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November 9, 1949

This document contains 86 pages

TIME SCALE MEASUREMENTS BY THE ROSSI METHOD

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Weapons Data

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I. INTRODUCTION

The neutron level in a chain reacting assembly near critical either grows or decays promptly as $e^{\alpha t}$, depending on whether the assembly is above or below prompt critical. Apparatus for measuring this α by the Rossi method has been assembled by Group W-2 at Pajarito Canyon with the electronic work done by Group P-1. Specifications submitted to P-1 for the design of the electronic components requested that the apparatus should be as versatile and have as wide a range as possible so that routine measurements of α could be made on all conceivable types of critical assemblies. These specifications were met in every detail. It is possible at the present time to make Rossi measurements on any critical assembly without advance planning by simply switching on the apparatus. The electronic circuits are described in rather complete detail since they are the heart of the apparatus to measure α.

A series of measurements has been made on a tuballoy tamped oralloy* assembly. Measurements have been made previously with low enrichment material and less uniform and complete tampers than the ones used in the present experiments.

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* Oralloy = Oy = Oak Ridge Alloy = Uranium enriched in U-235. The Oy used in these experiments contained approximately 94% U-235.

(LA-374, LA-4"9, LA-1036.) The purpose of the following experiments has been to check out the apparatus on a known assembly in order to discover "bugs" in our apparatus and to gain experience in making such measurements. Great care has been taken to utilize the flexibility of the assembly to keep perturbations to a minimum. Also, the effect of the unavoidable perturbations has been studied.

The experiments discussed here may be justified on the basis that apparatus for making time-scale measurements has been successfully constructed, and that the present measurements deal with a higher concentration of Oy, more complete tamper, and fewer perturbations than existed in previous measurements. As a long time program, the Rossi measurements can supply information that is valuable both from the theoretical and experimental points of view. A value for $d\alpha/dm$ is an indication of the value α may attain when an assembly is highly supercritical. Although measurements of α are made in a region of criticality far removed from the region in question, this is about the best one can do without making a measurement on a nuclear explosion itself. At least one is justified in comparing the effects of varying the tamper materials and core materials in the subcritical region and then extrapolating relative effects to the supercritical. Careful experiments may yield information on

[redacted]

quantities other than α. Other constants involved are: (1) τ_0, the mean life of a neutron in the assembly; (2) χ_2, a measure of the dispersion of the number of neutrons per fission; and (3) K_p, the prompt reproductive factor.

The following report deals with the time scale apparatus and its application to a solid Oy assembly. Discussion of measurements on other types of assemblies will be treated in future reports.

II. APPARATUS

A. Reactor at Pajarito

The present experiments were performed using the tuballoy-tamped, Oy assembly called "Topsy" at Pajarito Canyon. This reactor will be described completely in a future report. Topsy is described below in only enough detail to indicate its function in the Rossi measurements.

An over-all photograph of the reactor is shown in Figure 1. The tamper pseudosphere is on the platform at the right and contains approximately half of the active material. The tamper thickness is equivalent to about $8\frac{1}{2}$ inches, which approaches an effectively infinite thickness. The cart is shown at about the middle of the track which extends under the tamper table. A tuballoy can is mounted on the ram in the center of the cart. The lower half of the active material is stacked in this can. In operation the cart is run under the tamper table and the ram is raised hydraulically to assemble the tamper and active material. These assembly operations are accomplished by remote control from the control room 1200 feet distant. The assembly usually is stacked so that it contains almost one crit when assembled. It is then brought up to critical by insertion of the control rods. For subcritical operation,

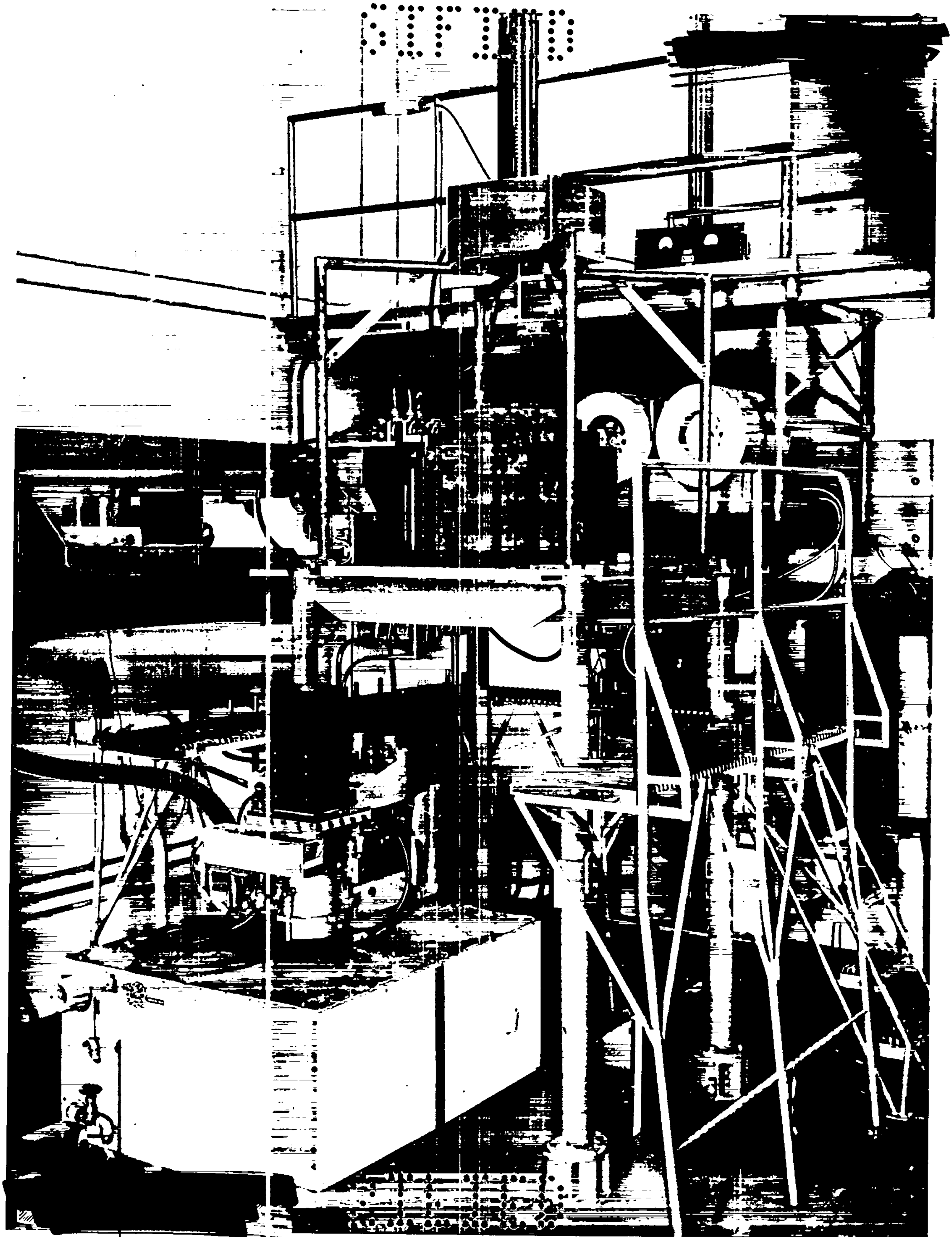

Figure 1

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cubes of Oy one-half inch on a side and weighing about 38 grams, can be removed.

Figure 2 is a phantom view of the assembled tamper and can assembly showing the relative positions of control rods, source tube, and counter tube (glory hole). The stove lid arrangement for supporting the upper pseudohemisphere of Oy is nicely evident in this picture.

Figure 3 is a close-up view of the tamper partially unstacked to show the control rods. The total control rod travel is approximately 10 inches. Control rod position can be read to .001 inch, although the settings are probably not accurate to more than .01 inch.

The assembly has been further unstacked in Figure 4, and the inner can exposed. The $4\frac{1}{2}$ inch 25 stovelid can be seen in place. Approximately half of a pseudosphere of Oy is stacked on the stovelid and the remainder of the can filled with Tu blocks.

In Figure 5 the source jerk mechanism is exposed. With this equipment the source can be removed quickly. The source may also be moved up and down slowly and stopped in any position. Mock fission sources of various strengths were available. These sources were in the form of cylinders 0.40 inches in diameter and 0.45 inches long. Such a source in the source jerk tube could be moved down to within about

