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INVESTIGATION OF PROPORTIONAL COUNTERS

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ABSTRACT

Experiments on proportional counters with various gas fillings have been carried out with the purpose of determining the gas multiplication as a function of voltage and pressure, and of investigating the uniformity of pulse height for a given primary ionization. It was found that counters can be made to operate satisfactorily with gas multiplications up to several hundred. The pulse height is independent of the distance from the wire at which the primary ionization takes place. No evidence was found for any spread in pulse height being introduced by gas multiplication. The gas multiplication decreases near the end of the wire because of the perturbation of the electric field by the supports at the wire. The normal value for the gas multiplication is only reached at a distance of the order of 10 times the diameter of the support.

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INVESTIGATION OF PROPORTIONAL COUNTERS

A study of proportional counters with cylindrical geometry has been carried out for the purpose of investigating:

A. Gas multiplication as a function of voltage and pressure.

B. Spread in pulse heights.

C. Pulse height as a function of distance of the ion track from the central wire.

D. End effects.

The counters investigated include:

1. Counters filled with a hydrogen containing gas for use as hydrogen recoil neutron detectors.

2. Boron trifluoride counters for use as (n,α) neutron detectors.

3. Counters with "inactive" gas fillings.

Some data regarding gas multiplication is available in the literature[1,2,3] but does not provide information on all the gases and pressures which are of interest.

The questions under B and C have been investigated previously by Brubaker and Pollard[4]. Their measurements indicate a large variation

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1) M. E. Rose and S. A. Korff, Phys. Rev. 59, 850 (1941

2) W. E. Ramsey and M. E. Rose, Phys. Rev. 61, 198 and 504, (1942)

3) S. A. Korff, Rev. Mod. Phys. 14, 1, (1942)

4) G. Brubaker and Pollard, Rev. Sci. Instr. 8, 255, (1937)

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of pulse height with distance from the wire and a large spread in pulse heights. The present investigation does not confirm the existence of either of these effects.

No information on end effects is found in the literature.

The counters used in the present investigation are represented by the diagrams in Figs. 1 and 2. In both counters a collimated beam of polonium alphas could be shot into the active volume through mica windows. In order to minimize the effects of straggling, the window thicknesses and pressures of the gas fillings were so chosen that the alphas completely traversed the counter. The pulses from the counter were amplified by an RC coupled linear amplifier in which the shortest time constant was one hundred microseconds. An electronic discriminator was used to determine the pulse height distributions.

A. Gas Multiplication

The gas multiplication is defined as the ratio of the total number of ions collected by the wire to the number of ion pairs produced by the ionizing particle. For a given gas, the gas multiplication M will be a function of the diameter of the wire, a, the diameter of the cylinder, b, the voltage across the counter, V, and the pressure, p. The nature of the cylinder may also influence the gas multiplication if the photoelectric effect on the wall plays any important role. If this is not the case, all the phenomena which are significant for the gas multiplication take place within a small distance from the central wire (up to a few times the wire radius). Hence M will not change if V and b are changed in

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such a way as not to alter the field near the wire. M will also remain unchanged if a and b are multiplied by a common factor k, p is divided by the same factor and V kept constant. In fact, by so doing all linear dimensions, including the mean free paths, are changed by the same factor k and the electric fields at corresponding points are also changed by the same factor. It follows that M can be expressed as a function of $V/\log(b/a)$ and of pa:

$$M = M\left[V/\log(b/a), pa\right]$$

Hence it is sufficient to investigate the dependence of M on only two variables, for which we have chosen V and p.

Experimentally, the gas multiplication was measured in the following way. Alpha particles from a polonium source were shot across the counter and the pulse height at the output of the amplifier was recorded. Then the voltage across the counter was reduced until the counter was operating as an ionization chamber without gas multiplication and the gain of the amplifier increased until the output pulses had again the same amplitude. The required increase of the gain of the amplifier was taken as a measure of the gas multiplication.

This procedure is not entirely accurate since, when the counter is operated as an ionization chamber, only that part of the pulses is recorded which is due to the motion of the electrons. However, the error is small because most of the voltage drop takes place in the neighborhood of the positive central wire.

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For low stopping powers, the pulse height was too small to measure without gas multiplication. In these cases the pulse height was computed from the value observed at a higher pressure by assuming that without gas multiplication the pulse height is proportional to pressure. This is not quite correct because of the variation of specific ionization with energy for alpha particles. It may be pointed out that neither of the sources of error mentioned will affect the relative values of the gas multiplication, but will only affect, in a small degree, the absolute value of this quantity.

The graphs in Figs. 3 to 12 give gas multiplication as a function of voltage for constant pressure and voltage as a function of pressure for constant gas multiplication for the following gases: hydrogen, methane, 90 per cent hydrogen plus 10 per cent methane, argon, 98 per cent argon plus 2 per cent CO_2. The data were taken with the counter in Fig. 2 ($a = .010''$, $b = 7/8''$). The beam of alphas is passed through the counter perpendicularly to the wire at a distance of 1/4" from the wire.

The graph in Fig. 13 gives gas multiplication as a function of voltage for 10 cm of boron trifluoride. These measurements were taken with the counter in Fig. 1 ($a = .010''$, $b = 1\ 1/2''$) in which the alphas were shot parallel to the wire. In this case, for the absolute evaluation of the gas multiplication, one must consider that when the counter is used as an ionization chamber, the collecting electrode includes the supports of the wire. In all cases, except for very low pressures, the limiting factor on the amount of gas multiplication observable was saturation of the pre-amplifier.

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From an examination of the graphs one can draw the following conclusions:

1) In all cases except for low pressures of hydrogen and argon, the gas multiplication in the region 20 to 500 is an approximately exponential function of voltage.

2) At high pressures (above 15 cm) all of the gases investigated are suitable for proportional counters. That is, the gas multiplication does not increase too rapidly with voltage. The change in voltage corresponding to a change of a factor two in gas multiplication is of the order of 100 volts.

   For low pressures of hydrogen and argon the increase of gas amplification with voltage is so rapid that the counters are difficult to use. The addition of a small amount of methane to hydrogen or of carbon dioxide to argon improves the operation of the counters very considerably.

In all the measurements discussed above, the counters were filled with gases directly from the tank with no purification. The rated purities are: Argon - 99.6 percent, hydrogen - unknown, methane - 85 percent, borontrifluoride - 97 percent. The gas amplification vs. voltage was measured also with a counter which was outgassed for 12 hours at 170° centigrade and filled with 22 cm of carefully purified hydrogen. The results do not differ appreciably from those obtained with ordinary tank hydrogen at the same pressure.

No data were taken with very pure argon during the present

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investigations. However, proportional counters have been operated in this laboratory with highly purified argon at 15 cm pressure (R. W. Thompson) and the gas multiplication was found to increase with voltage more rapidly than in the case of counters with non purified argon.

B. Spread in Pulse Height

If one plots counting rate as a function of bias setting one obtains curves of the type represented in Figs. 14 and 17. We shall measure the average pulse height by the value of the bias voltage at which the counting rate is reduced to one half of the value on the plateau. The spread will be measured by $\Delta V/V_0$ where ΔV is the difference between the bias voltage at which the counting rate is reduced to 75 percent and 25 percent respectively.

No relation has been established between the spread and either the amount of gas multiplication or the pressure. We believe that the observed spreads are mainly due to lack of monochromaticity of the source, to geometrical factors such as inequalities of path length of the alphas in the counter and to straggling of ionization. This belief is strengthened by the fact, that other conditions being the same, about the same spread is obtained both with and without gas multiplication. The smallest spreads were obtained by placing a very thin and clean polonium source inside the counter (Fig. 1, position c) so that no windows were traversed, and the alphas were far from the end of their range. The spreads $\Delta V/V_0$ observed varied from 5 per cent to 12 per cent with different fillings. The maximum

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difference in path lengths of the alphas in the counter amounted to 6.3 per cent. It should be noted that when alphas were introduced into the counter through windows, the spread was generally larger. Particularly large spreads were obtained with old windows that had probably become dirty.

The above results on spread of pulse height were obtained with CH_4 and H_2 plus CH_4 fillings, and pressures ranging from 10 to 40 cm. No definite assurance can be given at the present time that these results are valid also for other gases and pressures.

C. Variation of Pulse Height as a Function of Distance from the Wire

Since the gas multiplication takes place within a very small distance from the wire, one should not expect any variation of pulse height with distance of the ion track from the wire unless electron capture takes place. This effect, which is a priori not unlikely because of the weakness of the field near the cylinder, would tend to make the pulse height a decreasing function of distance from the wire.

Measurements on variation of pulse height with position were carried out with the counter in Fig. 1. The end plate (B) carries a number of holes arranged along a radius, which are covered with a thin mica window. Through these holes a well collimated beam of alpha particles can be shot parallel to the wire and at different distances from it. Great care must be taken to insure uniformity of the window since a variation of the thickness can easily cause a difference between bias curves observed at various positions of the source. Actually several

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different windows were used as a check upon this source of error.

We shall define the "edge to center" ratio as the ratio between the average pulse height produced by alphas passing near the cylinder to the average pulse height produced by alphas passing near the wire.

Some of the results on edge to center ratio obtained with wire supports shown in Fig. 1 are given in Table I.

Table I

Gas	Pressure (cm)	Gas Multiplication	Edge to Center Ratio
Purified H_2	22	512	.81
Tank H_2	22	500	.84
90% H_2 plus 10% CH_4	22	600	.80
Methane	11	380	.83

No dependence of edge to center ratio on gas filling is indicated by the above figures. Other experiments failed to detect any dependence on the magnitude of gas multiplication. Hence it was felt that the effects observed might be due to the distortion of the electric field by the supports of the wire. When the supports are considerably thicker than the wire, as in the measurements under consideration, the bending of the lines of force causes a smaller length to be collected from an ion track near the cylinder than near the wire (see Fig. 15). Accordingly the wire supports were changed as indicated in Fig. 16. With this arrangement the active length of the wire was limited by two tubes .025" in diameter, i.e. only 2 1/2 times larger in diameter than the wire itself.

