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THE DISTRIBUTED MULTIPLICATION OF SMALL PLUTONIUM CUBES
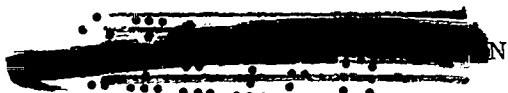
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"Nuclear Components

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ABSTRACT

The multiplication of small plutonium cubes has been measured in three different geometries. The cubes varied in dimension from 1/4" to 1". The multiplication of the 1" cube in air was found to be 1.15. With the aid of these measurements, ν of spontaneous fission has been evaluated as 2.36 $\pm$ 0.037 neutrons/fission. The error in ν does not include a $\pm 5\%$ uncertainty in the calibration of MF-11 nor does it include the $\pm 5\%$ error the the RaBe-44 standard.

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A determination has been made of the neutron background and apparent multiplication of plutonium cubes up to 1". Five cubes, nominally 1/4", 3/8", 1/2", 3/4", and 1" were fabricated by CMR-11 at the request of W-1. These cubes are all of the same material (J1438) which is nominally 620 MWD/T.

The neutron background of plutonium is of interest in evaluating the material for weapons use. The predominant source of neutrons in weapon material is the spontaneous fission of Pu^{240}. A small portion of the neutrons is produced by (α, n) reactions on light element impurities. Indications are that less than one neutron per gram second is produced in this manner, in well-purified material.

Thus the neutrons have initially a fission spectrum. For this reason all counting was done relative to a mock fission source.

Each cube was neutron counted in three W-1 geometries. The neutron rate of each cube was determined relative to a mock fission source in each geometry.

These data were then converted to values of apparent neutrons per gram second by dividing by the weight of plutonium for each cube. The reciprocal of this quantity, or gram seconds per neutron, was plotted as a function of cube height and found to be a straight line. Extrapolation to zero cube height is assumed to give the unmultiplied neutron rate of the material. Dividing each observed value by this quantity, one arrives at an apparent multiplication for each cube.

The geometries used were the W-1 "Bertha," the T-29 field surveillance geometry, and the "Two Headed Monster."

The "Bertha" is a right circular cylinder (Fig. 1A). The inner portion is a paraffin cylinder of 16" diameter and 19" height with a cadmium lined central cavity 8" in diameter and 13" long. The inner paraffin is encased in a 1" layer of boron carbide which in turn is surrounded by a water jacket for shielding. Four enriched boron lined chambers (G.E. Mod. BP-A7B) are located in the paraffin near the central cavity and parallel to the axis of the geometry. These chambers are operated in the proportional region at 600 volts. Under this condition the chambers are insensitive to gamma rays.

The electronics associated with this geometry consists of a 750 discriminator-scaler, a 503 amplifier, and a 503 preamplifier. When operated with an efficiency of about 0.4% for a source in the central cavity, the equipment has a background of less than one count per minute.

Material to be counted is placed approximately 5" above the bottom of the central cavity. At this height the geometry has a minimum sensitivity to variations in source position.

The T-29 is essentially a cylindrical can filled with water (Fig. 1B). An axial tube 2" in diameter receives the source. Four G.E. enriched boron lined chambers are placed as

close as practicable to this tube, and parallel to it. The chambers are operated at 600 volts as in the "Bertha." The output pulses from the chambers are fed into a 503 preamplifier and amplifier, and counted by a 750 discriminator-scaler. At an efficiency of 0.7% the background of this equipment was 0.75 count per minute.

The "Two Headed Monster" consists of two detectors similar to Hansen-type counters. These are so positioned that the axis of each points toward the material being counted (Fig. 1-C). The sample is positioned on a dural plate which is above the detectors and 50 cm away. RCL 40 cm pressure BF_3 chambers are used with these detectors. The chamber voltage was approximately 2100 volts, and was supplied by batteries. The output of each chamber was fed into a 222 counter. At efficiencies of about 0.025%, each detector has a background of about one count per minute.

