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Control Rod Calibration

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ABSTRACT

The maximum rod worth occurs at a control rod height of seven inches. The shutdown margin is estimated to be $14 by the rod drop method and by the integral rod worth curve for startup channel A. Although channel B gives estimates that are twice the magnitude of A, channel A is considered to give the most reliable data since it is the more conservative and the shutdown margin of $28 dollars predicted by B is too large (see Lamarsh, p 442).

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OBJECT:

The purpose of this experiment is the calibration of the control rods in order to enhance the safe operation of the reactor. The control rods were calibrated throughout their length of travel and the shutdown margin was also estimated by the rod drop method. The importance of this experiment lies in the fact that once the control rods are calibrated, any reactivity perturbations can be related directly to the change in control rod position necessary to maintain criticality.

THEORY:

The reactivity of a reactor is defined as the fractional change in the effective multiplication factor

$$\rho = \frac{k-1}{k} = \frac{\Delta k}{k}$$

The reactor period or 'e' folding time is the time required for the reactor power to increase by a factor of 'e'. The reactivity is related to the stable period of the reactor through the inhour or reactivity equation

$$\rho = \frac{l^*}{T} + \sum_{i=1}^{6} \frac{\beta_i}{1+\lambda_i T}$$

where:

$l^* = 1/k_\infty =$ prompt neutron generation time
T = reactor stable period
λ_i = decay constant of the ith precursor group
β_i = delayed neutron fraction of the ith group

In the case of one group of delayed neutrons whose decay constant is the weighted average of the six actual groups,

$$\lambda = \frac{\Sigma \beta_i}{\Sigma \beta_i/\lambda_i}$$

the reactivity equation is

$$\rho = \frac{l^*}{T} + \frac{\beta}{1+\lambda T}$$

where $\beta = \Sigma \beta_i$. This can be put in the form

$$T = \frac{l^*}{\rho} + \frac{(\beta-\rho)\tau}{\rho}$$

which gives the stable period explicitly for any given reactivity.

In the supercritical region, the control rods can be calibrated simply by putting the reactor on a positive period and determining the corresponding reactivity from the graph of the reactivity equation in Figure 1.

After the control rods have been calibrated in the supercritical region, they can be calibrated in the subcritical region. From the previous experiment

$$\frac{C_s}{C_t} = 1 - k = \Delta k$$

where

C_s = count rate due to source
C_t = count rate due to source + core fissions.

Near critical, $k \cong 1$, so $\Delta k \cong \Delta k/k = \Delta\rho$, where $\Delta\rho$ is the amount that the reactor is subcritical. Now $C_s = C_t \Delta k = C_t \Delta\rho$. $\Delta\rho$ can be found by integrating the positive period differential worth curve subject to these restrictions.

1. We can only integrate in a neighborhood close to critical so that the assumptions concerning $k = 1$ are valid.

2. We must have a knowledge of the slope of the differential rod worth curve in the subcritical region. Of course we don't know this since it is what we are trying to measure. But it is possible to extrapolate the information available into the subcritical region without introducing too much error since we are already restricted to areas near critical.

The amount below critical at each point is determined by merely measuring the count rate at that point. This information yields an integral worth curve from which a differential curve can be extracted.

The shutdown margin is the amount of negative reactivity which can be instantaneously inserted into the critical reactor. This is an important parameter since it determines the prompt drop of the thermal flux following a step insertion of reactivity $\Delta\rho$. The ratio of prompt post-drop flux to predrop flux is $\frac{\varphi_1}{\varphi_0} = \frac{1}{1 + \Delta\rho/\beta}$ or $\frac{\Delta\rho}{\beta} = \frac{\varphi_0}{\varphi_1} - 1$.

This assumes that there is no change in the delayed neutron precursor concentrations in the time between the flux measurements and that any response is due to the change in multiplication and not to spatial perturbations caused by rod insertion.

PROCEDURE:

For the supercritical calibration, the reactor is placed on a positive period and the corresponding reactivity determined from the inhour equation. This reactivity is divided by the change in control rod position from critical to supercritical, and plotted at the midpoint of the critical and supercritical positions. For bank positions in which a fast period is obtained, it is diffucult to measure a period. To obtain rod worths in this part of the supercritical region, a poison must be introduced into the core so the control rods can be withdrawn further without an excessively fast period.

The method for subcritical calibration is described in the theory and determination of C_s is shown in the calculations. Caution must be used in measuring C_t, particularly as k approaches 1 since it is necessary to insure that the system is in the steady state when counting.

When measuring the shutdown margin by the rod drop method a fast chart recorder should be used for maximum accuracy. With the reactor exactly critical, the system is scrammed and the charts observed to note the rapid drop in power. The shutdown margin in dollars is the ratio of the initial power level and the power level at which the drop first changes slope minus one.