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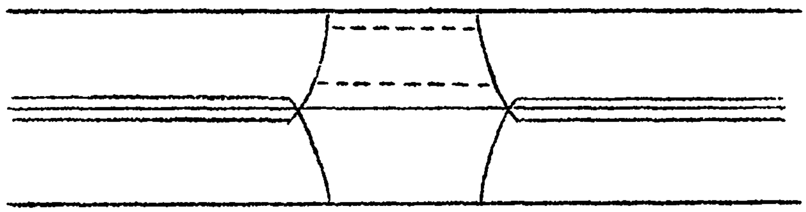

Fig. 15

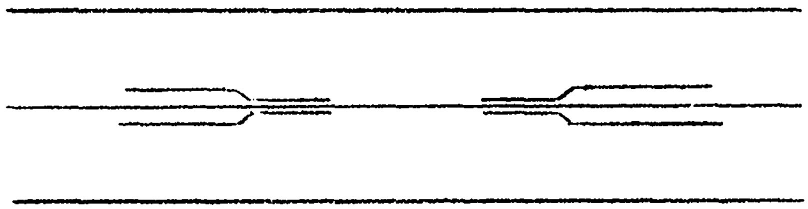

Fig. 16

Typical bias curves obtained near the wire and near the cylinder with the new wire supports are shown in Fig. 17. The edge to center ratios for various gases are given in Table II.

Table II

Gas	Pressure (cm)	Gas Multiplication	Edge to Center Ratio
H_2	22	250	1.02
CH_4	22	57	1.02
BF_3	10	80	1.00

These ratios may all be taken as unity within the accuracy of the experiment.

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In conclusion, no effects of electron capture on the operation of the proportional counter were detected for the pressures and gases used.

D. End Effects

It is customary to limit the effective volume of a counter by terminating the wire with a tube or a rod of a larger diameter. Such an arrangement, however, as shown by the results in the preceding section produces a perturbation of the field which may effect the gas multiplication in the neighborhood of the support. This effect has been investigated with the counter in Fig. 2. A collimated beam of alphas was passed through the counter perpendicularly to the wire at a distance of 1/4" from the axis of the counter. The .010" wire was terminated with tubes made from hypodermic needles .040" and .025" in diameter. Bias curves were taken with the alpha beam crossing the counter at different distances from the cross-sectional plane which contains the end of the supporting tube. The average pulse height increases rapidly with distance from this plane and reaches 75 per cent of the maximum value at 6 mm with the .025" tube and 8 mm with the .040" tube.

Some of the bias curves obtained for different positions of the beam of alphas are presented in Fig. 18. The average pulse height is plotted against distance from the end of the wire in Fig. 19. The large spread in pulse height for small values of this distance is accounted for by the finite width of the beam of alpha particles (approx. 1 mm at the center wire) and by the very rapid variation of gas multiplication along the wire.

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It may be noted that a small amount of gas multiplication takes place at the .025" tube if the multiplication at the wire is sufficiently high. With a gas multiplication of 256 at the wire, the gas multiplication at the tube is 10.

The reduction of gas multiplication near the end of the wire is most likely accounted for by a decrease in field strength due to the support.

The end effects described above introduce an uncertainty in the counting volume of a counter. These effects are not negligible for practical counter lengths, and cannot be decreased by decreasing the diameter of the support because gas amplification at the support becomes important if its diameter is less than 2.5 times the wire diameter.

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Fig. 1, Test Proportional Counter

The high-voltage electrode (a) is a brass cylinder 1 1/2" in diameter. Glass kovar seals are used as outlets for the high voltage electrode and for the central wire. The vacuum seals are made with fuse wire gaskets. 14 holes, 2 mm apart are drilled along a radius of the end plate (b). The holes are covered with a thin mica window (0.007g/cm^2) sealed with glyptal. A Po source carried by the plug (c) can be placed inside the case so that alpha particles can be shot across the counter through the hole (d) in the high voltage cylinder.

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This document contains information affecting the national defense of the United States within the meaning of [redacted]

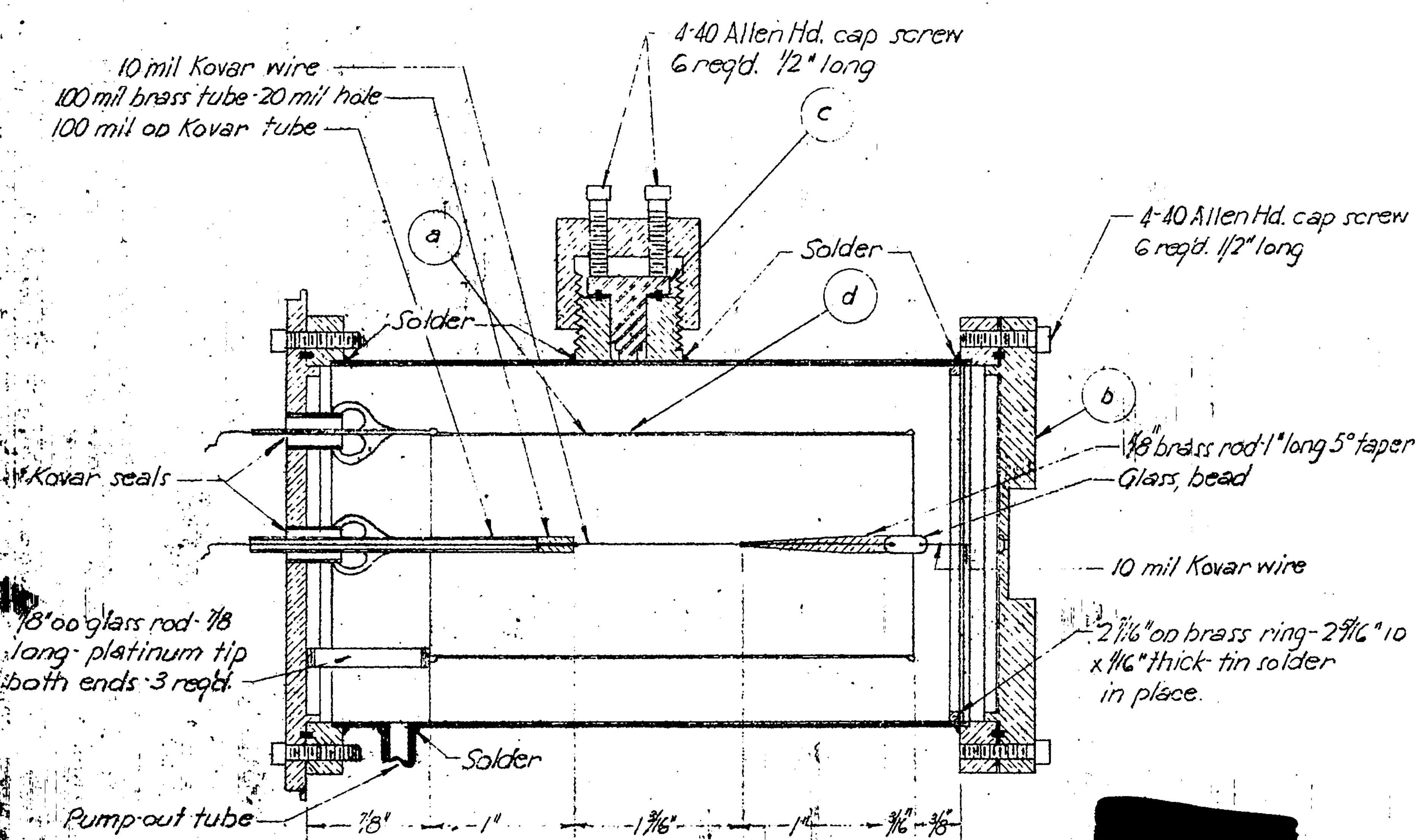

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FIG. 1

Scale: Full size

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Fig. 2, Test Proportional Counter

The high-voltage electrode is formed by a brass block with a cylindrical hole 7/8" in diameter. The outlets for the central wire are kovar glass seals. The kovar cylinders (a) (a) are grounded and serve as guard rings. Alpha particles from a well collimated Po source can be shot across the counter perpendicularly to the axis and at a distance of 1/4" from it, through a series of holes (b). These are covered by a thin mica window sealed with glyptal. The joints are soldered with pure tin so that the counter can be backed at about 200° C.

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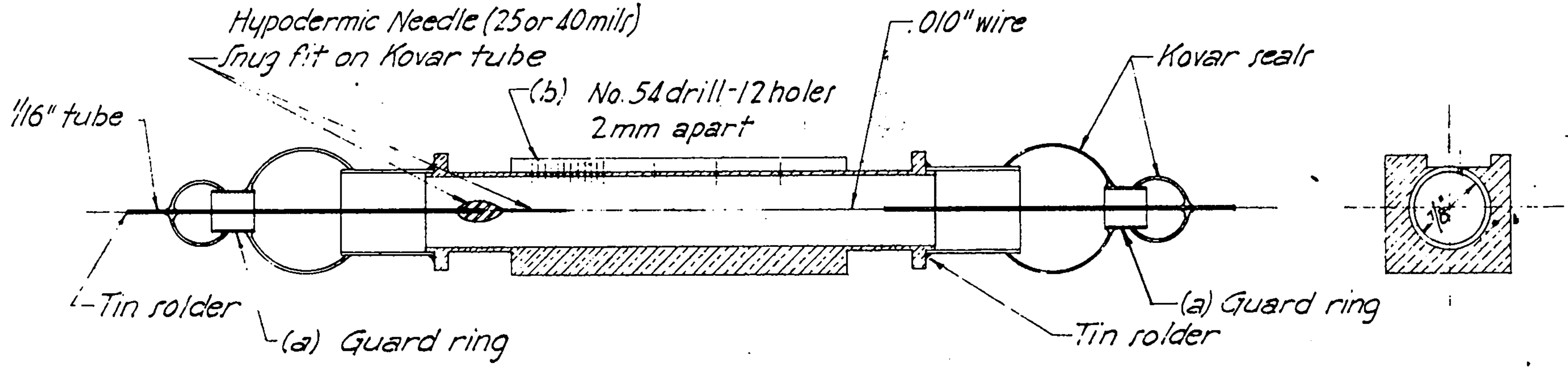

