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CRITICAL MASS MEASUREMENTS FOR A 25 SPHERE IN Tu AND WC TAMPERS

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A. EXPERIMENTAL PROCEDURE

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ABSTRACT

An estimate of the critical mass for U 235 was determined by measuring the neutron reproduction in 3-1/2-inch- and 4-1/2-inch-diameter β-stage-material spheres, surrounded by tuballoy and WC tampers. A fission source of neutrons was obtained from a beam of thermal neutrons from the water boiler striking a β-stage-material target placed at the center of the spheres. The β-stage material used is 74 percent 25. The multiplication obtained was determined by collecting fission fragments on cellophane catcher foils. One foil was placed so as to measure the fissions occurring throughout the mass of the sphere while a second foil was used to determine the fissions produced in the target.

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CRITICAL MASS MEASUREMENTS FOR A 25 SPHERE IN Tu AND WC TAMPERS

INTRODUCTION AND SUMMARY

This report describes experiments performed in February and March 1945 to determine the critical size for a 25 sphere tamped with uranium and tungsten carbide. The experiments were performed using spheres of about 3-1/2" and 4-1/2" diameter and of isotopic constitution of about 75 percent 25. The method consisted in observing the multiplication by the sphere of the neutrons produced by a source of fission neutrons placed at the center of the sphere. The source was obtained by allowing a beam of thermal neutrons from the thermal column of the water boiler to strike a beta-stage-material target placed at the center of the sphere. The multiplication was measured by determining the number of fissions taking place both in the mass of the sphere and in the source by collecting fission fragments on cellophane catchers.

The values found for the critical mass (with infinite tamper) of 100 percent 25 (density 19) were 15.8 Kg for natural uranium tamper, and 13.8 Kg for tungsten carbide tamper.

The report contains the following sections:

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A. EXPERIMENTAL PROCEDURE

A-1. Sphere and Tamper Arrangements. A strong source of thermal neutrons was obtained by making a large cavity in the thermal column of the water boiler. The cavity was 21" x 21" x 24" and was made one foot from the end of the thermal column. This permitted a small target placed 22" in front of the column to "see" an 18-1/2" circle 3 ft back in the column through a cone of 21° apex. Flux measurements gave an $nv = 1.15 \times 10^6$/KW at the target position. This gives a fission source of 1.3×10^7 neutrons per sec on the .482-inch-diameter target button of β-stage material when the boiler is running at 4-1/2 kilowatts.

Fig. 1 is a schematic drawing of the neutron beam port and the tuballoy tamper in front of the water boiler thermal column. The tuballoy tamper consisted of two large hemispherical shells 18-1/8 inch OD and 7-1/16 ID. Smaller nesting hemispheres filled up the central cavity so that either a 3-1/2" or 4-1/2" β-stage sphere could be inserted in the center.

The large hemispheres were mounted so that the splitting plane was horizontal. The lower half was mounted on a table of adjustable height. The upper hemisphere could be raised and lowered in vertical guides by means of a chain hoist.

The procedure for each bombardment was as follows. With the upper hemisphere removed, the source assembly (Fig. 6A) was inserted into the radial hole of the lower half of the nesting spheres; the collecting sandwich (Fig. 6C) is put in place; the upper half of the nesting spheres is assembled about the source tube. The central spherical structure is then rotated through 90° and the source-assembly tube pushed into the small recess in the cadmium cone. This rotation of the spherical structure is necessary in order to have the mass catcher perpendicular to the neutron beam from the boiler, thus minimizing the

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distortion due to the beam port. The final step is to lower the large upper tuballoy hemisphere. About one minute was required to remove the source assembly and catcher sandwich after each irradiation.

A special table and drawer arrangement were made for the WC tamper bricks in order to be able to duplicate the short disassembly time required for the tuballoy tamper. Figs 2, 3, 4, and 5 show the tamper arrangement in the process of assembly for an irradiation. Fig. 2 shows the aluminum source cylinder and catcher sandwich in place. Figs. 3 and 4 show the assembling of the 25 sphere segments. Fig. 5 indicates the complete assembly in place ready for an irradiation. The disassembly required the pulling out and tipping of the drawer and the removal with a hand clamp of the upper central WC block.

