



The Ohio State University

Research Foundation

1314 Kinnear Road  
Columbus, Ohio 43212

**MASTER**

PROGRESS REPORT

The Ohio State University  
Reactor Sharing Program

September 1, 1980

to

April 30, 1981

Contract DE-FG02-80ER 10727A000

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

*ECH*

## DISCLAIMER

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

Nine colleges and universities have participated to the present date in the Reactor Sharing Program. Fifty-nine students supervised by twelve faculty members have performed neutron activation analysis experiments, nuclear engineering experiments, health physics laboratories, and introductions to nuclear research.

Neutron activation analysis activities have been performed by students from the University of Akron, Clark Technical College, and Denison University. Nuclear engineering experiments such as approach to critical and control rod calibrations have been completed by the University of Cincinnati, Xavier University, the Air Force Institute of Technology, Miami University, and Terra Technical College. Students from Youngstown State University have performed a neutron irradiation damage study. These activities are summarized in Table I.

We anticipate additional utilization by the University of Cincinnati, Ohio Northern University, and Northern Illinois University students and faculty during this funding period.

We have also enclosed copies of two student laboratory exercises we have developed during this funding period. These are found as Appendices 1 and 2 to this report.

Table I  
OSURR and GRSS Utilization by RSP Participants for Sept. 1, 1980 to April 30, 1981

School	Principal Interest	Faculty	Dept.	Students	Number of Trips	Hours of Use	
						OSURR	GRSS
University of Akron	NAA	1	1	2	1	3	85.5
Clark Technical College	NAA	1	1			4	44.5
Denison University	NAA INR	1	1	7	1	2.5	1.0
University of Cincinnati	NEE	2	1	17	2	16	
Xavier University	NEE	1	1	17	2	13	
Air Force Institute	NEE	2	2	4	1	8	
Miami University	NEE	1	1	6	1	8	
Terra Technical College	NEE	2	1	5	1	6	2
Youngstown State Univ.	NEE	1	1	1	1	12	1

Appendix 1 to Progress Report  
Control Rod Calibration  
Laboratory

## CONTROL ROD CALIBRATION BY ROD DROP AND POSITIVE PERIOD.

Two methods will be used to calibrate shim safety rod #3 at the OSU Research Reactor. These two methods are positive period and 10 W rod drop.

### I. General Theory

#### POSITIVE PERIOD

If a reactor is critical and a step-input of positive reactivity is inserted, point reactor kinetics can be used to determine the change in reactivity due to the insertion. Using the point reactor kinetic equations below:

$$\frac{dn}{dt} = \frac{\rho - \beta}{\Lambda} n + \sum_{i=1}^6 \lambda_i C_i \quad 2-1$$

$$\frac{dC_i}{dt} = \frac{\beta_i}{\Lambda} n - \lambda_i C_i \quad i = 1, 2, \dots, 6 \quad 2-2$$

$$\Lambda = \ell/k = \ell_{\infty}/K_{\infty} \quad 2-3$$

and for a constant reactivity,  $\rho$ , we find the solution to these seven coupled differential equations is;

$$n(t) = n_0 \sum_{j=1}^7 A_j \exp(t/T_j) \quad 2-4$$

Where the  $T_j$ 's are the seven roots of the inhour equation

$$\rho = \frac{\Lambda}{T} + \sum_{i=1}^6 \frac{\beta_i}{1 + \lambda_i T} \quad 2-5$$

Therefore for a step-input of reactivity we can find a solution by using:

$$n = A \exp(wt)$$

$$C_i = \beta_i \exp(wt)$$

$$w = 1/T$$

Where T represents the positive root of equation (2-4). Solving equation (2-2) we find,

$$C_i = \frac{\beta_i n}{\lambda(w + \lambda_i)} \quad 2-6$$

Substituting this back into equation (2-1) yields.

$$n(t) = n_0 \sum_{j=1}^7 A_j \exp(t/T_j) \quad 2-7$$

and

$$\rho = \frac{\lambda}{T} + \sum_{i=1}^6 \frac{\beta_i}{T + \lambda_i T} \quad 2-8$$

For  $\rho > 0$  all of the  $T_j$ 's are negative except one. The negative roots represent the transients which decrease rapidly to zero. Therefore the positive root will dominate and n will increase with a steady period T, and yield the solution,

$$n(t) = n_0 A \exp(t/T) \quad 2-9$$

Equation (2-9) relates the change in reactivity to the reactor period through the inhour equation (2-8) therefore the reactivity of a rod can be found by measuring the power level doubling time,  $t_d$ , calculating the period by,  $T = t_d / \ln 2$ , and reading the reactivity off of a plot of reactivity - versus - period derived from the inhour equation. (plot supplied by reactor staff).

### ROD DROP .

From the point reactor kinetics, equation (2-5), it can be seen that a reactor at steady state will have a reactivity  $\rho \approx \lambda/n(t)$ , where  $\lambda$  is the neutron generation time and  $n(t)$  is the neutron population at time  $t$ . When a rod with reactivity  $\rho_0$  is inserted, we find;

$$\rho_0 = -\beta \left[ \frac{n_0 - n_1}{n_1} \right] \quad 2-10$$

Therefore we find that a rod drop input can be found by the relationship between  $\rho$  and  $n(t)$ .

$$\rho \approx \frac{n(t)}{n(t=0)} = \frac{n(t)}{n(0)} \quad 2-11$$

Standard plots of  $n(t)/n(0)$  - versus - reactivity can be found in several places. (The reactor staff will supply copies.) By choosing the ratio of  $n(t)/n(0)$  so as to eliminate prompt drop neutron effects and delayed neutron groups, an accurate reactivity worth for the control rod can be found. Typically we use  $t = 14$  seconds (after rod drop) and  $t = 100$  seconds. Therefore you can find the reactivity by calculating

$$\frac{n(t=14)}{n(t=0)} = \frac{n(14)}{n(0)} \quad \text{and} \quad \frac{n(t=100)}{n(t=0)} = \frac{n(100)}{n(0)}$$

## II. Procedure and Equipment

### ROD DROP AT 10 W POWER

For this part of the lab the reactor will be operating at 10 W power with Shim Safety Rod #3 at its minimum critical position. This position is when Shim Safety Rods #1, #2, and the regulating rod are banked at their upper limits (fully withdrawn), and Shim Safety Rod #3 is at its lowest position, and the reactor is critical.

