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ALPHA MEASUREMENTS ON THE GODIVA CRITICAL ASSEMBLY USING A BETATRON

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ABSTRACT

X-ray bursts from a betatron were used to produce a neutron population in a bare oralloy critical assembly at two reactivity settings between delayed and prompt critical. From a time analysis of observed pulses, the decay period of the leakage flux of prompt neutrons from the assembly was determined. The experimental values obtained for alpha (the reciprocal of the prompt neutron period) are $- 0.52 \pm 0.03$ and $- 0.26 \pm 0.03 \times 10^6$ sec^{-1} at reactivities of 51.9 and 73.9 cents, respectively. These results agree with the Rossi self-modulation method of measuring alpha.

A summary of the results of all alpha measurements on the Godiva critical assembly is included.

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Introduction

The value of alpha (the reciprocal of the prompt neutron period) for a bare oralloy sphere at delayed critical, using the best data available in September 1952, was calculated to be $- 1.35 \pm 0.10 \times 10^6$ sec^{-1}.[1] The lower limit (- 1.25) of this value is larger (in absolute magnitude) by 20% than the value measured using the Rossi self-modulation method.

When measurements are made by the Rossi self-modulation method, the critical assembly is operated at very low power, so that neutrons which are detected are separated by time intervals of the order of microseconds. The method consists of analyzing the relative frequency with which various time intervals (between neutron pulses) occur. There was some question as to whether the self-modulation method was giving the correct value of alpha. It was therefore thought desirable to check the results of the Rossi method measurements by a direct observation of the decay of the prompt neutron intensity in the critical assembly.

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(1) H. A. Bethe, LASL colloquium. ~~See Section 5 of this report for calculated values of alpha~~.

1. Experimental Arrangement

The procedure used for measuring the prompt neutron period was to produce an initial neutron population in the critical assembly by means of an X-ray burst, and to measure the decay of the neutron intensity with time.

Measurements were made on the remotely-controlled Godiva critical assembly at the Pajarito Canyon Site. The assembly consists of a bare sphere of 52.8 kg of oralloy, having the composition 93.71% U-235, 5.24% U-238, and 1.05% U-234. The density of oralloy pieces is 18.80 gm/cc. The oralloy sphere can be disassembled into three sections, as shown in Fig. 1. Gross changes in reactivity are obtained by the addition of 14 surface plugs of either 50 or 100 gm of oralloy. Small reactivity changes are obtained by two motor-driven oralloy control rods.

The experimental arrangement used for alpha measurements is shown schematically by the block diagram, Fig. 2. A 10.5 Mev betatron (see Fig. 3) built by General Electric[2] was mounted so that the X-ray beam would impinge upon the critical assembly at a distance 33.5" from the betatron doughnut target. By means of dosimeters, the average X-ray yield was measured to be 850 microroentgens per burst at the surface of Godiva. From previous measurements this X-ray intensity is known to produce approximately 50,000 neutrons near the surface of the uranium by (γ,f) and (γ,n) reactions. Since the photo-neutrons were produced in less than 0.15 μ sec (microseconds), the width of the X-ray burst, it was possible to define accurately a zero time at which the fission chains started.

(2) General Electric Research Laboratory reports RL-674 and RL-701.

