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NEUTRON BURST FROM A CYLINDRICAL UNTAMPED OY ASSEMBLY

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ABSTRACT

A neutron burst from an untamped cylindrical Oy assembly occurred at the Pajarito Remote Control Laboratory at 1800 hours on 18 April 1952. The circumstances causing the burst and a description of the assembly involved are given. There was no personnel hazard. Normal operations could have been resumed on other assemblies within two or three hours after the burst. No evidence of damage to the Oy was observed. It was determined that the burst resulted in 1.5×10^{16} fissions in the Oy. Also reported are some results of computations and post-burst tests and a discussion of probable time behavior of power level during the burst.

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NEUTRON BURST FROM A CYLINDRICAL UNTAMPED OY ASSEMBLY

I. INTRODUCTION AND IMMEDIATE OBSERVATIONS

At 1800 hours on 18 April 1952, there occurred a burst of neutrons in an Oy assembly in the Remote Control Laboratory at Pajarito Site of the Los Alamos Scientific Laboratory. The nearest personnel to the burst were in the control room about one-quarter of a mile away. A photograph of the assembly is shown in Fig. 1, and its description is given in the accompanying caption. Figure 2 gives a schematic diagram of the assembly with some additions that were used in the post burst tests which are described in Section III of this report.

Complete assembly of the two Oy components had been made previously with the six Oy plates on the lower component, but first with only three and then with only four Oy plates on the upper component. This corresponds to totals of 9 and 10 Oy plates, respectively. Figure 3 gives a curve of reciprocal multiplication[1] vs total Oy mass as obtained from these assemblies. Some information given on this figure was obtained from the post-burst tests as indicated. By referring to this curve, it is obvious that a complete assembly should not be made after the addition of the fifth plate on the upper component (for a total of eleven plates). The burst occurred, however, because such an assembly was attempted. This addition was made as a

(1) The multiplication is the ratio of the leakage neutron flux from the Oy assembly to the leakage flux from an identical Tu assembly. A centrally located mock fission source was in each assembly. The flux was measured by B-10 lined neutron counter tubes in long geometries placed near the assembly.

FIG. 1. The cylindrical untamped Oy assembly on the Comet remotely controlled assembly machine. The lower stack of 6 Oy plates can be raised on the hydraulic lift after the upper stack of Oy plates has been lowered into position by releasing the air from the air cylinder above. The Oy plates are 10½" in diameter and 8.0 mm thick. A Tu stove-lid 6.0 mm thick fits in the supporting Al ring of the upper component. A 0.875" diameter central hole through the plates was filled with Oy slugs with the exception of a small centrally located Tu source holder. A schematic diagram of the Oy assembly is given in Fig. 2.