FIG. 2
Construction of counter which was used to test end effects & to study gas multiplication as a function of voltage & pressure

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Scale 1/2 full size

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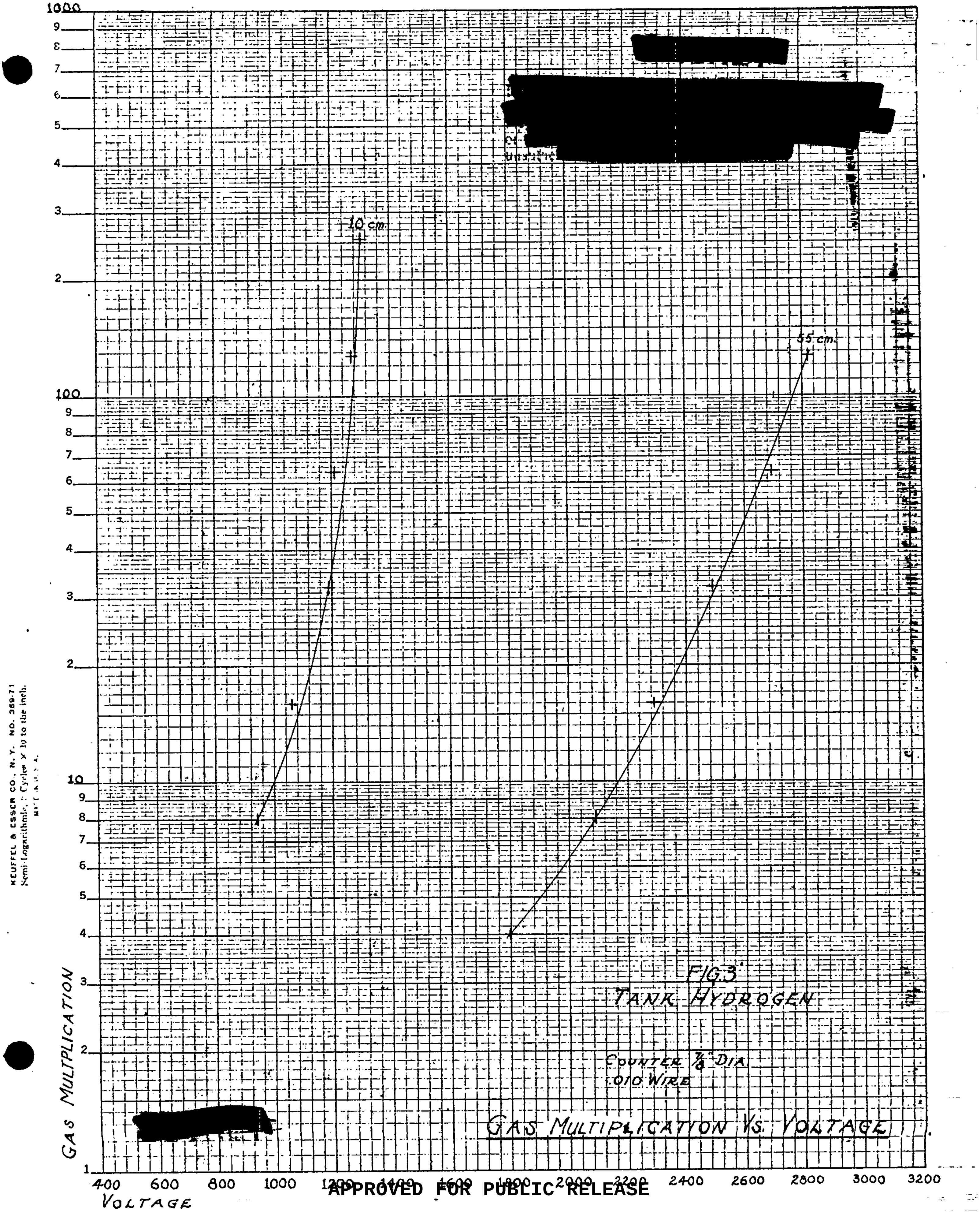
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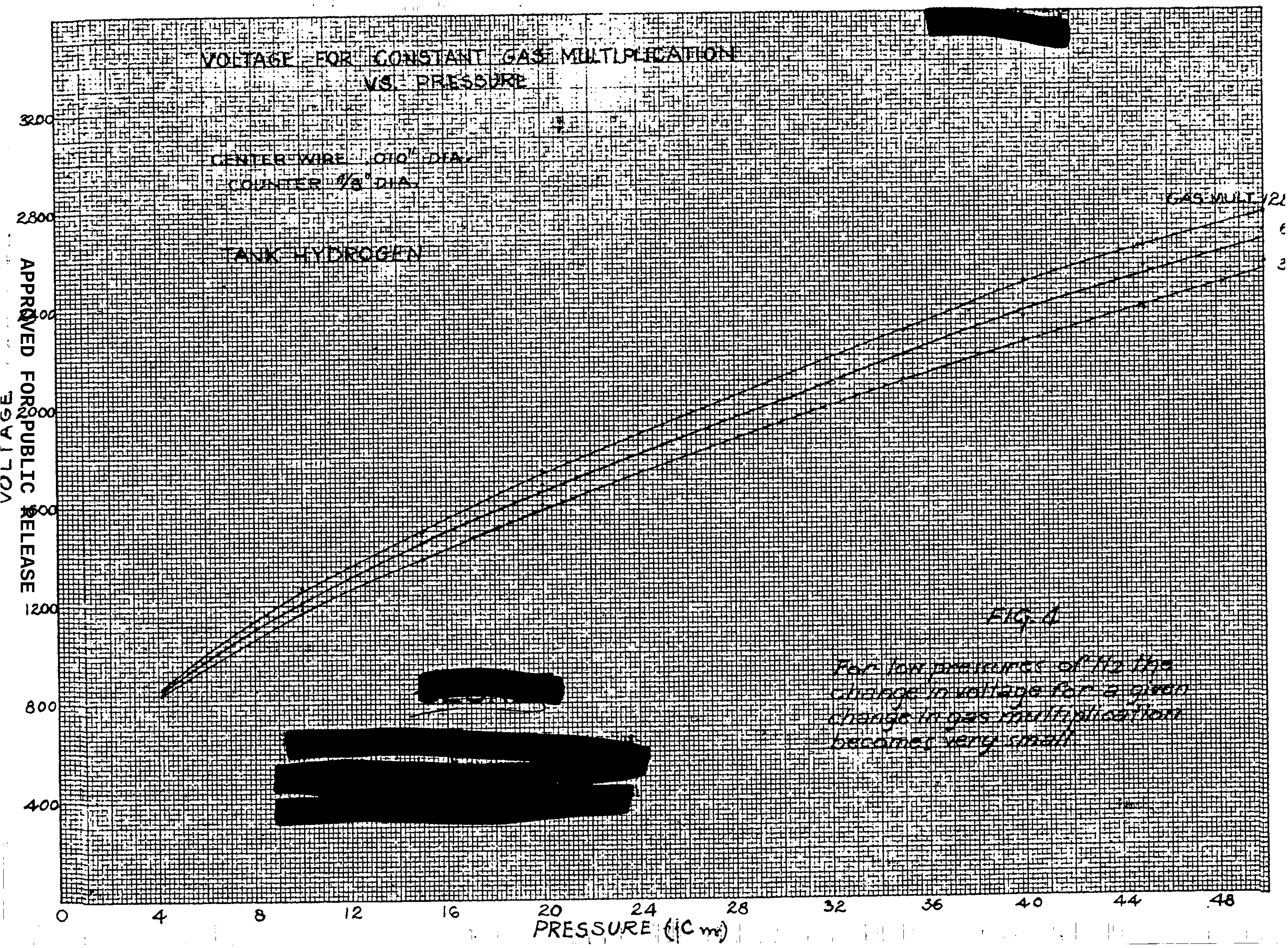
10 cm.
55 cm.
FIG.3
TANK HYDROGEN
COUNTER 7/8" DIA
.010 WIRE
GAS MULTIPLICATION VS. VOLTAGE
GAS MULTIPLICATION
VOLTAGE
400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200
KEUFFEL & ESSER CO., N.Y. NO. 359-71
Semi-Logarithmic, 3 Cycles X 10 to the inch.
[redacted]