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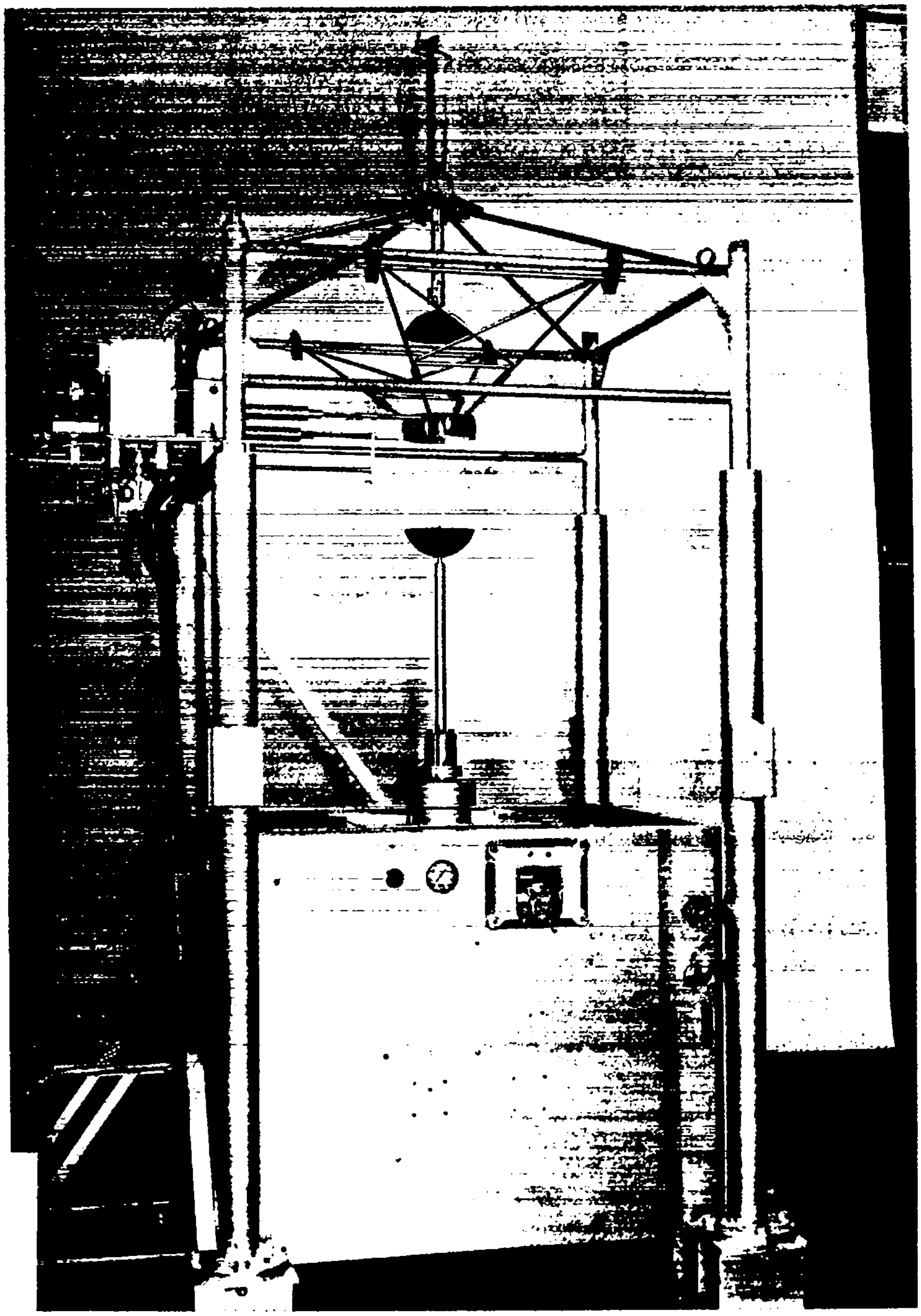

Fig. 1. The Godiva critical assembly, disassembled. The mechanism at the left operates control rods and source holder.