The 2-1/8 x 2-1/8 x 4-1/4 WC blocks were held in place by external clamps. A .010" steel sheet supplemented by side clamps was sufficient to support the blocks over the drawer cavity. The large WC pieces were made under the direction of Mr. Balke, one set with a 3-1/2" cavity and one set with a 4-1/2" cavity to hold the β-stage spheres.

Precautions had to be taken to avoid contamination of the counters and blank catcher foils. This was especially true for the tuballoy tamper.

A-2. Measuring Technique. As indicated in the preceding section, measurements were made with 3.5" and 4.5" spheres in both WC and Tu tampers. The essential measurement in each case consisted of finding the ratio of the fissions occurring in the sphere to those occurring in the source. It is unnecessary to make absolute measurements of these quantities if their ratio can be determined, and this fact simplifies the problems of measurement considerably.

The catcher foil technique was used to determine the number of

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fissions. Cellophane foils placed in the sphere and in front of the source were activated simultaneously and then were counted on two G-M counters with similar geometry for the two foils. The foils were interchanged during the counting to minimize errors due to difference in efficiency of the two counters.

The source catcher (S) was a cellophane disk .480" in diameter punched from 0.001" sheet. It was placed in front of the source button and was activated by a disk of 25 punched from the same foil which was used to activate the mass catchers to minimize any errors due to surface layers. Since the flux at the source was much higher than that in the sphere, an aluminum mask with a small hole was placed between the 25 foil and the cellophane. The size of the hole was chosen for each experiment so that the counting rates of the source and sphere catchers were nearly the same. The "mask ratio" was measured in a separate experiment described in the next section. The ratio was 22.25 for the 3.5" sphere and 10.16 for the 4.5" sphere. The arrangement of the source assembly with the target at the center of the sphere is shown in Fig. 6A. Some measurements were made with the target disc at R/2 and at R as well as at the center (Table I.). Calculations are given for the central position only in this report.

In order that the mass catcher activity be a true measure of the fission rate in the sphere independent of distribution, the catcher assembly was placed in a diametrical plane of the sphere perpendicular to the boiler beam, and aluminum shields were placed between the catcher and the activating foils to leave an exposed area proportional to r^2, where r is the radial distance from the center of the sphere. The shape of the shield is shown in Fig. 6B. The 1/2" diameter hole in the center was needed to allow room for the

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source assembly. A correction for this hole as well as for the beam part was made in the final calculations.

The sphere or mass catcher (M) was arranged to have a large surface area since the flux in the sphere was rather low and the mean-free-path large. The mass catcher "sandwich" is shown in Fig. 6C. As can be seen in the sketch, the cellophane foil catches fragments from six surfaces. Metal templates were used in cutting and punching the cellophane from 0.001" sheet. The catchers for the 3.5" sphere were 3.5 x 11.75" and those for the 4.5" sphere were 4.5 x 14.75". The .010" cadmium sheets shown in the diagram were used outside the sandwich to stop stray thermal neutrons.

The G-M counters used in the experiment are special dural counters 7-1/2" long and 7/8" ID with 0.007" walls. The thin portion of the counter is 6-1/2" long and tests showed that the counters are essentially constant in response to beta particles over a length of 5-1/2". The central wire of the counters is 0.005" tungsten; the counters are filled with alcohol (pressure, 1 cm Hg) and argon (9 cm Hg). The counters start to operate at about 850 volts and have plateaux approximately 150 volts wide. The background count is about 100 per minute when the counter is placed vertically in a Pb "pig" behind the 5-ft concrete-earth wall at Omega.

