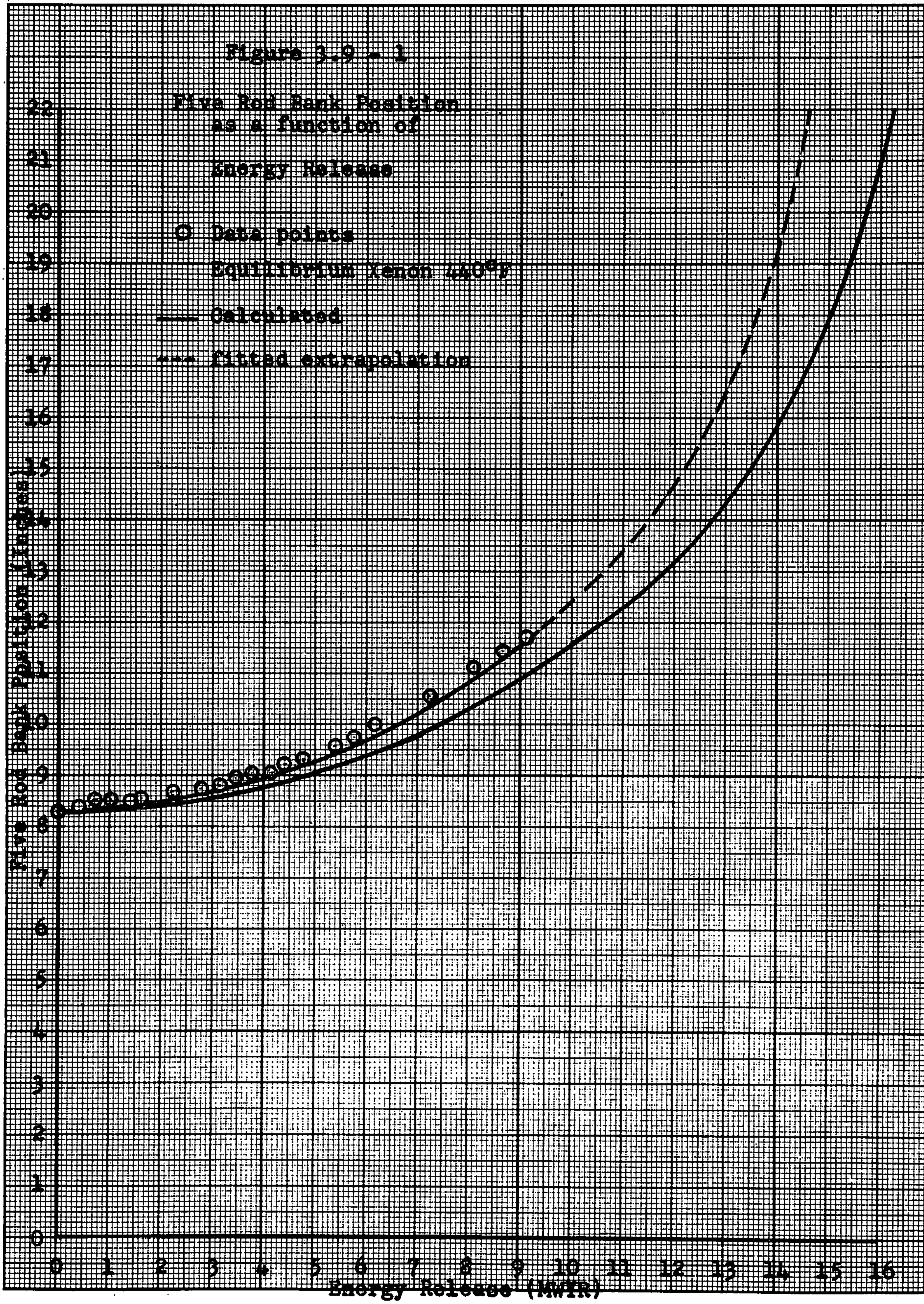

Figure 3.9 - 1
Five Rod Bank Position
as a function of
Energy Release
Data points
Equilibrium Xenon 440°F
Calculated
fitted extrapolation
Five Rod Bank Position (inches)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Energy Release (MWYR)

The bank position as a function of core energy release has been calculated on the basis on non-uniform burnup. The calculation utilized the modified two-group diffusion theory, but the fast constants were determined from a 58 group calculation(2). The results of the calculation are presented in Figure 3.9-1.

The curve plotted through the measured data points was extrapolated to the end of core life by taking 90% of the lifetime indicated by the calculated curve. Thus, a core life of 14.6 MWYR is predicted (with bank withdrawn 22 inches). The data points can also be extrapolated by a curve which is 1 MWYR less than the calculated curve indicating a core life of 15.2 MWYR. Therefore, the core lifetime is expected to be 15 MWYR.

4.0 CONCLUSIONS

The experimental measurements through 9.1 MWYR on the SM-1 core have shown that:

1) Nuclear control is satisfactory including stuck rod considerations.

2) The temperature coefficient is somewhat more negative than calculated, but has introduced no serious problems.

3) The beryllium plate photoneutron source is low but adequate for safe startup.