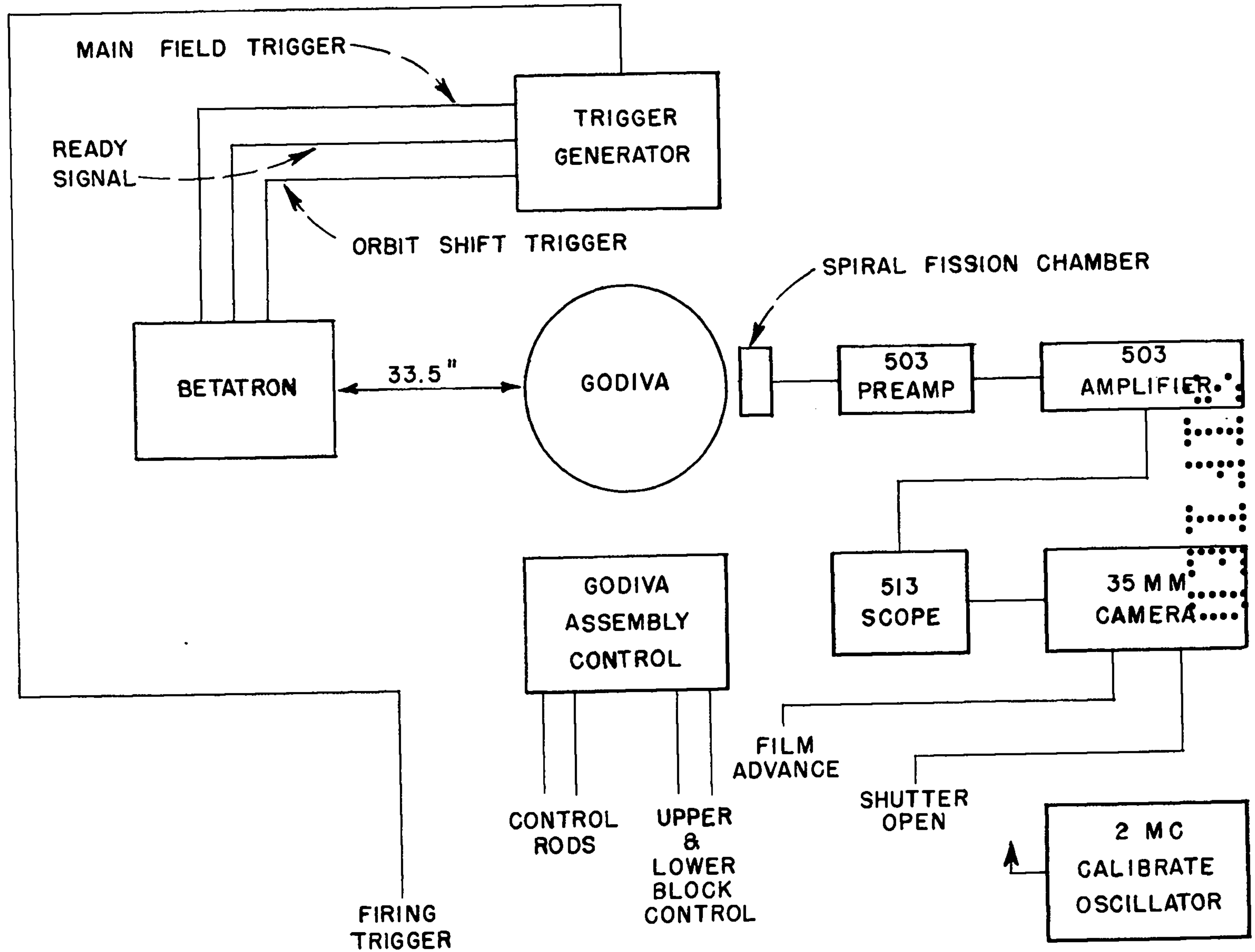

Fig. 2. Block diagram of the experimental arrangement used for making alpha measurements with a betatron.

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An oralloy spiral fission chamber, placed against the surface of the critical assembly and diametrically opposite from the betatron, was used as the neutron detector. This detector has the advantage of being relatively insensitive to gamma rays. The output pulses of the fission chamber were amplified by a Los Alamos model 503 preamplifier and amplifier and then presented as vertical pulses on a type 513 Tektronix oscilloscope. The sweep trigger of the scope was supplied by the orbit shift circuit of the betatron. The 20 μ sec oscilloscope sweep was photographed with a special 35 mm oscilloscope camera.

Due to the radiation hazard, all necessary controls for operation were handled remotely from a control room. Each cycle of operation consisted of six steps:

(1) Advance the camera film.

(2) Assemble Godiva.

(3) Open the camera shutter.

(4) Trigger the betatron.

(5) Close the camera shutter.

(6) Disassemble Godiva by raising the upper section.

Steps (2) through (6) were performed during a time interval of not more than 2 sec so that Godiva was fully assembled for only a short period and background counts were minimized. The cycle was repeated not oftener than once every 30 sec, because the power supply required this much time to recharge the main field condensers of the betatron.

2. Prompt Period Measurements and Results

To obtain statistical accuracy, it was necessary to repeat the cycle of operation approximately 600 times in the course of the experiment. For the 73.9 cents[(3)] setting of the critical assembly, 258 pictures of the oscilloscope trace were taken and 2690 pulses recorded. For the 51.9 cents setting, 340 pictures were taken and 2180 pulses recorded. The time scale was determined from pictures of the oscilloscope trace of a 2 megacycle oscillator signal. These calibrations were made several times a day during the course of the measurements.

Figure 4 (a) shows a typical background sweep. This picture was taken with Godiva disassembled. The fission chamber was partially shielded from direct radiation from the X-ray burst by the middle section of the assembly. The one pulse appearing near the start of the sweep is due to the intense X-ray burst, and was used as a fiducial mark for zero time. Figures 4 (b) and 4 (c) show typical scope traces with Godiva assembled at 51.9 and 73.9 cents, respectively.

The film was analyzed by projecting it with a Recordak projector, and visually counting pulses. The 20 μ sec sweep was divided into 1 μ sec intervals, and the number of pulses occurring in each interval was tabulated. The average number of pulses per microsecond in the first and second time intervals was between two and three.