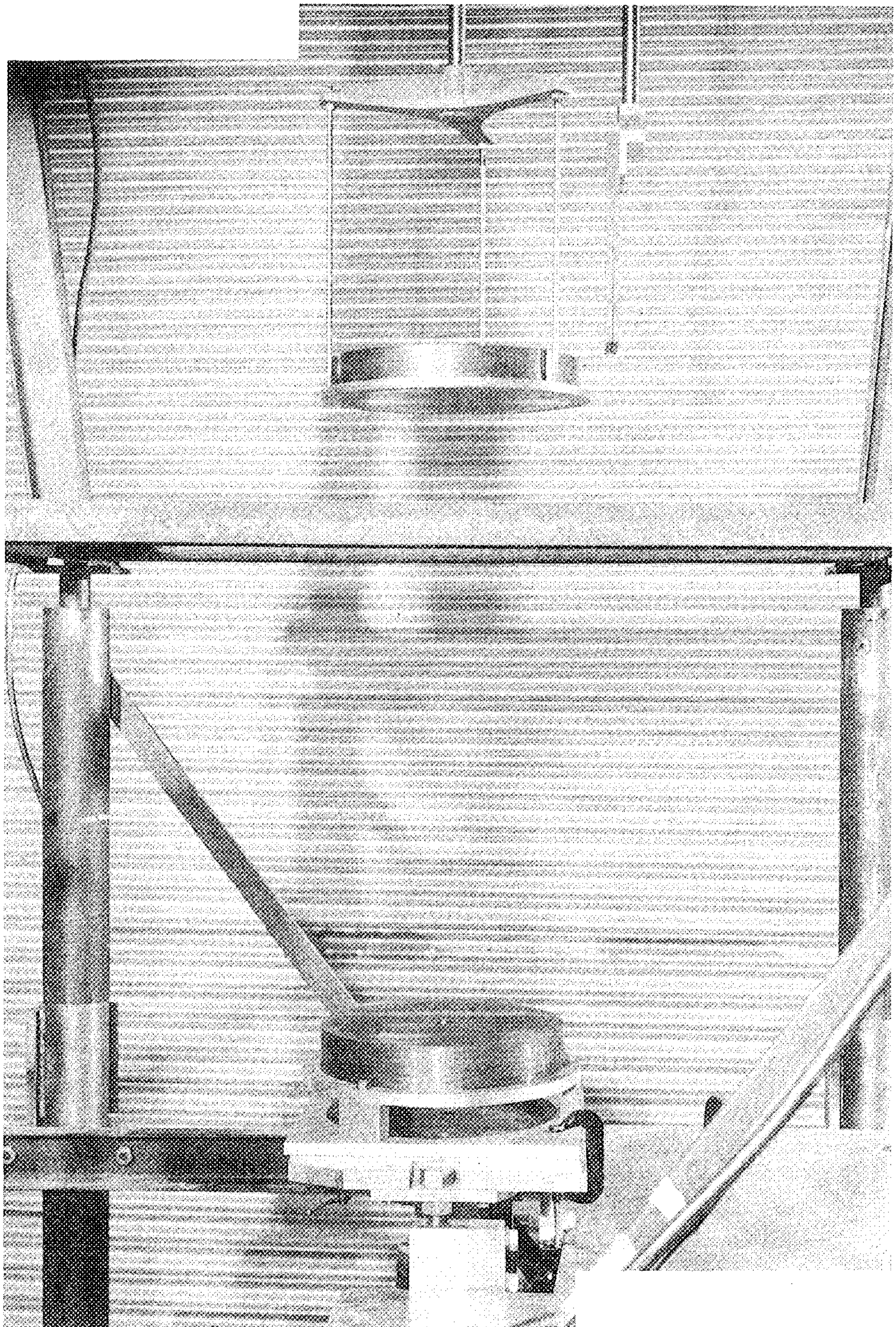
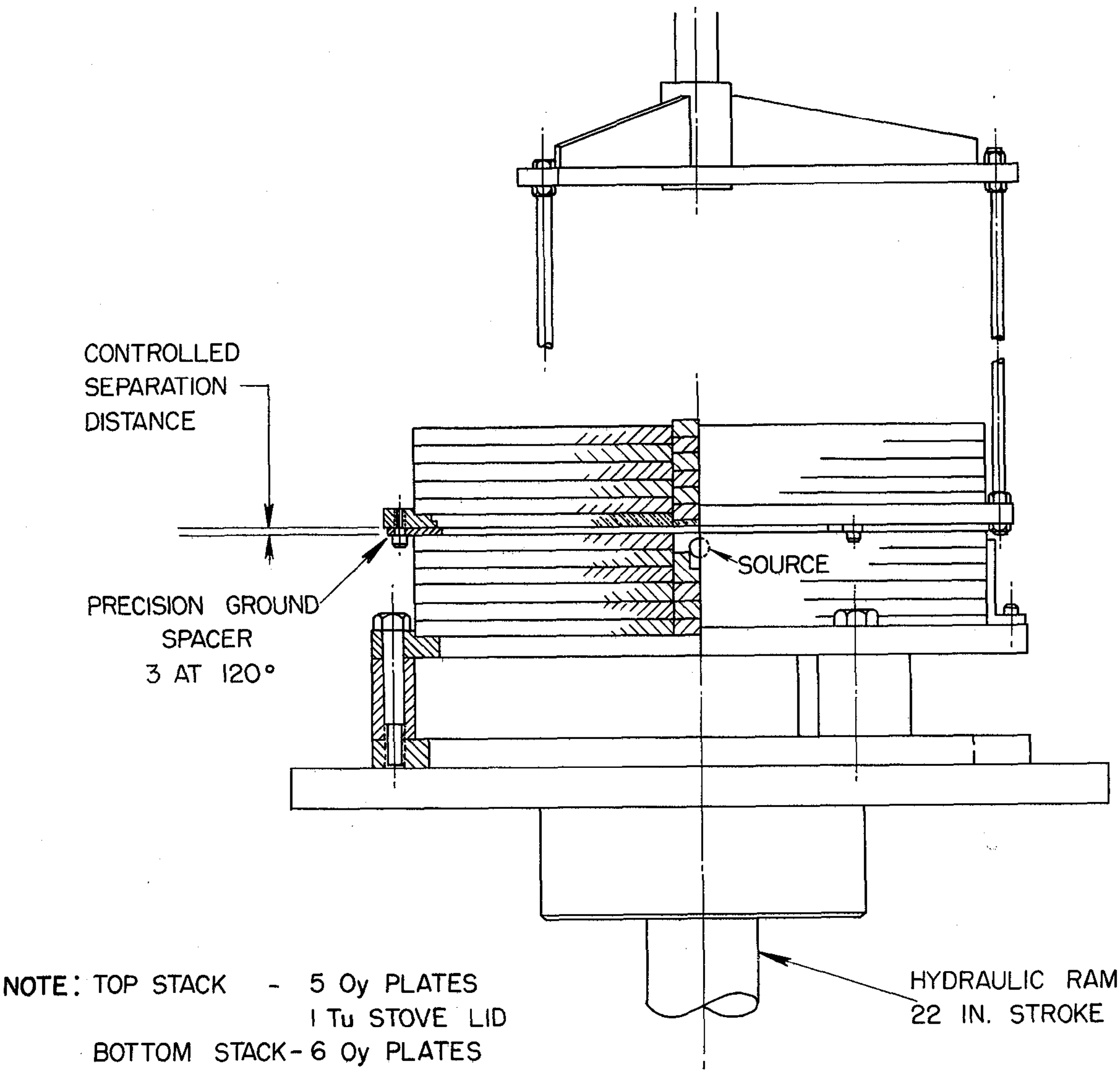