4) The total energy release will be approximately 15 MWYR.

APPENDIX A

I GENERAL RULES FOR CORE MEASUREMENTS

The following rules were developed to insure the consistency of the data:

1. Critical settings shall be taken not less than six minutes after power level changes or rod motion.

2. Steady state critical settings shall be determined by a constant power level ±0.5% indicated on the linear power for 2 minutes.

3. Temperature - determined critical settings shall be indicated by a maximum or minimum power level not less than 4 minutes after slight rod motion.

4. For rod calibrations, the trace from the log N recorder must be marked at the time of exact criticality indicated by the linear power recorder (see Procedure 5); also mark run number on the log trace. To get the zero in rod position reduce magnet current.

5. Read only primary outlet temperatures on the multipoint temperature indicator. Do not push two buttons at once.

6. Read and record rod positions to ±.01 inches. To obtain a bank position, read each rod position to ±.01 inches, compute the average and record it to ±.001 inches.

II TYPICAL PROCEDURE

The following procedure is typical of that followed during a physics measurement period:

1. The reactor was run at full power for 48 hours to establish the equilibrium bank position. Data was recorded on Data Sheet 2A.

2. The four rod bank (rods 1, 2, 3, 4) was positioned so that rod C was withdrawn 12 inches. The four rod bank was not moved until after peak xenon.

3. The xenon concentration in the core was built up from the equilibrium condition. The power was reduced as quickly as possible to approximately 100 KW with no load. The operating temperature (440°F) was maintained by controlling the power level with Rod C. The four rod bank was not moved from the position of (2). The following valves were closed:

    a) MS-1
    b) Mason-Nealon (both)
    c) Auxiliary steam line trip valve

d) Boiler feed line block valve
e) Superheater drain trip valve
f) Superheater block valve

The steam generator water level was not maintained, it was allowed to drop to -6 inches and was then refilled to +10 inches. Criticality was maintained with rod C; rod C position was recorded as a function of time. Data was recorded on Data Sheet 3A. Good critical rod settings were taken approximately every 15 minutes. The temperature at criticality was within a few degrees of 440°F. Temperature was recorded ±0.1°F at the exact time of criticality. This procedure was continued for 8 hours after power reduction. (The four rod bank was not moved during build-up to peak xenon).

4. The five rod bank critical position was determined when peak xenon concentration was achieved. Rods A and B were withdrawn to 19 inches for five rod bank critical setting.

5. Rod C was calibrated at peak xenon. Rod C was calibrated from 10.5 inches to 18 inches by reducing the power to approximately .0005 on the log N recorder, rod C position was adjusted to obtain a steady trace on the log N recorder for 2 minutes. The exact criticality was determined by the linear power recorder, the log N trace was marked at precisely the time of criticality. The temperature at the exact time of criticality was recorded. Rod C was then inserted to obtain a period of approximately 25 seconds and the power increased. The log N trace was marked at precisely the time of criticality to make it possible to correct for the temperature drop which took place between the time of exact criticality and the time at which the reactor was on a stable period. The temperature was raised to about 450°F before each calibration run in order that the temperature at the time of criticality be about 440°F. Rod C calibrations in this manner were terminated 10 hours after power reduction. During the calibration the rate of temperature decrease when the power level was below 0.1 on the log N was measured. The temperature and time was recorded every 30 seconds on Data Sheet 1B.

6. At the completion of rod C calibration at peak xenon, about 10 hours after power reduction, the four rod bank was placed at the equilibrium position i.e. the position of procedures 2 and 3. The xenon decay was followed using rod C with the four rod bank at the equilibrium position. During this time rod C was calibrated at each inch and data was recorded as per Data Sheet 3B. Calibration procedure of 5 was used. During the xenon decay when rod C reached a position of 11.8 ± 0.1 inches the four rod bank position was moved to compensate for resetting rod C at 18 inches. The first resetting of rod C occurred about 18 hours after the original power reduction. The five rod bank critical position was determined about every four hours. This calibration was continued until an equilibrium position was attained, about 50 more hours.

7. Rod C was calibrated from 0 inches to 18 inches as a function of the four rod bank position. The calibration was done at low xenon concentration with the temperature maintained at 440°F. Data was recorded on Data Sheet 3B.

8. Rod A was calibrated from 0 inches to 18 inches as a function of the five rod bank position. The calibration was done at low xenon concentration with the temperature maintained at 440°F. Data was recorded on Data Sheet 3B.

9. The temperature was increased to approximately 450°F. Rod A was positioned at approximately 18 inches and the five rod bank was adjusted to achieve criticality. The power was reduced to approximately .001 on the log N recorder and the temperature was allowed to decrease. The outlet temperature was read every 5 minutes and recorded on Data Sheet 1B. The temperature recorder was synchronized with the log N recorder. While the temperature was decreasing criticality runs were made by adjusting rod A position. Rod A was inserted so the reactor was slightly sub-critical - the position was recorded - the power level as recorded on the linear power recorder decreased, reached a minimum and then increased (due to reactivity increase from temperature decrease). The exact time of the power minimum was the time of exact criticality. The time of exact criticality was recorded (± 0.5 minutes) with other data as per Data Sheet 1C. Temperature at the time of exact criticality was determined from the synchronized temperature recorder. The pressurizer heaters were shut off and the procedure was continued using rod A over its entire length until the temperature reached 120°F.