DISCUSSION:

Although the delayed neutron fraction is .0065 for U-235, a value of .0078 is used for this reactor. This effective delayed neutron fraction is used instead of the actual fraction due to the difference in the fast nonleakage probability for the delayed neutrons as opposed to the prompt neutrons. When leakage is accounted for the actual fraction of delayed neutrons in the core is .0078. thermal

The procedure for determining the source strength is developed because we would have to disassemble the core in order to measure a true source level. Since the detectors were moved, it is not possible to use values of the source strength which were measured previously. With this method the rod worth can be measured for any critical assembly throughout the entire range of subcritical and supercritical positions? It is also particularly convenient for this core since the majority of rod travel is in the subcritical range.

At critical, it can be more than one value!!!

The slope of the integral worth curve at any point is related to the importance of that point in sustaining the chain reaction, that is to the loss in reactivity due to the absorption of neutrons at that point. The magnitude of the slope of the curve is proportional to the magnitude of the flux at that point. It should be remembered that these curves are actually a measure of the effect of the control rods on the point at which the detector is located. For example, the curves for detector C merely show that this channel doesn't come on scale until the rods are raised significantly. This explains the differential curve for C since it can almost be considered to show a step increase in detector response as flux increases. The differential curves for the startup channels show more realistically the effect of control rods on the reactor. The maximum on these curves occurs at the point of maximum flux in the core. The maximum flux does not occur at the center because it tends to be depressed by the absorbing rods in the upper part of the core and increased by the followers in the lower part of the core.

The subcritical multiplication procedure was begun with the rods fully inserted in order to save time. For most of the incremental rod withdrawls the limiting factor is the rate at which the rods can be driven; not until near k = 1 does the steady state requirement require any waiting. If we started at critical and inserted the rods incrementally however, we would have to wait all the time for the 55 second delayed neutron group to die out.

Since no single rods were calibrated, it is difficult to draw conclusions about rod interaction in this lattice.

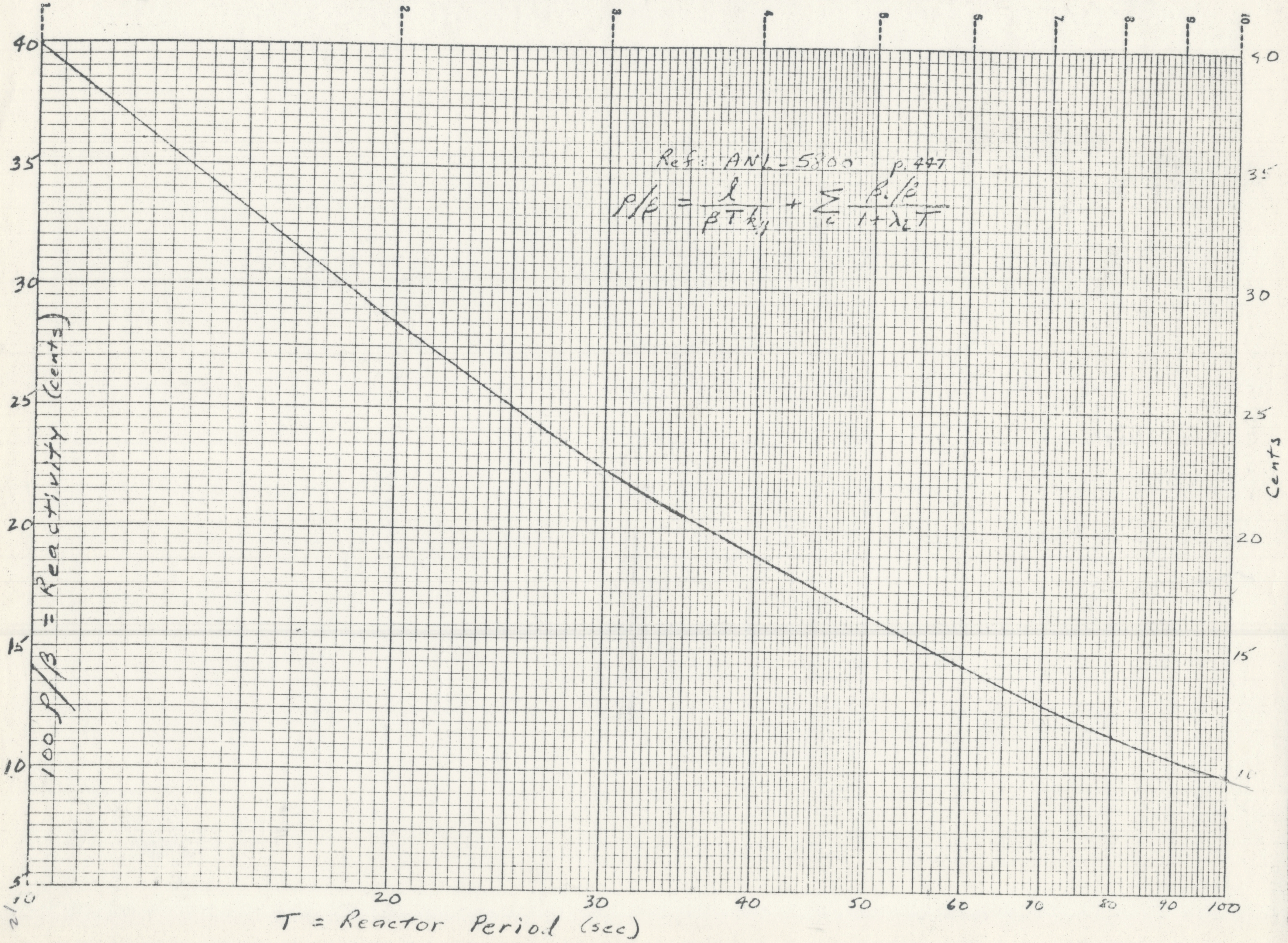
Rod worth reversal can occur in compact highly enriched cores having control rods with fuel followers which are near the upper limit of travel. If the rods are not yet fully withdrawn, further withdrawl will result in very little reactivity addition at the top of the core, but it does take fuel out of the reflector. This combination could result in a negative reactivity addition.