You will use the compensated ion chamber (CIC) set up beam port #1 (Figure 1-1), a picoammeter and a strip chart recorder. One channel on the strip recorder should have its sensitivity set at 10 mV/division, the other channel at 20 mV/division.

In the control room, data will be recorded from the linear power level CIC. Current readings will be taken before the drop,  $t = 0$ , at 14 seconds after the drop,  $t = 14$ , and at 100 seconds after the drop,  $t = 100$ .

The reactivity worth of the rod dropped will be determined by calculating the ratios,

$$\frac{I(14)}{I(0)} \quad \text{and} \quad \frac{I(100)}{I(0)}$$

[Where  $I$  = current of control room linear power level CIC and beam port #1 CIC.]

and finding the corresponding reactivity,  $\rho$ , from the standardized curves of  $\rho$  - versus -  $n(t)/n(0)$

NOTE: The ratio of  $I(t)/I(0) = n(t)/n(0)$ .

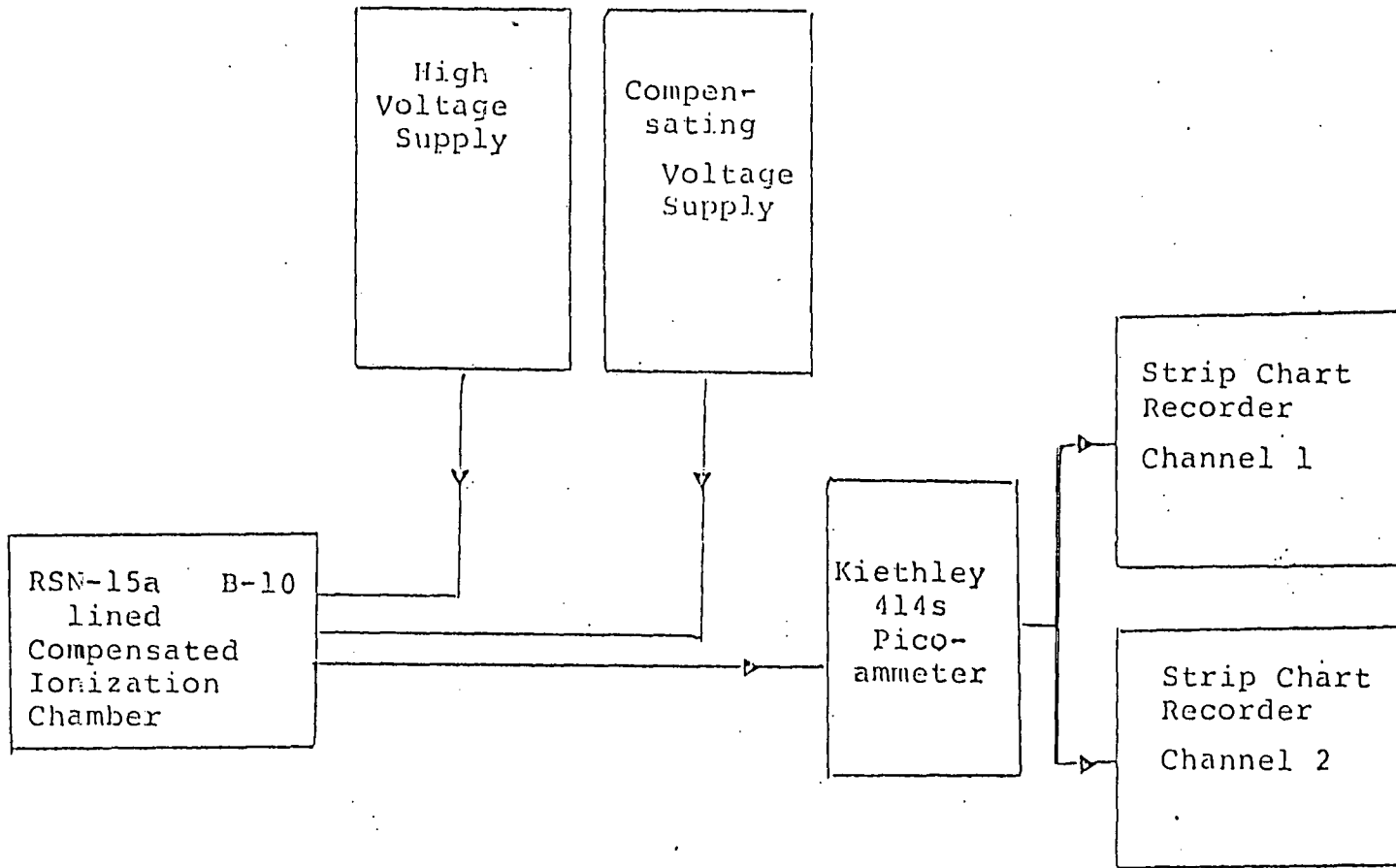


Figure 1-1. Equipment diagram for the 10 W rod drop.

### POSITIVE PERIOD

For this part of the lab, Shim Safety Rod #3 will be at its minimum critical position. (same as rod drop). However the reactor will only be at  $\sim 0.1$  W power.

From this point Rod #3 will be raised by the operator until the reactor period meter reads approximately 30 seconds. Wait a few seconds for the prompt neutrons to decay. Then, using a stop watch (supplied by the reactor operator) and the linear power meter in the control room, measure the time required for the reactor power to double. This is known as the doubling time,  $t_d$ . Record the doubling time and the length of Rod #3 withdrawn.