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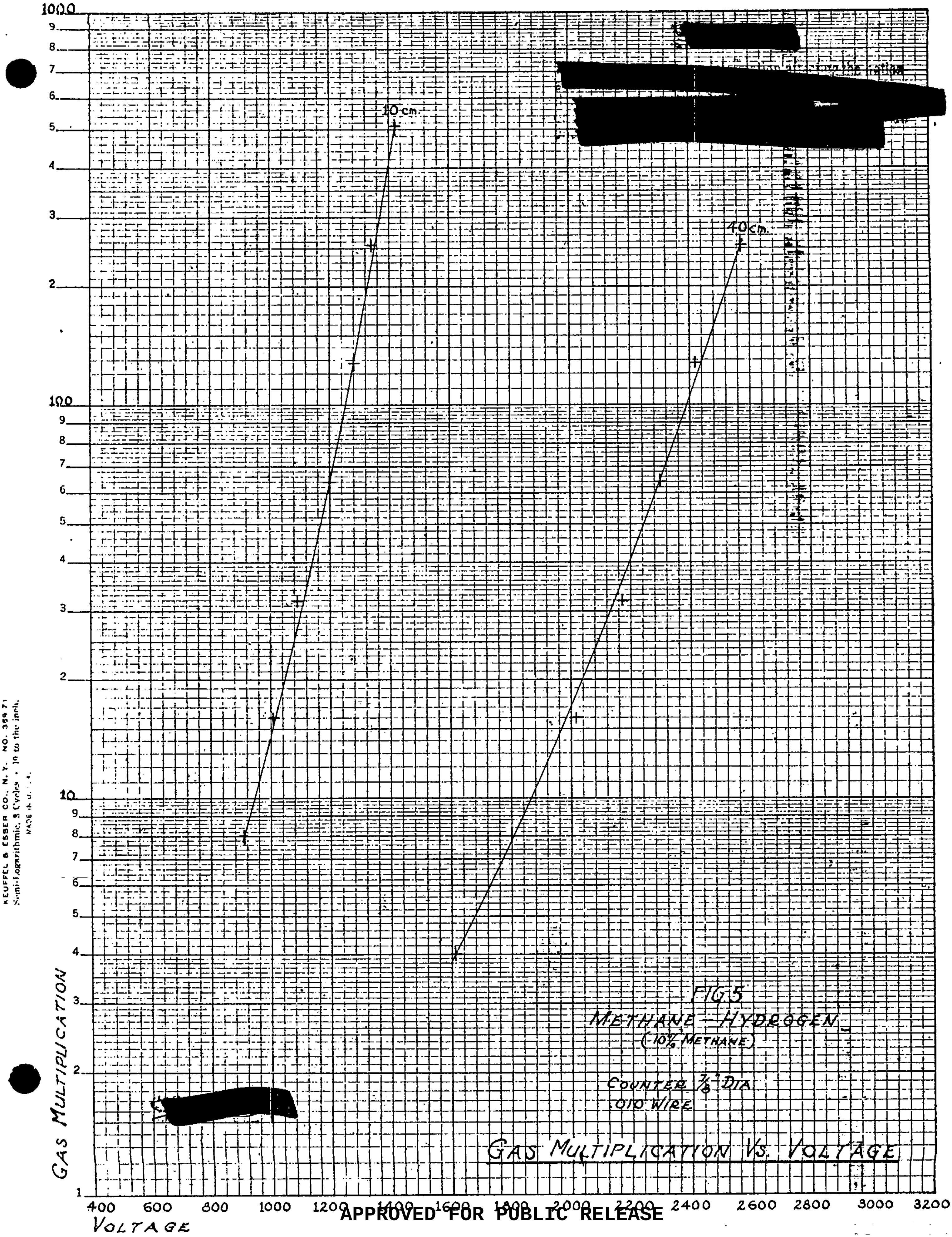

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10 cm.
40 cm.
FIG. 5
METHANE - HYDROGEN
(10% METHANE)
COUNTER 7/8" DIA
.010 WIRE
GAS MULTIPLICATION VS. VOLTAGE
GAS MULTIPLICATION
VOLTAGE
1000
100
10
1
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
KEUFFEL & ESSER CO., N. Y. NO. 359-71
Semi-Logarithmic, 3 Cycles × 10 to the inch.
MADE IN U. S. A.
[redacted]

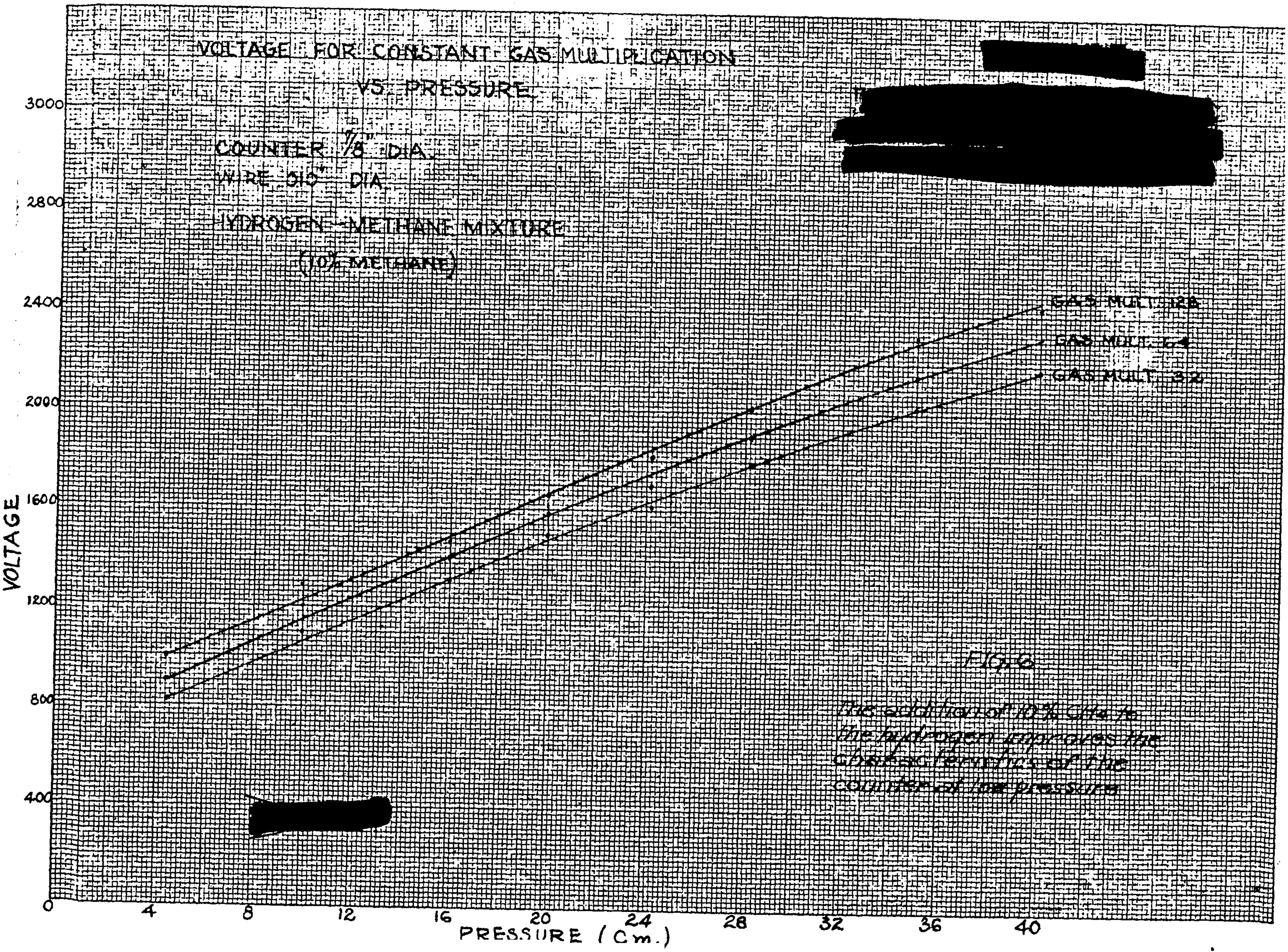
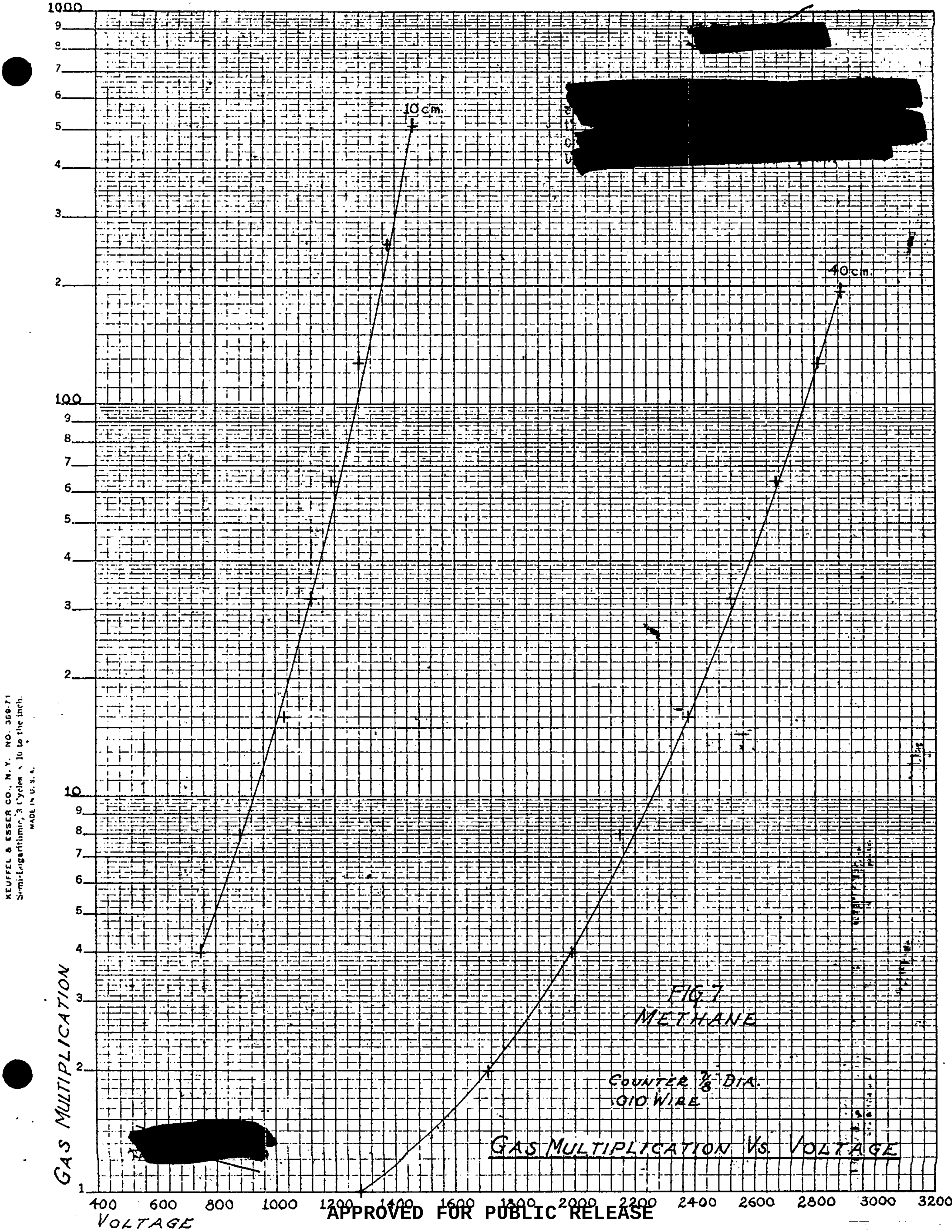
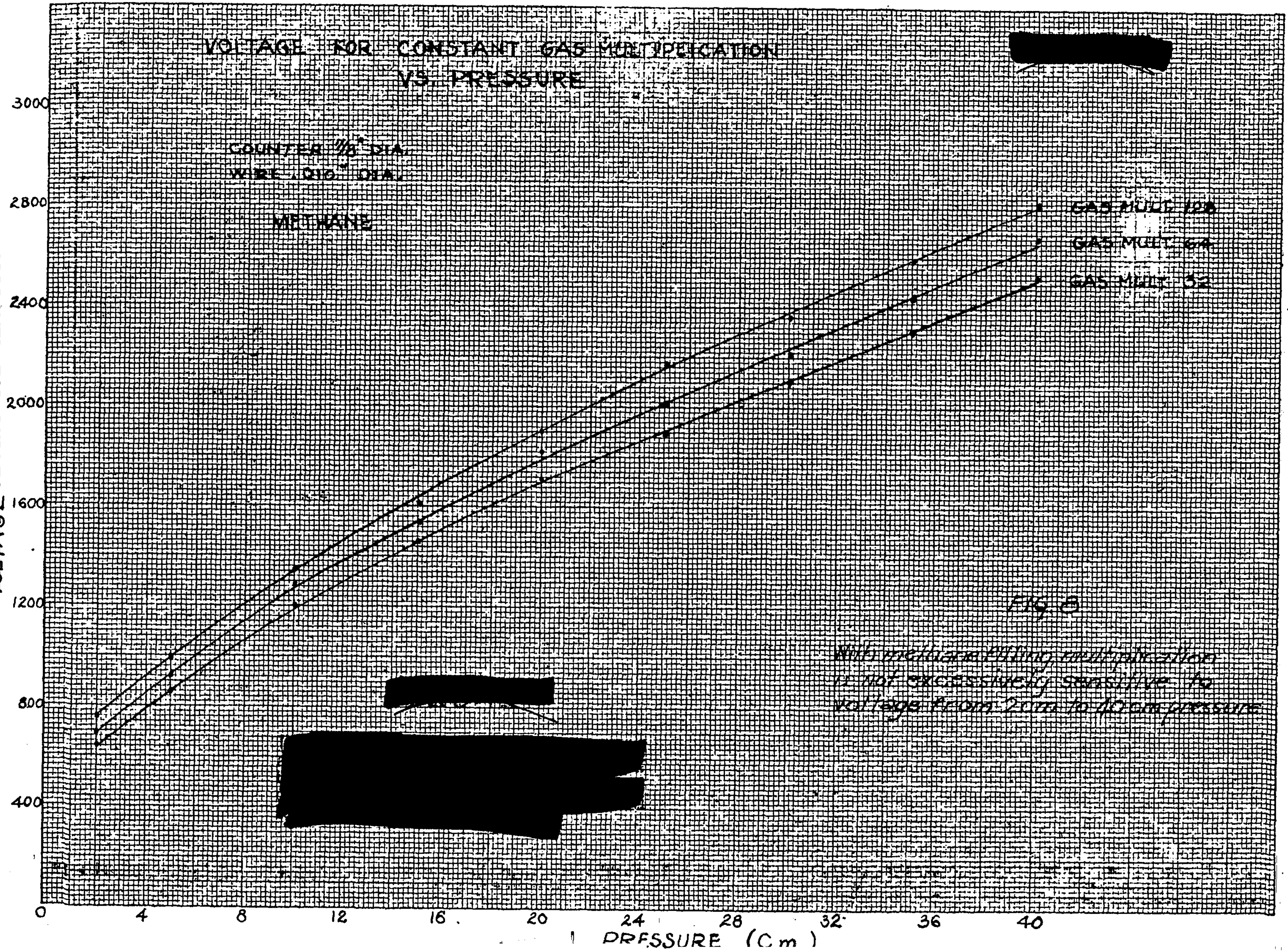