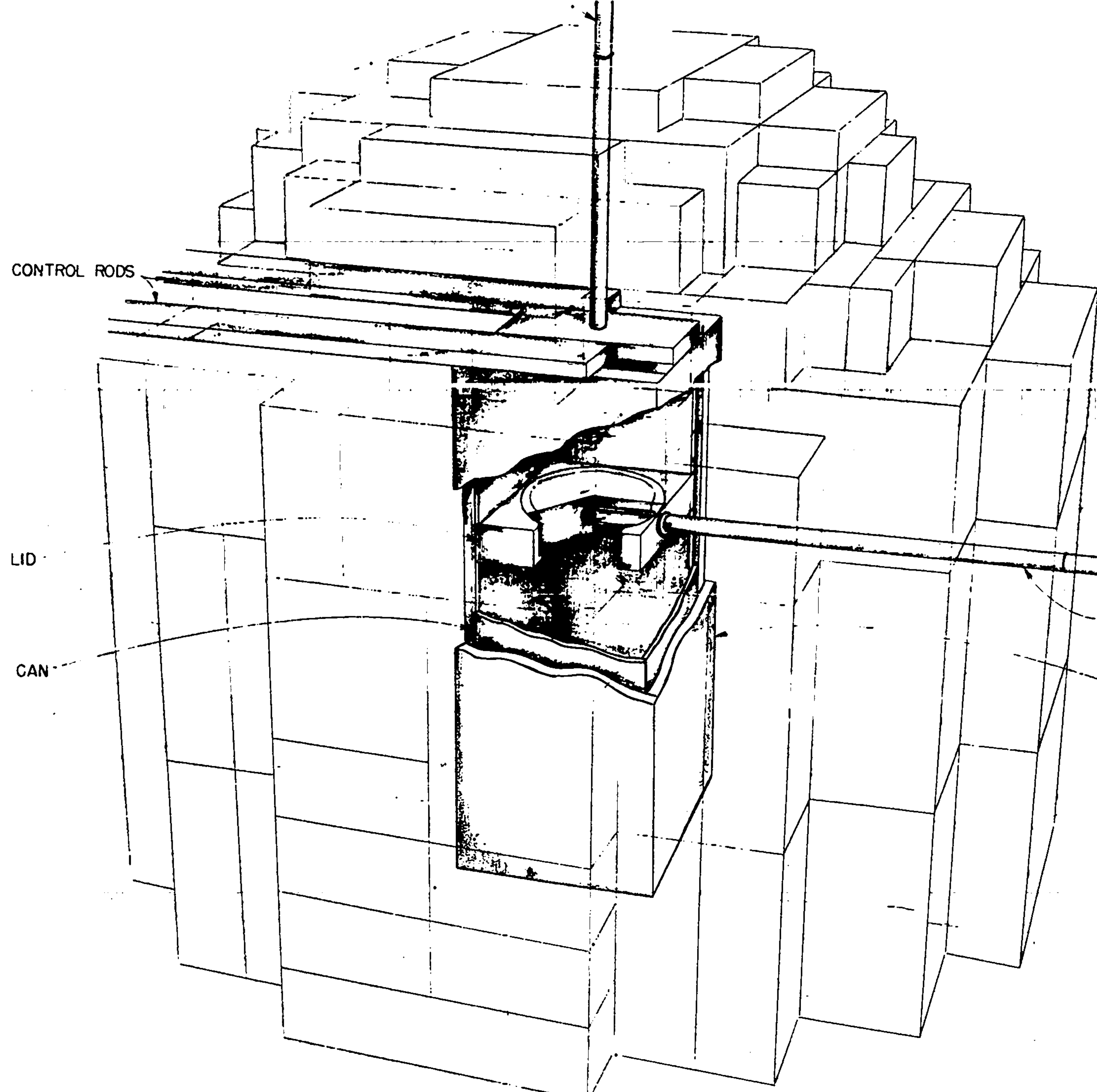

FIG. 8

TAMPER & CAN ASS'Y

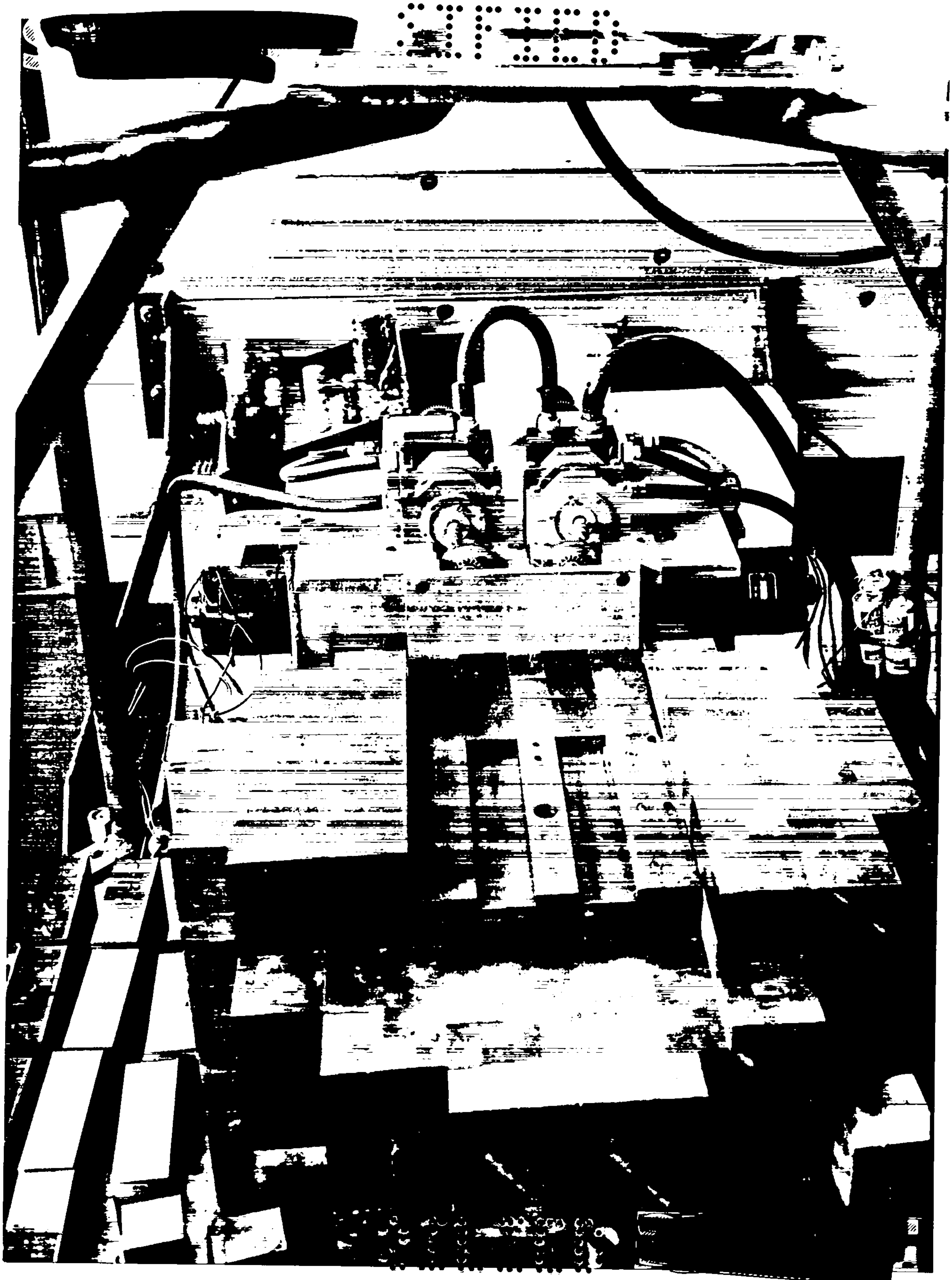

Figure 3

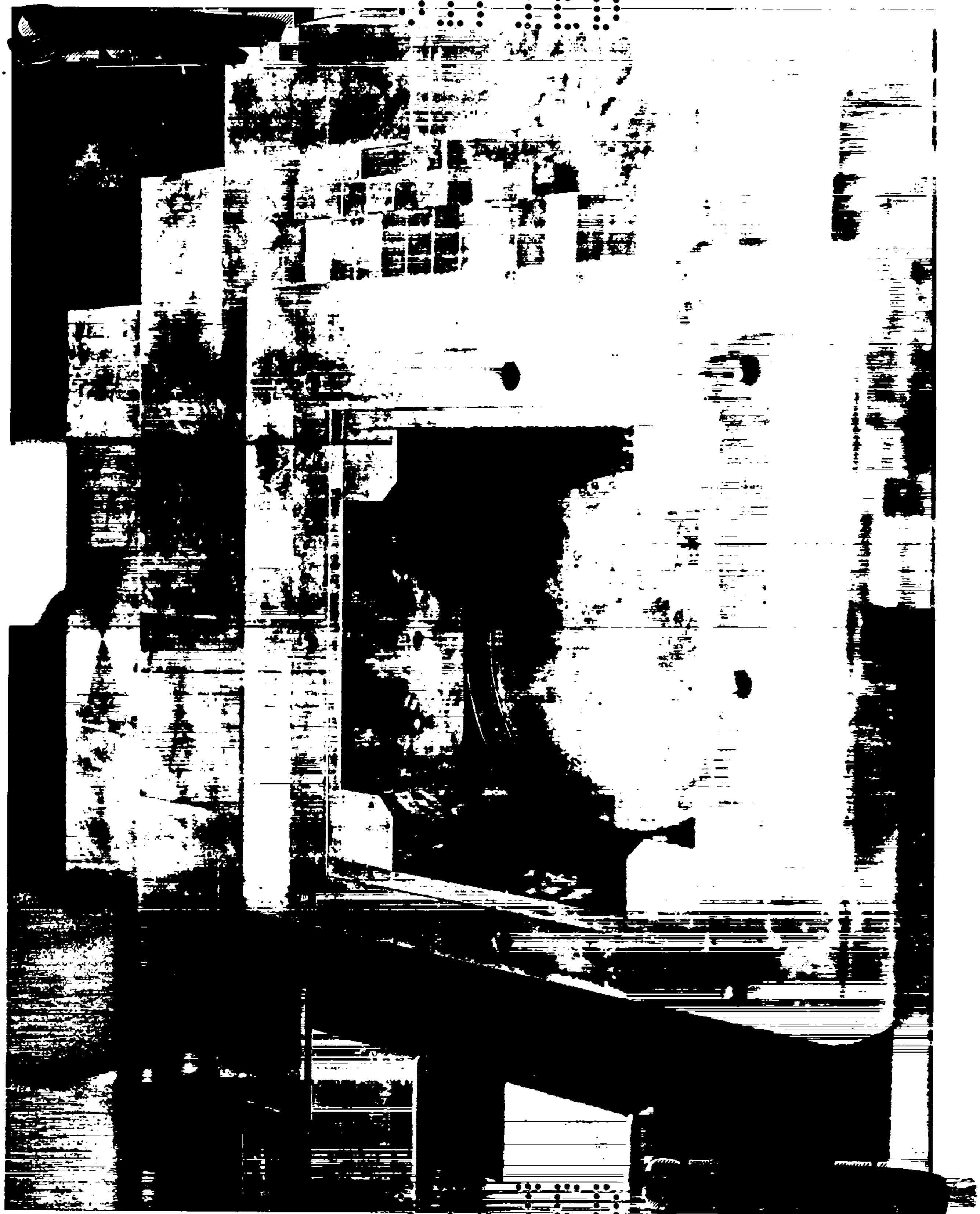

Figure 4

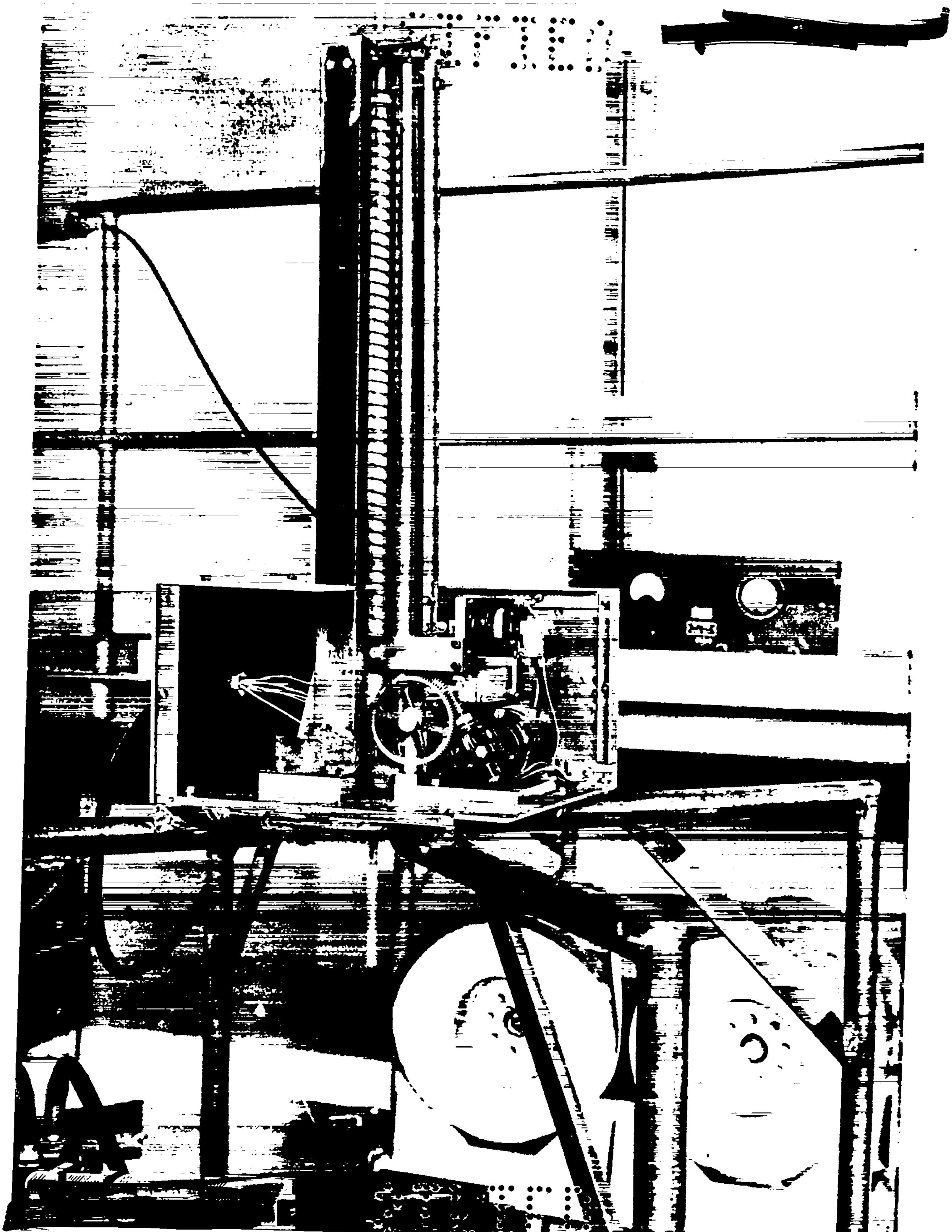

Figure 5

one inch of the active material. In certain of the Rossi runs, it was necessary to stack the source within the active material in order to produce a sufficiently high fission rate. A special $\frac{1}{2}$ inch cube containing a cylindrical cavity to hold the source was available for this purpose.

Either $\frac{1}{2}$ inch or 7/8 inch diameter spiral Oy fission counters (LA-1004) were used for all Rossi measurements. These chambers were constructed by J. C. Hoogterp. The detectors could be placed in the glory hole at any position along the radius of the reactor without introducing too great a perturbation. Figure 6 shows one of the spiral chambers in position in the glory hole and feeding into a modified model 500 preamp. An exploded view of the spiral chamber and tuballoy and Oy parts in the glory hole is given in Figure 7.

Figure 8 is a photograph of the control room instrumentation for remote control operations. The left center section of the console consists of the controls for Topsy. On the right may be seen the five recording meters for indicating reactor level. The three meters on the lower level are connected to the safety trip monitors. The two upper meters record for the logarithmic and linear amplifiers which operate from BF_3 ionization chambers.

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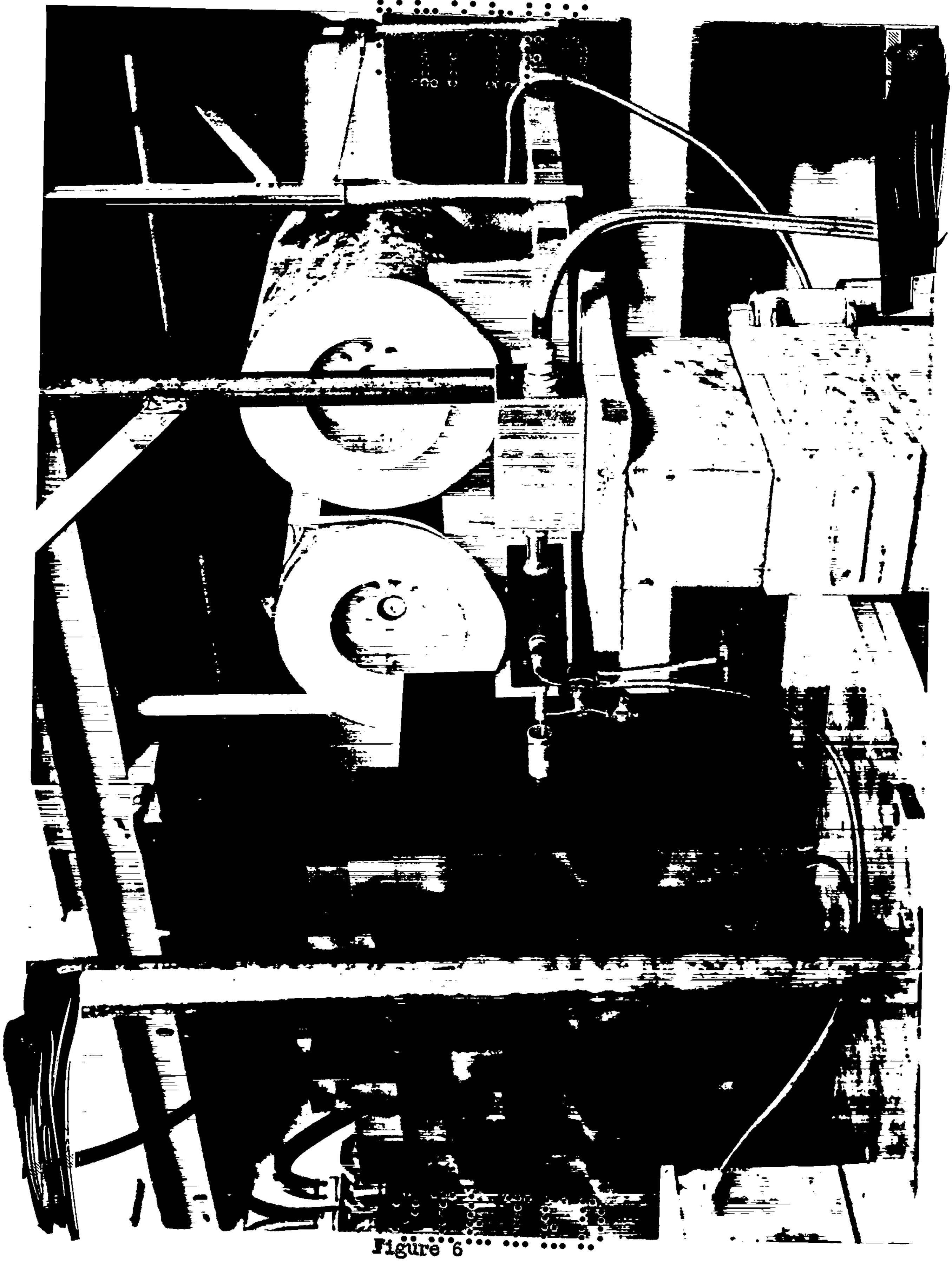

Figure 6

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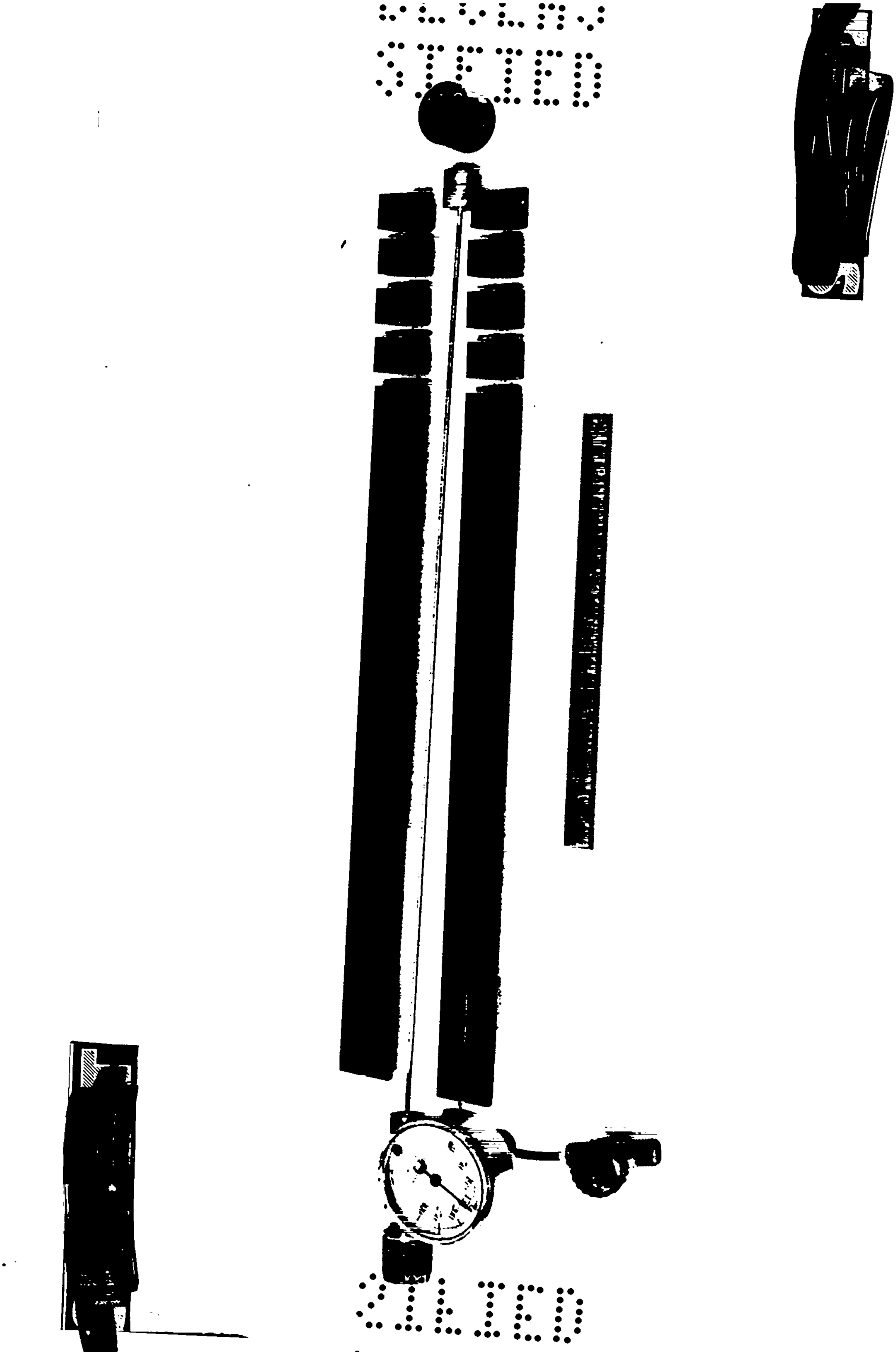

Figure 7

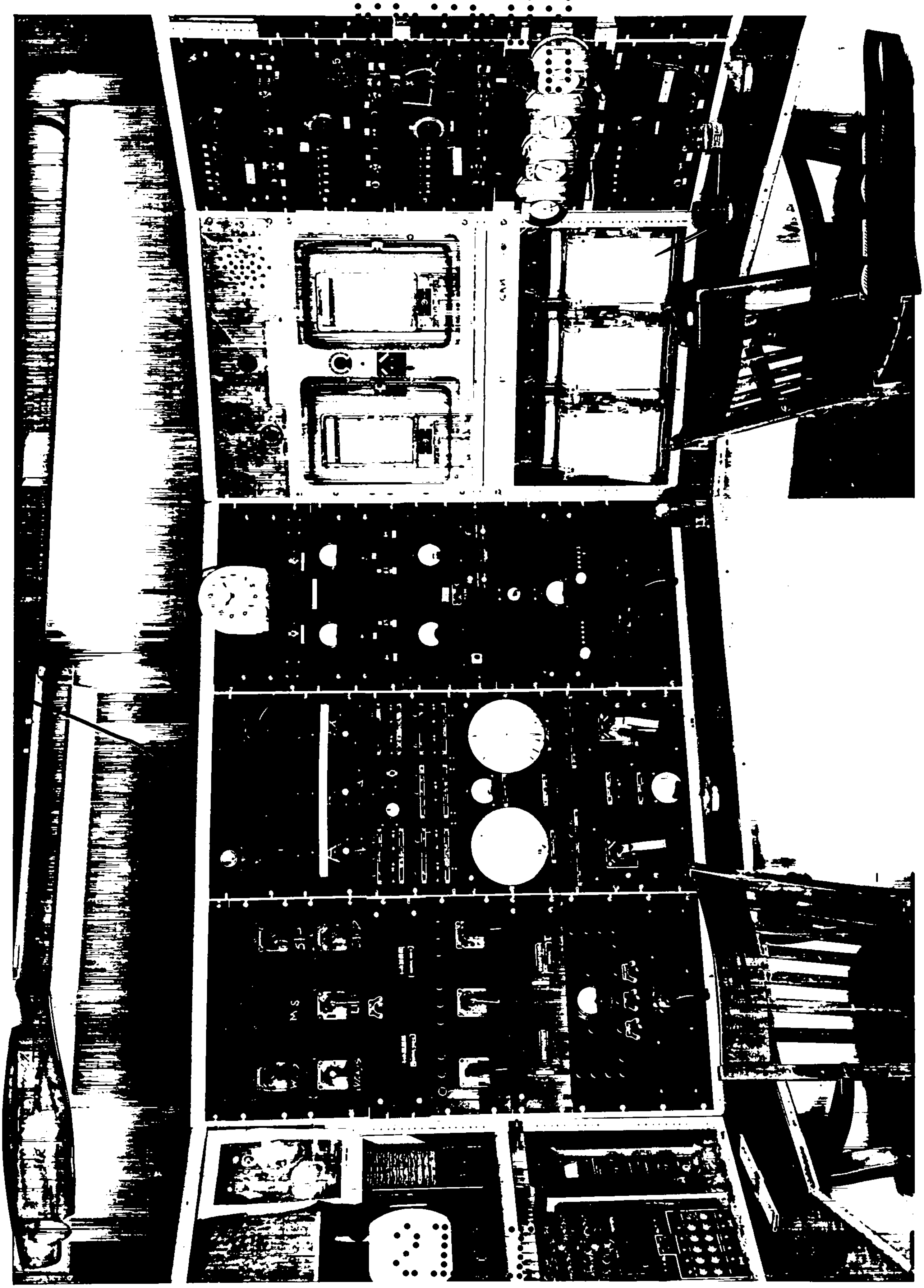

Figure 8

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B. Electronic Equipment

1. Model 200 Time Delay Analyzer

The Model 200 time delay analyzer is actuated by pulses applied to input #1 for double input operation or to input #2 for single input operation. For a predetermined period following each initiating pulse, subsequent pulses applied to input #2 are sorted and recorded as they occur in 10 equal and adjacent time intervals. When a sufficiently large number of initiations have taken place, the number of pulses that have appeared in each of the 10 recording channels will give an indication of the time relationship that exists between initiating and subsequent pulses. In particular, the Model 200 time delay analyzer is intended for use in Rossi time scale experiments as described in LA 1036.

Various individual time intervals or channel widths may be selected as follows:

0.5 μsec.	10. μsec	300 μsec
1.0 "	30 "	1000 "
3.0 "	100 "	3000 "

A periodic gate is provided which may be used to control the initiation circuit. Two successive time intervals or gates are generated independently and continuously. During an "on" interval or A gate open, the initiation will

[redacted]

respond to the first pulse occurring in that interval and to no more than one pulse per A gate. During the "Off" interval or B gate open, the initiating action cannot take place. For each channel width there is a B gate duration which is just sufficient to allow all transients to cease after the opening of the 10 channels. Thus, re-cycling at a maximum safe rate is permitted and errors due to too rapid re-cycling are prevented.

If initiating pulses occur only at relatively long intervals, the action of the periodic gate may not be required and it can be switched out.

The Model 200 time delay analyzer was originally conceived by Edward W. Dexter, who did not remain at Los Alamos to see its completion. P. Glore and one of the writers (C. W. J.) checked the completed unit and made circuit modifications which seemed advisable.

An overall view of the apparatus in the control room can be seen in Figure 9. It includes the time delay analyzer on the right, and associated scalers, power supplies and the delay calibrator on the left. One power supply chassis is behind the console and does not show in the photograph. In Figure 10 a back view of the time delay analyzer rack is shown. Figure 11 is a block diagram showing the continuity of the apparatus as established at Pajarito.

