B+

Experiment 2

Core Loading by Subcritical Multiplication

William M. Conlon

ABSTRACT

The minimum critical mass of the RPI critical facility was found to be 5.209 kg Uranium with the control rods raised 19. 923 inches. This is a total mass of 5.935 kg of Uranium. ✓

OBJECT:

The purpose of this experiment is the safe loading of the minimum critical mass at the RPI critical facility by the method of subcritical multiplication. In using this method, the critical mass is approached slowly, systematically, and in such a manner that the system is always known to be subcritical.

THEORY:

The subcritical multiplication rate of a neutron chain reacting assembly is defined as the ratio of the thermal flux due to the source and fissions to the thermal flux produced by the source alone. If k_{eff} neutrons result in one generation for each neutron in the preceeding generation, the multiplication rate is

$$M = 1 + k_{eff} + k_{eff}^2 + \ldots + k_{eff}^n + \ldots$$

$$= 1/(1 - k_{eff}), \quad k_{eff} < 1.$$

$$\text{Thus } 1/M = 1 - k_{eff} = \frac{\text{flux due to source}}{\text{Flux due to source \& fuel}} .$$

In a critical reactor $k_{eff} = 1$, implying that $1/M = 0$. Since the count rate from the detectors used in the reactor are proportional to the thermal flux, 1/M is equivalent to the ratio of the count rate from the source to the count rate from the source and fissions.

If 1/M is plotted against the fuel mass, the critical mass corresponds to the point at which the curve intersects the mass axis. Depending on the source-detector geometry, three types of curves can be generated. If the detector is located such that the proportion of neutrons counted from source and from fission is the same as the proportion in which they are produced, the curve will be a straight line. If a larger fraction of the neutrons counted come from the source than are actually produced, 1/M will always be too large, resulting in a curve which is concave downward. Linear extrapolations from such a curve will overestimate the minimum critical mass, a dangerous condition when loading since there is no bound at which the core is known to be subcritical. If neutrons produced in fission dominate the count rate of the detector, $\phi_S/\phi_S+\phi_F$ will always be less than 1/M, resulting in a curve which is concave upward. Linear extrapolations from this curve will always underestimate the critical mass, providing a safe bound on loading.

Although the last curve could increase the loading time, it is definitely the safest situation. It should also be noted that these geometric configurations can change during the loading since the core size changes and the relative position of the detector with respect to source and fission neutrons changes. In any case, no matter what type of curve is generated by a detector, it will eventually converge to the critical mass.

The basic idea of the approach to criticality by subcritical multiplication, then, is to load a mass of fuel which is known to result in a subcritical configuration. The flux ratio is then plotted as 1/M and a straight line is extrapolated to an estimate of the critical mass. Based on this estimate of m_c, additional fuel is loaded (subject to the constraints outlined under procedure).

PROCEDURE:

It is desirable to have as much information as possible about the core during the loading. The three detectors used in this experiment were the two startup channels (described in the previous experiment) and the linear power channel which uses an uncompensated ion chamber. By removing the source from the tank we verified that all three systems were detecting neutrons. Next the source level was determined. It was inconvenient to remove the control rods from the lattice, so the source level was was taken with the absorbing control rods in the tank.

Next the control rods were raised completely and the multiplication calculated. The rods were dropped and 4 fuel elements were loaded in the core. The multiplication was calculated with the rods in and out. After each step the multiplication was calculated with the rods in and out, and extrapolated to the minimum critical mass. The most conservative estimate of m_c was used as the basis for the next loading step. The following rules were also followed during the core loading.

1. No more than 4 elements loaded in any step.
2. Based on the most conservative estimate for m_c, no more than one-half of the fuel required to obtain m_c will be loaded in one step.
3. Voice contact is maintained between control room and reactor room during loading.
4. If the count rate on any channel increases by more than one-half decade during the addition of any single element, fueling will stop.
5. Insofar as possible, core symmetry will be preserved.
6. The minimum surface to volume area will be achieved.
7. the number of elements added at any given step may not exceed that of the previous step.

When the final fuel elements were loaded, 1/M was plotted against the control rod position. After the reactor became supercritical the control rods were adjusted to the critical position.