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(3) In this report reactivity is expressed in terms of "cents." By definition, 100 cents equals the change in reactivity equivalent to the difference between delayed and prompt critical. Zero cents is at delayed critical; reactivities above delayed critical correspond to positive cents values.

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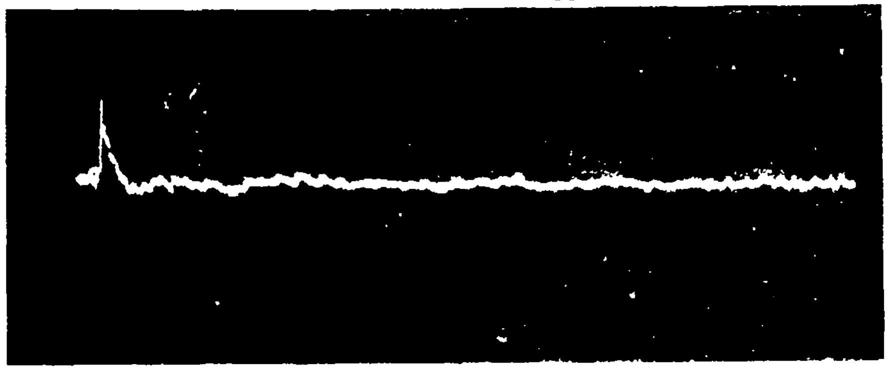
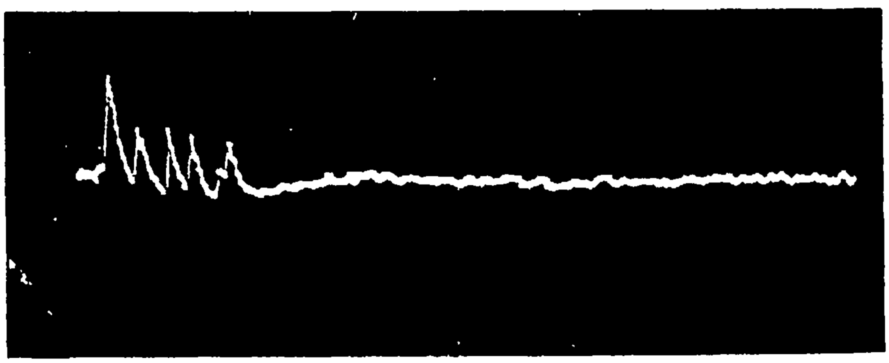
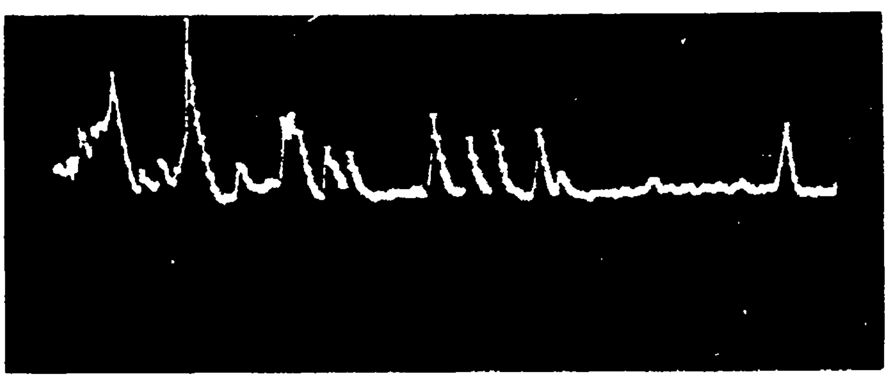


A. BACKGROUND



B. 51.9 CENTS



C. 73.9 CENTS

Fig. 4. Typical oscilloscope traces of pulses from the spiral fission chamber.