Calculate the period by,

$$T = t_d / \ln 2$$

Then using the plot of  $\rho$  - versus -  $T$ , supplied by the operator, you can find the worth of the rod withdrawn.

The operator will then bring the reactor back to criticality by lowering Rods #1, 2, and the regulating rod. He will withdraw Rod #3 again for another measurement. This procedure will be continued until the entire rod has been withdrawn.

### III. Lab Procedure:

#### ROD DROP

1. The reactor will be critical at 10 W power with shim safety Rod #3 at its minimum critical position, record the rod positions (all four rods).
2. Set up the brush recorder as stated in Section II. (Figure 1-1) Remember to set one channel to 10 mV/division and the other to 20 mV/division.
3. Record the current readings from the linear power level in the control room and the CIC in the Beam Port #1.
4. Start the chart paper drive on the recorder at Beam Port #1 (125 mm/min).
5. The control Room operator will give a 10 second countdown to rod drop. At the 3 second mark, switch the chart recorder speed to 125 mm/sec.
6. The operator will then count after the drop. At 14 seconds push the event marker button on the chart recorder. The control room personnel will record the current level off of the linear power level at this time also.
7. Reduce the chart speed to 5 mm/sec.
8. The control room operator will continue the count of the rod drop to 100 seconds. At 100 seconds push the event marker button again. The control room personnel will record the current off of the linear power level too.
9. Calculate  $I(14)/I(0)$  and  $I(100)/I(0)$  for both sets of data and find the reactivity off of the graphs supplied by the reactor operator.

Special Note:

It will be necessary to change the range of the piocammeter at Beam Port #1 during the rod drop. The reactor personnel will explain how/why this is done and also how to read the data off of the brush chart paper.

DATA FROM 10 W ROD DROP

	CIC, Beam Port #1	CIC, Control Room
I (0), Amps		
I (14 sec), Amps		
I (100 sec), Amps		
I (14)/I (0)		
$\delta K, \%$		
I (100)/I (0)		
$\delta K, \%$		
$\delta K, \%$ (average)		

Reg Rod Position (cm) =

Shim Safety Rod #1 Position (cm) =

Shim Safety Rod #2 Position (cm) =

Shim Safety Rod #3 Position (before drop), (cm) =

Shim Safety Rod #3 Position (after drop), (cm) =

### POSITIVE PERIOD

1. The operator will bring the reactor to a 0.1 W with shim safety rod #3 again at its minimum critical position.
2. Withdrawn shim safety rod #3 until the period meter shows a 30 second period.
3. Using a stopwatch, measure the time required for the linear power recorder reading to double. (If you start the stopwatch when the recorder is at 20% and stop it at 80%, you will have 2 doubling times)
4. Use the beam port #1 CIC with the brush chart recorder at 5 mm/sec. Doubling times can then be measured directly.
5. After measuring the doubling times, reduce the reactor power by inserting shim safety rods #1, and #2 and the reg rod. DO NOT MOVE SHIM SAFETY ROD #3. Bring the reactor back to 0.1 W or as close as possible.
6. Calculate the period,  $T = t_d / \ln 2$  and the  $\delta K$  from the graphs supplied by the reactor staff.
7. Record the new positions of all 4 control rods.
8. Add the 1st  $\delta K$  to the  $\delta K$  determined by the rod drop. This will give you the worth of the rod,  $\delta K_T$ , for the rod drop length plus the amount of the rod withdrawn for the 1st positive period.
9. Repeat steps 3, 4, 5, 6, and 7 adding each new  $\delta K$  to the previous  $\delta K_T$  until the entire rod is withdrawn.
10. A calibration curve for shim safety rod #3 can then be plotted using  $\delta K_T$  versus rod #3 position (Figure 2-2).

DATA FROM POSITIVE PERIOD

Pull #	1	2	3	4	5	6
Reg Rod Position, cm	60.00					
Rod #1 Position, cm	60.00					
Rod #2 Position, cm	60.00					
Rod #3, cm Position Before Pull						
Rod #3, cm Position After Pull						
<hr/>						
Control Room						
$t_d$ , sec						
T, sec						
$\delta K$ , %						
$\delta K_T$ , %						
<hr/>						
Beam Port						
$t_d$ , sec						
T, sec						
$\delta K$ , %						
$\delta K$ , %						