DISCUSSION:

Although we were not able to measure a true source level (without control rods) this did not make any difference in the loading. The reason for this lies in the definition of the multiplication -- the generation by the assembly of a number of neutrons for each neutron produced by some steady source. In fact it doesn't matter what one takes as the source of neutrons, since as fuel is added to the assembly the neutron level maintained in the assembly will be multiplied still further. As long as the assembly is subcritical, the critical mass can be estimated by the method of subcritical multiplication independent of the choice of source. This is what we did as we approached

4 element limit is because there are 4 fuel followers & each step has Been already been done with the rod out plot

critical with the control rod bank position measurement. The source level was defined as the neutron population with the fuel loaded but rods fully inserted.

The initial fuel loading consisted of 4 fuel elements which preserved symmetry. The initial loading was 1088 g, which is considerably less than half of the more than 2 kg of pure U-235 required for a critical mass in a homogeneous light water reactor. Considering cladding, structure, and control rods, this is certainly a safe loading, yet one which can give enough multiplication to make a good estimate of the next fuel loading.

One reason for maintaining core symmetry is so that at any loading step each detector will give a reasonably similar estimate of the multiplication. If one detector performs grossly different it might be suspected of malfunctioning. Although the core may be loaded symmetrically, the detectors are not located symmetrically with respect to the core. This problem is related to the type of curve generated by the detectors. Although a particular curve is being generated, when we add fuel and change the core configuration, we have no a priori knowledge that the same type of curve will be continued. By using a linear extrapolation we tacitly assume that an ideal geometry exists, which is just a compromise between the two possible extremes. The geometric situation is also illustrated in the loading curves which show that startup channel B was consistently more conservative than the other two detectors. This resulted from the source being placed in an asymmetric position. Had the source been placed in the center of the core, the three detectors would have yielded more similar results. — Yes

This is for conservative reasons and also the most recent data points are the most reliable

The 1/M plot with rods inserted always indicated a larger critical mass at each step than the plot with rods withdrawn since the control rods reduce the multiplication. By superimposing the two plots one can estimate the shutdown margin provided by the rods, since this is merely the relative change in k_{eff} when the rods are inserted. Similarly the plot of 1/M against the bank position shows the rod worth as a function of height. ✓

The PuBe neutron source performs an important safety function in the loading. In the early stages of loading it is important to use a strong source so that reliable statistics can be obtained on which to base the next loading step. After the reactor is loaded the source is used to provide a large enough flux so that the multiplication is obvious as the rods are withdrawn. ✓ Without a source it would be possible to remove the rods into a critical or supercritical position without being aware since the flux would be so low. Some of the automatic scrams might not work since the power channels might not be on scale.

One might argue that it would be safer to have one rod fully withdrawn during the loading so that in case a supercritical mass is loaded there will be a backup safety system.. Since this reactor is loaded manually such an excursion could be particularly tragic. The best way to protect people is to prevent tthe possibility of such an excursion occurring. This is done by having the maximum negative reactivity in the reactor. If a mass was to be loaded where there was the possibility of an excursion ocurring (a foolish action) it would be safer to dump the water moderator during loading. In any case, we always insured that the minimum m_c with the rods in was greater than the fuel loading.

TABLE 1: Multiplication with Rods IN

Mass of U(kg)	COUNT RATE A	$1/M_A$	COUNT RATE B	$1/M_B$	CURRENT C	$1/M_C$
0	715.5	1	84	1	1.25×10^{-12}	1.
1.088	835	.857	140	.60	1.35×10^{-12}	.93
1.861	941	.76	238	.35	1.50×10^{-12}	.83
2.634	1267.5	.56	455.33	.18	$.75 \times 10^{-12}$ *	1.0
3.149	1514.5	.47	757	.11	$.8 \times 10^{-12}$	.94
3.665	2045.25	.35	946.3	.088	$.95 \times 10^{-12}$	.78
4.181	2644.25	.271	1208	.0695	1.1×10^{-12}	.682
4.694	3402.2	.21	1766.3	.0476	1.25×10^{-12}	.60
5.209	4265	.17	1807	.0465	1.6×10^{-12}	.469

* redefined source level resulting from instrument adjustment.