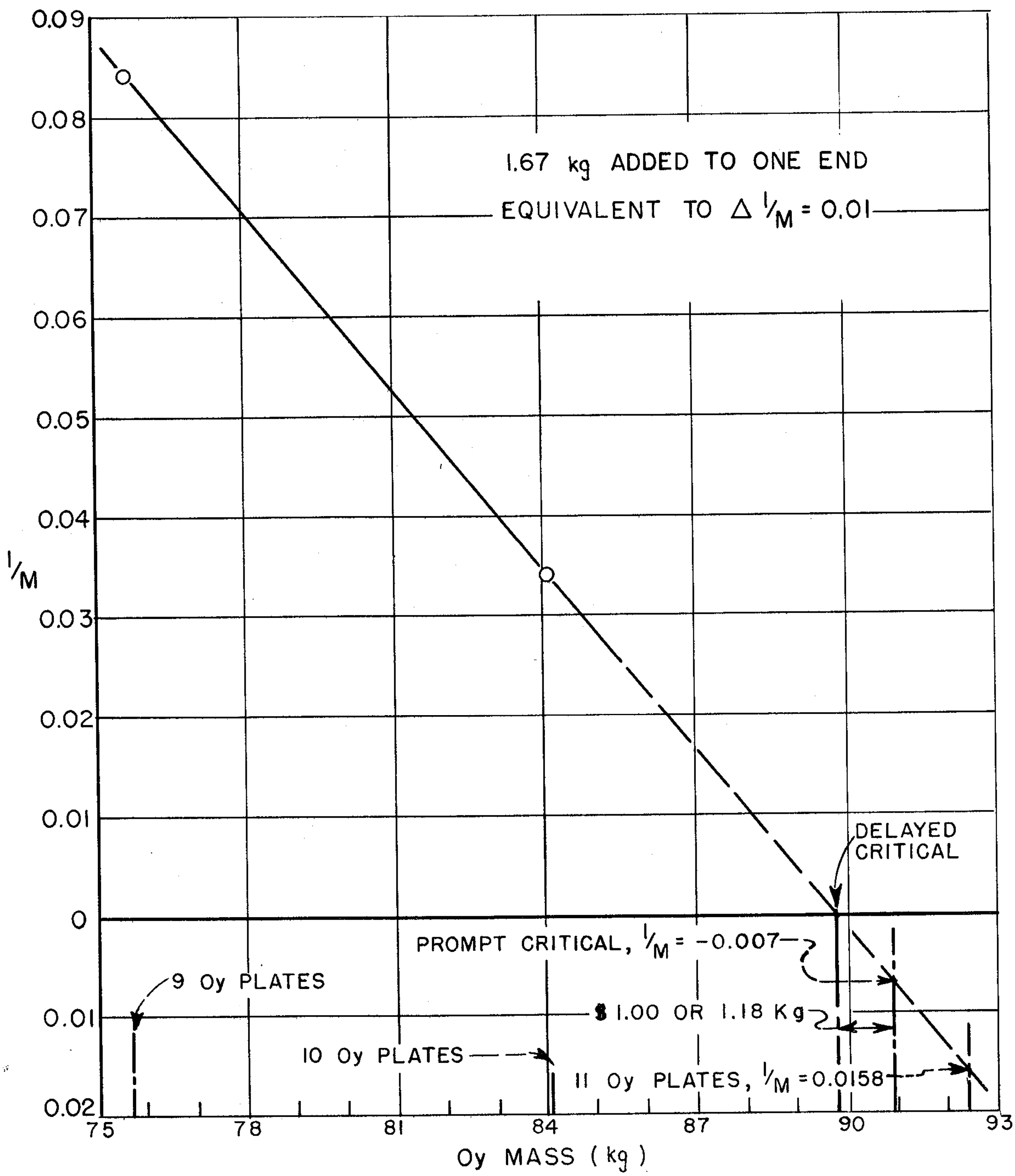