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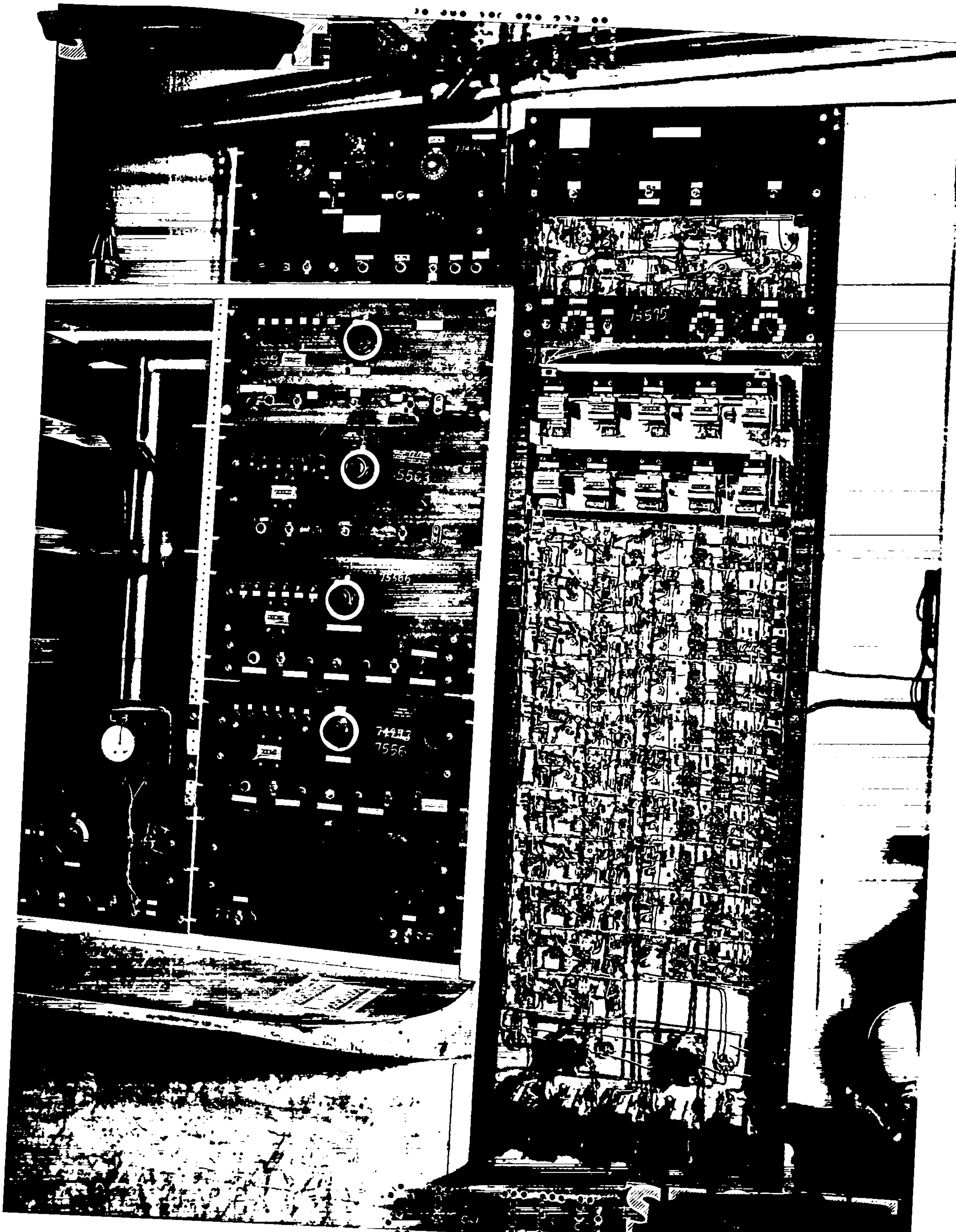

Figure 9

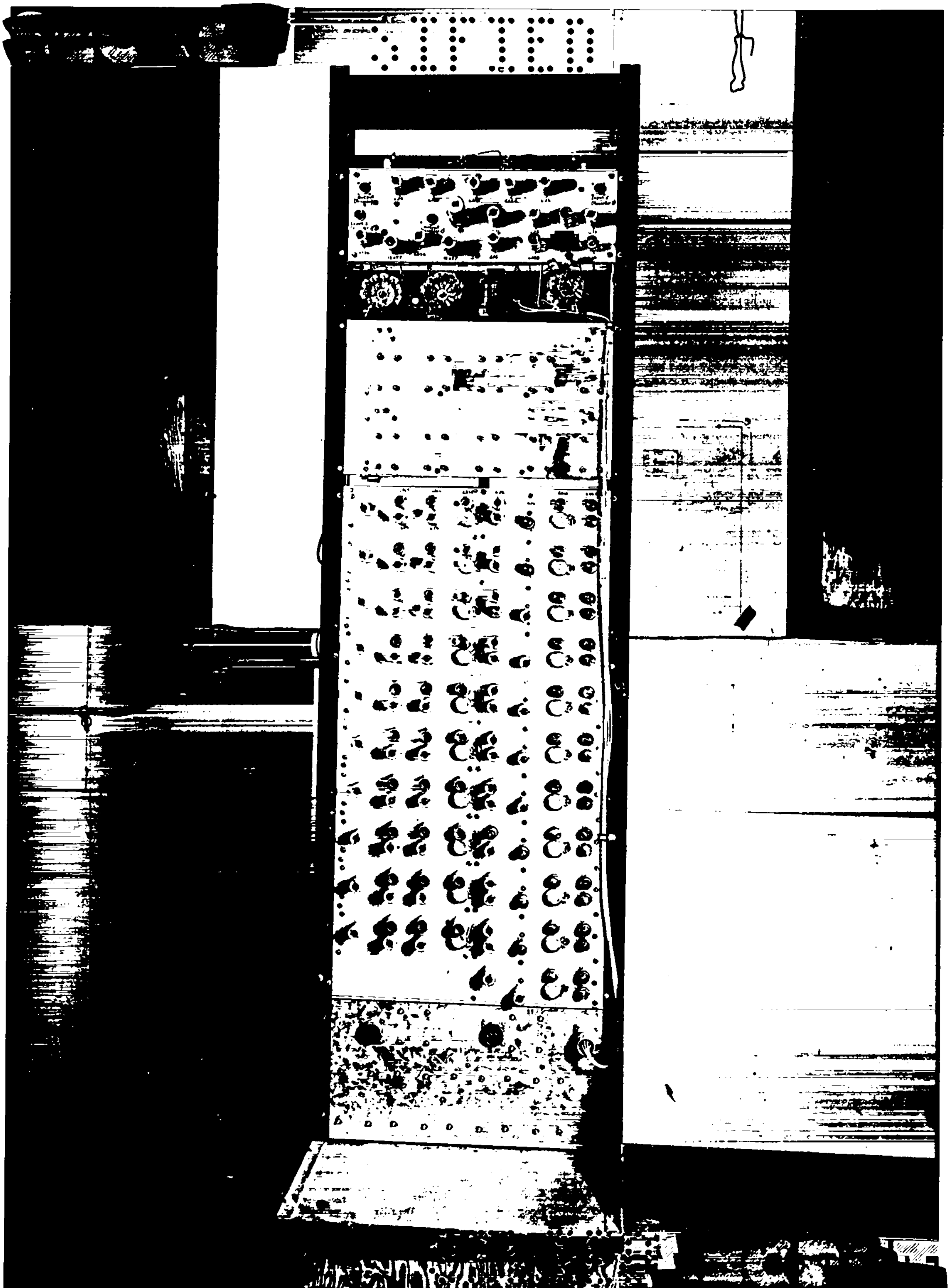

Figure 10

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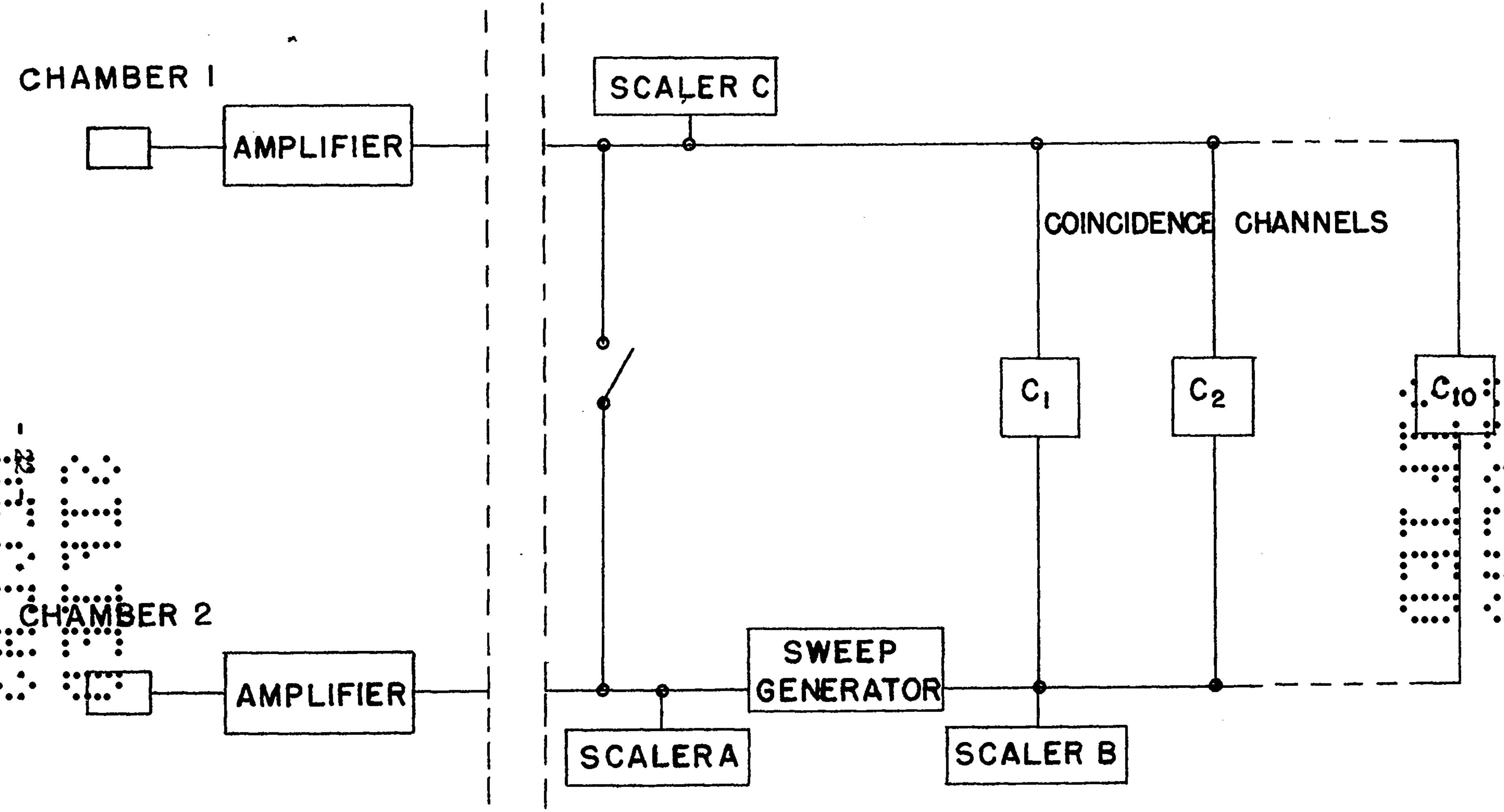

FIG. 11
BLOCK DIAGRAM
10 CHANNEL TIME DELAY ANALYZER

a. Control Circuit

The diagram for the control circuit is shown in Figure 12. Its operation will be discussed in the following six sections.

(1) Initiation-gated. In double input operation, positive pulses applied at input #1 fire blocking oscillator V-101. Positive output pulses obtained from the grid winding of the blocking oscillator transformer are fed to the control grid of V-102, which is a gated amplifier. The periodic gate operates on the suppressor grid of V-102, and the "A" interval of the gate drives the suppressor positive, allowing amplification of the pulse from V-101. During the "B" interval, the suppressor is held negative, preventing the transmission or amplification of pulses.

The first pulse to arrive in coincidence with an "A" gate triggers a "flip flop" V-103 and V-104. The positive jump in voltage at the plate of V-104 triggers blocking oscillator V-106, which in turn starts the sweep which opens the recording channels. This gating process introduces about 0.15 microsecond delay.

V-106 can be triggered only once per "A" gate since the "flip flop" is unresponsive to further pulses until it is reset after the "A" gate ends. The reset pulse comes from differentiating the positive going wave form on the screen of the "B" gate phantastron, V-111, which corresponds

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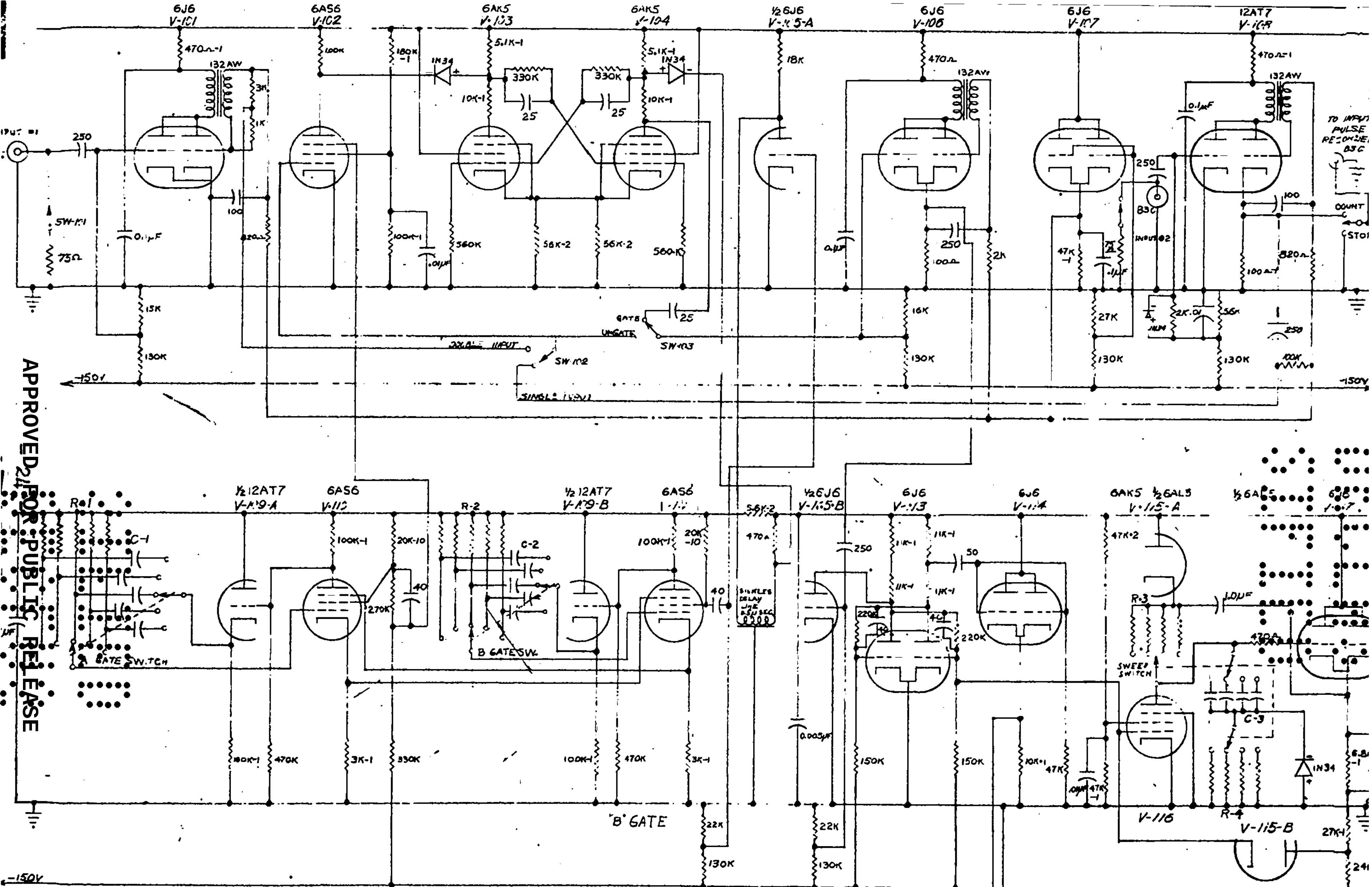

'A' GATE

LENGTH	R-1	C-1
3 μSEC	330K	4-30 μμF
5 " "	680K	4-30 " "
10 " "	1 MEG	4-30 " "
20 " "	3 "	4-30 " "
100 " "	5.1 "	25+(4-30) " "
300 " "	5.1 "	70+(7-45) " "
1000 " "	5.1 "	270+(7-45) " "
3000 " "	5.1 "	1100 μμF APPROX.
10,000 " "	5.1 "	3400 " " "

'B' GATE

LENGTH	R-2	C-2
10 μSEC	330K	4-30 μμF
18 " "	510K	10+(4-30) " "
40 " "	1 MEG	50+(4-30) " "
130 " "	3 "	50+(4-30) " "
360 "	5.1 "	70+(7-45) " "
1200 " "	5.1 "	400 μμF APPROX.
3500 "	5.1 "	1300 " " "
12,000 "	5.1 "	.0045 μF " "
34,000 " "	5.1 "	.0125 μF " "

SWEEP LENGTH

LENGTH	R-3	C-3	R-4	CHANNEL WIDTH
5 μSEC	100K	50+(10-80) μμF	5.1K	0.5 μSEC.
10	220K	50+(10-80) " "	12K	1.0 μ SEC.
30 "	220K	200+(10-80) " "	12K	3.0 " "
100 " "	430K	500+(10-80) " "	24K	10.0 " "
300 "	820K	750+(10-80) " "	47K	30.0 " "
1000 " "	2 MEG	1000 μμF APPROX.	120K	100.0 " "
3000 "	2 "	3000 " " " "	120K	300.0 " "
10,000 "	2 "	.01 μF " "	120K	1000.0 " "
30,000 " "	2 "	.03 " "	120K	3000.0 " "

TO SWEEP RECORDER
83-C

NOTE:
ALL RESISTORS ½ W EXCEPT AS INDICATED
ALL CONDENSERS μμF EXCEPT AS INDICATED

[redacted]

Figure 12

to the end of the "A" gate. This pulse is amplified in V105A and delayed 0.5 microseconds before being applied to the flip-flop. The 0.5 microsecond delay is inserted to make sure the flip-flop will respond to the reset pulse. The initiating pulse may come at the very end of an A gate, and the flip-flop needs nearly 0.5 microsecond after being triggered before it will respond to the reset pulse.

For single input operation, V-101 is not used and blocking oscillator V-108 receives all input pulses, through Input #2. In both double and single input operation, V-108 supplies pulses to be counted in the 10 recording channels but in the latter type of operation, it must provide all initiating pulses as well. By means of SW-102, pulses appearing across the cathode resistor of V-108 are routed to the grid of V-102 to take the place of pulses from V-101.

(2) Initiation Ungated. If gated operation is not required, switching sw-103 to UNGATE causes V-106 to be triggered directly by pulses from either V-101 or V-108, thus bypassing tubes V-102, V-103, and V-104. Ungated operation should be used only when the probability is low for sweeps occuring in too rapid sequence to allow complete recovery.

(3) Periodic gate. The A and B intervals which comprise one complete cycle of the periodic gate are mutually independent and capable of being varied between wide limits.

Two phantastrons (Electronics, April, 1948) are used,

[redacted]

V-110 and V-111. They differ from an elementary phantastron in two respects: (a) Cathode resistors are used and cross coupling is employed between cathodes and suppressor grids. This positively insures that one phantastron is started when the other reaches the end of its cycle, with a minimum of undesirable interaction. (b) Each phantastron uses cathode follower coupling (V-109A and V-109B) between plate and control grid. To establish stable time intervals, a phantastron needs a large plate resistor. This conflicts with the requirement for rapid recharging of the grid condenser at the end of a cycle. The cathode followers supply the recharging current and permit rapid recycling.

Each phantastron will operate at any duty cycle up to about 97% with no appreciable change in period. For example, a 100 microsecond B gate may be used with any A gate from 3 to 3000 μ seconds. By switching grid time constants, gate durations of from 3 to 30,000 microseconds are obtained.

The B + supply for the periodic gate was reduced to about 230 volts because the screen dissipation of a 6AS6 in this circuit reaches its limit with a B + of about 250 volts.