TABLE 3: Critical Bank Position

BANK POSITION (in)	COUNT RATE A	$1/M_A$	COUNT RATE B	$1/M_B$	CURRENT C	$1/M_C$
0	4265	1	1807	1	1.6×10^{-12}	1
8	9278	.483	4879	.370	2.2×10^{-12}	.727
12	22044	.19	13289	.136	3.8×10^{-12}	.421
13	28712	.152	17521	.103	4.5×10^{-12}	.356
15	48022	.089	31415	.058	7.0×10^{-12}	.229
17	95238	.0448	64945	.027	12.5×10^{-12}	.128
18	148893	.0286	111191	.0163	22.0	.0727

19.923 Critical Bank Position

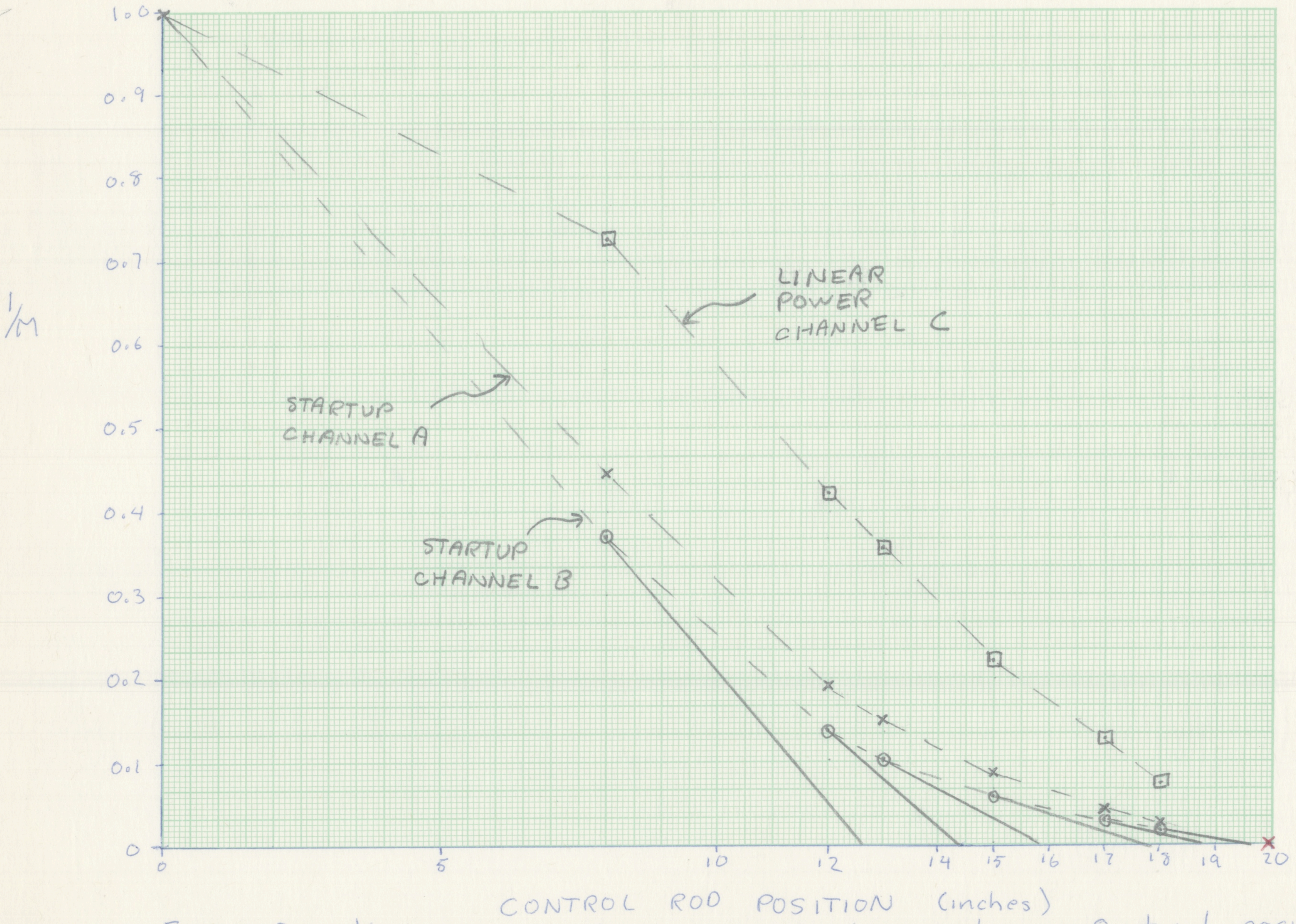

Figure 3. 1/M vs. control rod bank position. Critical position is 19.923 inches. Only the most conservative estimates, Channel B, are extrapolated to critical position