FIG. 2. Schematic diagram of cylindrical Oy assembly (Jemima) being used when the burst occurred. The precision ground spacers shown were added for the post-burst investigation. All of the central slugs were Oy except the Tu source holder. The mock fission source had a source strength of about 6×10^6 neutrons per second.



JEMIMA SET UP IN ASSEMBLED POSITION

FIG. 3. Reciprocal multiplication vs Oy mass in assembly for a closed assembly; i.e., zero separation distance. The information shown on the figure for prompt critical was determined in the post-burst investigation that follows in Section III.


1.67 kg ADDED TO ONE END
EQUIVALENT TO Δ 1/M = 0.01
DELAYED CRITICAL
PROMPT CRITICAL, 1/M = −0.007
9 Oy PLATES
$ 1.00 OR 1.18 Kg
10 Oy PLATES
11 Oy PLATES, 1/M = 0.0158
1/M
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.01
0.02
75
78
81
84
87
90
93
Oy MASS (kg)

result of human error of computation based on the numerical data given graphically in Fig. 3. The same error was made independently by two different people. The attempted assembly was made as usual in steps and the last pause prior to the burst was at a separation of Oy components between 0.25" and 0.30". It was shown in the post-burst tests that followed that delayed critical was reached at a separation of 0.1135" and that prompt critical was reached at a separation of 0.0525" (unless expansion of Oy due to heating from fission reduced this required separation distance). It was not known if the burst occurred while the lower component was being raised under full power or if the power had been cut off and the lower component was coasting upwards. Post-burst tests indicate the latter to be true.