A high impedance attenuator connected between the screen of the A gate phantastron, V-110, and the -150 volt bus, supplies output to the gated amplifier tube V-102, at

[redacted]

the proper voltage level. A "speed-up" condenser is incorporated to drive the suppressor of V-102 sharply at the gate edges.

The B gate durations chosen are sufficient to allow complete recovery of the sweep circuit for particular channel widths.

Tube replacement in the periodic gate circuit may cause a few per cent change in gate duration.

(4) The sweep circuit includes V-105B, V-113, V-115, V-116, and V-117. V-113 is a flip flop triggered in one direction through V-105B. Its negative going grid is connected to the grid of V-116, the sweep clamp tube. When triggering occurs, V-116 is cut off and the plate voltage rises. This rise is coupled to the top of R-3 through cathode follower V-117. A constant current is maintained in R-3, charging C-3 at a constant rate, which generates a linear sawtooth of voltage or sweep. When the sweep reaches sufficient amplitude, feedback occurs through diode, V-115B, thus resetting the flip flop and terminating the sweep.

R-4 is for the purpose of adding a steep step at the beginning of the sweep, and the crystal diode aids in speeding up the discharge of condenser C-3 at the end of a sweep.

The sweep is used to open and close each recording

[redacted]

channel in turn. One channel width corresponds to a 15 volt rise on the sawtooth. Channel 1 is triggered by the initial step at the start of the sawtooth. A portion of the sweep flip flop wave form is differentiated and sent through cathode follower V-114. This provides an output to a scaler to indicate the total number of sweeps.

(5) Input #2. V-106 is a blocking oscillator which responds to positive pulses from Input #2. It will fire on a minimum trigger pulse of 5 or 6 volts but for single input operation it requires more than about 10 volts of trigger to fire twice within 0.5 microsecond. An output connection is provided to permit monitoring the total number of times V-106 fires. The size and shape of the cathode pulse is nearly independent of the size and shape of input trigger. The narrow pulses from the cathode of V-106 are supplied to coincidence tubes in each of the recording channels and with single input operation, a large fraction of these pulses act as initiating pulses as well. If a pulse occurs when any recording channel is open, it should constitute a count in that channel.

Only the top of the output pulse is utilized in any recording channel and the effective width is found to be 0.05 microsecond or less. This blocking oscillator stage serves a very useful purpose since it converts the input

[redacted]

pulses, which are at least several tenths of a microsecond wide and not necessarily of standard shape and size, into uniform very narrow pulses. The need for having narrow pulses for this purpose should be clear if one considers the question of channel overlap with 0.5 microsecond channels, particularly in view of the fact that effective overlap of adjacent channels has been found to vary as much as a factor of 2 between different pairs of adjacent channels.

(6) Bias Tube. V-107 is a cathode follower which supplies bias voltage for the blocking oscillators at a sufficiently low impedance to preclude any interaction among them.

b. Recording Channels

The circuit diagram for the recording channels is shown in Figure 13. Before beginning a detailed study, it should be mentioned that all channels are alike with the following minor exceptions: (a) Channel #1 does not supply a shut-off pulse from its blocking oscillator since no channel exists ahead of it. (b) Channel #11 contains only a discriminator, blocking oscillator and bias tube. It exists for the sole purpose of shutting off channel #10. (c) Odd numbered channels contain a bias tube V-6 which supplies bias to the blocking oscillators in two adjacent channels. (d) Even numbered channels contain a dual shut-off

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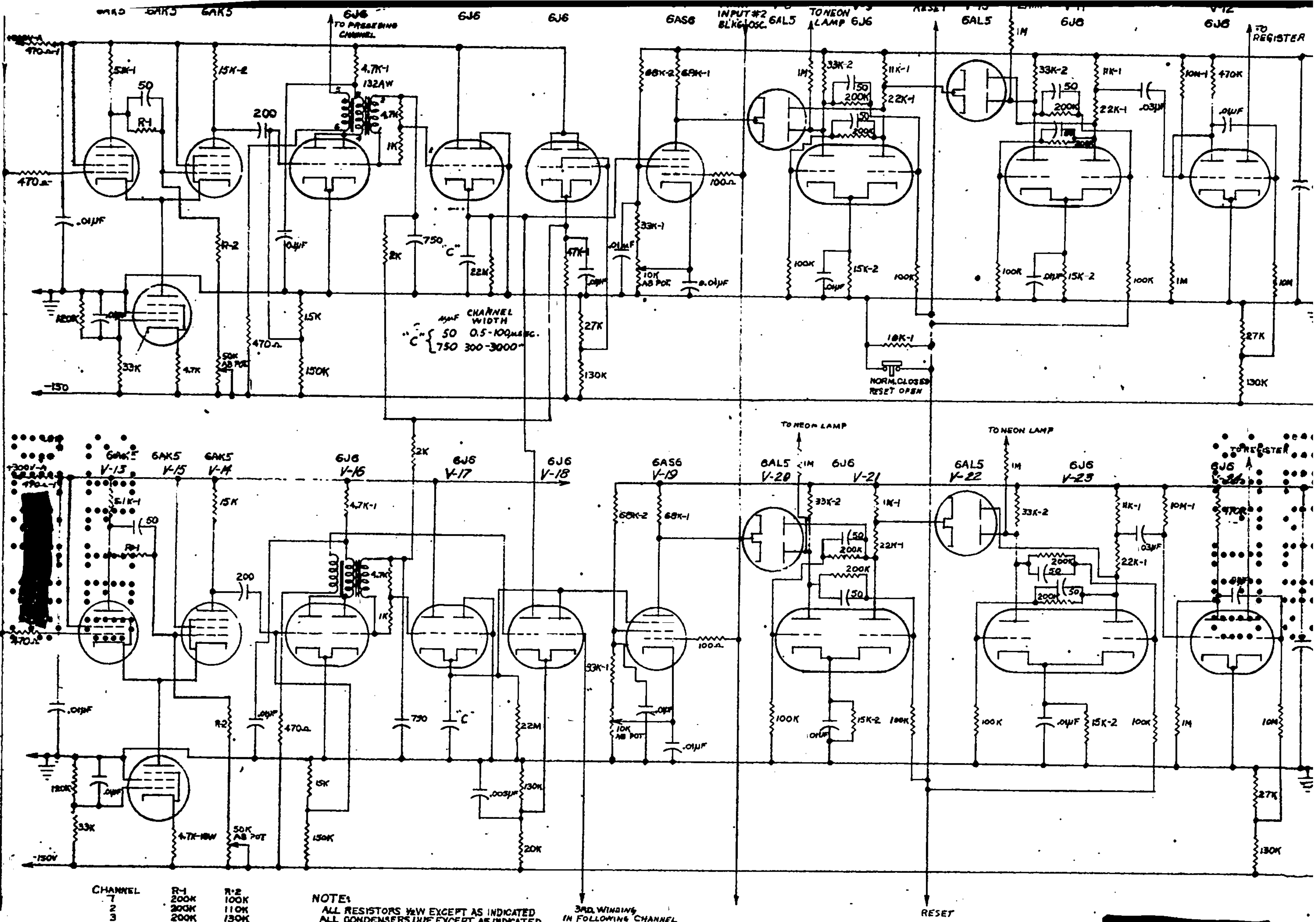

CHANNEL	R-1	R-2
7	200K	100K
2	200K	110K
3	200K	130K
4	200K	150K
5	200K	180K
6	100K	100K
7	100K	110K
8	100K	130K
9	100K	150K
10	100K	180K
11	100K	220K

NOTE:
ALL RESISTORS ½W EXCEPT AS INDICATED
ALL CONDENSERS μμF EXCEPT AS INDICATED

[redacted]

Figure 13

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tube V-18 whose plates connect to coincidence tube suppressor grids in two adjacent channels.

The eleven discriminator circuits fire in sequence, each interval corresponding to a 15 volt rise of the sawtooth. This means that the linear portion of the sawtooth must rise at least 150 volts. With a 15 volt step at the beginning, the overall amplitude needs to be 165 volts. In practice, to allow a factor of safety, the sweep is made longer than this by about one channel width or a total of 180 volts.

The eleven discriminators reset themselves at the end of the sweep with #1 being the last one reset. The firing point of each discriminator is adjusted by an individual potentiometer. With the delay calibrator to be described later, the discriminator settings can all be made in five or ten minutes.

The equipment should be allowed to warm up for about thirty minutes before making final adjustments in the discriminator settings.

The components and action of the 10 recording channels are discussed in the following four sections.

(1) Discriminator and blocking oscillator. V-1, V-2, and V-3 comprise a discriminator. V-3 is a constant current tube. Since V-1 is normally cut off, V-2 carries all the

[redacted]

current until triggering occurs. When triggered, the current is swiftly transferred to V-1 and the positive jump in voltage on the plate of V-2 is differentiated. The resulting trigger causes the blocking oscillator V-4 to fire. Two simultaneous blocking oscillator output pulses are obtained. The third winding, which is at a potential of -150 volts, supplies a shutoff pulse to the previous channel. From the grid winding, which is normally at -15 volts, a steep positive pulse is applied to the grid of a cathode follower V-5A.

(2) Gate forming circuit. Condenser "C" is quickly charged to about 25 volts by the pulse on the grid of V-5A. It will normally remain in this condition until the blocking oscillator in the next channel fires. When this happens, the shutoff pulse applied to the grid of V-18 causes a pulse of current which is sufficient to quickly reduce the charge on "C" to zero. A diode V-5B prevents the potential on "C" from going negative. Thus a small gate is generated which represents the open time of that particular channel.

The value of "C" is not critical, but for the narrowest channel operation a value of 50 mmf was found to give sufficiently steep gate edges. The edges are short compared to 0.1 microsecond. For channel widths of the order of milliseconds it is necessary to increase "C" to prevent too

[redacted]

rapid discharging through the parallel resistor. A value of 750 mmf is a good upper limit. If "C" is larger than this it cannot be charged and discharged reliably.

If there were no tube leakage current, it would not be necessary to shunt "C" with a resistor. Apparently about two-thirds of all stock 6J6's show leakage currents of over 0.5 microamperes, when used in the cathode follower position, V-5. This is the upper limit of allowable leakage in the present circuit. Low leakage current is important, because during long intervals between gates, condenser "C" will charge up. With 22 megohms in shunt, and a leakage current of 0.5 microampers, "C" will charge to $\sim$11 volts which is the tolerable limit, if the coincidence tube cathode is set at $\sim$21 volts. For the greatest channel width of 3000 microseconds a long time constant is needed. 750 mmf and 22 megohms gives 16,500 microseconds which cannot be reduced very much.

It is unfortunate that the circuit requires selected tubes, but there is no easy way to improve the situation. Fortunately, the selected tubes have not changed noticeably after several months use.

(3) Coincidence Tube. The gate is applied to the suppressor grid of V-7, whose cathode should be set at about 20 volts. The control grid is normally at ground potential

[redacted]

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so all plate current is cut off unless a pulse arrives at the grid in coincidence with the gate on the suppressor. In this case an amplified pulse appears at the plate and this acts as a trigger for the scaler which follows.

There is a 100 ohm resistor in series with each coincidence tube grid. The blocking oscillator V-108, feeds all 10 of these grids in parallel. A count-stop switch can break the line which comes from V-108 when it is desired to stop the count.

(4) Scalers. Two conventional scale of 2 circuits are used in each channel using diode trigger tubes. A 6J6 driver tube operates a Mercury type register. To get the actual number of coincidences from any channel the register count should be multiplied by four and the interpolator light indications added.

The scalers in all 10 channels are reset by a single push-button switch.

c. Power Supplies

The following regulated power is required:

+ 300	50 ma.	Top panel
+ 300-A	110 ma.	Discriminators & bias tubes
+ 300-B	135 ma.	Scalers & coincidence tubes
+ 300	50 ma.	Registers
- 150	175 ma.	Total

All the above voltages should come up simultaneously. If the + 300-A supply is not on when the top panel voltages

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are applied, the sweep circuit cathode follower will draw excessive current and the 6.8 K-2W resistor must be replaced.

2. Remote Equipment

For measurements involving the narrowest channels (0.5 microsecond) of the Time Delay Analyzer, a number of stringent requirements must be met. In order that pulses may be counted in the first channel, starting 0.5 microsecond after initiation, all pulses must be effectively shorter than 0.5 microsecond. Overshoot or base line distortion following a pulse must be small to minimize any undesirable influence on the second pulse of a pair. Sufficient gain must be available to obtain pulses of several volts from fission chambers or possibly other types of detectors.

The model 501 amplifier and preamplifier meet the above requirements with minor modifications. A 0.1 microsecond RC clipping time constant was used, 50 mmf and 2000 ohms. The output cathode resistor was effectively reduced from 10,000 ohms to 1000 ohms to prevent lengthening of pulses when working into several feet of coaxial cable (See Figure 14).

A distance of 1200 feet separates the remote equipment from the time delay analyzer. To transmit pulses

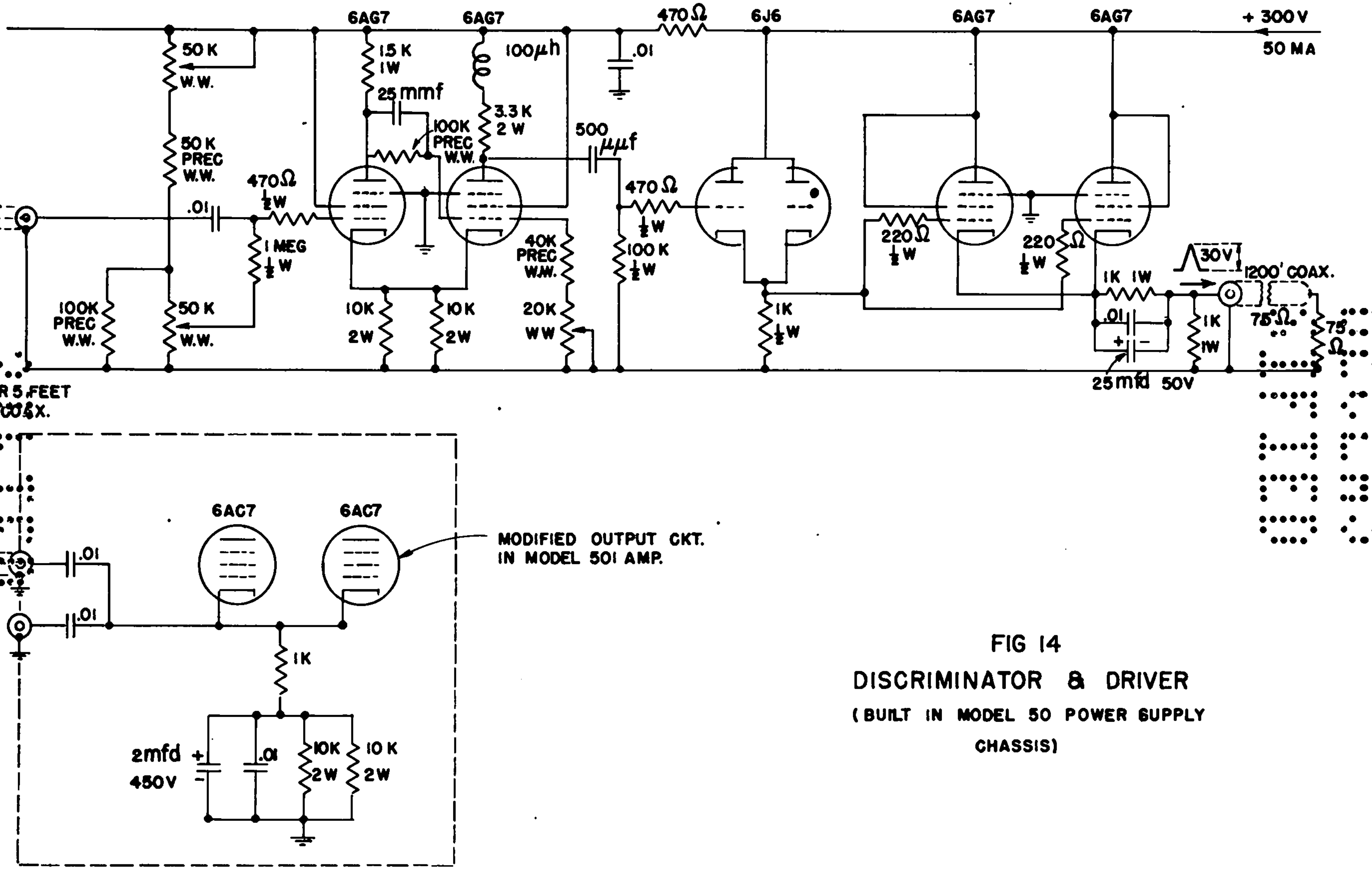

FIG 14

DISCRIMINATOR & DRIVER

(BUILT IN MODEL 50 POWER SUPPLY CHASSIS)

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over this distance, 75 ohm coaxial cable is used terminated in 75 ohms. It was found best to locate a discriminator at the remote or transmitting end so that pulses sent down the cable are all the same size. At the receiving end of the line all pulses are approximately 20 volts in amplitude and between 0.25 and 0.4 microseconds wide, depending on the amplitude of the original pulse. If the discriminator (Figure 14) has a recovery time which is short compared to 0.5 microsecond, two pulses 0.5 microseconds apart will have equal probability of tripping the discriminator.

3. Modified Model 200 Scaler

In order to provide accurate counting of pulses as close as 0.5 microsecond apart occuring in pairs, it was decided to improve the resolving time of an existing scaler. The model 200 scaler normally has a resolving time of 5 to 7 microseconds. A new plug-in scaler unit was designed which uses two 6SN7's and has a resolving time of 0.4 to 0.5 microsecond. The model 200 scaler was adapted to use 2 of these fast scaler units, thus providing a fast scale of 4 ahead of the remaining standard stages.

The fast scaler uses cathode follower coupling between the two halves of an otherwise conventional scale of 2 circuit. The cathode followers serve to remove some of the

[redacted]

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capacitive load from the scaler plates, and greatly reduce the impedance through which the scaler grids are driven.

The modification resulted in increased power requirements. The B+ supply in the Model 200 scaler is adequate, but a larger filament transformer was substituted. The circuit diagram as modified is shown in Figure 15.

The discriminator was modified to supply a narrower trigger pulse. This caused a decrease in "sharpness" of pulse amplitude discrimination which is not serious, since all input pulses are practically the same amplitude, having come through the discriminator at the input end of the 1200 foot coaxial line, also a blocking oscillator in the Time Delay Analyzer.

For high counting rates it was necessary to connect a second Model 200 scaler in series with the modified model giving an overall scaling factor of 4096. The register driver tube was removed from the first unit and a connection made from the last scale of two to the input of the second unit.

Two standard Model 200 scalers were likewise connected in series to record the number of sweeps from the Time Delay Analyzer. The fastest sweep can occur no oftener than every 10 microseconds so the standard scaler is adequate.