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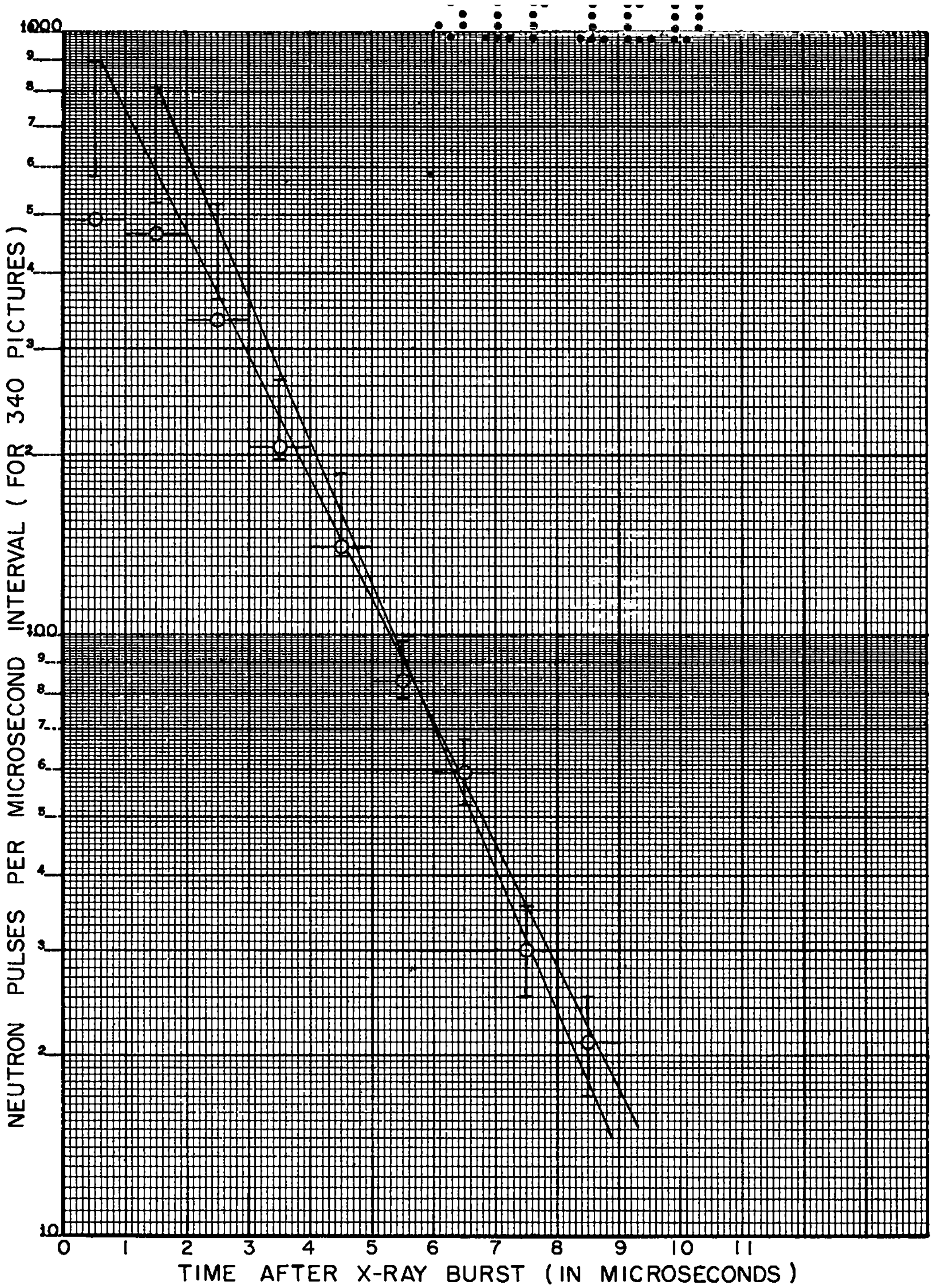

Fig. 5. Histogram of the number of pulses counted per microsecond with the critical assembly at 51.9 cents reactivity.