These quoted background rates are those observed in the low background room of TA-41. All counting was done in this room.

Table I shows the total number of counts obtained in each geometry for each cube. In "Bertha" the smallest cube counted 80 times background, and in the T-29 this counting ratio was approximately 300. With the "Two Headed Monster" the ratio was less than 3. For this reason the data on the 1/4" cube in the latter geometry have been discarded.

Table I

TOTAL COUNTS OBTAINED

	Cube Size				
	1"	3/4"	1/2"	3/8"	1/4"
"Bertha"	175,000	170,000	10,000	10,000	5,700
T-29	200,000	250,000	70,000	65,000	24,000
"T.H.M."	100,000	65,000	70,000	25,000	--

Table II gives the apparent neutron per gram second rate for each cube in each geometry. The values are all relative to source MF-11, and are computed on the basis of grams of plutonium metal.

Table II

NEUTRONS PER GRAM SECOND

	Cube Size					
	1"	3/4"	1/2"	3/8"	1/4"	0
"Bertha"	59.5	55.9	52.8	51.1	50.1	47.2 ± 1.0
T-29	59.1	55.4	52.7	51.2	49.4	47.2 ± 0.4
"T.H.M."	54.3	51.9	49.9	49.6	--	46.5 ± 1.0

Average 0: 47.1 ± 0.3
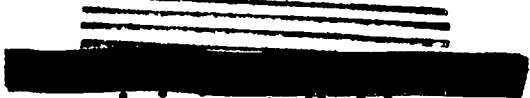
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Figures II, III, and IV are graphs of the quantity (gram second per neutron) against cube height, for "Bertha," the T-29, and the "Two Headed Monster," respectively. The solid lines were fitted by the method of least squares, and are described by the associated equations. The reciprocal of the zero intercept represents the unmultiplied neutron rate of the material. These values are tabulated as the zero-th cube in Table II, and are included on the graphs as the unmultiplied neutron rate. The errors quoted for the unmultiplied neutron rate are computed on the basis of counting statistics only.

The unmultiplied neutron rate, coupled with the Pu^{240} percentage of the active material, will give a value of ν of spontaneous fission. The weight percent of Pu^{240}, as measured by mass spectrometry by J. E. Hand of W-1, is $4.32 \pm .04$. Using Segre's value of the spontaneous fission rate of $Pu^{240}\left((1.66 \pm .02) \times 10^{6} \text{ fissions per gram hour}\right)$ gives as a value of ν 2.36 ± 0.037 neutrons per spontaneous fission. All errors are taken into consideration except the MF-11 source calibration of $\pm 5\%$ and the $\pm 5\%$ in the standard RaBe-44 source. Figure V is a graph of reciprocal multiplication vs cube height. The data as plotted represent the equations of the fitted solutions of Figs. II, III, and IV normalized to unit multiplication at zero dimension.