[redacted]

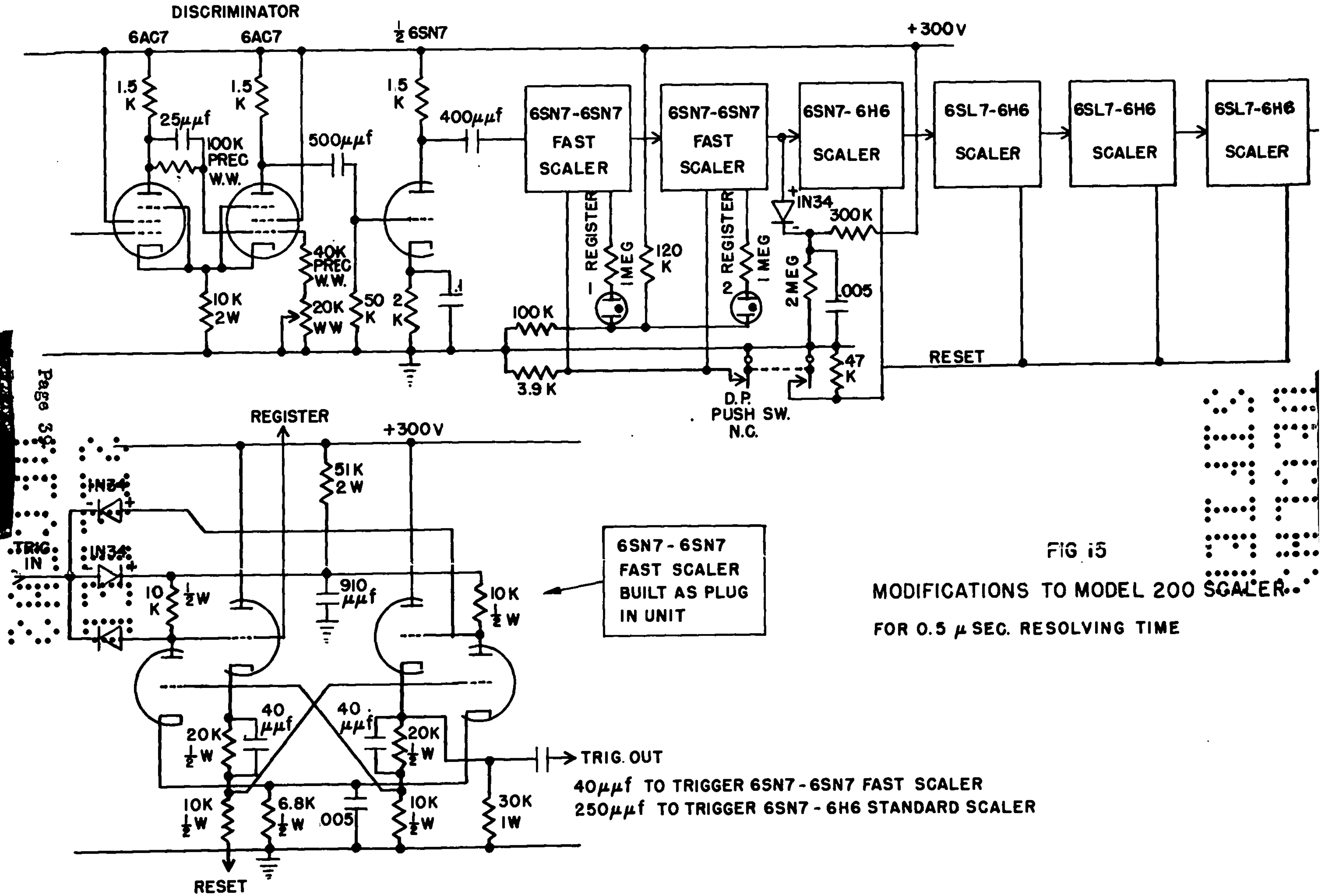

FIG 15

MODIFICATIONS TO MODEL 200 SCALER

FOR 0.5 μ SEC. RESOLVING TIME

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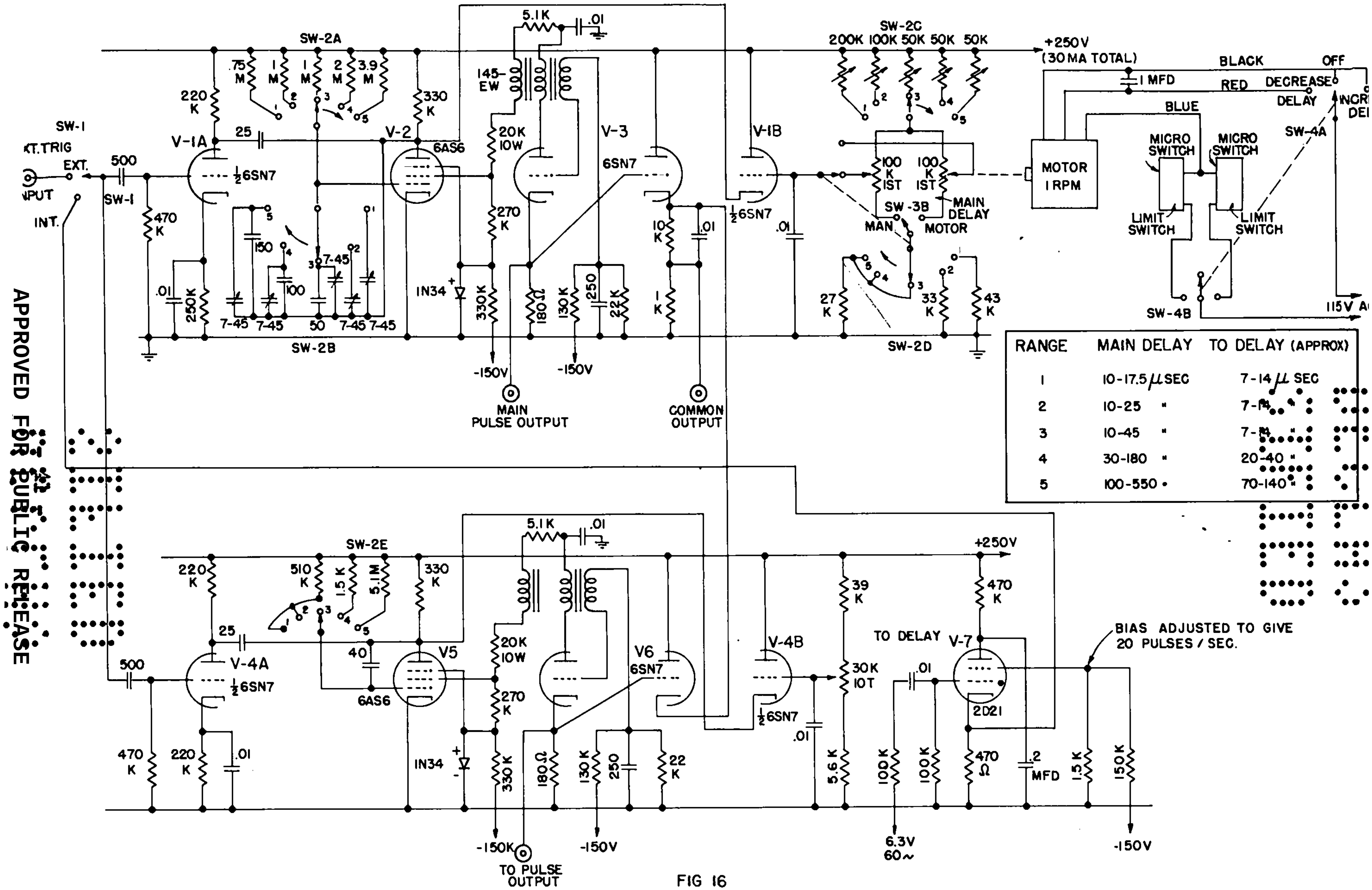
4. Delay Calibrator

The circuit diagram of the delay calibrator is shown in Figure 16. This calibrator produces two pulses independently delayed and available either at separate outputs or mixed on a common output. This permits calibration for either double or single channel operation.

The two delayed pulses are controlled by phantastrons, using 6AS6 tubes. When triggered, the plate voltage of a phantastron falls linearly with time until in this circuit it is stopped by the conduction of a triode whose cathode is connected to the plate of the phantastron. The grid voltage of the triode which determines the stopping point and thus the delay produced by the phantastron is variable over a wide range. When the phantastron plate is stopped, the resulting sudden change in screen current triggers a blocking oscillator.

The two delay circuits are triggered simultaneously, either from an external source or by means of a built-in relaxation oscillator which is synchronized with the 60 cycle line frequency to deliver 20 pulses/second.

Several ranges of delay are provided to permit accurate calibration of channel widths from 0.5 to 30 microseconds. When the calibrator is properly adjusted, by comparing it



RANGE	MAIN DELAY	TO DELAY (APPROX)
1	10-17.5 μSEC	7-14 μ SEC
2	10-25 "	7-14 "
3	10-45 "	7-14 "
4	30-180 "	20-40 "
5	100-550 "	70-140 "

FIG 16
DELAY CALIBRATOR
FOR
MODEL 200 TIME DELAY ANALYZER

with a frequency standard and set to the appropriate delay range, one revolution of the 15 turn Helipot dial corresponds to one channel width.

Normally the "T_0" pulse acts to initiate the action of the Time Delay Analyzer and the "main" pulse is used for calibrating purposes. When both pulses are fed into Input #2 from the common output, and the Time Delay Analyzer set for single channel operation, whichever pulse occurs first will act as the initiating pulse and if the second pulse is appropriately delayed it will appear and be counted in one of the channels. Since there is considerable overlap between the ranges of delay of the two pulses, it is possible to determine the interval between initiation and the start of channel #1. This is done by moving the "main" pulse on either side of the T_0 pulse and noting the time difference between the two points where channel #1 just starts to count. One half of this time difference represents the delay in the start of channel #1.

A motor drive is provided for the "main" pulse. This is necessary for calibration of the narrowest channels in view of the fact that the 0.5 microsecond channels overlap by amounts varying between 5% and 10%, thereby increasing their effective widths. When the calibrator is switched to motor drive, the "main" pulse can be made to move at a rate which corresponds to one nominal channel width per minute, thus taking 10 minutes to move through all ten channels. This is done using the internal pulse generator which supplies 1200 pulses per minute synchronized with the power line frequency. After a complete 10 minute run through all channels, the number of pulses in excess of 1200 in each channel gives a measure of the effective channel widths, including overlap. The motor drive is reversible and provided with limit switches. Accuracy of the calibrator has been shown to be within 1 to 2% over periods of several months.

Due to switch position limitations, the calibrator is not capable of calibrating channels wider than 30 microseconds. It was intended to be used only for narrow channels. To calibrate the wider channels, the same circuit is applicable with larger time constants associated with the phantastrons. The motor drive feature is not necessary for channels wider than 30 microseconds, since these will overlap considerably less than 1%.

[redacted]

III THEORY

A. Fluctuations

It has been observed that fluctuations exist in a near critical reactor that distinguish this type of source from the usual random source. These fluctuations may be explained on the basis that a single neutron in the assembly may initiate a long chain, so that for a short time interval, the reactor may act as though it were supercritical. Since in reality the assembly is subcritical, every chain must be finite and eventually decay as

$$N = N_o \; e^{\alpha t}, \qquad (1)$$

where the α in this case is negative. If one observes the reactor on a time scale that is of the order of $1/\alpha$, these fluctuations may be observed and measured. The decay time $(1/\alpha)$ for chains in the observable region of criticality is short compared to the shortest delay neutron period even for a reactor as slow as the water boiler, so that delay neutrons play no part in α observations except in-as-much-as they may serve to initiate long chains. At prompt critical on the average a neutron chain lasts forever when fed by prompt neutrons alone, so that α equals zero. Actually at prompt critical the level rises rapidly because of the increasing source due to delay neutrons. If one introduces a strong source into a reactor, and then suddenly removes such a source and watches the prompt decay of the assembly, he is making a direct measurement of the decay constant α. A more subtle measurement suggested by Rossi and referred to as the Rossi Method makes use of the smaller order fluctuations resulting from chains initiated by single neutrons. The Rossi Method then instead of measuring the average behavior due to a large number of chains observes individual chains and then averages after data is accumulated for a great number of processes.

The value of α depends upon (1) K_p -criticality and (2) τ_o -mean life of a neutron in the assembly. The criticality determines the average length of chains and τ_o determines the average time between fissions in a chain. It can be shown that

$$\alpha = \frac{K_p - 1}{\tau_o} . \qquad \underline{2}$$

B. Rossi Method

The development of the theory for the Rossi experiment has been published elsewhere (Feynman, LA-591, and Frisch, LA-1033), and so only the consequences of this development will be considered below.

The following equation is approximately correct for any chain reactor near critical. Since α measurements are

[redacted]

made near critical, equation 3 may be considered valid:

$$P(t)dt = Cdt + \frac{E\chi_2}{2\nu^2 \tau_0 (1-K_p)} e^{\frac{K_p - 1}{\tau_0} t} dt \qquad \underline{3}$$

where C = chamber counting rate

E = chamber efficiency in counts/fission

χ_2 = twice the average number of pairs of neutrons per fission (second moment)

ν = average number of neutrons/fission

τ_0 = mean life of a neutron in the assembly

K_p = prompt multiplication factor

This is an equation for the statistics of counts from neutrons originating in a chain reactor. $P(t)dt$ is the probability for a count at time t within an interval of time dt following a count at $t = 0$. This equation indicates that fluctuations exist in a chain reactor that do not exist in a random source. The second term on the right of equation 3 is a measure of these fluctuations. The probabilities for a random source would be simply

$$P(t)dt = Cdt \qquad \underline{4}$$

where the probability of a count at time t in an interval dt following a count at $t = 0$ depends only on the counting rate and the width of the time interval. From the definition of a "random source" we know that this probability should

[redacted]

be independent of the time t. For a reactor far from critical, the exponential term approaches zero because of a large negative α and the statistics become those of a random source. The interesting term from our point of view is the second term on the right in equation 3. The value of this term may be obtained by measuring probabilities for coincidences from pairs of neutrons and subtracting a background term (Cdt) due to accidental coincidences, i.e. coincidences between neutrons not in the same chain. The ten channel time discriminator previously described is able to measure P(t) dt for all types of near-critical assemblies.

The measurement of α is quite straightforward. A plot of P(t)dt - Cdt on semi-log paper gives a straight line whose slope is α . The intercept of this straight line at t = 0 in addition gives a value for

$$\frac{E\chi_2 \, dt}{2\nu^2 \tau_0 (1-K_p)} .$$

This quantity is of no value unless some of the quantities appearing in it can be determined independently. The average number of neutrons per fission is of course quite well known for both U-235 and Pu. Some discussion of the

[redacted]

other constants and methods for their measurement is in order.

1. Determination of E

The determination of the efficiency, E, of the counter in counts per fission is more direct than any of the other constants although the precision with which E can be found is questionable.

One approach is to measure the total fission rate F of the reactor. Then knowing the input counting rate C, the efficiency is C/F. F can be measured by two general methods:

(a) A direct measurement of the fission rate at some point in the reactor plus a measurement of the fission rate distribution across the core.

(b) A central source multiplication experiment.

The fission rate at a point in the reactor can be measured by the foil-fission catcher technique or by the use of a fission chamber containing a known "effective" amount of U-235. Using the measured fission rate at some r, the overall fission rate may be found by an integration or a summation over the core using the fission rate distribution curve. In either of these methods some calibration experiment is necessary in order to measure absolute fission rates. The most convenient calibration method is to compare the catcher activities and the Oy chamber counts with the counts from a standard Oy chamber in any arbitrary flux. The standard Oy chamber is a parallel plate fission chamber containing a known quantity of U-235 which will count 100% of the fissions occuring in its U-235. Such chambers can be constructed. One then has a detector which will measure absolute fission rates. The accuracy of the calibration depends primarily on how well the amount of material in the standard chamber is known. A small spiral fission chamber calibrated in this manner makes a convenient probe to measure fission rate distributions throughout an assembly without introducing serious perturbations.

The second method for determining the efficiency of a detector consists of determining the fission rate in a reactor by means of a multiplication experiment. The net or leakage multiplication is defined in LA-335 as

$$M = 1 + Q_f (\nu - 1 - \alpha) \qquad \underline{5}$$

where the introduction of one neutron results in the production of Q_f fissions. For a fast reactor the value of α, the ratio of non fission capture to fission capture, is small and can be neglected. The overall fission rate can be written as

$$F = S.Q_f \qquad \underline{6}$$

[redacted]

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where S is the source strength. There are two main sources of error in this measurement: (a) the source is not a true fission source, and (b) the source strength, S, is not known accurately. The error due to (a) can be minimized by making the multiplication measurements with a long counter geometry which has essentially a uniform response to neutrons of all energies involved.

2. Determination of χ_2

Considerable work has been done on establishing a value for the dispersion of the number of neutrons per fission, χ_2, since the probability for predetonation of a bomb depends directly on its value. χ_2 is defined by

$$\chi_2 = \sum_{\nu=1}^{\nu=\infty} \nu(\nu-1)P_\nu \qquad \underline{7}$$

where ν is the number of neutrons per fission and P_ν is the probability for the emission of ν neutrons. The quantity which we usually call ν is actually $\bar{\nu}$, the average number of neutrons per fission. Measurements of χ_2 have been made by DeHoffman (LA-101, LA-183, LA-183A) who studied fluctuations in the water boiler, and by de Benedetti (MonP-437) who used coincidence counting to get fission neutron angular correlation which was used to calculate χ_2.

[redacted]

Determinations of χ_2 have agreed on a value slightly higher than 4 for U-235. A value of 4 would mean 2 neutrons per fission 50% of the time and 3 neutrons per fission 50% of the time. The value 4 is not outside the range of error in the experiments. The value of χ_2 is probably known to about 20%.

3. Determination of τ_o

Very little can be said about a direct experimental determination of τ_o. If α can be measured by the Rossi Method and K_p for the assembly can be assigned, then τ_o follows. Other than this possibility the theoretical estimates of τ_o must be used. They should be fairly accurate for an all-metal spherical assembly.

4. Determination of K_p

The value of the reactivity constant for a chain reactor is probably the most abstract of all the constants. There are no good methods for an absolute measurement of K. Any reactor can be accurately set at $K = 1$, but any δK from this value is difficult to determine. For a slow reactor an absolute measurement of K has been made by the "boron bubble" method. (LA-1033). Other relative measurements can be made by introducing sudden changes in reactivity

[redacted]

(control rod jerk), by introducing sudden changes in level (source jerk) and by positive period measurements (LA-1033). All of these measurements give K in terms of γ or γf, where γ is the relative effectiveness of delayed neutrons for producing fission in the assembly compared to the prompt neutrons and f is the fraction of neutrons which are delayed. These quantities are not readily measurable nor accurately known.

Two new schemes have been conceived: (a) An active material interchange method for an absolute measurement of K, and (b) A modulated source method of determining δ K in terms of γ_f. These methods appear to have some merit and are discussed below.

(a) Determination of K by an active material interchange method. This method is based upon being able to replace an element Δ m of Oy with a special Pu element which differs from the Oy only in ν, the number of neutrons per fission. This means that the Pu element will contain a fewer number of atoms than the Oy element as determined by their relative cross sections for the neutron spectrum existing. One wishes the total fissions in the Pu to be the same as in the replaced element of Oy for equal reactor level. When the number of atoms in the special Pu piece is adjusted in this fashion, one can assume

[redacted]

that scattering and non-fission processes are closely enough the same for the two pieces that their effects can be neglected when the Pu and Oy pieces are interchanged.

If a cube of Oy be replaced by a cube of Pu as specified above, essentially all that happens is that the average ν for the assembly has been changed. This change will be given approximately by

$$\Delta \nu = (\nu_{49} - \nu_{25}) \frac{\Delta m}{m} \qquad \underline{8}$$

that is, it is the difference in ν between Pu and Oy multiplied by the fraction of the assembly in which the change takes place. Either the change must be effected in an "average" position in the assembly or several changes should be made, distributed properly over the assembly.