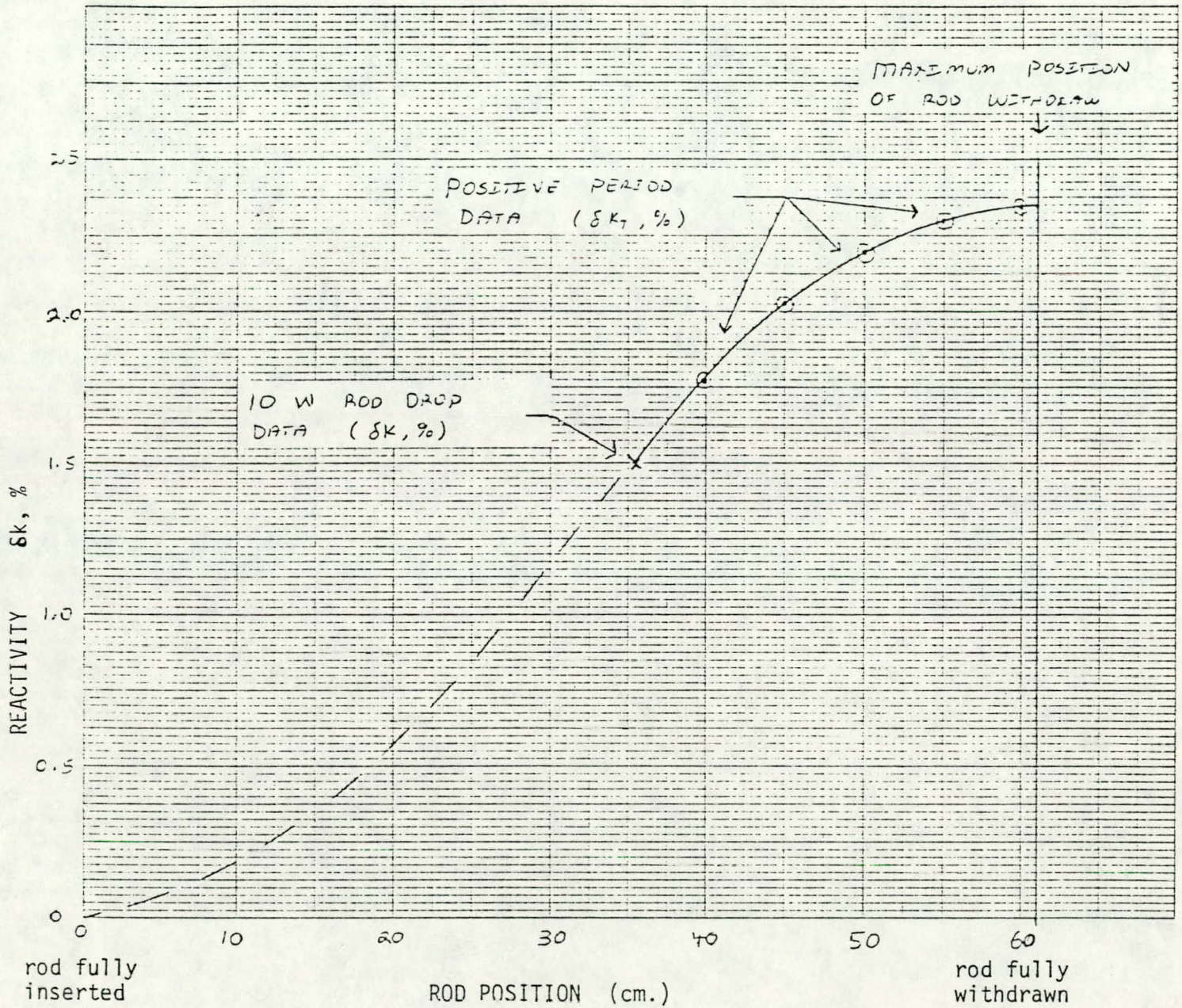
$T_d$  = Doubling time from control room linear power level, or beam port # 1 CIC.

T = Period calculated using appropriate  $t_d$ .

$\delta K$ , % = % reactivity for length of rod #3 withdrawn for that special pull.

$\delta K_T$ , % = Total reactivity of rod = sum of all previous  $\delta K$ 's and  $\delta K$  for rod drop.

Figure 2-2 Reactivity - versus - Rod Position for Shim Safety Rod #3.



NOTE: You can extrapolate the rod worth from the rod drop data down (dash line). Usually the bottom half of this plot will be a mirror image of the upper half. Calibration of the lower part of the shim rod requires the use of more complicated techniques and is normally left for graduate level courses.

Appendix 2 to Progress Report  
Approach to Critical  
Laboratory.

## APPROACH TO CRITICAL

### I. General Theory

Consider a fuel-moderator reactor where  $k < 1$ , (Note: when  $k = 1.0$  the reactor will be critical). A steady neutron level can be obtained by introducing an external neutron source to the reactor. With all of the control rods inserted and the neutron source next to the fuel assembly, there are  $n_0$  neutrons per second, where the subscript represents a time interval equal to the neutron generation time,  $\lambda$ , of the reactor. At the start there are  $n_0$  neutrons per second. By the first generation time there are  $n_0 + n_0K$  neutrons per second. Then for succeeding neutron generations:

$$\begin{aligned} n &= n_0 && 0^{\text{th}} \text{ generation} \\ &= n_0 + n_0K && 1^{\text{st}} \text{ generation} \\ &= n_0 + n_0K + n_0K^2 && 2^{\text{nd}} \text{ generation} \\ &= n_0 + n_0K + n_0K^2 + \dots + n_0K^M && M^{\text{th}} \text{ generation.} \end{aligned}$$

The subcritical multiplication factor,  $M$ , is defined as:

$$M = n/n_0. \quad [1.1]$$

For the  $m^{\text{th}}$  generation,  $M = 1 + K + K^2 + K^3 \dots + K^m$ , and since  $K < 1$  the higher powers of  $K$  are very small and can be neglected. Therefore  $M$  is finite. When  $K = 1$  and the number of generations becomes very large,  $M$  approaches infinity. As  $M$  approaches infinity,  $1/M$  must approach zero.

To find the critical rod positions using the subcritical multiplication factor, the operator need only to determine when  $1/M = 0$ . This can be done by plotting rod position on the X-axis, and  $1/M$  on the Y-axis. After determining two points on the plot, a straight line through these points is extrapolated to the X-axis. The value at this intercept is the new estimated rod position where  $1/M = 0$ . Following each rod movement a new  $M$  is calculated and a new line is drawn through the last two points.

The final graph of all data points will not be a straight line but will curve somewhat. Whether the curve is positive or negative and the degree to which the curve deviates from a straight line depends on the position of the detector relative to the neutron source. (See Figure 1-1) Therefore it is wise to use more than one detector and to use the most conservative estimate of the critical rod positions when deciding how far to withdraw the rods for the next neutron population count.

## II. Procedure and Equipment

For this part of the experiment four detectors will be used. The B-10 proportional counter will be set up in an external tube leading down to the core, the CIC will be set up in beam port #1, and the control room boron-10 lined fission chamber will be lowered into place. The control room CIC connected to a Kiethley 411 micro-microammeter is also used.