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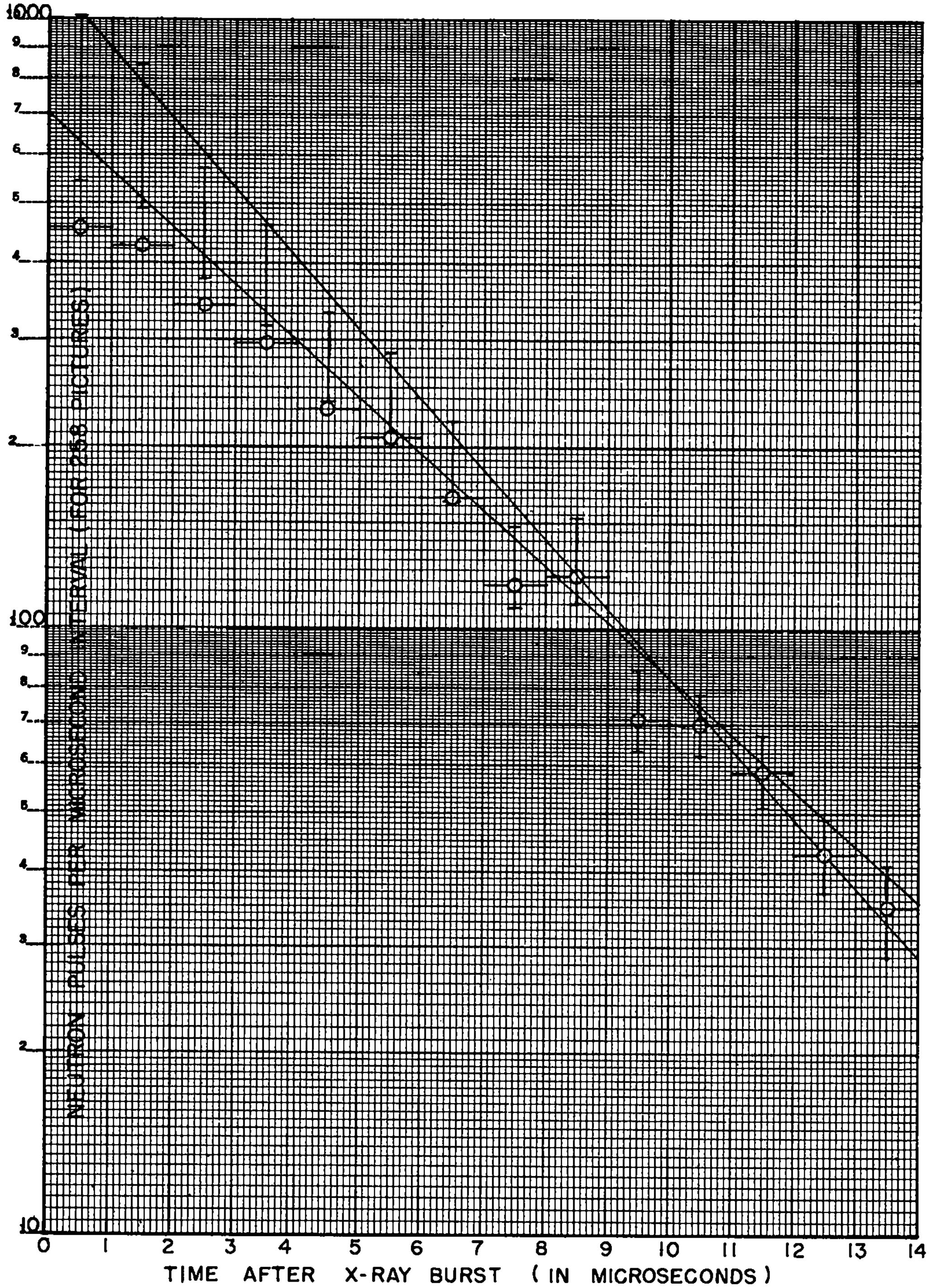

Fig. 6. Histogram of the number of pulses counted per microsecond with the critical assembly at 73.9 cents reactivity.

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Figures 5 and 6 present in semi-log histograms the results of time analysis of the photographs. The circled points on the histograms are the observed number of pulses per interval, obtained by scanning all the pictures taken at one reactivity.

Figure 4 (c) shows that the width of the fission chamber pulses varies considerably with pulse height. This made it difficult to determine accurately the resolution time of the counting system. It was estimated that the resolution time was well within the limits of 0.1 and 0.3 μ sec. The average number of observed counts per interval, n_o, was corrected for counting losses using the formula

$$n = \frac{n_o}{1 - n_o T} \tag{1}$$

where n is the corrected average number of counts in the interval, and T is the resolution time. The vertical bars on the histograms represent the combined corrections for statistical uncertainty and counting loss. The upper end of the bar equals the observed count plus the standard deviation plus the counting loss calculated for 0.3 μ sec resolution. The lower end of the bar is the observed count minus the standard deviation, plus the counting loss calculated for 0.1 μ sec resolution.

The straight lines drawn on Figs. 5 and 6 indicate estimated limits on the slope of the prompt neutron decay curves. The values obtained for alpha from the slopes of these lines are $- 0.52 \pm 0.03 \times 10^6 \text{ sec}^{-1}$ at 51.9 cents reactivity, and $- 0.26 \pm 0.03 \times 10^6 \text{ sec}^{-1}$ at 73.9 cents reactivity.

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3. Determination of Godiva Reactivity

For direct comparison with the calculated values of alpha, the measurements should have been made with the critical assembly at delayed critical. However, the decay period of the prompt neutrons is about 1 μ sec at delayed critical, and this was too fast a decay to observe conveniently with the detection system that was used. Therefore, measurements were made at two reactivities above delayed critical, by about 1/2 and 3/4 the separation between delayed and prompt critical. At these reactivities, the decay periods of the prompt neutrons were about 2 and 4 μ sec, respectively.