Critical Position	Supercritical Position	Midpoint	Period (sec)	Reactivity (¢)	¢/in
19.894	20.500	20.197	59.0	14.6	24.1
19.883	20.650	20.267	45.0	17.7	23.1
19.883	20.800	20.342	36.0	20.3	22.1
19.923	20.460	20.192	62.3	14.1	26.3
19.920	21.000	20.460	29.3	22.8	21.11
19.935	21.000	20.468	30.0	22.5	21.13
19.935	20.350	20.143	92.0	10.4	25.1
19.900	21.250	20.575	21.0	27.8	20.6
19.896	20.900	20.443	30.3	22.4	22.3
19.896	20.700	20.298	40.0	19.0	23.6
19.450	20.200	19.825	32.4	21.5	28.7
19.450	19.750	19.600	113.0	8.8	29.3
19.450	19.950	19.700	57.0	15.0	30.0
19.4575	20.100	19.779	40.8	18.7	29.1
19.4575	20.440	19.949	21.0	27.8	28.3
19.4575	20.550	20.004	18.87	29.3	26.8
19.4275	20.000	19.729	46.51	17.25	30.1

Table 1. Positive Period Differential Rod Worth Calculations.

Critical Position	Supercritical Position	Midpoint	Period	Reactivity	¢/in
20.190	22.000	21.095	48.83	16.7	9.23
—	—	22.000	—	—	5.0
—	—	21.800	—	—	7.0
—	—	21.300	—	—	12.5
—	—	21.000	—	—	16.0
—	—	19.000	—	—	37.5

POSITION (in)	$\frac{C_S}{C_T} = \Delta k_A$	$\frac{\Delta\rho}{\beta} = \$_A$	$\frac{C_S}{C_T} = \Delta k_B$	$\frac{\Delta\rho}{\beta} = \$_B$	$\frac{C_S}{C_T} = \Delta k_C$	$\frac{\Delta\rho}{\beta} = \$_C$
0	.125	14.23	.284	28.37	2.04×10^{-2}	2.57
4	.104	12.11	.243	25.07	1.875×10^{-2}	2.36
7	.077	9.21	.147	16.43	1.73×10^{-2}	2.18
9	.055	6.71	.094	11.04	1.67×10^{-2}	2.10
10	.046	5.63	.074	8.89	1.55×10^{-2}	1.96
11	.038	4.71	.058	6.98	1.50×10^{-2}	1.89
13	.024	3.00	.034	4.22	1.25×10^{-2}	1.58
15	.014	1.74	.018	2.30	9.375×10^{-3}	1.19
17	.006	.803	.008	1.03	5.92×10^{-3}	.75
19	.004	.558	.001	.152	1.13×10^{-3}	.144
19.15	.00076.	.097	.00081	.103	7.62×10^{-4}	.098
19.30	.00042	.053	.00041	.053	4.09×10^{-4}	.052