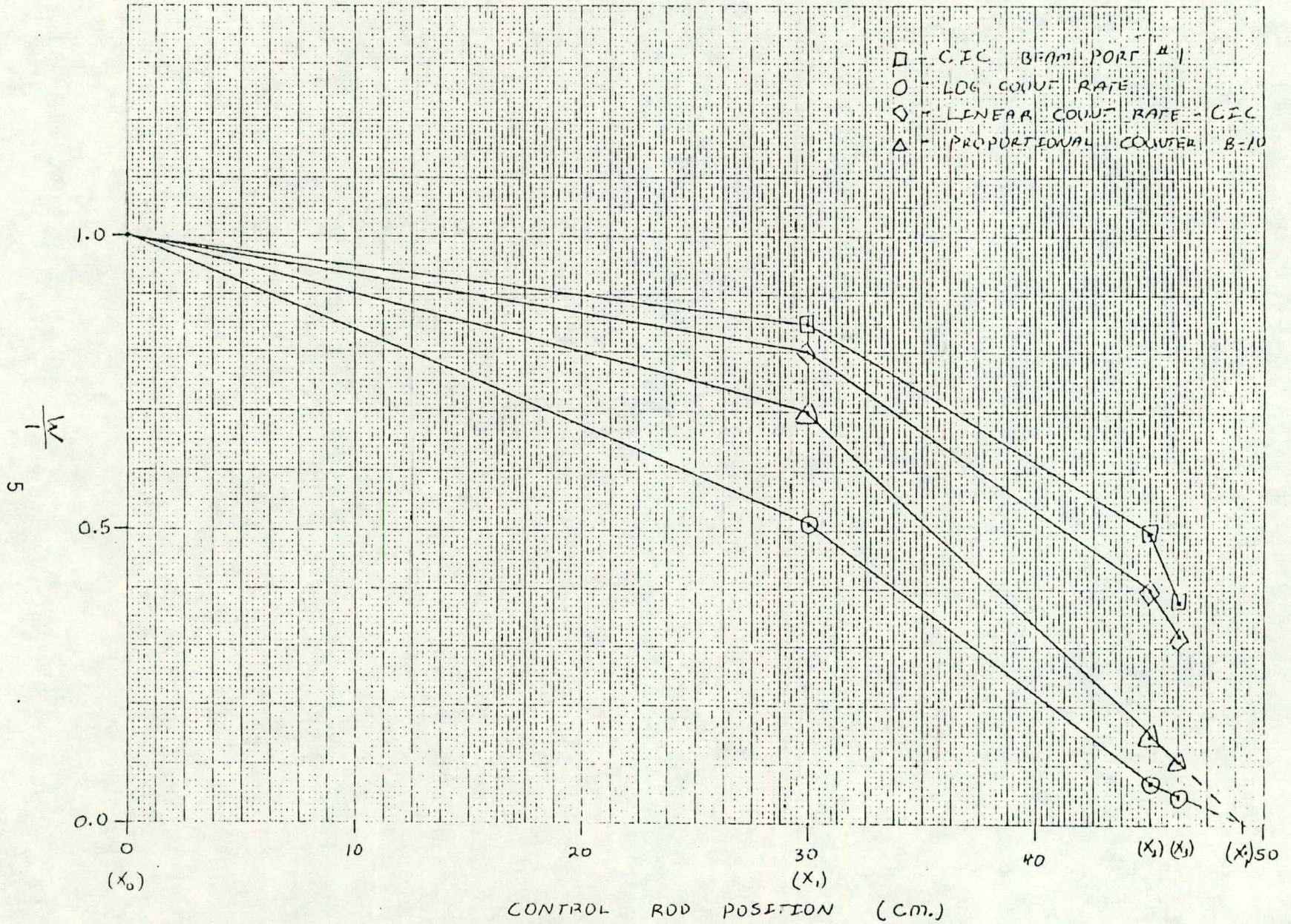
The first task is to set up the equipment as shown in (Figure 1-2), and find the operating (bias) voltage of the B-10 proportional counter and set the discriminator level. The discriminator is a threshold-setting for pulse energies which allows lower energy gammas to be excluded from the higher energy neutron pulses. To find the bias voltage the discriminator is set at zero (all pulses pass). With the source in the start-up configuration, the count rate from the detector will be taken as a function of applied voltage, up to 850 volts. A plot of count rate versus bias voltage determines a plateau at which small fluctuations in voltage do not change the count rate appreciably. (Figure 1-3). In Figure 1-3 we see that 750 volts is a good operating voltage.

With the bias at 750 volts, a plot of count rate versus discriminator setting will be made (Figure 1-4). The gamma counts were assumed to be omitted after the first knee; so from Figure 1-4 your operating point setting is 3.0. Verification of gamma discrimination was done by observing the pulse shapes before and after on an oscilloscope. (Figure 1-5)

With all of the control rods fully inserted (position  $X_0$ , Figure 1-1) count rates,  $C_0$ , is taken for all four detectors. Next you will gang raise all of the control rods to 30 cm (position  $X_1$ ). 30 cm is known by previous reactor operations to be subcritical, allowing for conservative rod movements. At this new position, the count rate,  $C$ , is measured for all detectors.

The multiplication factor  $M = C/C_0$  is calculated. You then plot  $1/M$  versus rod position drawing a line through the two points and extrapolating to the axis where  $C/C_0 = 0$ . (See Figure 1-1) This is your new estimate of the critical rod position. As a conservative estimate to prevent accidental criticality, the lowest estimate of the critical rod position is used, and the rods are moved to  $1/2$  distance between the old and new positions (position  $X_2$ ). This procedure of predicting critical positions and moving  $1/2$  the distance, (positions  $X_j$ ), will be repeated until the reactor is critical with the neutron source in place. When the source is removed the reactor will be slightly sub-critical, and the rods will be raised to reach criticality.