The reactivity of Godiva when alpha measurements were made was established by measuring the positive period of the assembly. This positive period is determined by the delayed neutrons and is several orders of magnitude slower than the decay period of the prompt neutrons (4.8 sec at 50 cents, and 1.05 sec at 75 cents). The equation by which cents are obtained from the positive period is an approximation of the kinetic equation:

$$\text{Cents} = 100 \sum_i \frac{a_i \tau_i}{T + \tau_i} \tag{2}$$

T is the positive e-folding period of the assembly. The τ_i are the delayed neutron periods. The a_i are the fraction of the delayed neutrons in each neutron period. In this equation it is assumed that the effectiveness (for producing fission) of the delayed neutrons in each of the periods is the same. To calculate cents, we have used the Hughes[4]

[4] D. J. Hughes, J. Dabbs, A. Cahn, and D. Hall, Phys. Rev. 73, 111 (1948).

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values of τ_i and a_i.

While reactivity measurements were being made, Godiva was fully assembled for a length of time equal to about three positive periods. During this time, the build-up of the neutron level was recorded automatically on a 10-channel time analyzer. The observed positive periods, T, corresponding to the two reactivities at which alpha was measured were 4.27 ± 0.06 sec and 1.12 ± 0.025 sec. The corresponding reactivities were 51.9 and 73.9 cents.

Temperature drift of the reactor while alpha measurements were being made introduced an uncertainty in the above values for the reactivity. The temperature drift amounted to 0.5 cent during the measurement at 51.9 cents, and to 2 cents during the measurement at 73.9 cents.

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4. Comparison with Rossi Measurements

If the correct delayed-neutron periods and abundances are used, a plot of alpha versus reactivity in cents will be linear, and will go to zero at 100 cents (prompt critical; see Fig. 7). Thus the values of alpha at delayed critical can be predicted by extrapolation from measurements made at higher reactivities.

A number of Rossi self-modulation measurements of alpha (LA-744) have been made between zero and 91 cents on the Godiva critical assembly by J. Orndoff and members of LASL Group W-2. Most of these measurements have been made with the detector located at the center of the assembly. In order to determine whether the detector position has a measurable effect on the experimental alpha value, four additional Rossi measurements of alpha were made with an external detector. These are indicated by triangles on Fig. 7, and are given in Table 1 along with the other measured values of alpha. These values agree within experimental error with those obtained by the Rossi method with the internal detector (except at delayed critical), and with those obtained by the betatron method using an external detector.