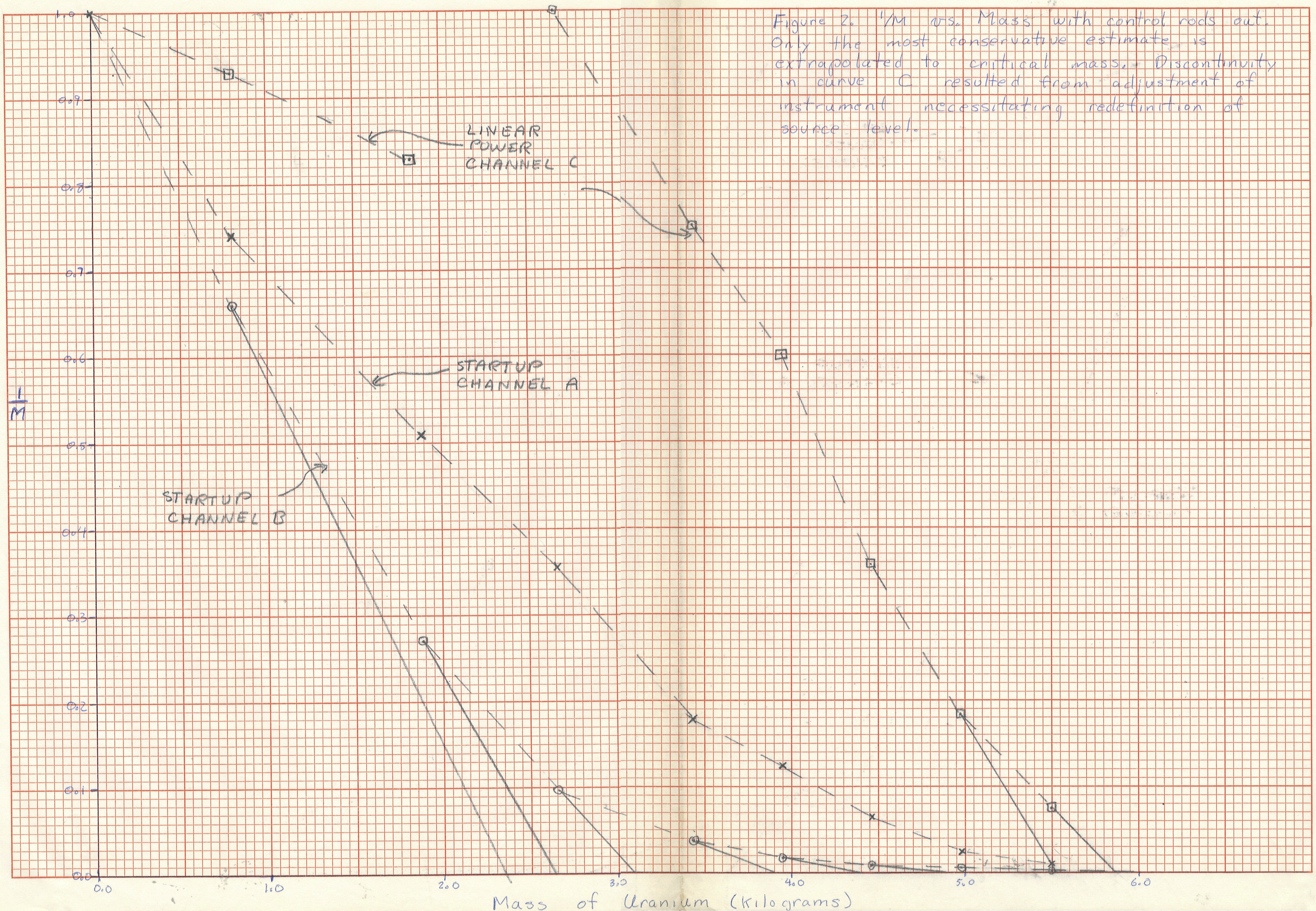

Figure 2. 1/M vs. Mass with control rods out. Only the most conservative estimate is extrapolated to critical mass. Discontinuity in curve C resulted from adjustment of instrument necessitating redefinition of source level.