Figure 1-1 1/M versus Rod Position for Approach to Critical



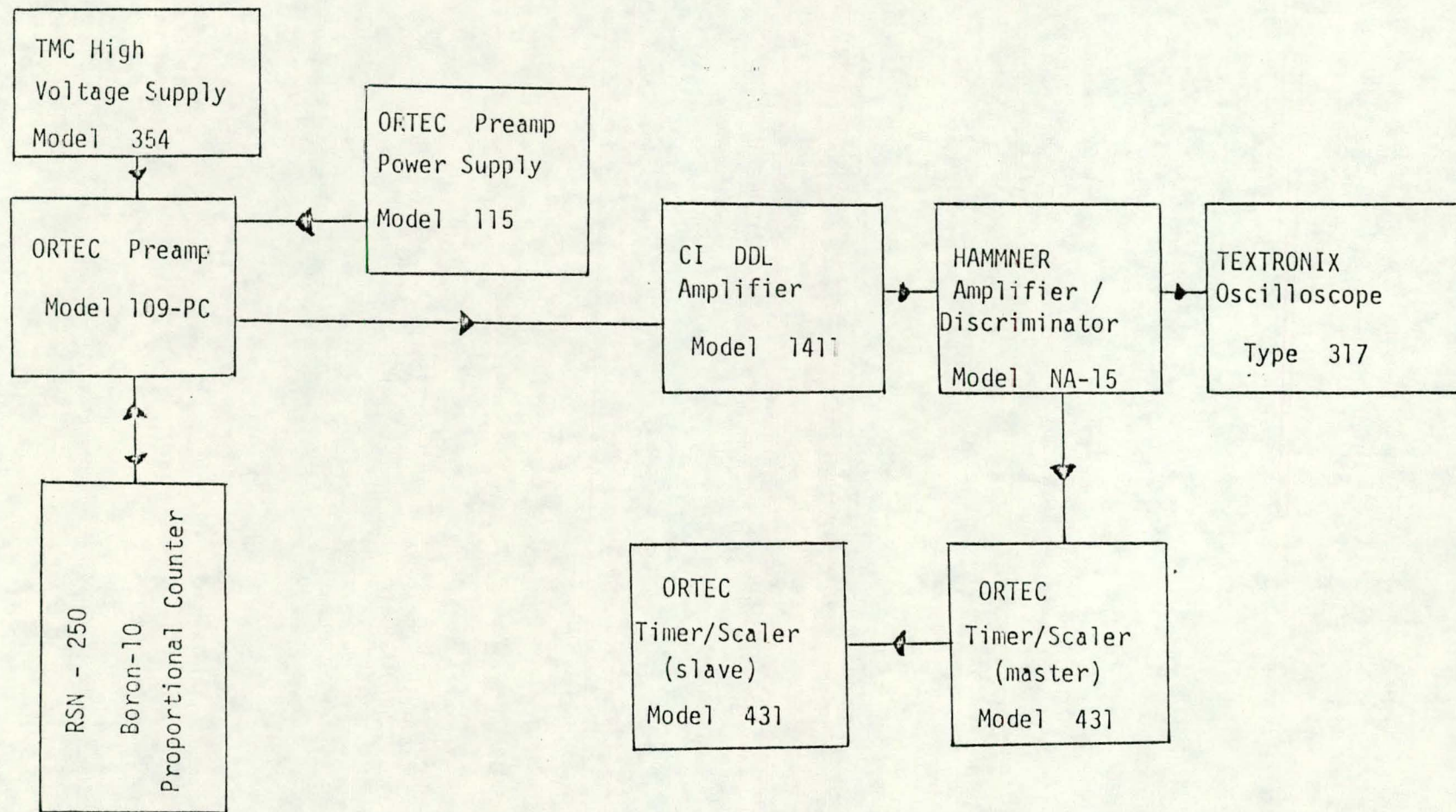


Figure 1-2 Equipment Diagram for the Calibration of the B-10 Proportional Counter