At the instant of the burst, or immediately thereafter, the following occurred: a smoke or steam puff originated in the Oy assembly and was observed on the television screen in the control room; the assembly was immediately disassembled by the action of the safety monitors; all three safety monitor indicators in the control room went off scale; all four B-10 lined neutron counter tube scalers in the control room jammed; and the linear amplifier indicator in the control room registered the radiation on the least sensitive scale. The counter tubes for the neutron counters and the ionization chambers for the linear amplifier and safety monitors were in the laboratory with the Oy assembly.

A Geiger counter with its continuous recorder in a laboratory adjacent to the control room was observed to have gone off scale and returned to its normal position almost immediately. A fission chamber in this same laboratory was counting background and the total number of counts registered the next morning indicated a background considerably higher than normal. However, about five minutes after the burst, no radiation meters in the laboratory adjacent to the control room could detect any radiation; nor did the film badges in the control room during the burst receive any detectable radiation.

Three minutes after the burst, one safety monitor indicator was back on scale and five minutes afterwards, the neutron counter scalers were no longer jammed.

Two hours after the burst, the background of the neutron counters was twice the normal value and the linear amplifier, which had been observed since the burst, still indicated a decay. At this time, the laboratory was safely entered for a short time. Four hours and fifteen minutes after the burst, the Oy in the assembly was dispersed with radiation exposure to personnel of only $\sim$ 0.6 R. At this time, the neutron counters were down to normal background and the linear amplifier was almost at its normal background reading. An inspection of the Oy indicated that there was no noticeable oxidation or damage of the material due to the burst. On the morning of 22 April 1952, the same assembly was restacked without giving any measurable radiation to personnel involved.

II. CALCULATIONS ON THE BURST

1. Total Fissions

The residual gamma activity from an Oy slug (0.875" diam. x 0.315" thick) that had been approximately centrally located in the stacking (the lower slug in the upper stacking shown in Fig. 2) was compared with a radium standard by means of a Geiger counter 18 hours after the burst. An identical unirradiated slug was placed in the center of the spherical untamped Oy assembly (Godiva) which was operated at 3.1×10^{11} fissions per second for thirty minutes. The radium equivalent gamma source strength of this second slug was determined in a like manner 18 hours after irradiation. Thus, by comparison, a calculation of the total number of fissions in the burst could be made.

The first slug had a radium equivalent gamma source strength of 4.65 millicuries. The second slug had a radium equivalent gamma source strength of 0.33 millicuries which was equivalent to 5.6×10^{14} total fissions. Multiplying the total number of Godiva fissions by the ratio of irradiated slug strengths (4.65/0.33) and by the ratio of the masses of the Oy assemblies involved in the burst and in Godiva (92.4/53.2) gives $\sim 1.4 \times 10^{16}$ for the total number of fissions in the Oy assembly. This is assuming that the ratio of average to maximum fission rates is the same for both assemblies. Actually, it has been calculated that this ratio is four per cent higher for the particular Oy stacking used in the burst. Therefore, the total number of fissions that occurred in the cylindrical Oy assembly for the burst was 1.5×10^{16}. No correction has been made for the presence of the Tu stovelid or the gap between components of the assembly when the burst occurred.

The morning after the burst, the normal total background fission count in the laboratory adjacent to the control room was subtracted from the counts registered by the fission chamber that ran all night there (Section I). This gave the counts contributed by the burst neutrons. Then, using a mock fission source of known Q-value and the inverse square law, it was computed that 1.2×10^{16} fissions occurred in the burst. As no absorption or scattering was considered, this value represents a lower limit.