FIG. 6

The addition of 10% CH_4 to the hydrogen improves the characteristics of the counter at low pressure


10cm.
40cm.
FIG 7
METHANE
COUNTER 7/8 DIA.
.010 WIRE
GAS MULTIPLICATION VS. VOLTAGE
GAS MULTIPLICATION
VOLTAGE
1000
100
10
1
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
KEUFFEL & ESSER CO., N.Y. NO. 359-71
Semi-Logarithmic, 3 Cycles x 10 to the inch.
MADE IN U.S.A.



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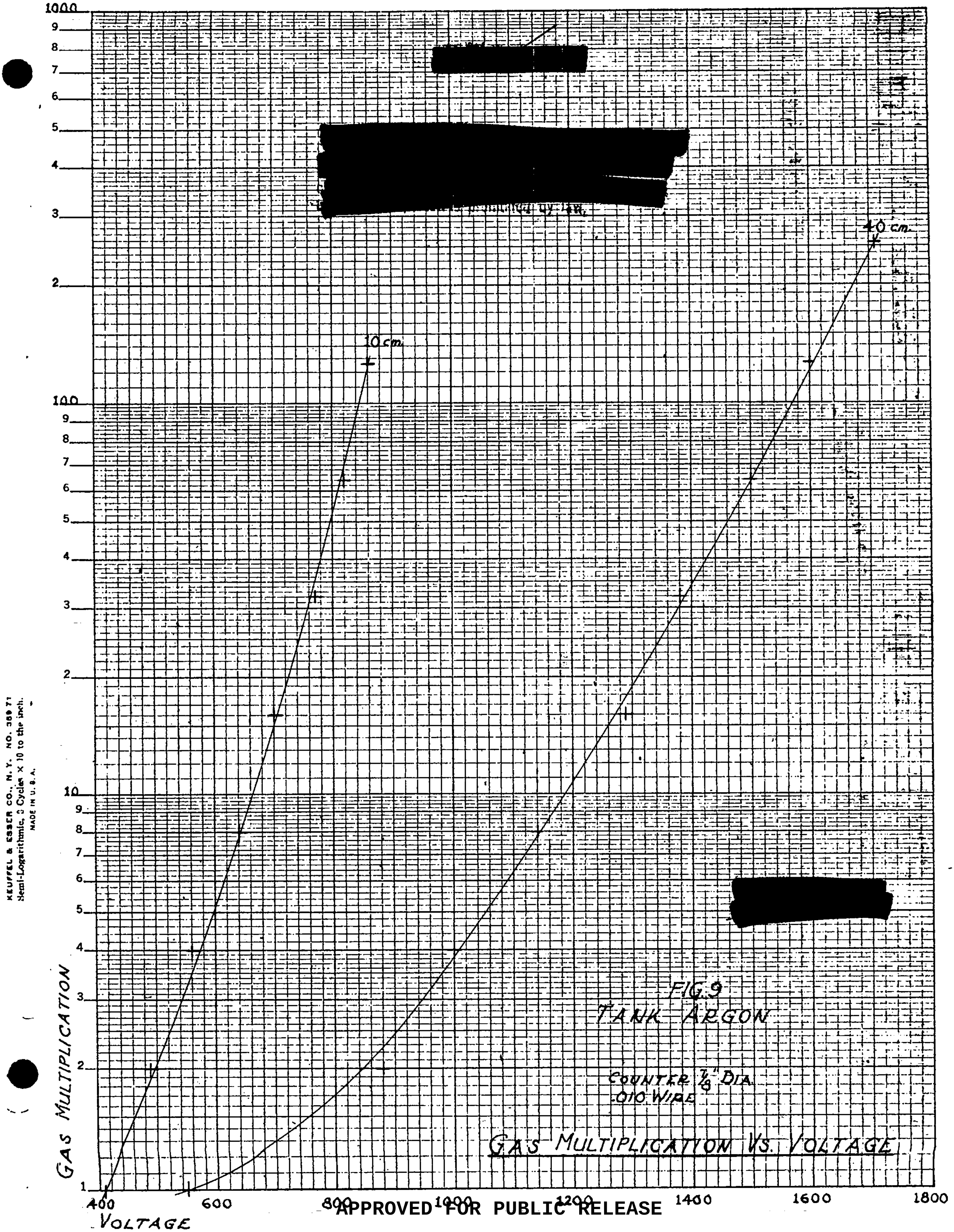