Figure 1-3 Proportional Detector Bias Curve

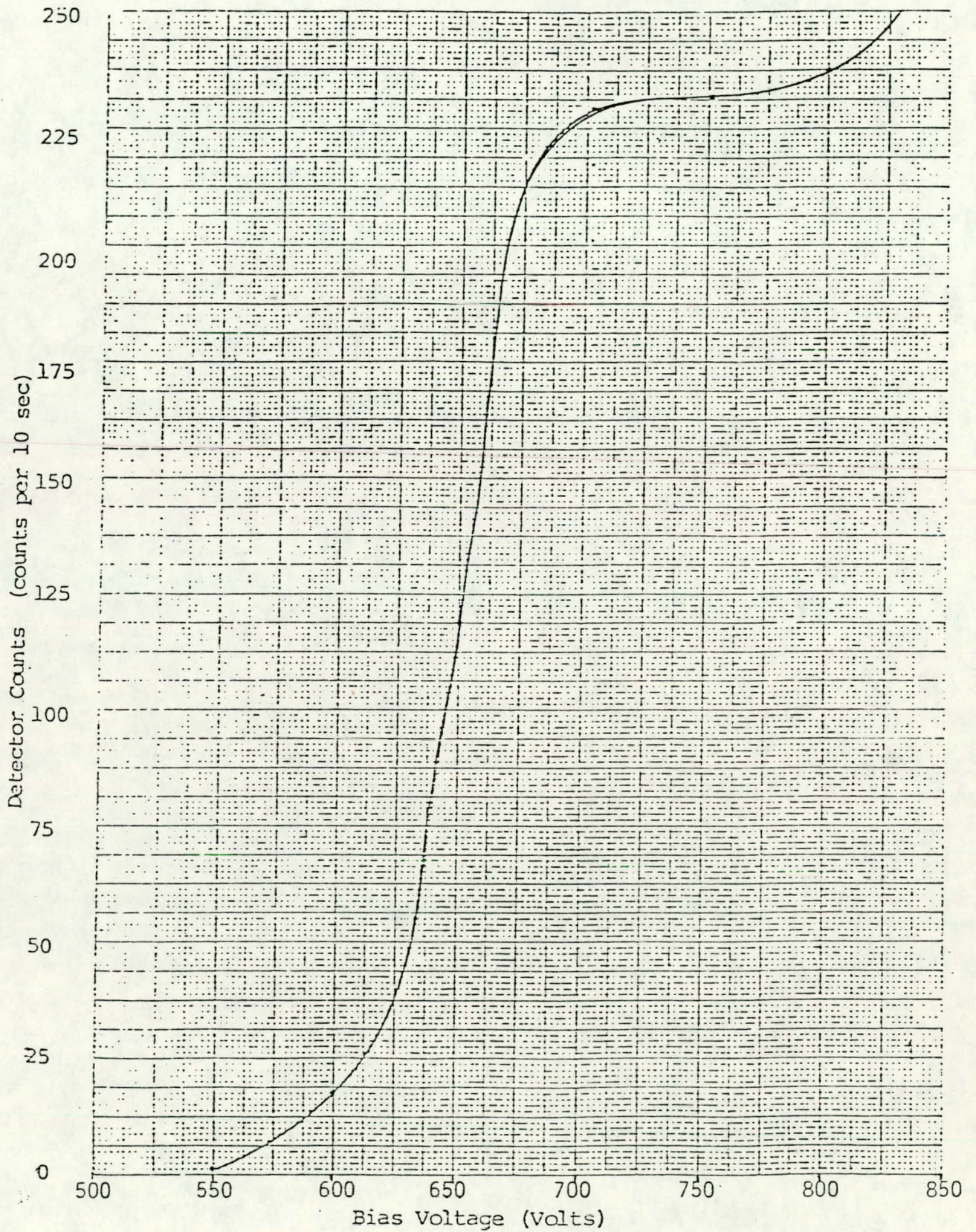
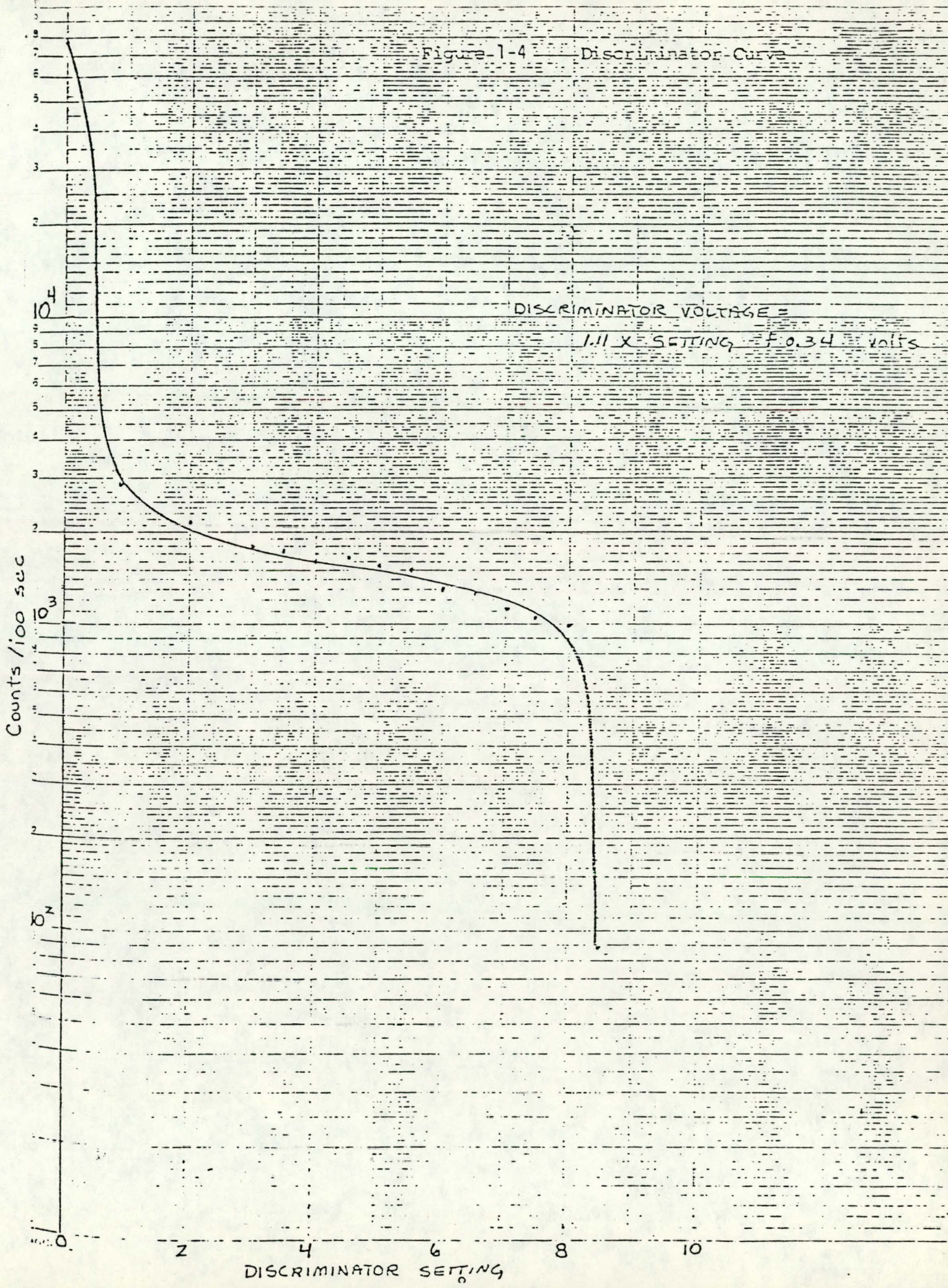
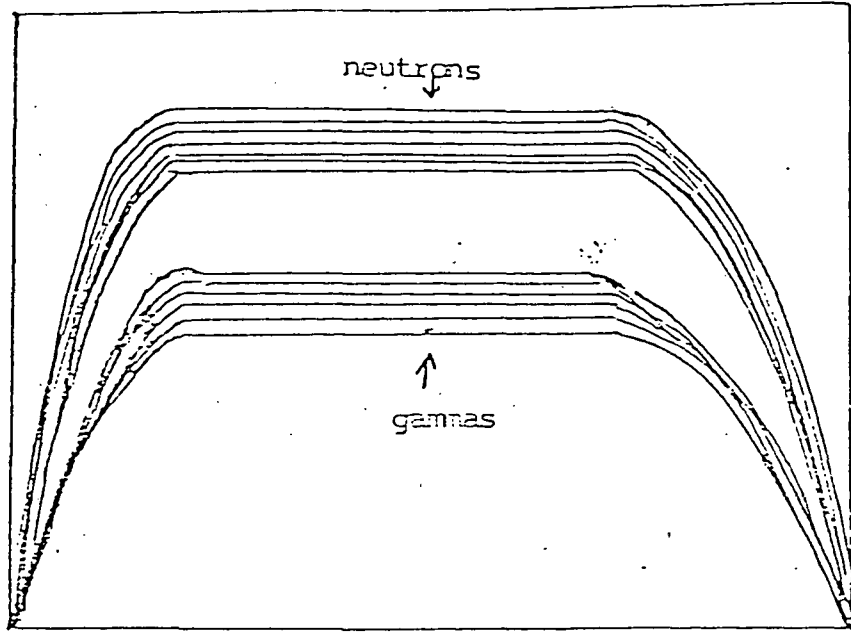
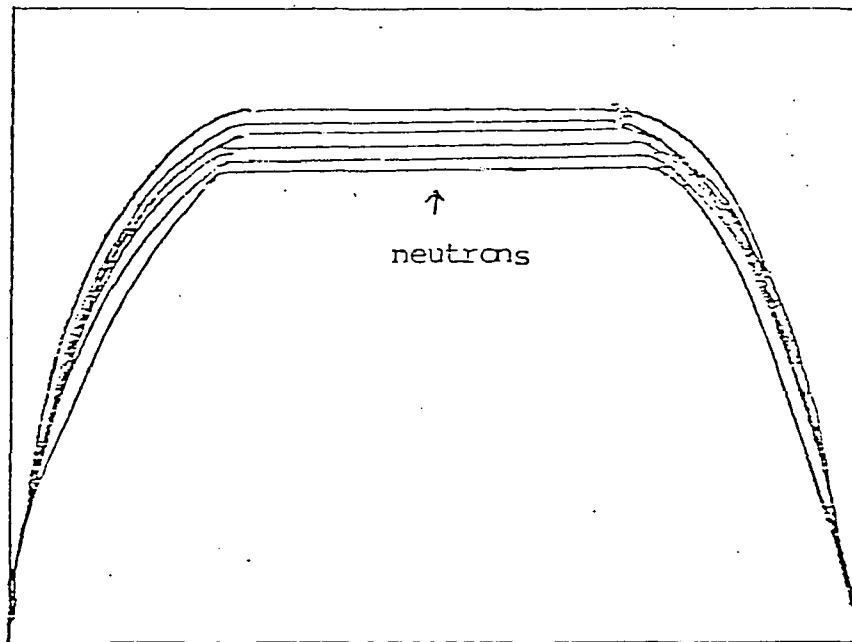