10. Rod A was calibrated from 0 inches to 18 inches at 120°F as a function of the five rod bank position. Calibration procedure (5) was used.

11. Source multiplication data was taken at 110°F. Criticality was achieved with rod A at 16 inches rod B at 19 inches and the five rod bank at the critical position. The power level was approximately .001 on the log N recorder. Rod A was inserted to 14 inches and the count rate and temperature was recorded every 5 minutes for 30 minutes. Rod A was withdrawn to 15 inches and the count rate was recorded for 30 minutes. Criticality was achieved by adjusting rod A position - the new critical position was recorded. The reactor was scrammed and simultaneous recordings from the log N and count rate recorders were taken during the neutron flux decay. Count rates were recorded for:

   a) All rods at 0 inches
   b) Rods A and B at 19 inches and the five rod banks at 0, 2, 4, 5 and 6 inches

12. Rods were positioned as per Data Sheet 5 for stuck rod configurations. The critical position for the rod was found and the rod was calibrated at the critical position. Calibration data was recorded on Data Sheet 1A.

III Data Sheets

The following 4 pages are data sheets for recording Task VII data.

Date ______________

Page No. ______________

Data Sheet 1A

Rod Calibration at ________ °F

Rod No. __________

Attach log traces to this sheet

Time	Run No.	Critical Position	Temp	Super-Critical Position	Temp. °F Log .01	Bank Position	Pressure	

Date ______________

Page No. ______________

Data Sheet No. 1B

Temperature Coefficient - Temperature Data

Attach 2-Pen Recording

Record Temperature Every 5 Minutes from Multipoint

Time	Inlet Temp.	Outlet Temp.	

Data Sheet No. 1C

Temperature Coefficient - Rod Data

Date ____________

Page No.____________

Exact Time of Criticality	Rod A Position	Bank Position	Pressure	Pressurizer Temperature

Data Sheet 2A

Date ____________

Equilibrium Bank Position

Record data at approximately 30-minute intervals for a 4-hour period

Hours of <u>Uninterrupted</u> Full Power Operation Preceding Data: ________

Time (hours)	Integrated °F days	Output Temp. (multipoint)	Inlet Temp. (multipoint)	Core Δ T recorded	Log N	Flow Rate	5 Rod Bank Position

Note: This data is to be recorded at approximately 7-day intervals and for the four hours preceding each R & D shutdown

Data Sheet No. 3A

Xenon Buildup and Decay vs. Rod C

Date ______________

Page No. ______________

Date and Exact Time of Power Level Reduction ______________

Rod A and B at 19.0 inches

Good Critical Settings to be Taken Approximately Every 15 Minutes

Time Nearest Minute	Temp. °F Nearest .1 °F on Multipoint	Pressure psi	Log N	4 Bank Position inches	Rod C Position inches

Data Sheet No. 3B

Calibration of Rod C vs. Xenon

Date ______________

Page No. ______________

Date and Exact Time of Power Level Reduction ______________

Rods A and B at 19.0 inches

Temperature 440°F

Calibrate from 11 inches to 18 inches

Start Calibration at 8 hours after power level reduction

Reset 4-rod bank at 10 hours after power level reduction

Mark log traces at time of criticality

Time	Run No.	Critical Position	Temp	Super-Critical Position	Temp. °F Log .01	Bank Position	Pressure	

Data Sheet No. 4

Source Multiplication

Date ______________

Page No. ______________

Counter No. ______________

Amplifier No. ______________

High Voltage ______________

Gain ______________

Pulse Height ______________

Band Width ______________

Time	Rod A Position	Count Rate	Bank Position	Temperature	Pressure

Data Sheet 5

Stuck Rod Conditions

Date ______________

Case	Rod Positions							Temp °F	Pressure psi
	1	2	3	4	A	B	C		
A	19.00	0	0	0		0	0		
	19.00	0	0	0		0	0		
B	19.00		0	0	0	0	0		
	19.00		0	0	0	0	0		
C		0	0	0	19.00	0	0		
		0	0	0	19.00	0	0		
G		0	0	0	19.00	0	19.00		
		0	0	0	19.00	0	19.00		
H	0	0		0	19.00	19.00	0		
	0	0		0	19.00	19.00	0		
I	0	0	0	0	19.00	19.00			
	0	0	0	0	19.00	19.00			

REFERENCES

1. AP Note 114, "Program No. 67, Temperature Coefficient". S.D. MacKay, C.J. Stueck

2. APAE No. 18, "Initial Operation and Testing of the Army Package Power Reactor, APPR-1". J.L. Meem

3. "American Institute of Physics Handbook". D.E. Gray

4. APAE No. 8, "Army Package Power Reactor Zero Power Experiments". J.W. Noaks, W.R. Johnson

5. AP Note 126, "APPR-1 Burnout Calculation". T.G. Williamson