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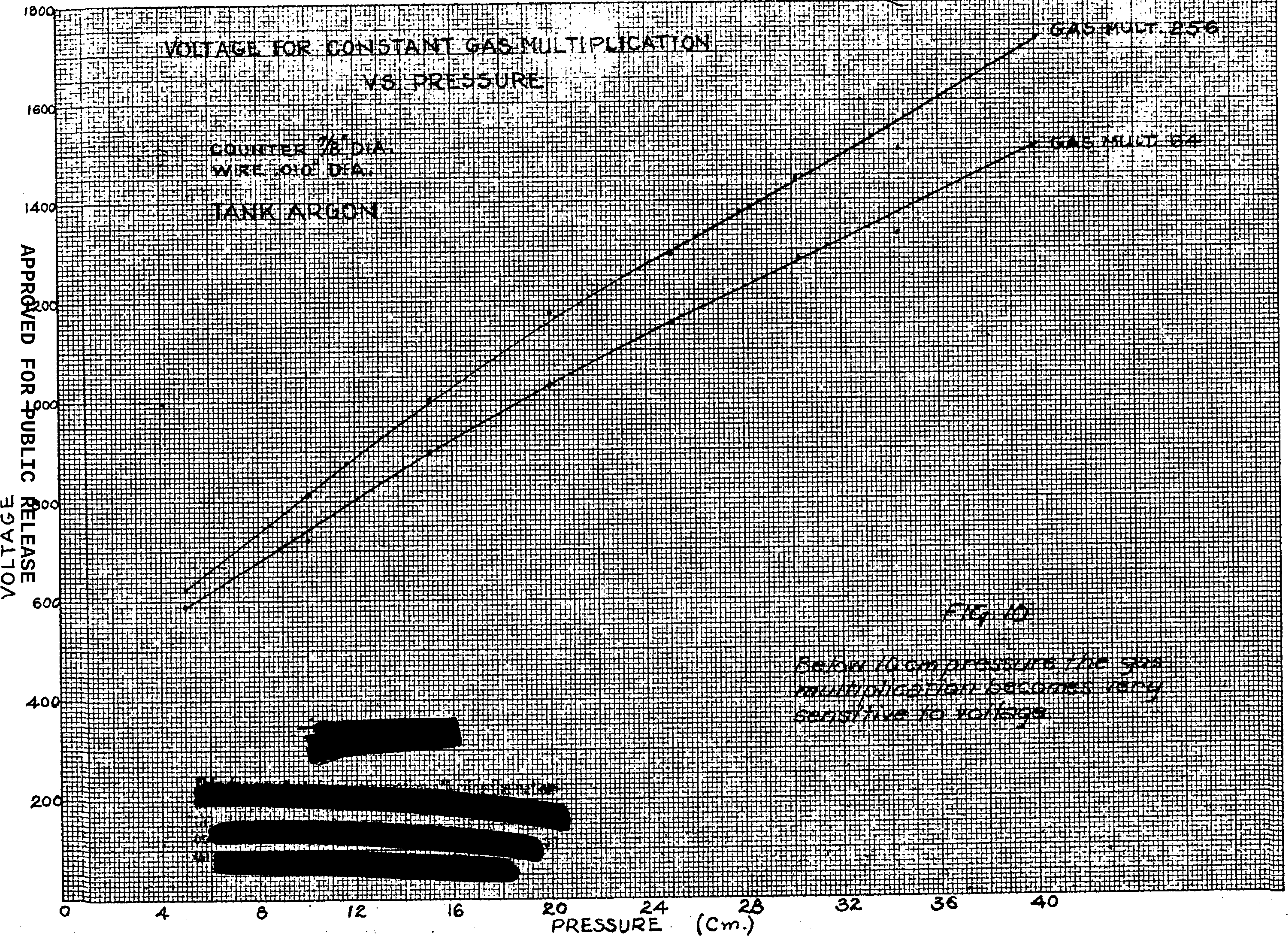

Fig. 10

Below 10 cm pressure the gas multiplication becomes very sensitive to voltage.

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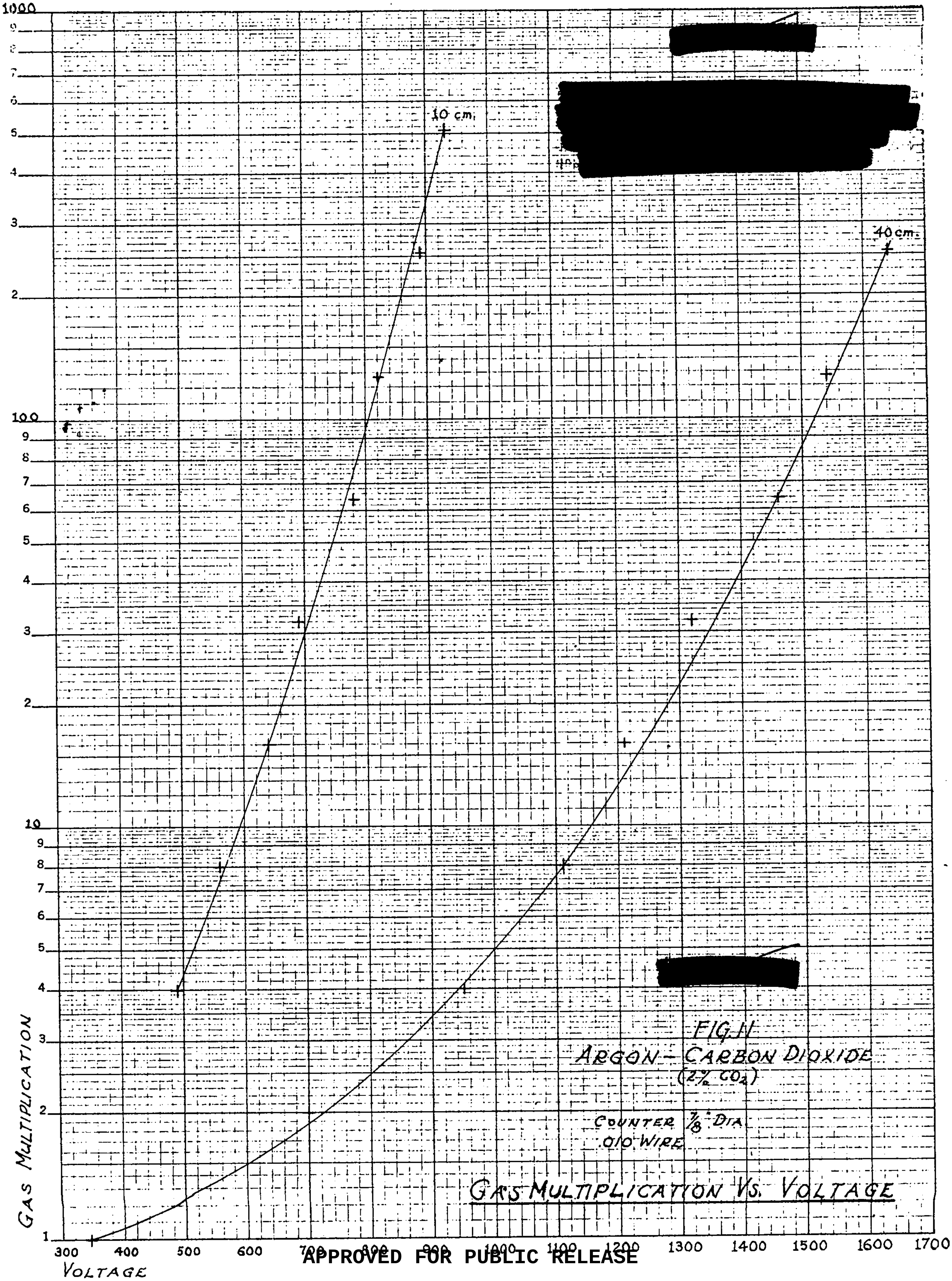

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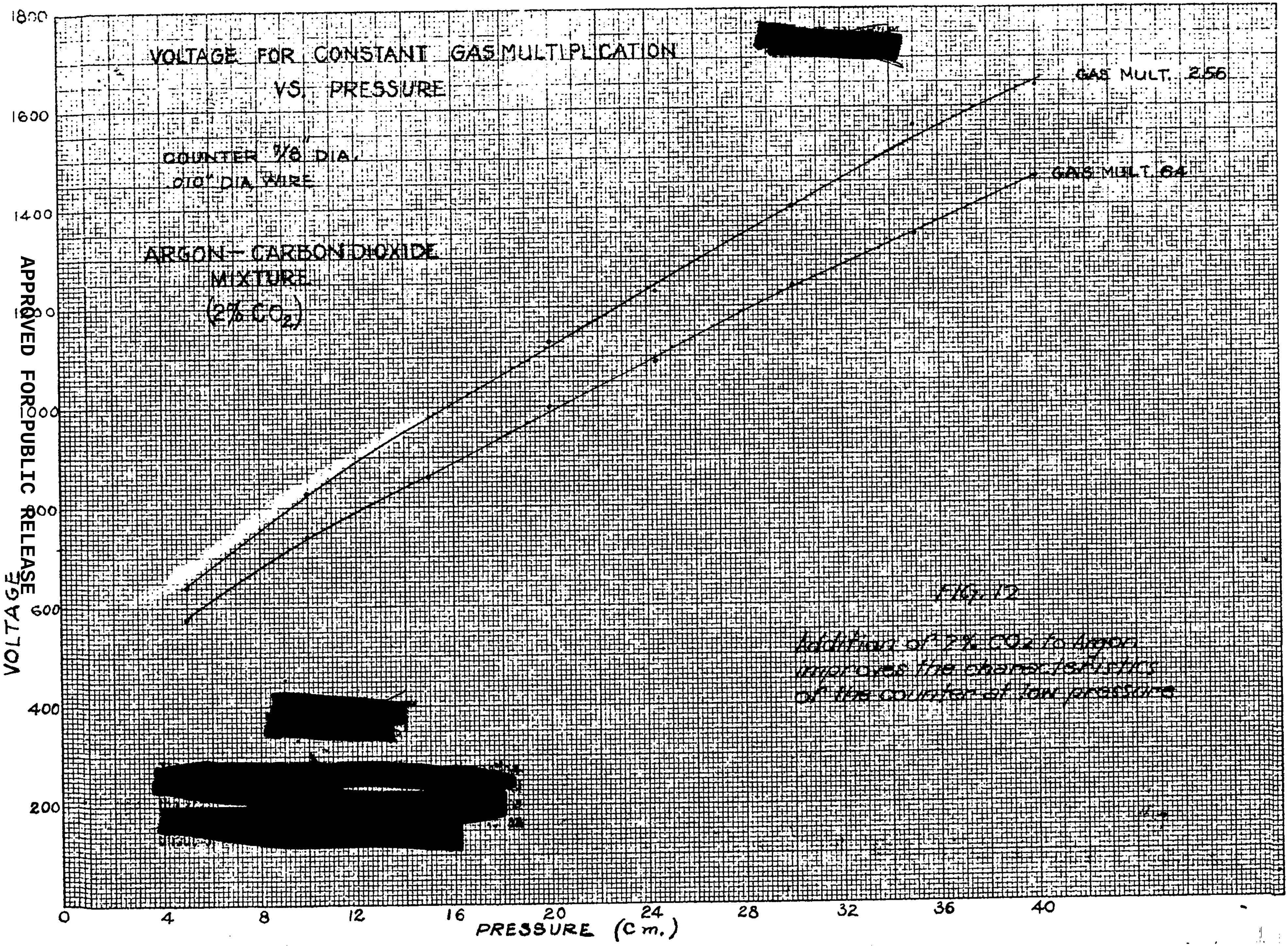