Ref: ANL-5800 p. 447
$\rho/\beta = \frac{l}{\beta T k_{ij}} + \sum_i \frac{\beta_i/\beta}{1+\lambda_i T}$
$100\ \rho/\beta$ = Reactivity (cents)
Cents
T = Reactor Period (sec)
10
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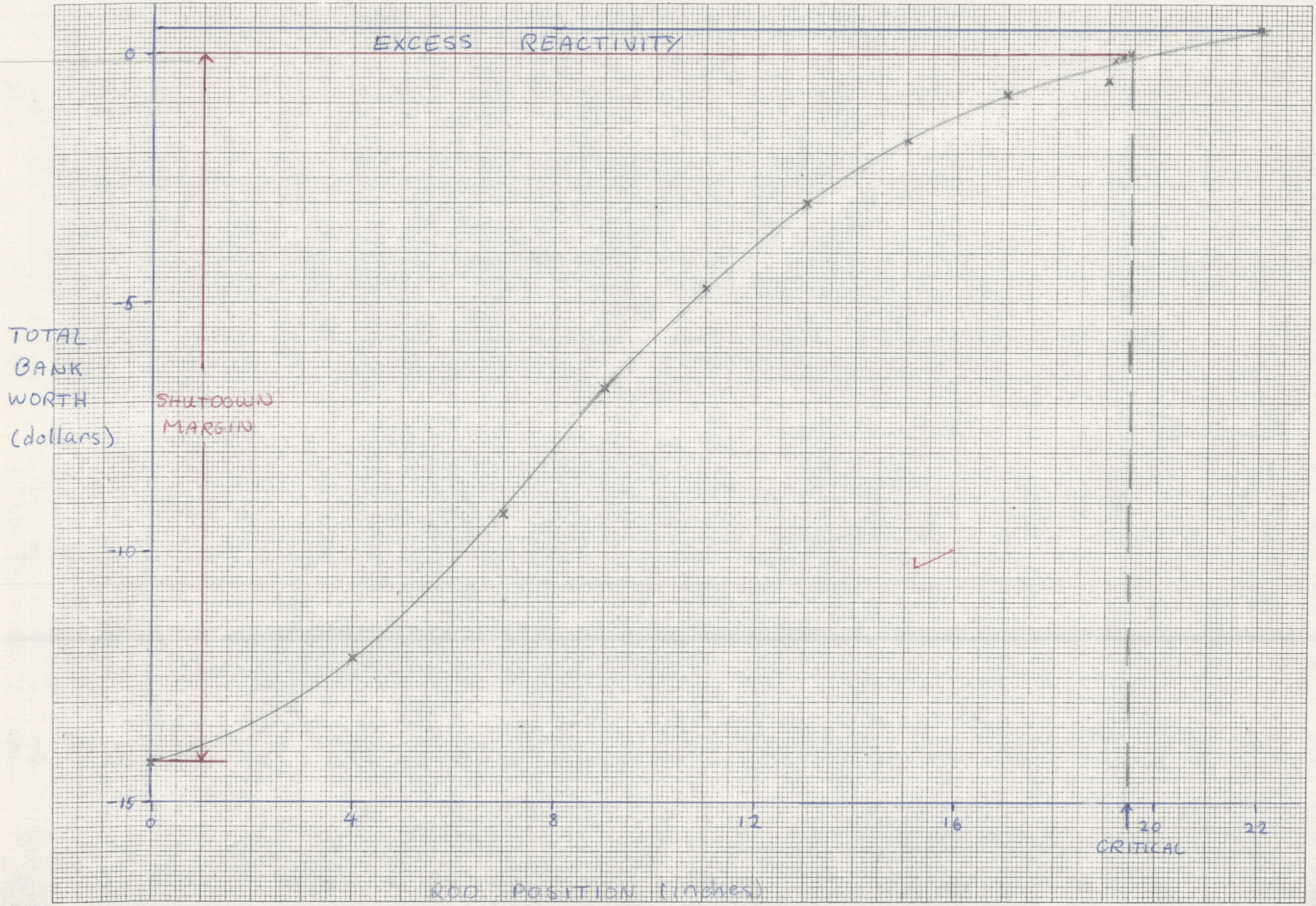
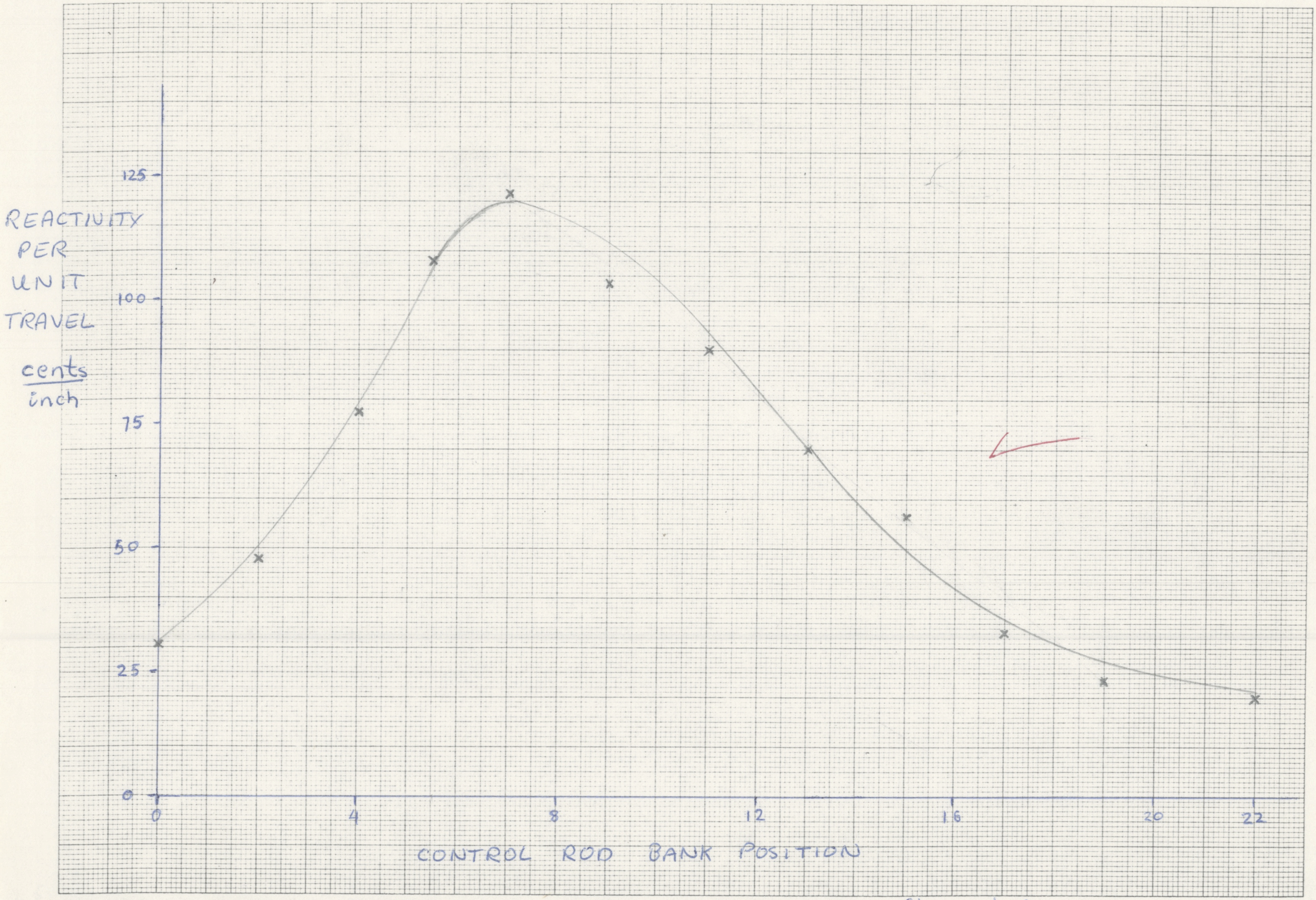
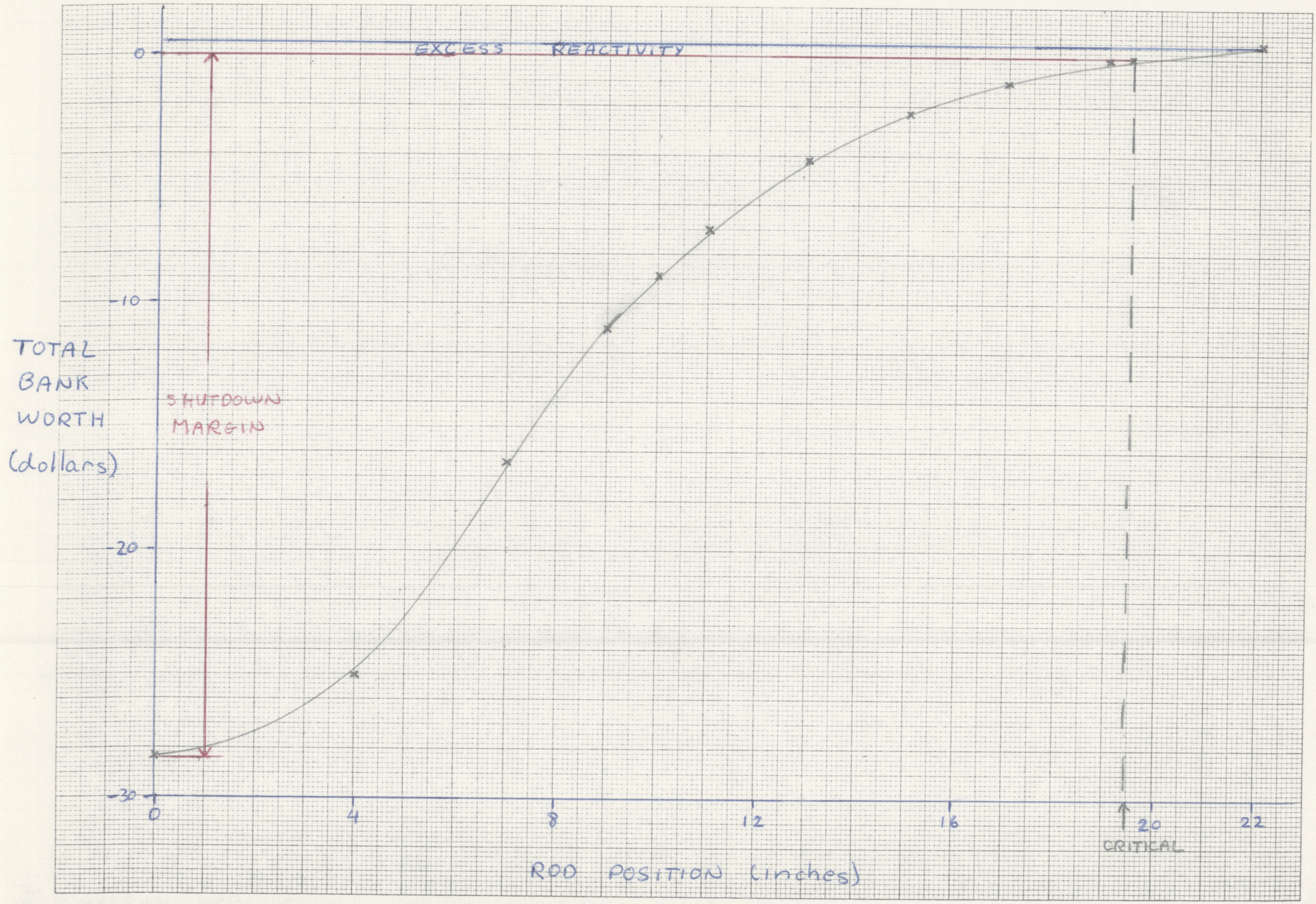