Near critical one can say that

$$\frac{\nu}{\nu_{cr}} \doteq K$$

where ν_{cr} is the number of neutrons per fission that would be necessary to make the assembly just critical. Then

$$\Delta K = \frac{\Delta \nu}{\nu_{cr}} = \frac{\nu_{49} - \nu_{25}}{\nu_{cr}} \frac{\Delta m}{m} \qquad \underline{9}$$

The experiment is performed in the following way. Replace a cube of Oy with Pu. Run the assembly just up to

[redacted]

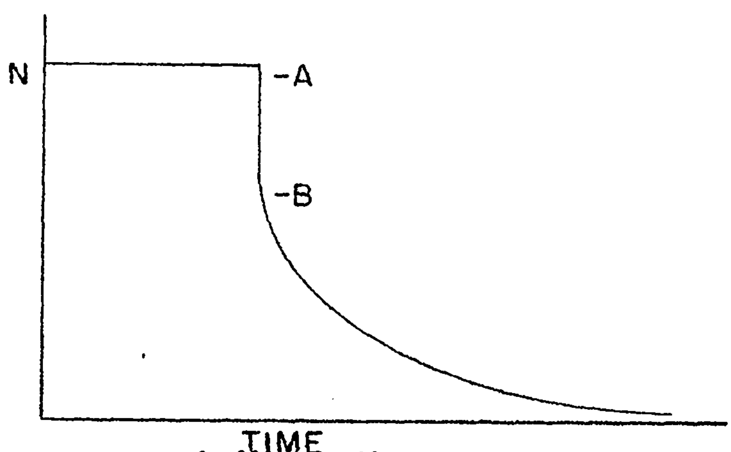
critical, when

$$\gamma_{cr} = \gamma = \gamma_{25} + (\gamma_{49} - \gamma_{25}) \frac{\Delta m}{m} \qquad \underline{10}$$

Then replace Pu with Cy and run the control rods to the same position as before when the assembly will be subcritical by an amount given by 2. Move the control rod until the assembly is just critical again. This then gives a motion of the control rods equivalent to a known Δ K.

The above experiment is an elaborate and rather touchy one. Performing this experiment can only be justified by the fact there exists no known better method for a direct measurement of K.

(b) An intermittent source method of determining δ K in terms of γ f. The conventional source jerk experiment provides a simple means for measuring δ K in terms of γ f. Unfortunately, experimental difficulties have not permitted accurate measurements by this method. The curve below shows the reactor variation during a source jerk.



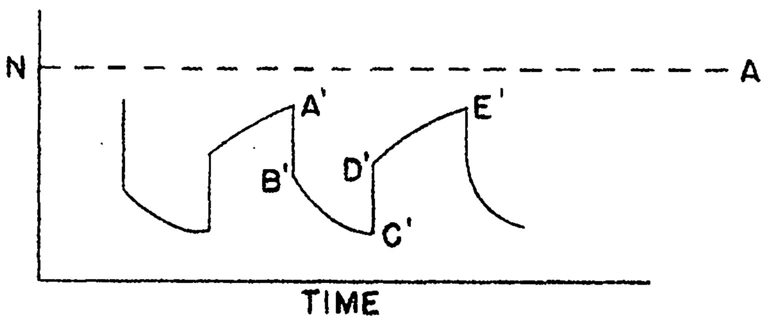
[redacted]

The source is suddenly removed at A. Then the following equation holds near critical:

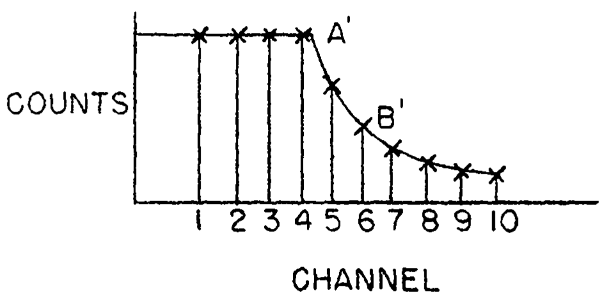
$$\frac{\delta \; K}{K \gamma f} = \frac{A-B}{B} \quad . \qquad \underline{11}$$

Experimentally it is very difficult to determine the breakaway point B with any accuracy because of the short delay neutron periods.

It is proposed that a source in the center of the assembly be suddenly turned on for say one second, turned off suddenly for one second, and this 2 second cycle repeated continuously. This can be accomplished either by means of a special modulated source or by a mechanical motion of the source. Possibly a much shorter cycle can be accomplished. The figure below shows the effect on the reactor of such a source.



Level A is the static level the reactor will attain if the source is left in continuously. A'B'C'D'E' constitutes one complete cycle for the source. The value of $A'-B' = D'-C' = A-B$ where A-B refers to the jump shown in the previous figure of the conventional source jerk. This jump in all cases is due to the prompt multiplication of the source. It is planned then to scan the region A'B' or C'D' with a 10 channel time discriminator which is synchronized mechanically with the source. A plot of the data obtained with this instrument should be similar to the curve below.



Points can be obtained at millisecond intervals on either side of the source jerk time. A-B can then be accurately determined with the intermittent source experiment while A is easily found from a static experiment. The accuracy of the determination of δK will depend upon how rapidly a source can be "turned on or off" in the assembly. It is necessary only that the rise time of the source be small

[redacted]

compared to the shortest delay neutron period.

F. de Hoffman (LAMS-179) has discussed a modulated source experiment in which the source is turned off and on at very high repetition rates. The modulate source experiment and the intermittent source experiment are in no sense equivalent and are used to study two completely different effects.

[redacted]

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IV EXPERIMENTAL

A. Control Rod Calibration

The control rod characteristics were among the first considerations when Topsy was originally assembled. Since small changes in criticality were usually made by moving the control rods it was necessary to get as complete a control rod calibration as possible. One would like to have a curve relating control rod motion to ΔK, but this is very difficult to obtain. Multiplication vs. control rod position curves were obtained and measurements were made of positive period vs. control rod position.

The latter measurements resulted in curves such as Figure 17A. One control rod according to the curve is 23.5 cents on this criticality scale. Measurements showed that the two control rods have very little interaction so that the total travel of the two control rods is then equal to a change in criticality of 47 cents. The relation between positive period and cents comes from calculated curves based on delayed neutron periods. The equation for the calculation has been published as

$$\text{cents} = 100 \frac{\Delta K}{\gamma f} = 100 \sum_{i=1}^{i=5} \frac{a_i T_i}{T - T_i} \qquad \underline{1}$$

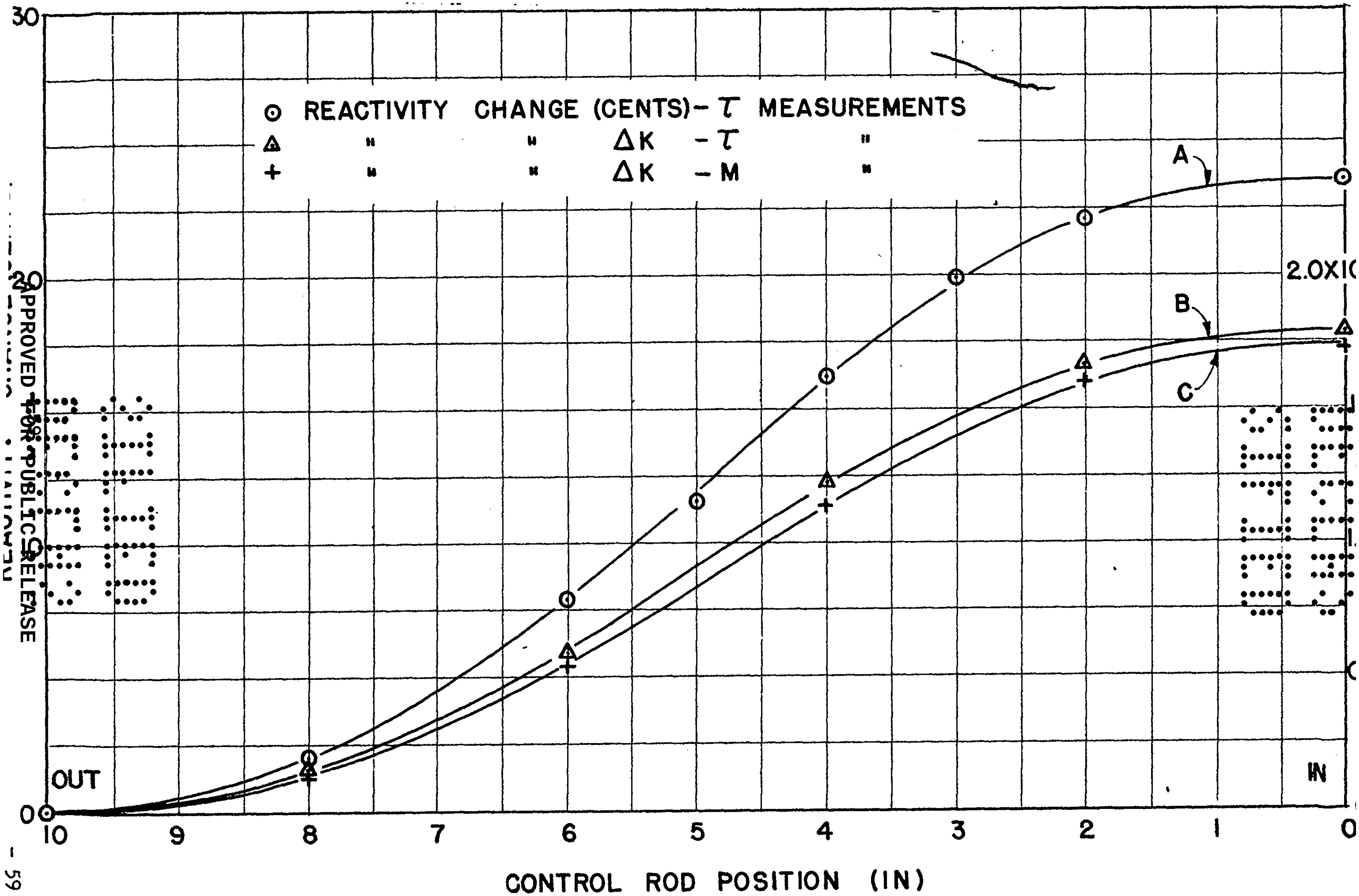
30
20
0
⊙ REACTIVITY CHANGE (CENTS) – τ MEASUREMENTS
Δ " " ΔK – τ "
+ " " ΔK – M "
A
B
C
2.0X1(
OUT
IN
10
9
8
7
6
5
4
3
2
1
0
CONTROL ROD POSITION (IN)

FIG 17

where usually the delayed neutrons are split up into 5 groups with decay periods τ_i and relative abundance a_i. T is the resulting pile period. The equation is valid for all $T \gg \tau_i$. Various investigators do not agree exactly on the delayed neutron data. For example, refer to Physical Review, Vol. 74, No. 10, pages 1330-1337, November 15, 1948.

The control rod calibration in cents can be converted to absolute units of ΔK by multiplying by γf and dividing by 100. The fraction of neutrons delayed has been taken as .00755 for U-235 (Phys. Rev. Vol. 73, No. 2, pages 11-124), while $\gamma \sim 1$ for a small metal assembly. Using these values, Curve B in Figure 17 results.

By means of inter-relations explained in LA-335, central source multiplications can be converted into ΔK. The relations used are

$$M_o/M_n = 4/3 \text{ (for high multiplications)} \qquad \underline{2}$$

$$\frac{M_n - 1}{T_n - 1} = \frac{\nu - 1 - \alpha}{\nu} \qquad \underline{3}$$

$$T_n = \frac{1}{1-K} \qquad \underline{4}$$

where M refers to net or leakage multiplications, T to total multiplications, the subscript o to central source, and the subscript n to normal mode source. For high multiplications then the following relation is approximately true:

$$\Delta K = 4/3 \; \frac{\nu - 1 - \alpha}{\nu} \; \frac{1}{M_o}. \qquad \underline{5}$$

Assuming $\nu \sim 2.5$ and α very small,

$$\Delta K = 4/5 \; \frac{1}{M_o}. \qquad \underline{6}$$

Applying the above equation to the multiplication vs. control rod position, data results in Curve C in Figure 17. B and C agree quite well.

Positive period measurements were also made by going into the delay critical region by the addition of cubes of Oy to the outside of the active pseudosphere. These positive periods were then converted to cents and the result plotted in Figure 18. Extrapolation of the curve to 100 cents gives 426 gm of outside Oy between delay and prompt critical. Comparison of Figures 17 and 18 gives 200 gm of outside Oy (5.22 half-inch cubes) equivalent to the two control rods near critical. The mass difference extrapolation between delay and prompt critical is important for fixing the position of the point for $\alpha = 0$ in the Rossi measurements.

[redacted]

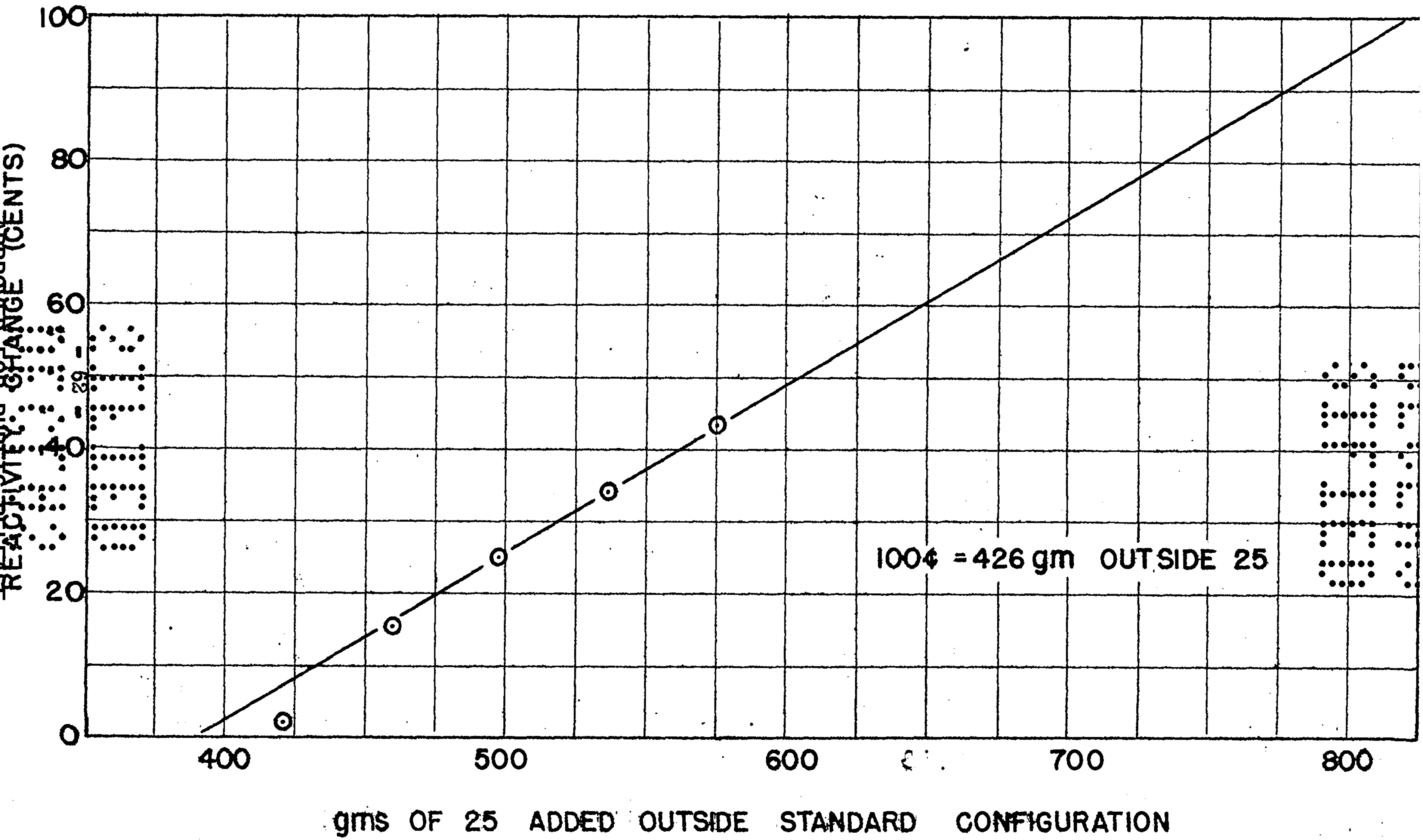
REACTIVITY CHANGE (CENTS)
100
80
60
40
20
0
400
500
600
700
800
100¢ = 426 gm OUTSIDE 25
gms OF 25 ADDED OUTSIDE STANDARD CONFIGURATION

FIG 18

B. Measurement of Reactor Fission Rate

1. Multiplication Method

Central source multiplication measurements were made using a calibrated mock fission source (MF#5). In Figure 19 these multiplications are plotted against logarithmic amplifier deflections. The logarithmic amplifier was always set to a standard deflection before any measurements were made with it, by means of a radium-beryllium source in a standard position. This procedure assured using the log amplifier at the same sensitivity level from day to day. The log amplifier was intended to have a range of 3 decades full scale but Figure 19 shows that the range was a little less than this. The curve for the fission rate vs. log amplifier deflections was calculated from the central source multiplications and the source strength $S = 8.45 \times 10^5$ n/sec by the use of equations 5 and 6 in Section III, giving

$$F = S \frac{M-1}{\nu-1} .$$

These multiplication measurements were repeated at various times and satisfactory agreement obtained.