Figure 1-4 Discriminator Curve





a) Without discriminator



b) With discriminator set at 3.0

Figure 1-5. Discriminator Output on Oscilloscope.

## LAB PROCEDURE

1. All control rods will be fully inserted at the beginning of the experiment.
2. The operator will raise the start-up source.
3. After the flux becomes constant, record the data from the four sets of instrumentation and the four rod positions. Calculate  $1/M$  for each set of data and plot versus rod position.
4. The operator will withdraw all rods to 30 cm.
5. Repeat Step 3.
6. Obtain the first prediction of critical rod position by drawing a straight line through the last two data points until it bisects the X axis (rod position). There will be four predictions. Using the most conservative position predicted, calculate the difference between the predicted position and the present rod position. Divide this difference in half and add it to the present rod position. This will be the new predicted position.
7. The operator will withdraw all rods to the new predicted position.
8. Repeat Steps 3 and 6.
9. Observe the flux (fission chamber) recorder as the reactor approaches criticality as predicted by your plot of  $1/M$  versus rod position. If the flux becomes constant, the reactor is subcritical. Move the rods out 0.5 cm and observe the

recorder again. When the flux ceases to become constant the reactor is critical or slightly super-critical.

10. The operator will then lower the start-up source and adjust the control rods until the reactor is critical and all control rods and the regulating rod, are at the same position. Critical rod position for the O.S.U. Research Reactor is around 49 cm.

Data for Approach to Critical

Pull No. (i)	0	1	2	3	4	5	6
RR, cm	00.00	30.00					
SS1, cm	00.00	30.00					
SS2, cm	00.00	30.00					
SS3, cm	00.00	30.00					
CIC, amps							
1/M							
PCP, cm							
B-10, c/sec							
1/M							
PCP, cm							
CIC*, amps							
1/M							
PCP, cm							
FC, c/sec							
1/M							
PCP, cm							

RR = Regulating Rod  
 SS1, SS2, SS3, SS4 = Shim-Safety Rods #1, 2, 3, 4  
 CIC = Compensated Ion Chamber in Beam Port #1  
 CIC\* = Compensated Ion Chamber, Control Room Readout  
 FC = Fission Chamber, Start-up Channel in Control Room  
 B-10 = Boron-10 Proportional Counter  
 1/M = Inverse Multiplication Factor (Equation 1.1)