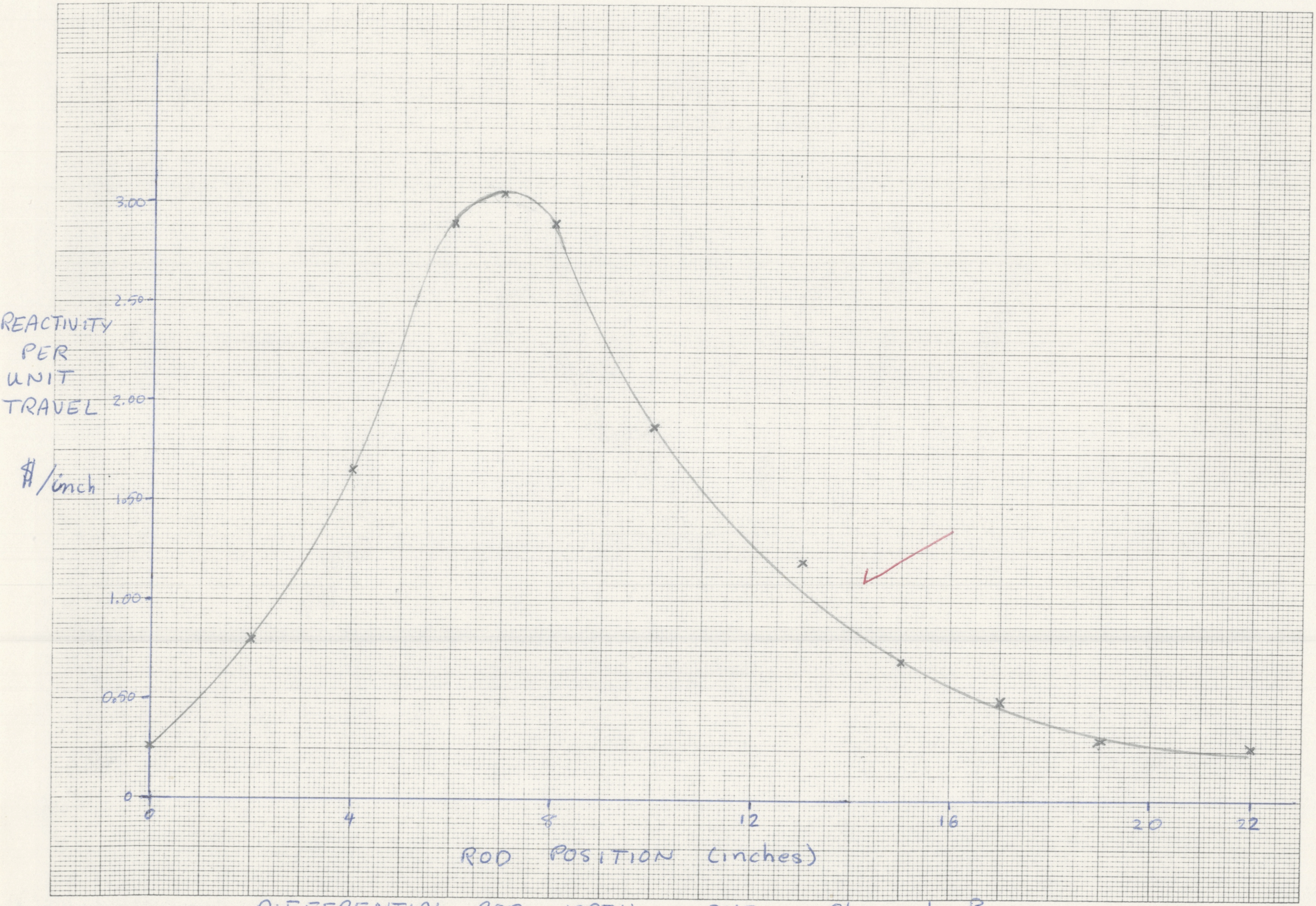
INTEGRAL ROD WORTH CURVE — CHANNEL A



DIFFERENTIAL ROD WORTH CURVE - Channel A



INTEGRAL ROD WORTH CURVE - Channel B



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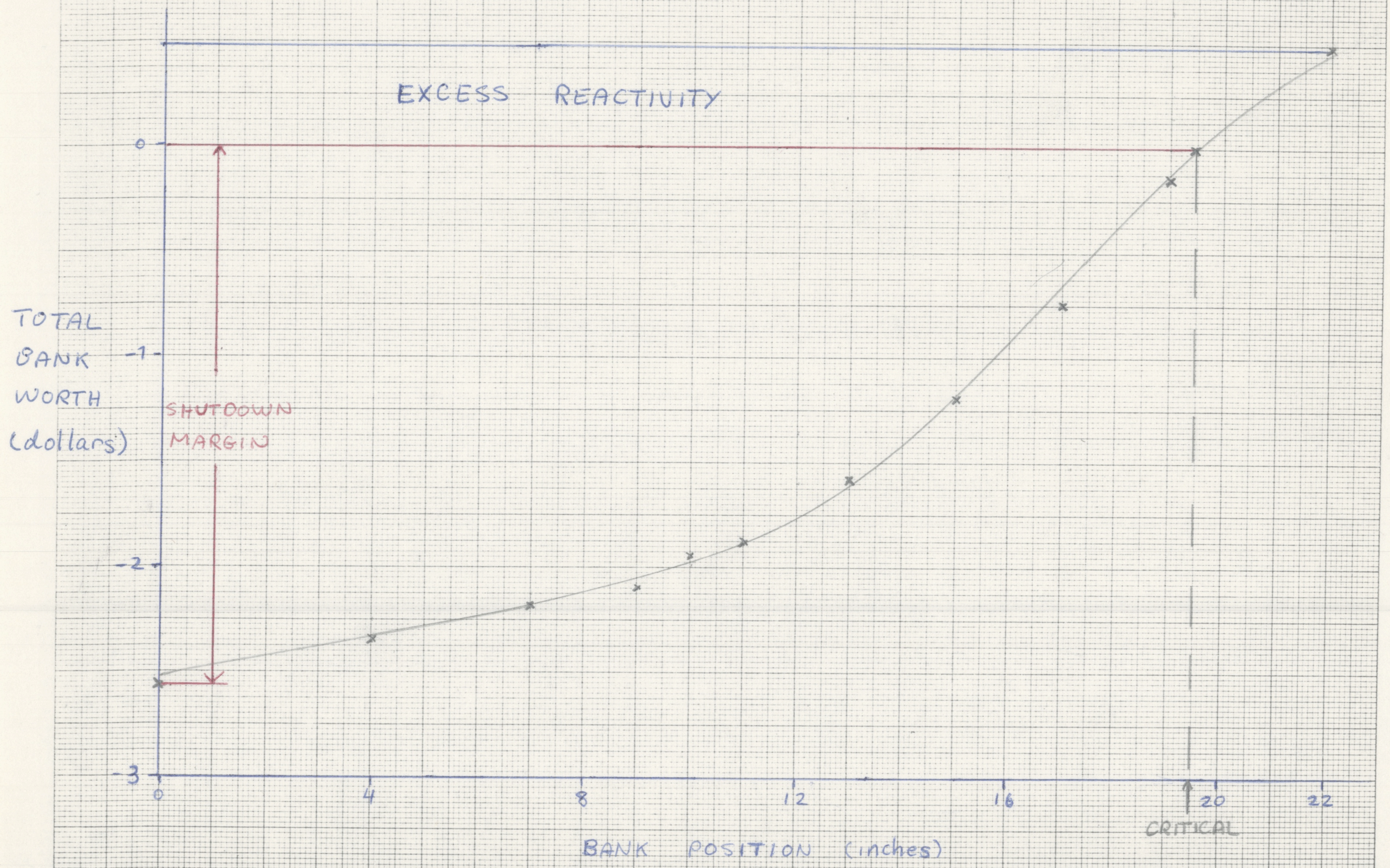