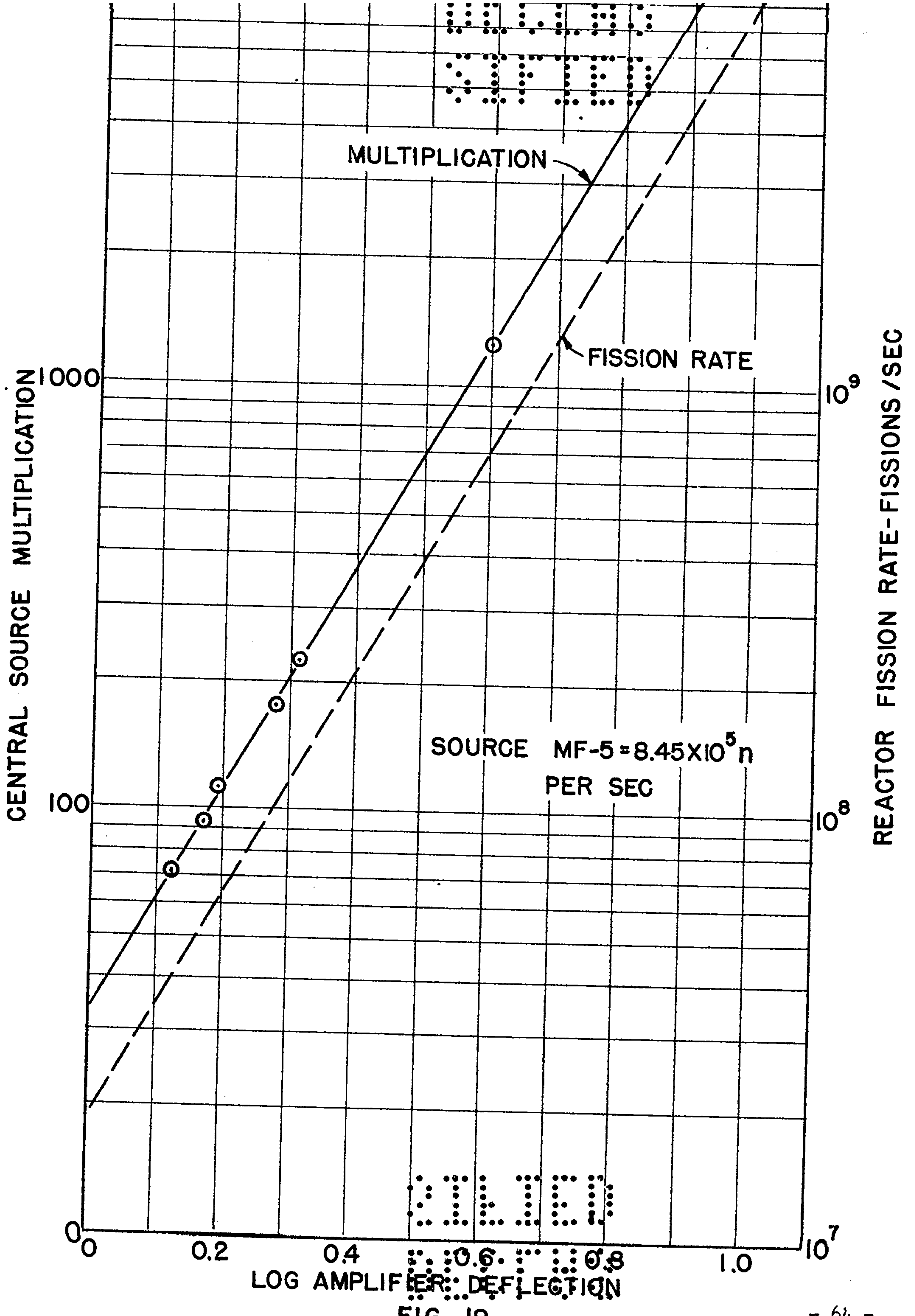
MULTIPLICATION
FISSION RATE
SOURCE MF-5 = 8.45X10^5 n PER SEC
CENTRAL SOURCE MULTIPLICATION
REACTOR FISSION RATE-FISSIONS/SEC
1000
100
0
10^9
10^8
10^7
0
0.2
0.4
0.6
0.8
1.0
LOG AMPLIFIER DEFLECTION

FIG. 19

2. Calibrated Chamber Method

A special parallel plate fission chamber (F 252) was constructed by J. C. Hoogterp having a good geometry and a thin Oy coating of a known thickness. The chamber was filled with spectroscopic argon and the pressure adjusted to give maximum pulse heights. The total amount of U-235 in the chamber was 11.1 mg. spread out to a thickness of 0.15 mg/cm^2.

A discriminator bias curve for this chamber is given in Figure 20. The horizontal slope of the curve at zero discriminator setting indicates that all fissions are counted at this point. At the discriminator setting of 20 used, the correction for low pulses was the factor 1.10. A 7/8 inch spiral fission chamber (2522) was compared with this chamber in a standard flux. The data appears below.

TABLE I

Ratio of counting rates 2522/F252:	16.4
Mass of U-235 in F 252:	11.1 mg.
Effective mass of U-235 in 2522:	182. mg.

Chamber 2522 was placed in the center of the Oy assembly and the assembly run up to power. Presumably the chamber now could indicate fission rate per gram in the active material immediately surrounding the chamber provided the perturbation due to the chamber was not excessive. Fission chamber counting rates and logarithmic and linear

[redacted]

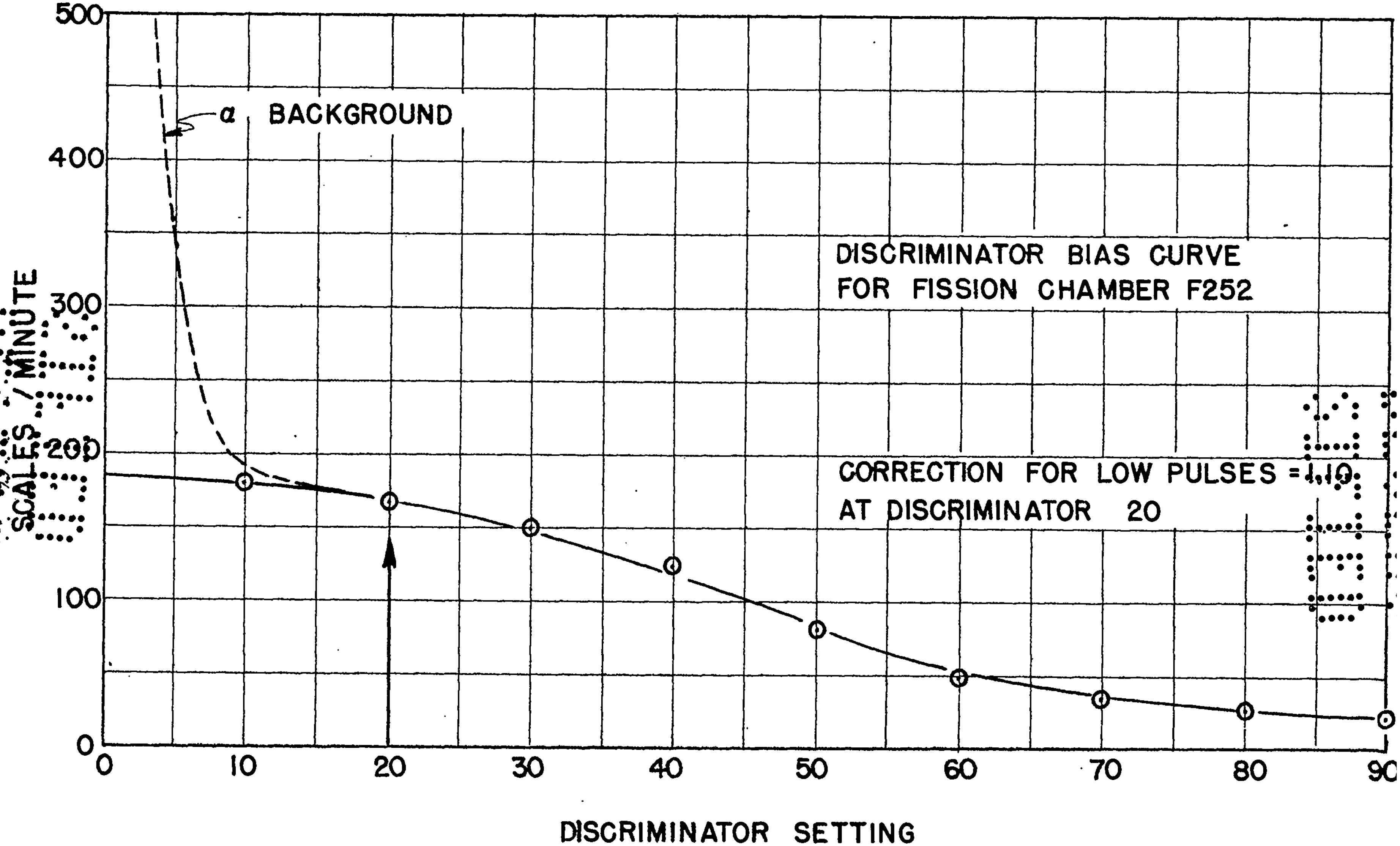

FIG 20

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amplifier reading were recorded. The determination of fission rate for one of these points follows.

TABLE II

Counting rate ≅ 22.35 S/m Scale 4096
Fission pulses/sec. ≅ 1.53×10^3
Fissions/gm sec. ≅ 8.38×10^3
Log amplifier ≅ 0.31
Mass of Oy in assembly ≅ 17.94 kg.

The radial fission distribution relative to the center had been measured with small 25 spiral chambers. Using this data the following table was compiled.

TABLE III

r Distance from center in cm.	F' Relative fission rate	$F = 8.38 \times 10^3 F'$ Absolute Fission rate	$4\pi\rho r^2 F$
0	1.00	8.38×10^3 F/gm sec	0
1	.995	8.34	1.96×10^6
2	.960	8.05	7.56
3	.885	7.41	15.7
4	.800	6.70	25.2
5	.711	5.96	35.0
6	.610	5.11	43.2
7	.495	4.15	47.8
8	.400	3.35	50.4

A plot of column 4 is shown in Figure 21. The area under this curve up to a radius of the Oy core should yield the total fission rate of the assembly. The

[redacted]

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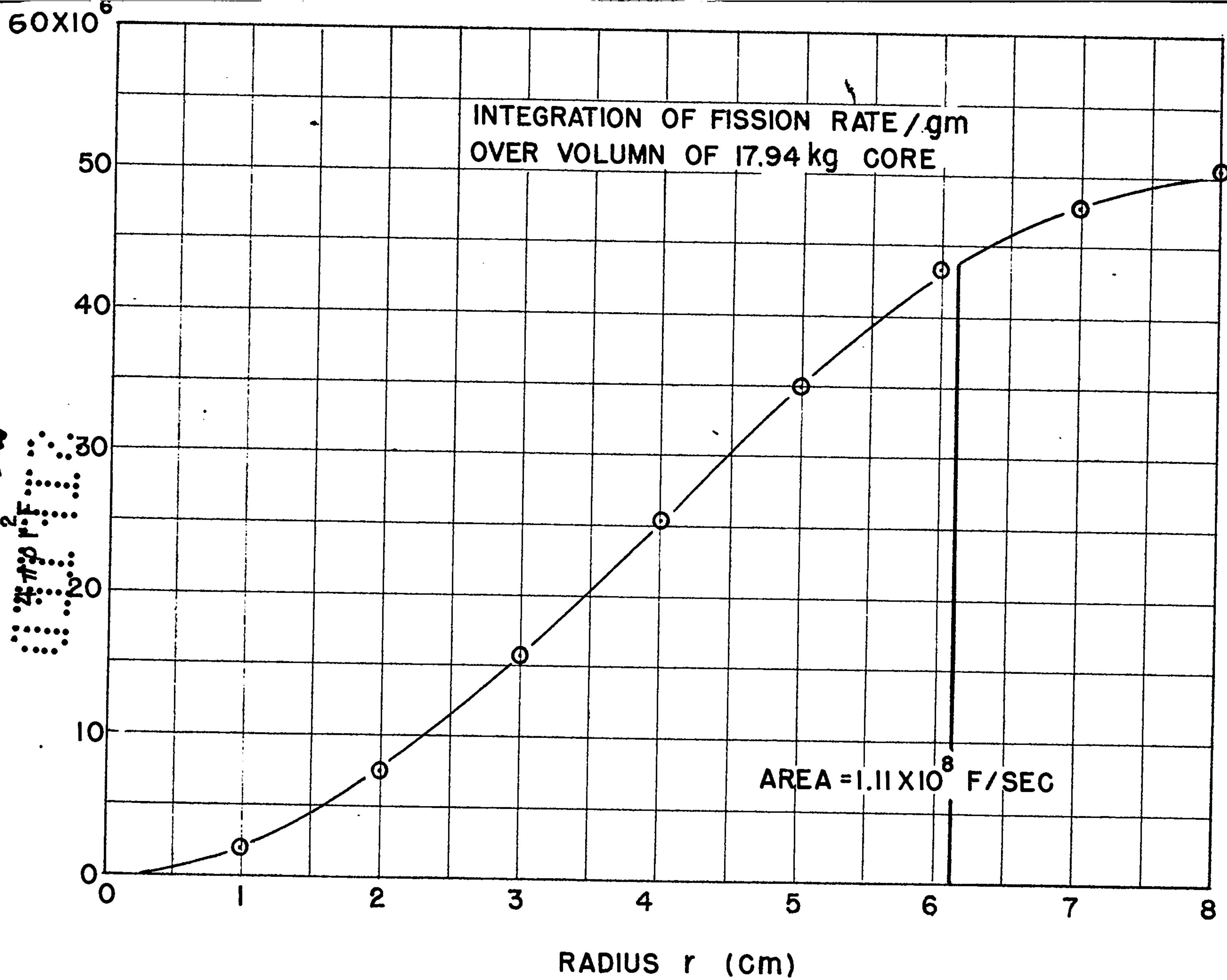
60X10^6
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
INTEGRATION OF FISSION RATE / gm
OVER VOLUMN OF 17.94 kg CORE
AREA = 1.11 X 10^8 F/SEC
RADIUS r (cm)

FIG 21

calculated radius of a 17.94 kg core of density 18.7 turns out to be 6.12 cm. According to the area under the curve then, for 100% concentration Oy the total fission rate at a log amplifier reading of 0.31 would be 1.11×10^8 fissions per second. Since the Oy in the assembly averaged only 94% concentration, this value must be reduced 6% to 1.05×10^8 fissions per second. Comparison with the results of the previous multiplication method (Figure 19) shows that the agreement is very good. Corresponding fission rates for other power levels may be obtained by multiplying the above value by the central spiral chamber counting rate ratios.

C. Rossi Measurements

1. Rossi Run at Critical

The complete procedure involved in measuring an α will be discussed by describing in detail a typical run with the reactor at delayed critical.

The electronic apparatus was designed to operate with a single input channel or a double input channel. In the double channel type of operation, two spiral fission chambers are used with two separate amplifiers feeding into the timing apparatus. One channel (initiating channel)

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provides neutron pulses which initiate the timing sweep. The ten coincidence circuits then record pulses from the second chamber-amplifier network (counting channel) which occur within the interval of the sweep. This cycle is repeated by subsequent pulses from the initiating channel. When the circuits are switched over to single input operation, the first neutron pulse which comes along initiates the sweep and the next following pulses coming from this same input are recorded in the coincidence channels and consequently their time separation from the initiating pulse is measured. Single input operation was usually used because of the greater convenience in using only one chamber-amplifier combination. Also the insertion of a single spiral chamber into the assembly resulted in less perturbation. The requirements on amplifiers and pulse shaping are much more stringent with single input operation because then one has to resolve two pulses from the same amplifier about 0.5 microsecond apart. The requirements are even more severe than this. Since pulses from the amplifier have all variations of pulse height, it is necessary that there be no interaction between the two pulses. in order to be able to count these pulses with equal probability. If the amplifier does not completely recover before the second pulse comes along, then the second pulse may be shoved up or down

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by riding on the tail of the first pulse and the relative probability of detecting the second pulse will be changed. Using pulses originating from two different amplifiers the pulses cannot interact and quite wide pulses can still give good resolution if one looks at their initial fast rise. Single input operation seemed to be quite satisfactory. Some small corrections had to be made to correct the first three coincidence channels when half microsecond channel widths were used.

The table of Figure 22 gives the data and calculations involved in a typical Rossi run at critical. Some comments are necessary to explain the way in which the data are obtained.

Run #23C was made at delay critical so no source was necessary. For the metal assembly the decay is so rapid that either 0.5 μsec or 1.0 μsec channels are necessary. The first channel delay is the time between the initiating pulse and the opening of the 1st timing channel. It is necessary to know this time in order to determine the absolute time position of the center of each channel with respect to the initiating pulse. Gated operation was unnecessary because of the low efficiency of the detector. Fission rates were obtained by the log amplifier deflection and Figure 19.

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FIGURE 22

Criticality: K = 1
Source: None
Log amplifier: 0.335
Fission rate: 1.2 x 10^8 F/sec

Rossi run: #23C
Channels: 0.5 microsecond
1st channel delay: 0.8 microseconds
Periodic gate: Ungated

	Scale of 4096		channel counts scale of 4									
Time	inputs	sweeps	1	2	3	4	5	6	7	8	9	10
Calibration with double pulser			923 603 320	451 117 334	383 053 330	013 706 307	820 484 336	172 846 326	721 399 322	915 595 320	144 822 322	883 560 323
Channel overlap correction			.938	.898	.909	.977	.893	.920	.932	.938	.932	.929
Random Correction			1.060	1.051	1.027	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Total correction factor			.994	.944	.934	.977	.893	.920	.932	.938	.932	.929
Rossi data 30 min.	2961 2447 514	4210 3725 485	8794 4766 4028	3691 0167 3524	9067 5999 3068	8982 6506 2476	0578 8286 2292	6526 4547 1979	0711 9047 1664	1647 0238 1409	4653 3436 1217	4196 3130 1066
Corrected	514	485	4004	3327	2866	2419	2047	1821	1551	1322	1134	990
	$P_t dt$ $P_o dt$ $P_o dt$	= 10^{-5} X = 10^{-5} X = 10^{-5} X	806 58 748	670 58 612	577 58 519	487 58 429	412 58 354	367 58 309	312 58 254	266 58 208	228 58 170	199 58 141

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Channel widths were adjusted with the double pulser. The dividing lines between successive channels were set 0.5 microsecond apart. The final effective channel widths were obtained by driving the delay helipot in the double pulser with a 1 rpm synchronous motor. This sweeps the delayed pulse through the 10 channels at the rate of 0.5 microseconds per minute. If the channels are exactly 0.5 microseconds wide, one gets 300 register counts per channel. Any counts over the 300 are considered as overlap and a channel overlap correction was obtained. It can be seen that the average overlap was a little less than 10%. A final correction to the channel counts had to be obtained due to the fact that pulses within about 1.5 microseconds of each other were not completely independent. This correction, called a random correction, was applied to the first three channels. It was obtained by using the Rossi apparatus with a random source. With the random source it was found that the first three channel counts were lower than the expected value and a correction factor was calculated which would just bring them up to the expected. These two corrections were then incorporated into a single factor for each channel which was used to multiply the observed channel counts in order to get the corrected value.

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The corrected Rossi data were then used for the calculations. P(t)dt for any channel n is just the average number of counts recorded each time the channel is opened, e.g. in the time interval 0.5 microsecond. This obviously equals the total counts in the channel divided by the number of times the channel is opened. As an example, in Channel 1 the total counts were 4004 x 4 and the number of times the channel was opened was given by the sweeps or 485 x 4096. The factors of 4 and 4096 enter because the coincidence channels were scale of 4 and the sweep scaler was scale of 4096. Thus

$$\left[P(t)dt\right] = \frac{4004 \times 4}{485 \times 4096} = 806 \times 10^{-5} .$$

One can write a general formula which takes into account the scaling factors and the result is

$$\left[P(t)dt\right]_n = \frac{C_n}{S} \times 9.77 \times 10^{-4}$$

where C_n are the channel counts (Scale of 4) in the nth channel and S is the sweep register counts scale of 4096.

The background term or $P_o dt$ is the number of counts which would be expected for each opening of a channel if the input pulses were coming from a random source instead of a chain reacting assembly. This is the chance coincidence rate per channel opening and is constant for all channels.

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The background term is then the input counting rate times the channel width. The input counting rate for the case under consideration was 514 x 4096 divided by 1800, the time in seconds. Consequently

$$P_o dt = \frac{514 \times 4096}{1800} \times 0.5 \times 10^{-6} = 58 \times 10^{-5}.$$

A general formula for this term is

$$I/t \times 3.41 \times 10^{-5}$$

where I is the total input scales of 4096 and t is the time of the count in minutes.

Subtracting the chance coincidence probability from the total coincidence probability yields the related chain coincidence probability $P_c dt$. In terms of the quantities of Equation 3 of Section III, the relationship is as follows.

$$P(t)dt = Cdt + \frac{E\chi_2}{2\nu^2 T_o(1-Kp)} e^{\alpha t} dt$$

or, in abbreviated notation,

$$P(t)dt = P_o dt + P_c dt.$$

A plot of $P_c dt$ against t should be a straight line on semi-log paper with a slope α and an intercept at $t = 0$ of

$$\frac{E\chi_2 \, dt}{2\nu^2 T_o(1-Kp)}.$$

Figure 23 shows this graph. The probable statistical errors are indicated.