2. Other Computations

The computations given in this paragraph are those that could be made from a knowledge of the burst strength, some physical constants of uranium,[1] and the energy per fission that could be used to heat such an assembly.[2]

The average temperature rise of the assembly was computed to be $\sim 38^{\circ}$C. Since it can be shown that the ratio of maximum fission rate to the average fission rate in this assembly is 2.2, the maximum temperature rise was 83°C. The room temperature was 21°C so that the maximum temperature in the assembly was $\sim 104^{\circ}$C. This is believed consistent with the observation of the smoke or steam puff and the minimum

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(1) Linear coefficient of expansion of uranium = $\alpha = 14 \times 10^{-6}/^{\circ}$C between 20°C and 100°C. This was furnished by H. L. Laquer of Los Alamos Scientific Laboratory.

Specific heat of uranium = 0.029 cal/gm/$^{\circ}$C. This came from National Nuclear Energy Series and was measured at the Bureau of Standards in 1946.

(2) The energy released in heat per fission = 174 Mev. This assumes that 167 Mev of fission fragment kinetic energy, 4.6 Mev of prompt gammas, and 2 Mev of neutron kinetic energy go into heating the Oy. This value is based on work done by R. B. Leachman, Los Alamos Scientific Laboratory.

damage and oxidation to the Oy.

Since the critical mass (at constant height-to-diameter ratio) varies inversely as the square of the density, a uniform increase in temperature of 38°C would increase the critical mass by 0.293 kg of Oy. However, due to the fact that the temperature rise was not uniform and the density change is greater at the center of the assembly, the critical mass is changed by a factor roughly 1.6 times this, or $\sim$ 0.46 kg of Oy. For comparison with tests where mass was added at the end only, this now has to be multiplied by 1/1.9 giving $\sim$ 0.25 kg of equivalent Oy end mass. This factor was computed from the shape factor curve for untamped Oy cylinders as given in LA-1155.

III. POST-BURST TESTS

The primary purpose of the post-burst tests was to find the reactivity of the assembly as a function of separation distance of the two components and to find the maximum assembly rate and the time required to activate the scramming mechanism.

Table I gives the results of the time-motion study of the hydraulic lift.

TABLE I. Results of time-motion study of hydraulic lift.

Maximum lift velocity	=	0.35"/sec
Time required to activate the scrams	=	0.3 sec

In preparation for the post-burst reactivity measurements, the precision ground positive stop shims shown in the diagram of Fig. 2 were added. This allowed a precisely known separation distance of the upper and the lower components of the assembly. Figure 4 gives the separation of the complete Oy assembly components both as a function of the reciprocal multiplication and ΔK, the reactivity above delayed critical. The multiplication was measured as described in Section I and ΔK was determined by measuring the e-folding time of the assembly in the delayed critical region. The relation between ΔK and the e-folding time is given by the inhour equation (LA-1033) involving data on delayed neutrons from Hughes, et al (Phys. Rev. 73, 111 (1948)).

Table II gives a summary of the information taken from curves of Figs. 3 and 4, and Table III gives a summary of the computations made.

TABLE II. Information taken from Figs. 3 and 4.