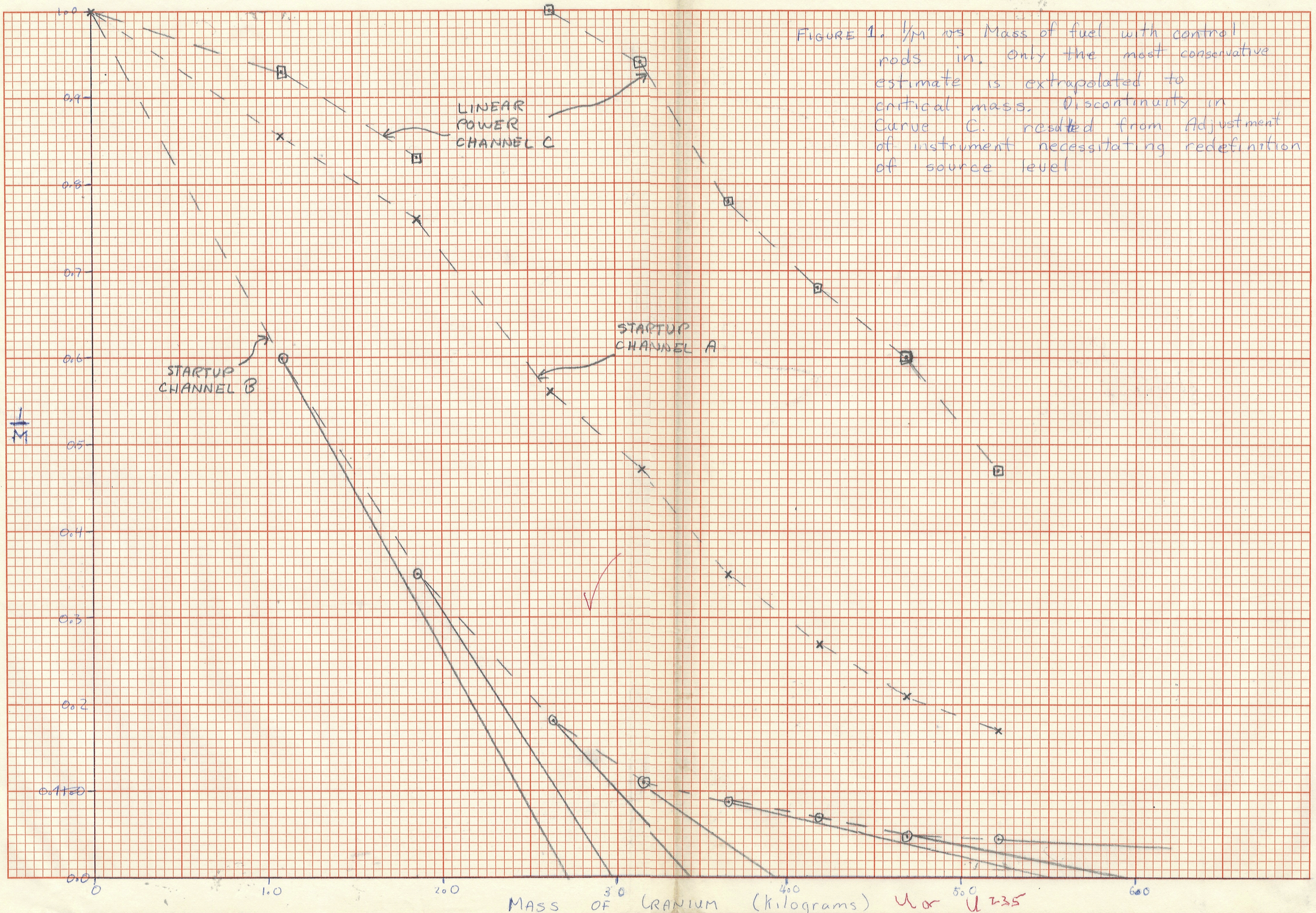

FIGURE 1. $1/M$ vs Mass of fuel with control rods in. Only the most conservative estimate is extrapolated to critical mass. Discontinuity in Curve C. resulted from Adjustment of instrument necessitating redefinition of source level