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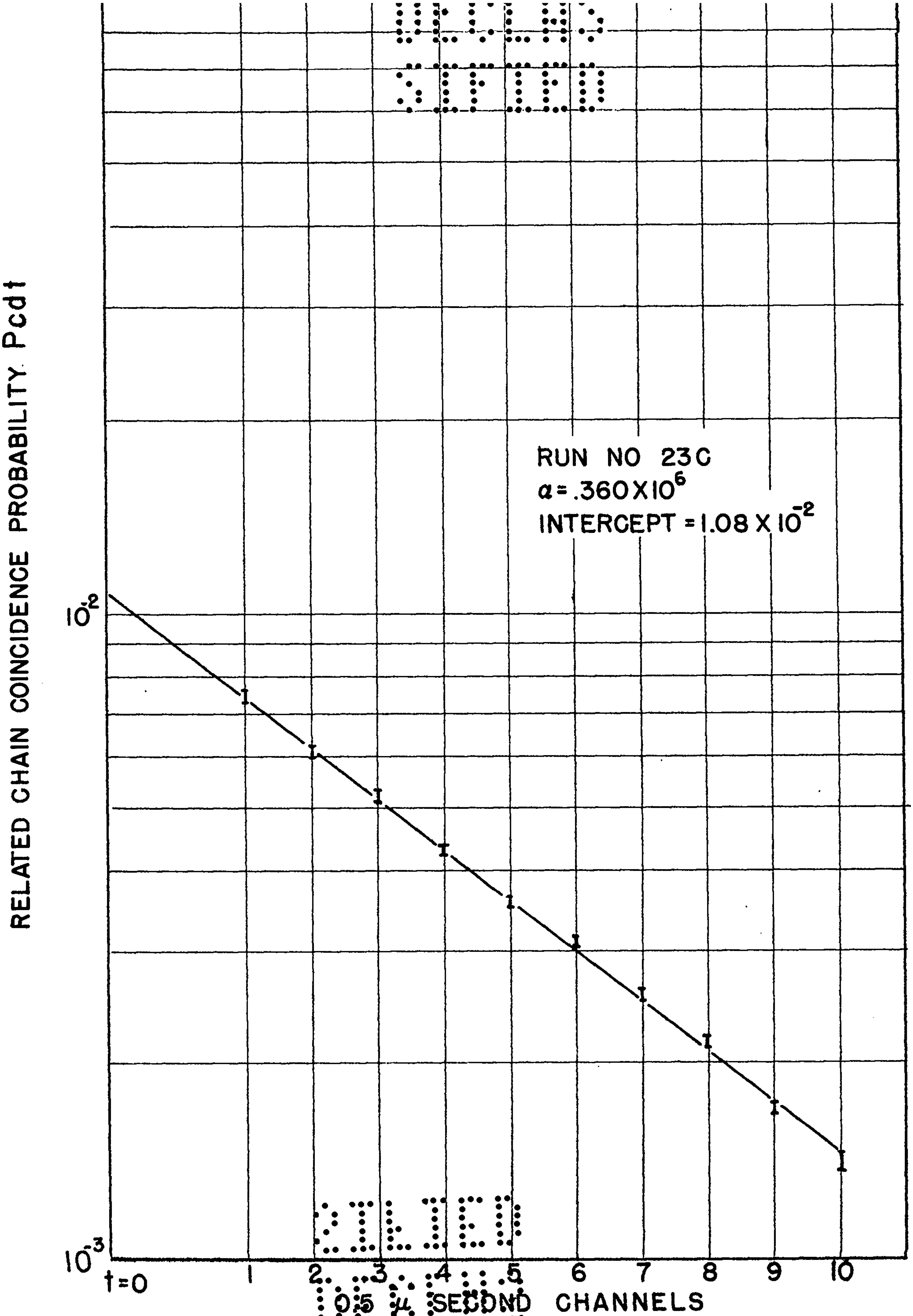

FIG. 23

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This run is typical of the runs near critical. Conditions are not so favorable subcritical and eventually the background term becomes so large that a limit is reached due to the statistical uncertainty of the points. Two or more separate runs were made at each criticality.

The slope of the curve for #23C yields an α of 0.36×10^6.

$$\frac{1-K_p}{\tau_0} = .36 \times 10^6$$

At delay critical assume $1-K_p = .00755$. Hence we get

$$\tau_0 = 2.10 \times 10^{-8}.$$

The evaluation of the intercept is at present not too reliable due chiefly to the uncertainty in the determination of the fission rate of the reactor. From the curve the intercept is

$$\frac{EX_2\, dt}{2\nu^2 \tau_0 (1-K_p)} = 1.08 \times 10^{-2}.$$

E, the efficiency of the counter, is the input counting rate divided by the fission rate or

$$E = \frac{514 \times 4096}{1800 \times 1.2 \times 10^8} = 0.975 \times 10^{-5}$$

counts per fission. Substituting the values for E, ν, and dt, the following relation is obtained.

$$\frac{\chi_2}{\tau_0(1-K_p)} = 2.88 \times 10^{10}.$$

The above inter-relation between χ_2, τ_0, and $1-K_p$ is the thing that one gets experimentally from the intercept value. If one believes the previously mentioned determination of τ_0 and accepts .00755 for $1-K_p$ at $K=1$, then substituting their values, $\chi_2 = 4.6$ is obtained.

It should be pointed out that the values deduced above are not presented as being authoritative but are simply illustrative of the manipulations. The results above are based on a single 30 minute Rossi run where a determination of α was stressed rather than an evaluation of the intercept. It is planned to direct some experiments specifically at this evaluation at a later date.

2. Determination of $d\alpha/dm$ and τ_0

Measurements of α were made at various values of Δ m removed from critical. These measurements were accomplished by removing ½ inch cubes from the outside of the pseudosphere and replacing them with tuballoy. It is true that these cubes were not always exactly equivalent. In the pseudosphere type of assembly not all cubes which

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were removed were in identical geometry with respect to the center. These differences were not great, however, and should cause very little error. Figure 24 gives the plots of Rossi data at the various criticalities. The departure from critical was expressed in terms of cubes of Oy, in grams and in central source multiplication. The data are summarized in the following table.

TABLE IV

Cubes	Δm	$1/M_0$	α	$1-K_p$	τ_0
0	0 gm.	0	$.367 \times 10^6$	.0076	2.07×10^{-8}
-2	-76.6	.00170	.415	.0090	2.16
-4	-153	.00335	.470	.0103	2.19
-6	-230	.00505	.542	.0116	2.14
-8	-306	.00675	.607	.0130	2.14
-10	-383	.00845	.661	.0143	2.16
	+426		0	0	

Avg = 2.14×10^{-8} sec.

The value of Δm for $\alpha = 0$ (i.e. prompt critical) was obtained as previously mentioned by positive period measurements. The value of $1-K_p$ was obtained by adding .0076 to the value of 1-K obtained from multiplication measurements. τ_0 was calculated for each run from the measured value of α and $1-K_p$. The resulting values of τ_0 appear to be

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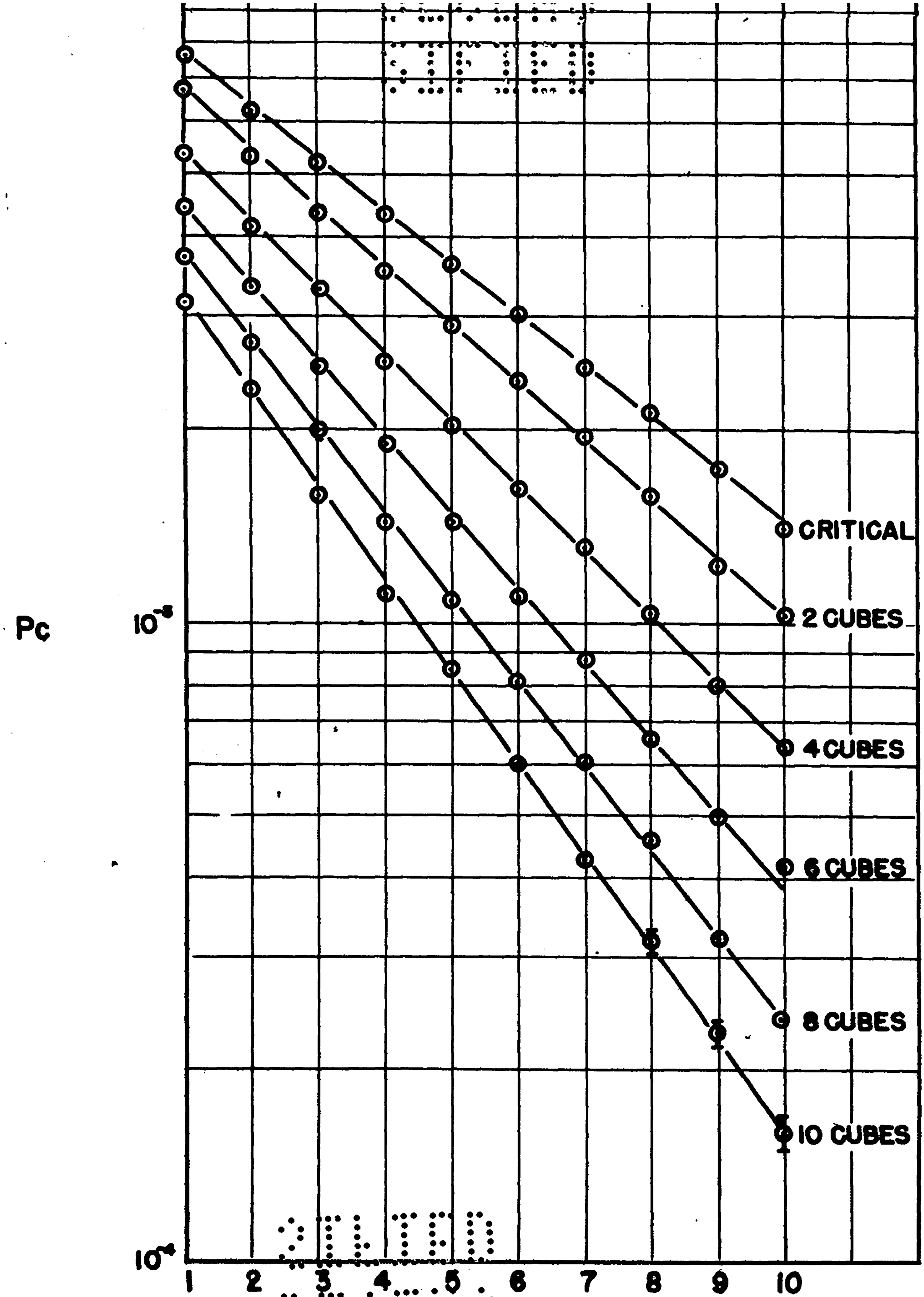

[redacted] 0.5 μ SEC CHANNELS

FIG 24

essentially constant with an average value of 2.14×10^{-8} seconds. One would not expect τ_0 to vary much over the small range of criticality considered here.

The data from Table IV are plotted in Figure 25. The slope of curve A gives a value of $d\alpha/dm = .82 \times 10^{3}\ gm^{-1} sec.^{-1}$. This value is a factor of two higher than a previous measurement (LA-374). In the previous measurement, however, lower enrichment Oy was used (79% vs. 94%). Also, the previous geometry did not permit changes of mass at the outside of the active sphere. Changes were made in the center and a calculation was made to get the equivalence between inside and outside cubes. The present measurement then should be more reliable since it was more direct and was made with higher enrichment material.

3. <u>Other measurements</u>

a. Perturbation due to chamber: An attempt was made to see if the finite size of the chambers seriously affected the value of α. The detectors used were as small as could feasibly be used. Two sizes of spiral fission chambers were available with diameters of ½ inch and 7/8 inch. Measurements of α at delayed critical were made with each of these. The chambers were placed in the center of the active pseudosphere in order to perturb the assembly as

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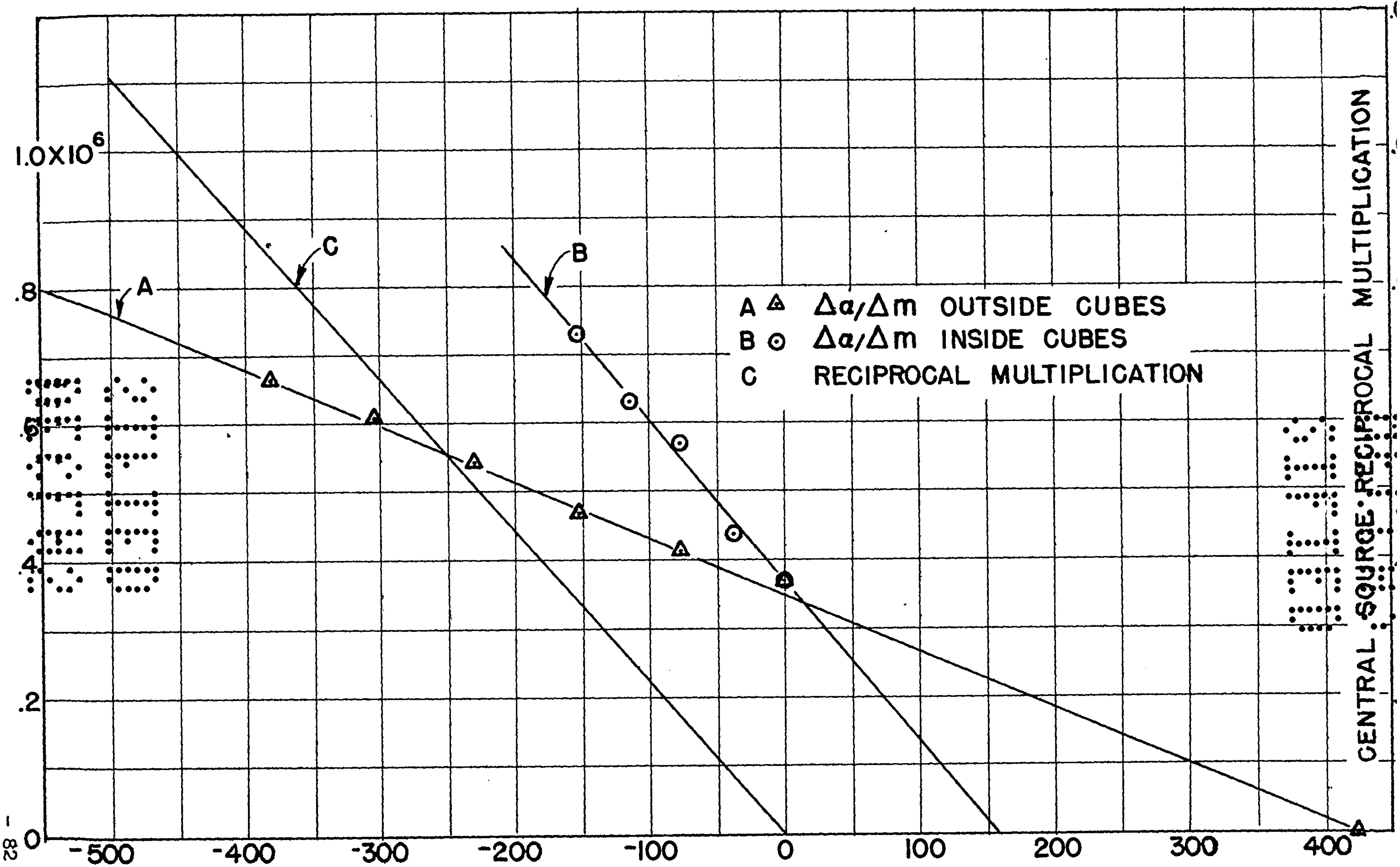

Δm-gm FROM CRITICAL

FIG 25

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much as possible. Within statistics, the data from the chambers of different size were identical.

A second series of measurements at critical was made by placing the 7/8 inch spiral chamber in the center and making a run and then placing the chamber at the oralloy-tuballoy interface and repeating the measurements. Again no effect of the chamber could be detected. It appears that with the small chambers used in the present measurements, any perturbations due to the presence of the chamber are negligible.

b. Double chamber operation: A few test runs were made at critical using separate initiating and coincidence chambers. As was stated previously, in this type of operation coincidences are observed between a pulse from one chamber-amplifier combination and another pulse from a second chamber-amplifier combination. Since the pulses are completely independent of each other, the amplifier requirements are not so stringent and better resolution near zero time is possible. Except for this one advantage, single channel operation is preferred because of its greater simplicity. Tests with double input operation were made simply to assure ourselves that no error was appearing with the single type operation. Measurements at critical were identical using either single or double input. About the only difference one might expect would be due to an error in the random correction mentioned previously. No random correction is necessary with double input operation.

c. Subcritical measurements of α by removing central cubes: The variation of α with mass removed from the center was investigated in two ways: (1) Removing $\frac{1}{2}$ inch cubes from the center and replacing with tuballoy; (2) removing $\frac{1}{2}$ inch cubes from the center, leaving voids. In each case the critical condition was obtained and then the desired number of cubes removed from this configuration. It was found that replacing oralloy with tuballoy yielded an appreciably more critical assembly than with the corresponding configuration containing voids. The variation of α with m for (2) above is included in Figure 25. Comparison of the slopes for inside and outside cubes gives a value of 2.87 outside cubes equivalent to one inside cube.

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V. CONCLUSION

It should be remarked again that the purpose of this report is to serve as a primer for Rossi measurements. Apparatus and procedures have been described in great detail. The present report will be used as a reference for subsequent measurements. In addition, possible experiments have been suggested and it is hoped that they may be performed in the near future.

A few remarks should perhaps be made regarding the present measurements. The value of α itself should be of considerable importance. Although the measured values here are in a criticality range far removed from that involved in atomic weapons, comparisons made at these criticalities should hold qualitatively in the far supercritical region. For example, if the α for an oralloy assembly is lower in a WC tamper than in a tuballoy tamper in the neighborhood of delayed critical, one would expect this also to be true when highly supercritical. Thus comparisons of active materials and tampers made in the laboratory should be valid for bomb considerations.

It is questionable whether the measured value of $d\alpha/dm$ has much significance. It would seem that a measurement of $d\alpha/d\rho$ would be more appropriate in consideration of implosion weapons. There is a possibility that $d\alpha/d\rho$ could be determined over a limited range by making Rossi measurements at different temperatures. The present Topsy assembly would not be suitable for such measurements since a change in density of the cubes might not result in a corresponding average change of density over the whole pseudosphere. A solid Oy core would be necessary for temperature measurements.

It is not as yet certain how much information can be obtained from Rossi measurements about other constants of a critical assembly. A pretty good evaluation of τ_0 can certainly be obtained. τ_0 is important for calculations of bomb efficiencies.

Any information about K or K_p is important, and the Rossi apparatus seems to be the best tool so far devised for an absolute measurement of K. Once K has been determined, other quantities immediately follow, such as χ_2 and γ or possibly even f. χ_2 is important since it enters directly in predetonation probabilities. γ and f are of no particular interest for weapon design but are very important in predicting pile behavior.

It would be over-optimistic to expect to solve all the problems mentioned above. It does appear, however, that the Rossi measurements may open up interesting experiments which as yet have not been explored adequately.

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