Δ " DC - P.C
.061"/¢

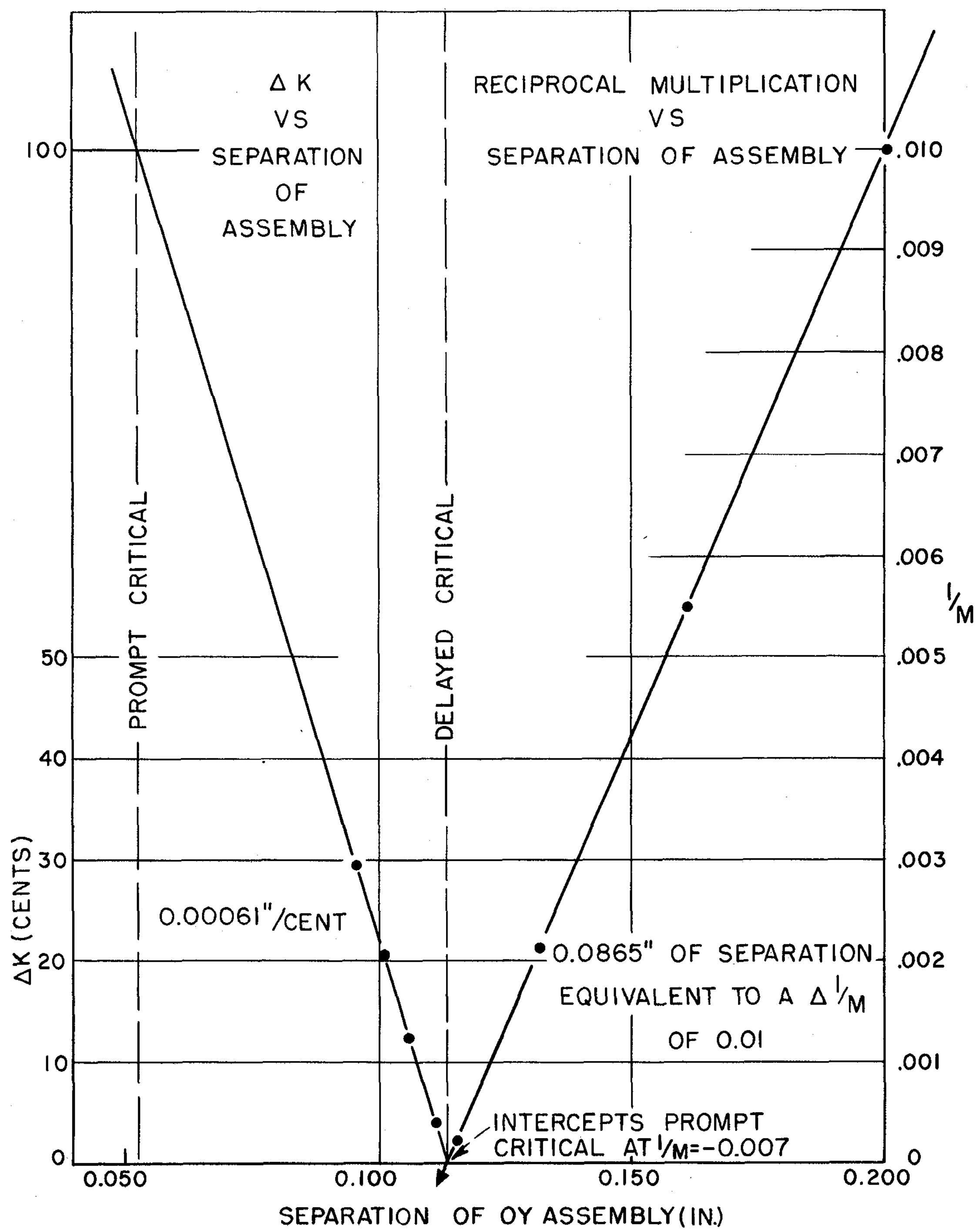
Separation of components at delayed critical	0.1135"
Separation of components at prompt critical	0.0525"
End mass increment equivalent to a $\Delta 1/M$ of 0.01	1.67 kg of Oy
Separation increment of components equivalent to a $\Delta 1/M$ of 0.01	0.0865"
Equivalence between ΔK and separation of components	0.061"/cent

TABLE III. Computed data.