Fig. 12

Addition of 2% CO_2 to Argon improves the characteristics of the counter at low pressure

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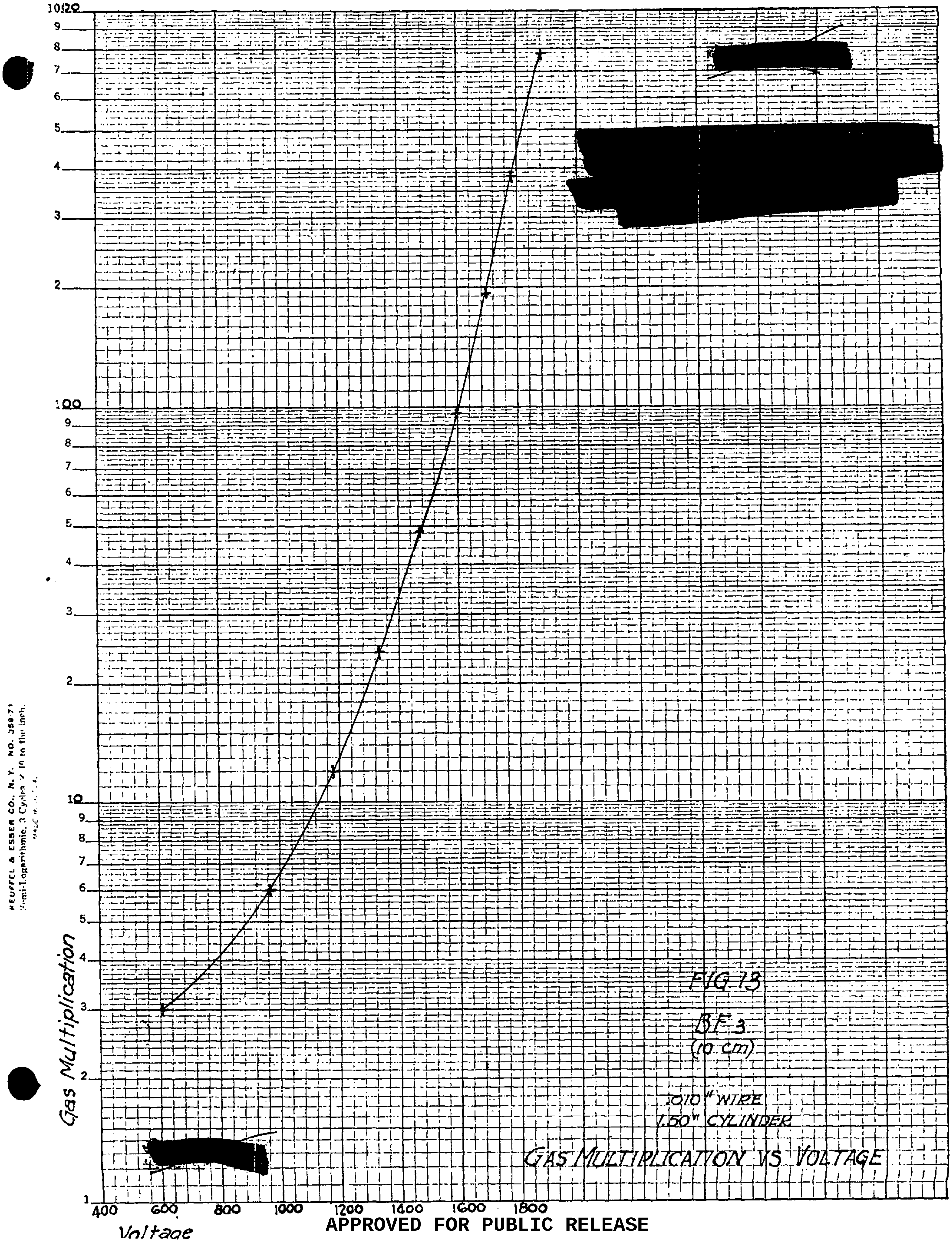
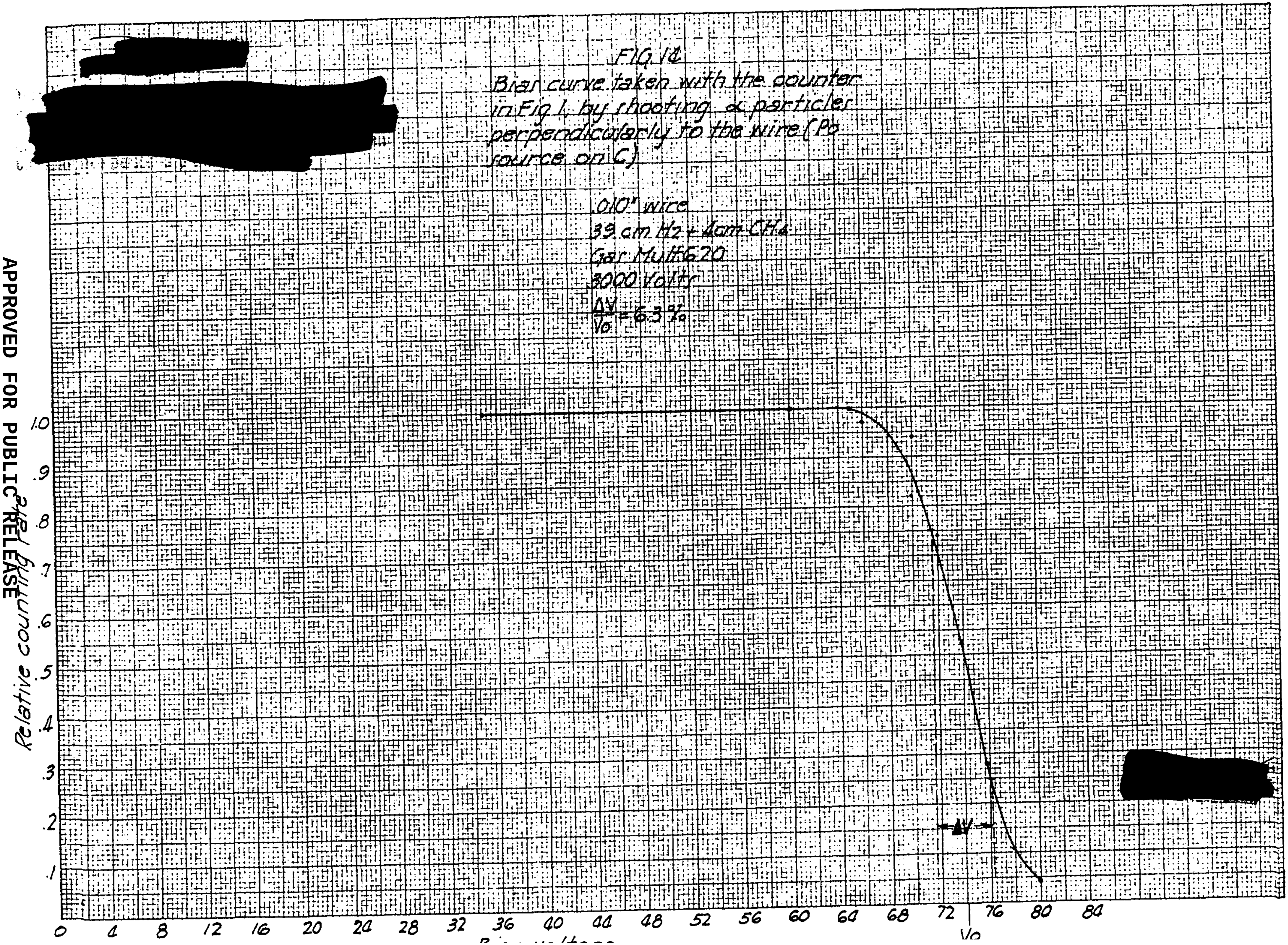


FIG 13
BF 3
(10 cm)
.010" WIRE
1.50" CYLINDER
GAS MULTIPLICATION VS VOLTAGE
Gas Multiplication
Voltage
1000
100
10
1
400
600
800
1000
1200
1400
1600
1800
[redacted]
[redacted]
[redacted]
KEUFFEL & ESSER CO., N.Y. NO. 359-71
Semi-Logarithmic, 3 Cycles X 10 to the inch.