It is thought that the largest source of error in the results is the uncertainty in the calibration of MF-11. In the present report the Q of this source has been extrapolated from a value of 3.62×10^{5} neutrons per second determined on January 30, 1952. This value is as reported by Group P-4, and has a 5% uncertainty. It is thought that the Q value may be reduced about 3% in the near future. Should this be the case, the multiplication values will be unchanged; but the unmultiplied neutron rate of the material will change linearly with the source Q.
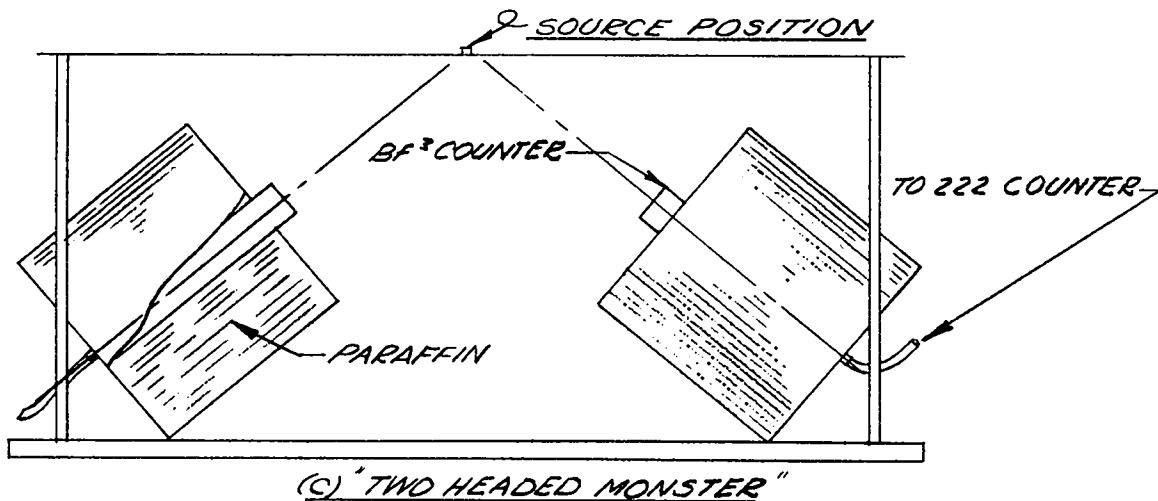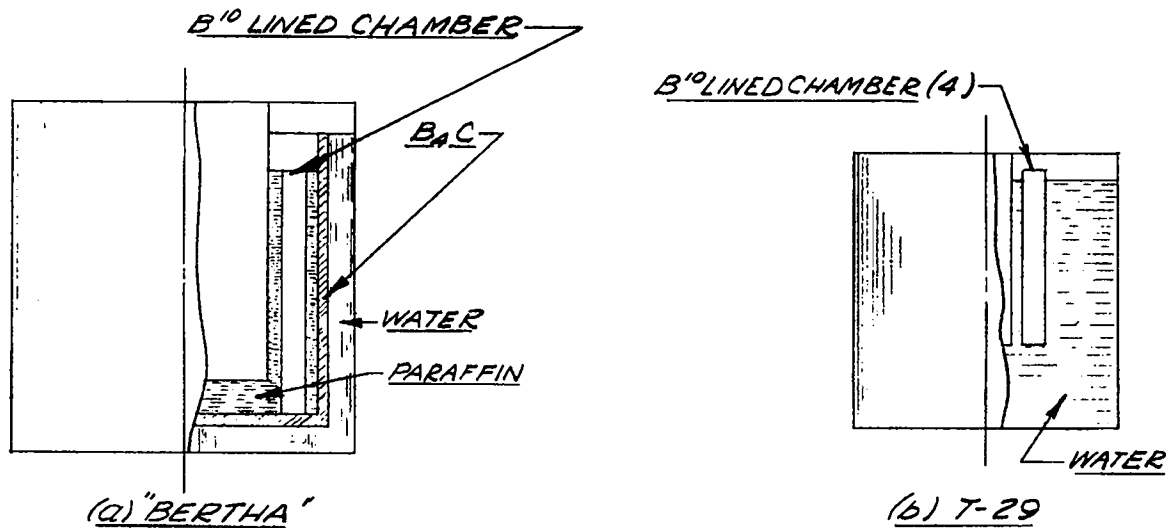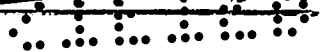
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B¹⁰ LINED CHAMBER

B₄C

WATER

PARAFFIN

(a) "BERTHA"

B¹⁰ LINED CHAMBER (4)

WATER

(b) T-29

SOURCE POSITION

BF³ COUNTER

TO 222 COUNTER

PARAFFIN

(C) "TWO HEADED MONSTER"

Fig. I. Geometries.