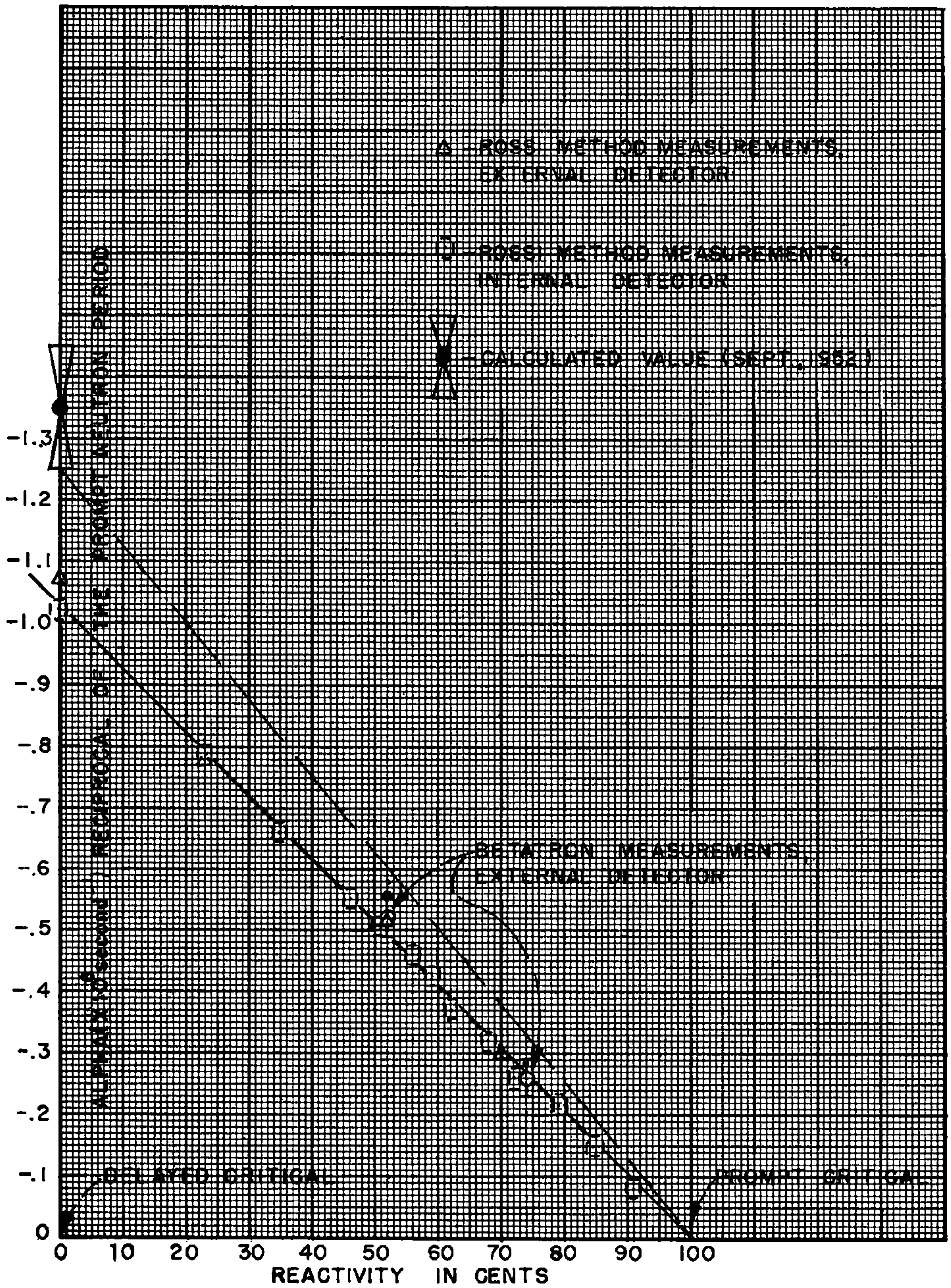

Fig. 7. Measurements of alpha on the Godiva critical assembly.

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TABLE 1

ALPHA MEASUREMENTS ON THE GODIVA CRITICAL ASSEMBLY.

(Rossi method measurements were made by J. Orndoff and members of LASL Group W-2)

	Alpha measurements (units are sec^{-1})		
Reactivity (cents)	Rossi, internal detector	Rossi, external detector	Betatron, external detector
0.0	-1.02×10^6	-1.08×10^6	
23.3	- 0.79	- 0.78	
34.9	- 0.66		
46.2	- 0.55		
50.4	- 0.51		
51.9		- 0.52	$-0.52 \pm 0.03 \times 10^6$
55.7	- 0.46		
59.2	- 0.43		
62.3	- 0.37		
67.8	- 0.32		
69.8		- 0.31	
72.3	- 0.26		
73.9			-0.26 ± 0.03
79.0	- 0.22		
84.6	- 0.15		
90.8	- 0.08		

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5. Conclusions

Within the accuracy of the measurements, the results obtained with the betatron are in agreement with the results of the Rossi method, and tend to confirm the Rossi experimental values of alpha at delayed critical.

The Rossi self-modulation method gives data more easily and rapidly than the betatron pulsing method, although the latter technique is conceptually a more direct approach to the measurement of the neutron decay rate.

Two difficulties were encountered with the experimental procedure used with the betatron. First, the detection system had comparatively long resolving time. This caused large counting losses in the first few microsecond time intervals, and also made it inconvenient to measure alpha at delayed critical. These counting losses substantially increased the experimental uncertainty in the alpha measurements. Second, accumulating enough data for adequate statistics is very slow with this method. At 51.9 cents reactivity, an average of five pulses per photograph was obtained, and the repetition rate was less than two photographs per minute. In addition, the time consumed scanning photographs was considerable.

Scintillation detectors were tried because of their greater sensitivity and much shorter resolution time. A trans-stilbene crystal, a liquid toluene-stilbene mixture, and a lithium iodide crystal activated with SnO all were tried. Most of the experimental difficulties experienced with scintillation detectors could be traced to their high sensitivity to gamma rays. The lithium iodide scintillator showed the most promise, but lack of time prevented an adequate investigation.

If further experiments are made on pulsing a reactor with a betatron, a faster and more convenient method of taking data should be developed. Further work on scintillation counters should produce a better detector than the fission chamber which was used for these measurements.

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