Oy end mass increment between delayed and prompt critical	1.18 kg of Oy
Equivalence between separation increment and mass increment	0.0518"/kg
Maximum rate of change of reactivity	5.6 \$/sec
Closest possible distance of separation 0.0525 - 0.25 x 0.0518	0.0396"
Equivalence between number of fissions and dollars	

$$\frac{1.5 \times 10^{16} \text{ total fissions}}{0.25 \text{ kg end mass } M_c \text{ increase}} \times 1.18 \text{ kg/\$} = 7.1 \times 10^{16} \text{ fis./\$}$$

FIG. 4. Separation of the complete Oy assembly as shown in Fig. 2 as a function of both the reciprocal multiplication of the assembly and ΔK, reactivity change above delayed critical. The separation for prompt critical is shown as $\Delta K = 100$ cents above delayed critical.


Δ K
VS
SEPARATION
OF
ASSEMBLY
RECIPROCAL MULTIPLICATION
VS
SEPARATION OF ASSEMBLY
PROMPT CRITICAL
DELAYED CRITICAL
100
50
40
30
20
10
0
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
1/M
ΔK (CENTS)
0.00061"/CENT
0.0865" OF SEPARATION
EQUIVALENT TO A Δ 1/M
OF 0.01
INTERCEPTS PROMPT
CRITICAL AT 1/M=-0.007
0.050
0.100
0.150
0.200
SEPARATION OF OY ASSEMBLY (IN.)

IV. PROBABLE TIME BEHAVIOR OF POWER LEVEL DURING THE BURST

The 0.3 second required for the scram signal to start the mechanical disassembly is sufficiently long that the mean fission rate, F, during this interval of time is related to the mean assembly rate, dK/dt, by

$$F = \frac{dK}{dt} \cdot \frac{d\int Fdt}{dK}$$

where $\frac{d\int Fdt}{dK} = 7.1 \times 10^{16}$ fissions per dollar (Section III). Since 1.5×10^{16} fissions were produced by the burst, then $F = 1.5 \times 10^{16}/0.3 = 5 \times 10^{16}$ fissions per second, and $dK/dt = 5 \times 10^{16}/7.1 \times 10^{16} \cong 0.7$ dollar per second, a value well under the 5.6 dollars per second corresponding to full lift speed. As long as a positive assembly rate is maintained, the system remains very nearly at prompt critical. If the lift coasted to a stop at some instant within the 0.3 second interval, the reactivity would tend to diminish from prompt to delayed critical in a time comparable to the mean delayed neutron period; i.e., $\sim$ 10 seconds, the relatively low power level during this time being $\sim 7.1 \times 10^{16}/10$, or 7.1×10^{15} fissions per second. Thus, one would expect essentially the same burst size for all cases in which the net travel of the lift beyond the initially prompt critical configuration was $1.5 \times 10^{16}/7.1 \times 10^{16} \cong \$0.21$.

One may suppose that the time behavior during the incident was somewhat as follows: At the instant when the Oy assembly reached prompt critical, the lift was coasting and giving a mechanical assembly rate of $\sim$ 1 or 2 dollars per second. A short (1 millisecond) prompt burst consisting of $\sim 10^{15}$ fissions then occurred (See LA-596 or LA-1441 for details of such a burst) thereby reducing the total reactivity slightly below prompt critical and also starting the scram signal down its long path. The power level now rapidly (several milliseconds) stabilizes at a value of $\sim 10^{17}$ fissions per second; i.e., a value such that the disassembly rate by thermal expansion just equals the mechanical assembly rate. After the lift stops coasting (this final position corresponding to a configuration which would have been $\sim$ \$.21 super prompt critical at the initial temperature), the power level sinks to $\sim 7 \times 10^{15}$ fissions per second. In a time, 0.3 second after the prompt burst, the lift is forcibly dropped thus terminating the reaction.

V. CONSEQUENCES OF BURST

This neutron burst, with the subsequent tests and analysis, along with previous experience of this type, has indicated the feasibility of experiments with controlled self-terminating (by thermal expansion) prompt neutron bursts of predetermined magnitude. Computation of burst characteristics as functions of assembly parameters have been made (LA-1441) and laboratory studies are now in progress on the conduct of such experiments.