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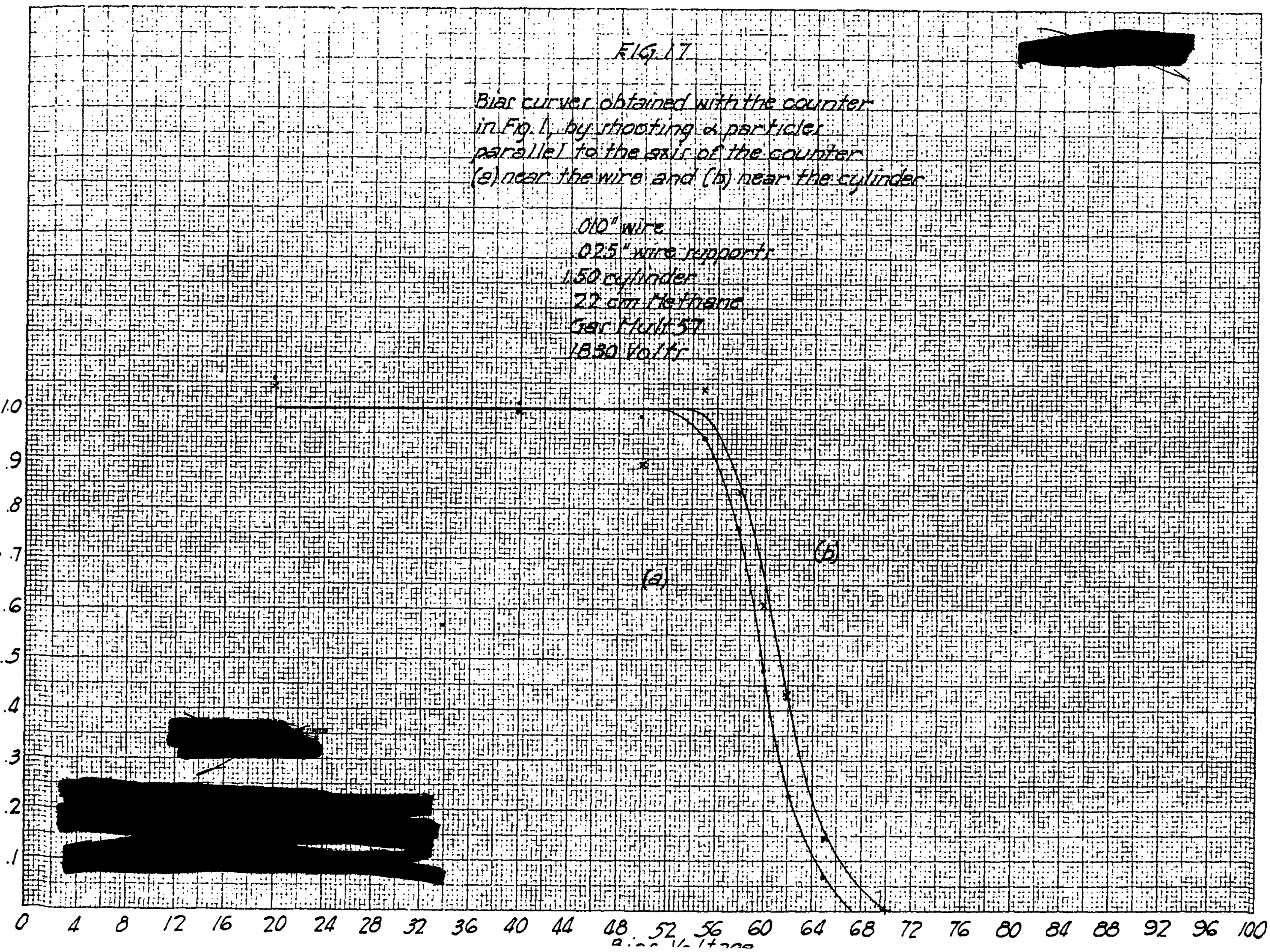

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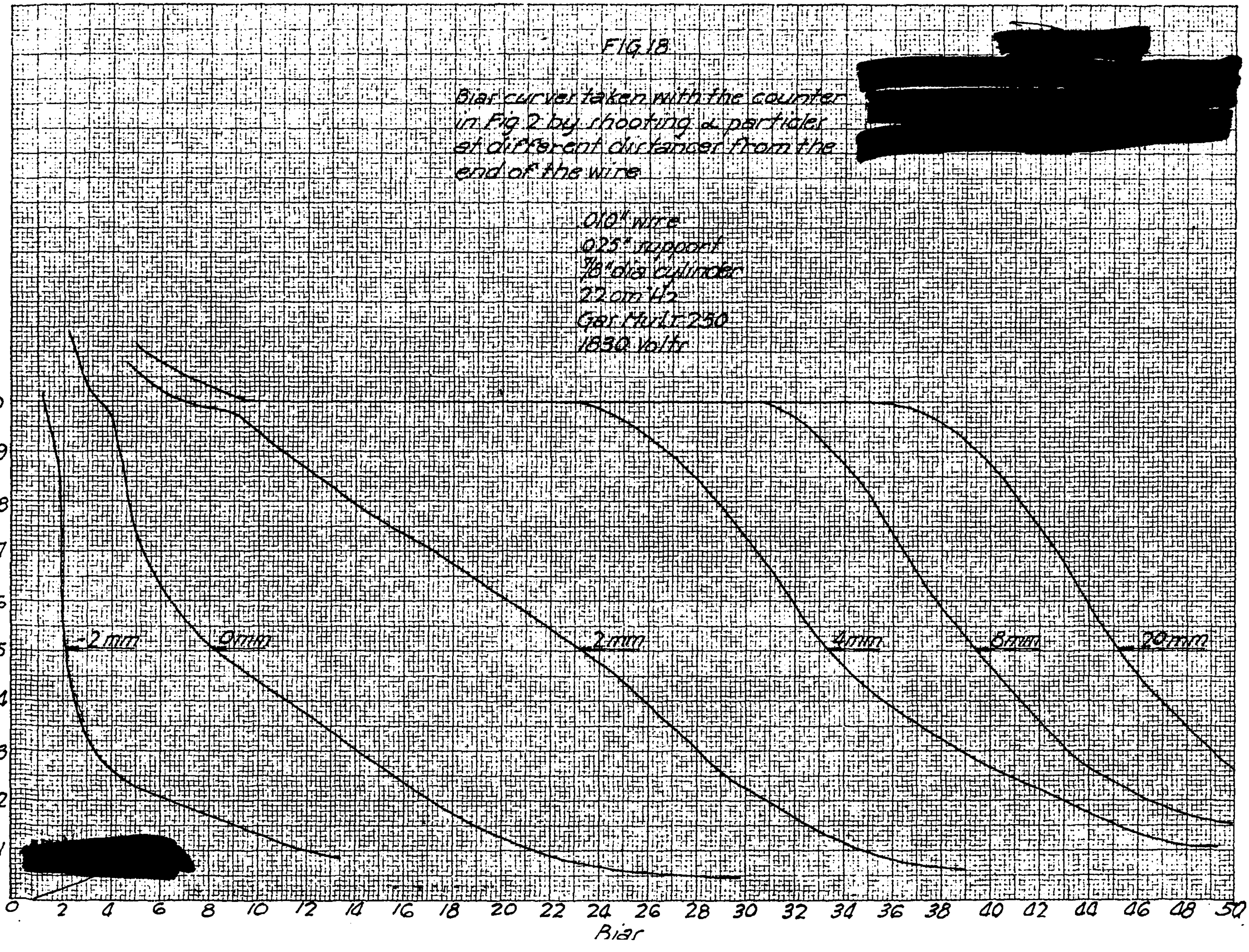

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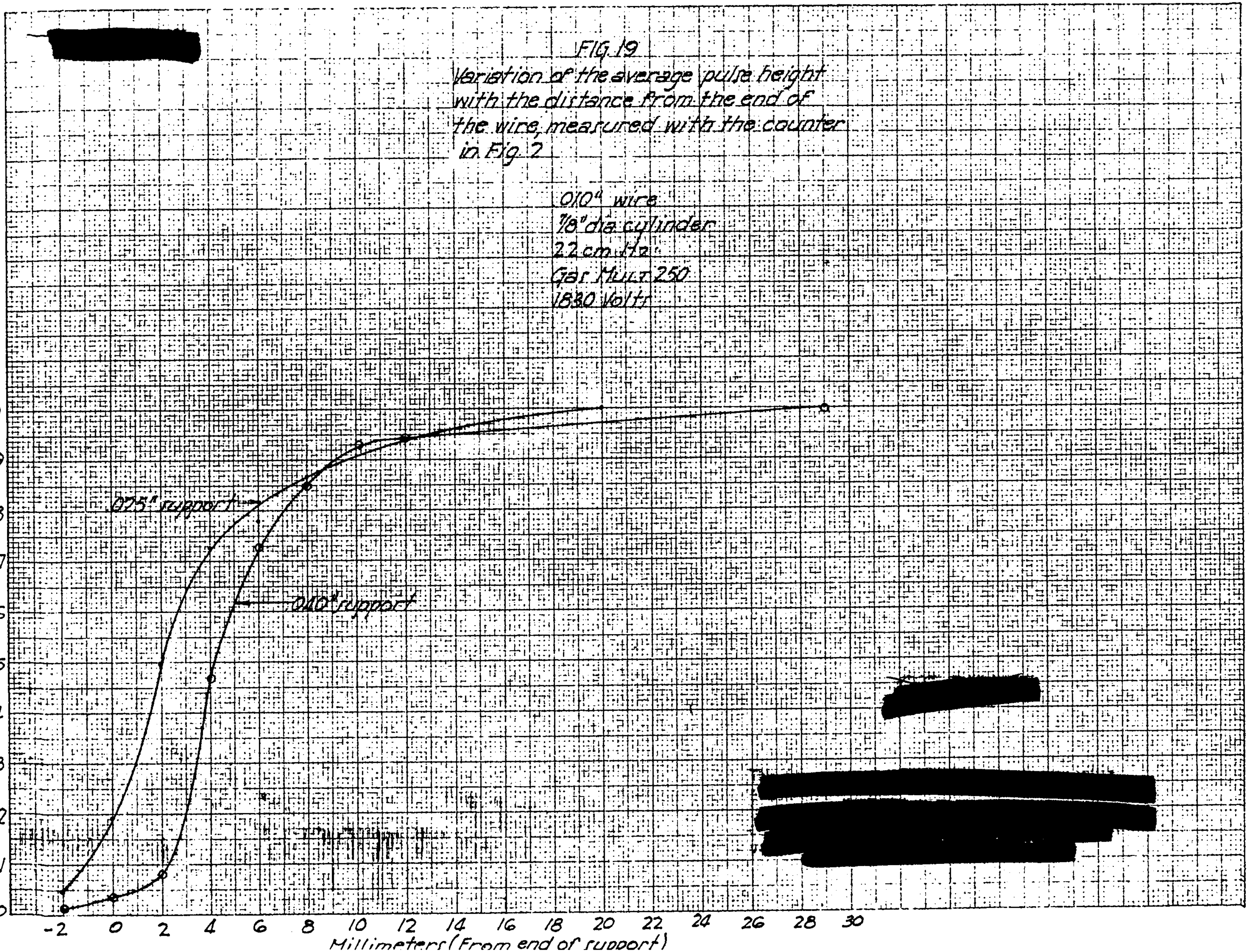

FIG. 19
Variation of the average pulse height with the distance from the end of the wire, measured with the counter in Fig. 2

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