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- 7 -
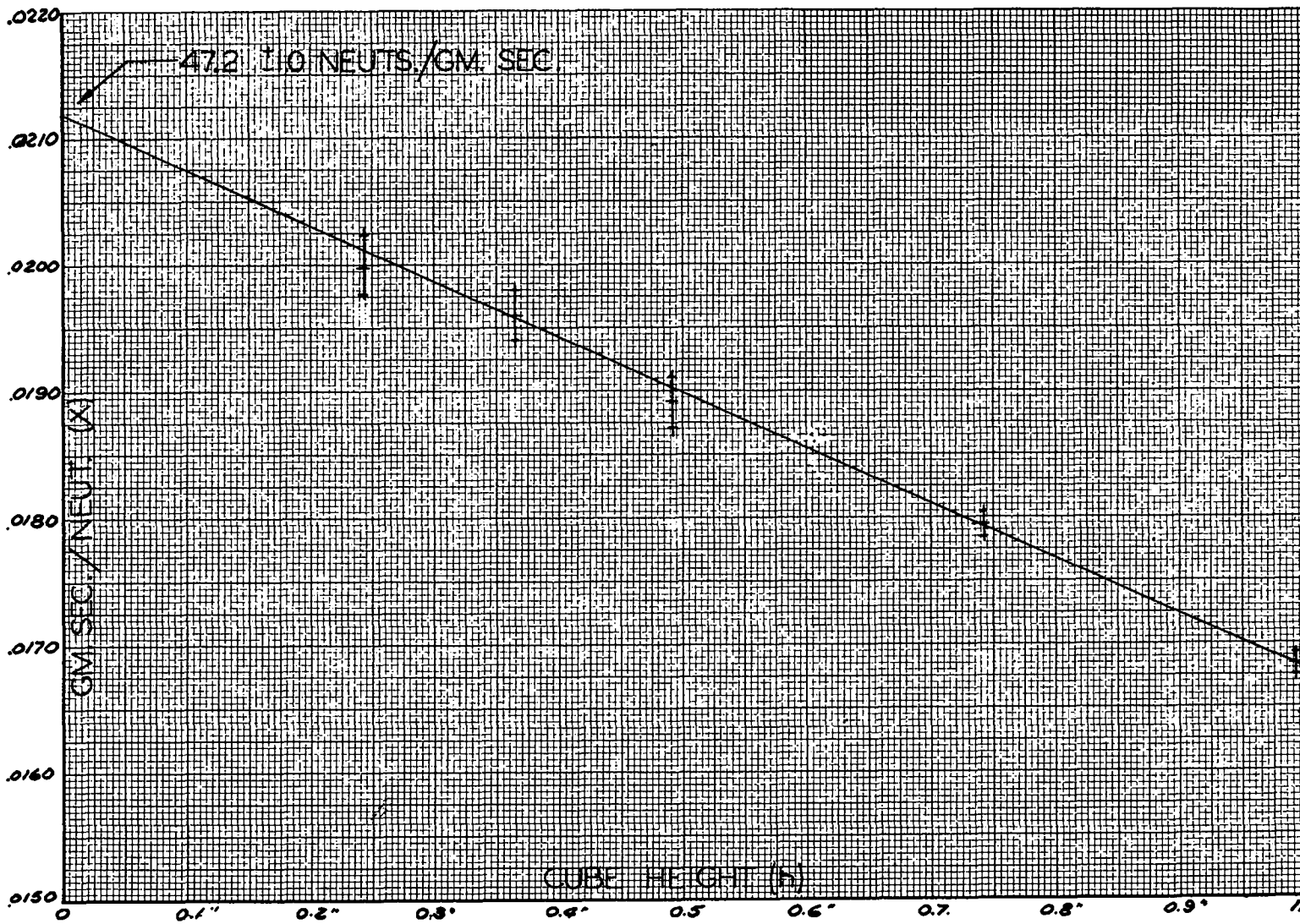
Fig. II.   "Bertha" counting data.   X = 0.02119-0.00439 h.