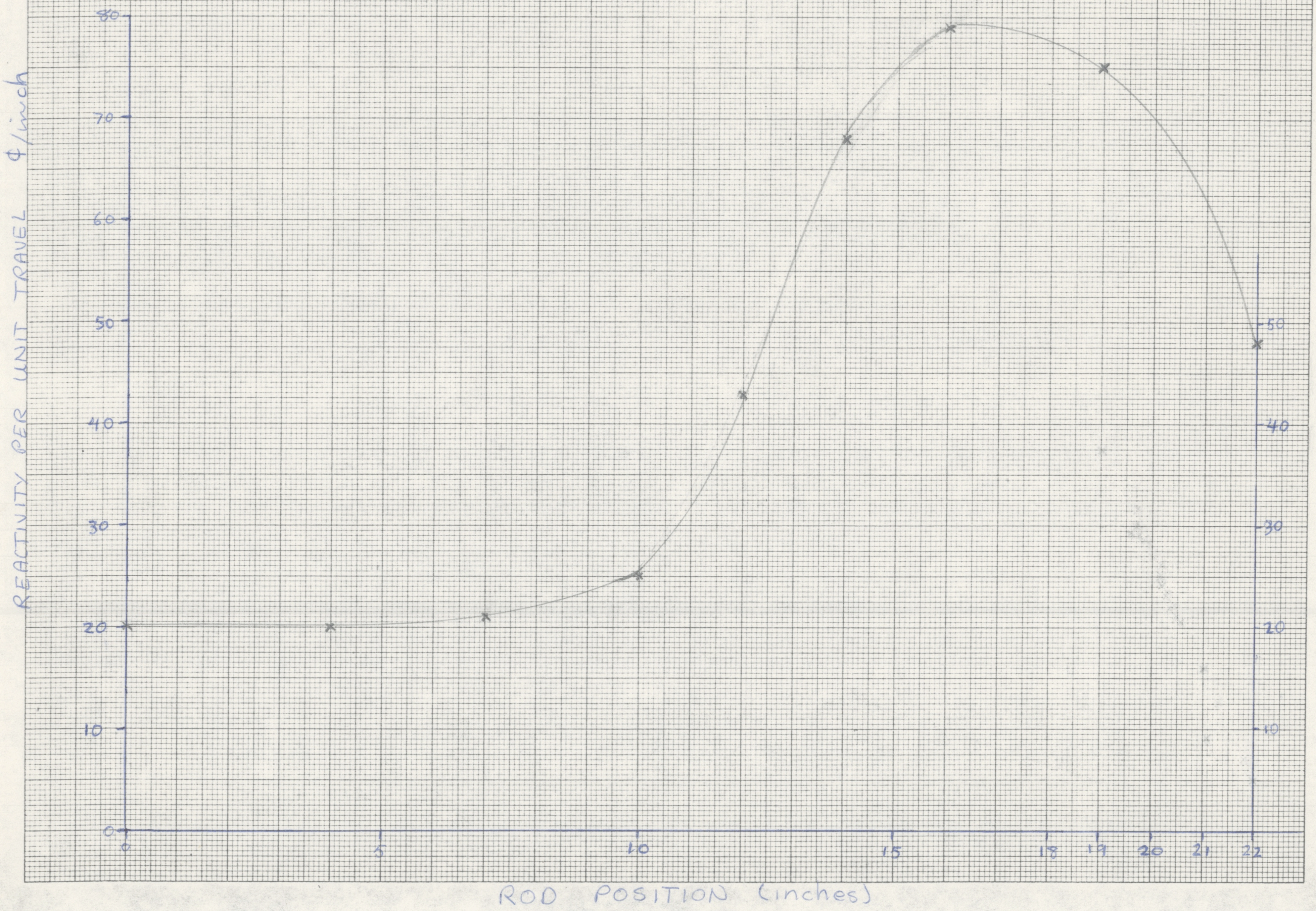


INTEGRAL ROD WORTH CURVE- Channel C



DIFFERENTIAL ROD WORTH CURVE - channel C

CALCULATIONS:

AREA = $(19.4575 - 19.300)\ \text{in} \times 33.3\ ¢/\text{in}$

$= 5.24\ ¢ = \$5.24 \times 10^{-2} = \dfrac{\rho}{.0078}$

$\rho \cong \Delta k = 4.09 \times 10^{-4}$

C_t @ 19.30 in =

CHANNEL

A: 332114

B: 259225

C: $.5.5 \times 10^{-11}$

$C_s = C_t\, \Delta k$ =

CHANNEL

A: 138

B: 106

C: 2.25×10^{-14}

EXCESS REACTIVITY

$= \left(\frac{1}{2}\right)(22.0 - 19.4575)(32.5 - 5.6)$

$+ (5.6)(22.0 - 19.4575)$

$= 48.43\ ¢$