- 9 -
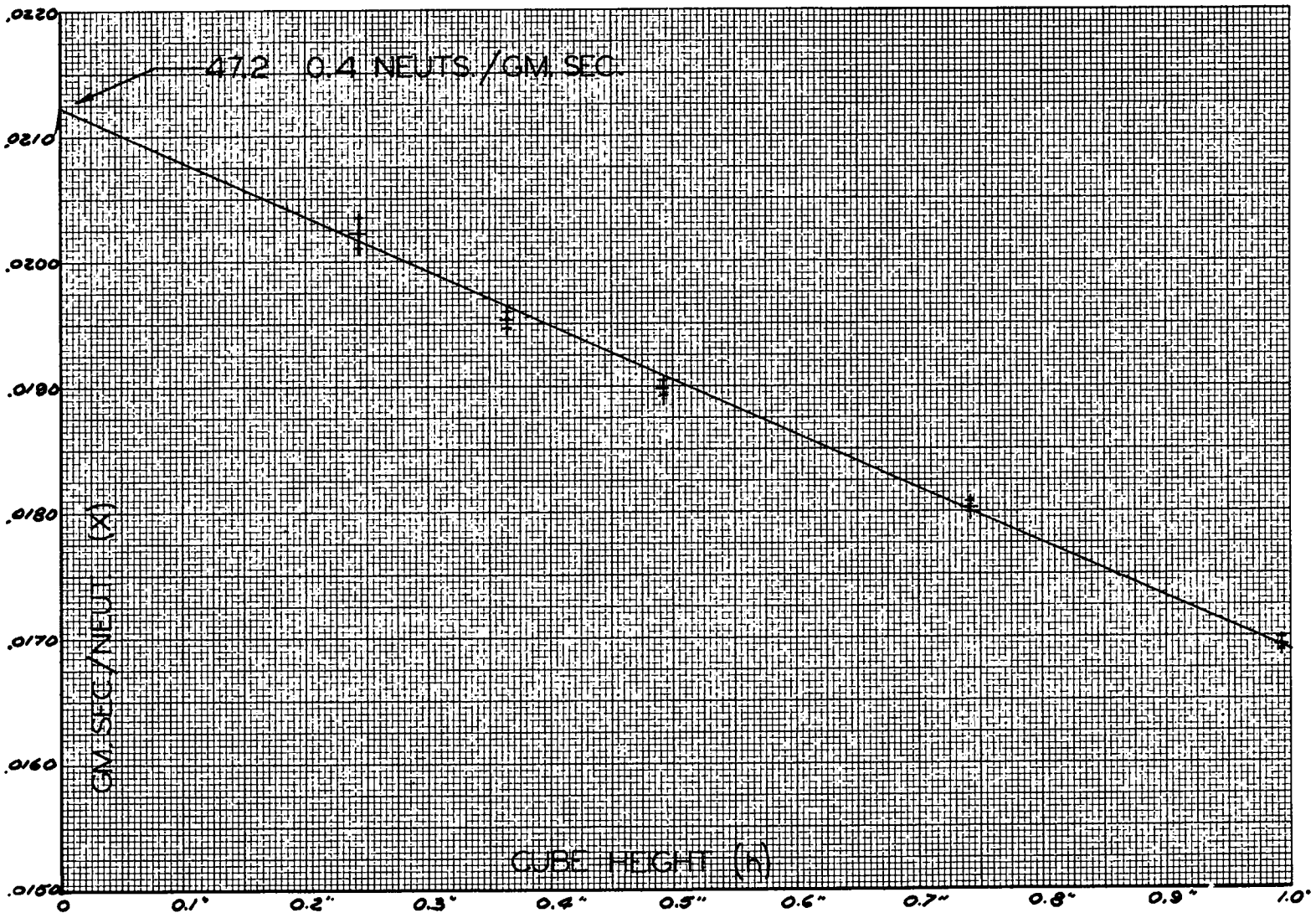
Fig. III.   T-29 counting data.   X = 0.02117-0.004266 h.
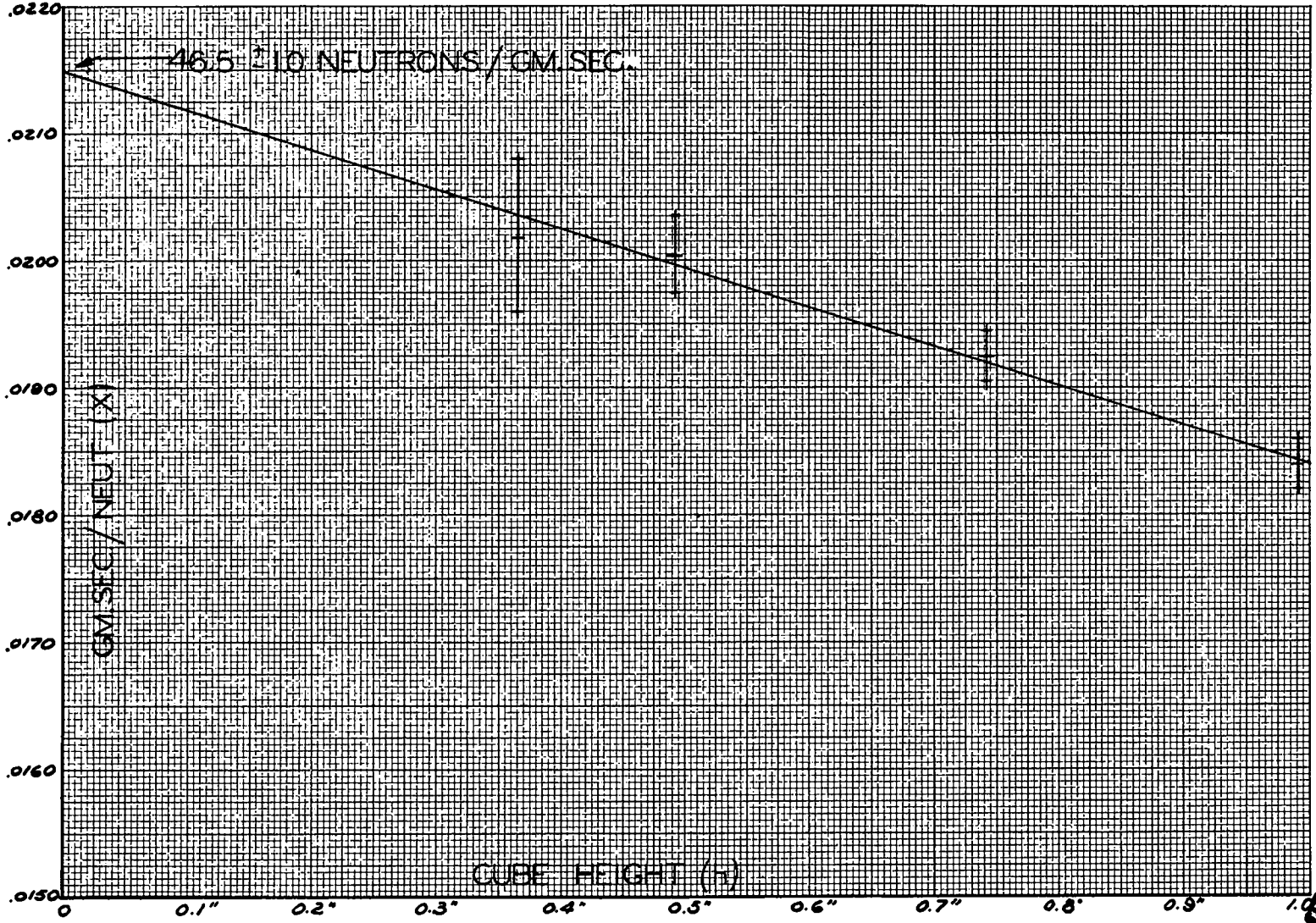
Fig. IV. "Two Headed Monster" counting data. X = 0.02149-0.003085 h.

- 11 -

Fig. V. 1/M vs cube height.