The irradiated mass catcher was rolled on a dural sleeve with 0.003" walls which fitted snugly over the G-M counters. A Pb reflector was slipped over the sleeve and catcher. In order that the source catcher disk be counted with similar geometry, a cellophane blank of the same size as the mass catcher foil was wrapped on the second sleeve and the source catcher was placed in the middle fold. The absorption due to the cellophane was about 1

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per cent per layer and there were either 5 or 6 turns (depending on the size of the sphere) in each counter assembly.

Uncertainty in the results due to slow drifts of counter sensitivity was minimized by interchanging the source and mass catchers on the two counters during each counting cycle. It was found by experiment that equal total counts were obtained in the periods 3 to 6.5 min., and 7 to 13 min. (time measured from end of a 10-minute bombardment), so this schedule was followed. The power of the boiler was adjusted so that approximately 20,000 counts were obtained in each interval.

The experiments were run on a 21-minute schedule as follows:

M = mass catcher S = source catcher

Time, minutes	Operation
0	Start bombardment No. 1
10	Stop " " "
13	M on Counter I, S on Counter II, start count
16.5	" " " ", stop count
17.0	S on Counter I, M on Counter II, start count
21	Start bombardment No. 2
23	S on Counter I, M on Counter II, stop count

During the 10 minutes between the end of the counting on No. 1 and the start of the counts on No. 2, the counter operators take 3-min. backgrounds with each of the holders for M and S and run a 2-min. standard count. On each successive run, the order of counting was interchanged between M and S. A "cadmium run" was made at intervals so that the effect of the fast-neutron background could be taken into account. In the cadmium run, the usual procedure was followed with the exception of placing a disk of cadmium in front of the source assembly.

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Each measurement consisted of at least 10 runs. The data were analyzed as soon as each run was completed to maintain a continuous check on the operation of the apparatus.

The data thus obtained require two additional measurements before they can be used to compute the multiplication due to the sphere: 1) determination of the "mask-ratio" of the source mask and, 2) measurement of the penetration of the boiler neutrons into the source plug to determine the effective depth of the source. These measurements are discussed in the following sections.

In order to develop the above measuring technique several runs were made initially using normal uranium for the 3-1/2" sphere and the catcher foils. The type of decay curve obtained from the catcher foils is shown in Fig. 7.

Table I shows data taken with the 3.5" β-stage sphere in a uranium tamper. In using the counter-switching technique described two corrections x and y had to be used. y was a correction for a difference in efficiency of the two counters, and x was a correction applied to take care of any difference in total number of counts occurring in the two time intervals used: 3 to 6.5 minutes, and 7 to 13 minutes, as mentioned above.

These correction factors dropped out in finding $M/S = \sqrt{M^2xy/S^2xy}$ where S and M were interchanged on alternate runs.

Counter No. 1	Counter No. 2	Time, minutes
yM	S	3 to 6.5
xyS	xM	7 to 13

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A-3. <u>Mask Ratio for Source.</u> The "source cellophane" caught fission fragments produced by the capture of thermal neutrons in 73.7 percent enriched 25. The "mass cellophane" caught fragments produced by the capture and subsequent multiplication of the progeny of these incident neutrons in 73.9 percent-average material for the 3-1/2" sphere and in 76.7 percent-average material for the 4-1/2" sphere. The ratios of the activity of these two foils were for both the spheres 10 and 20 respectively.

In order to avoid uncertain Geiger-counter corrections, it was decided to absorb some of the activity of the source, and thus equalize the counting rates of the source and mass cellophane foils. This was done by placing between the 25 source plug and the cellophane catcher a .003" Al disk with a hole in its middle. Thus only the fraction of fragments which went through the hole was caught in the cellophane. The ratio of the activities with and without the Al mask is known as the mask ratio. In the final calculations the value of this mask ratio enters directly, so it must be well known.

In determining this quantity experimentally (it was not calculable) equal counting rates for equal bombardment times again were desirable. This meant using different boiler powers for runs with and without mask, and obtaining in some way a number proportional to $\bar{n}v$ at both powers. The first device was a small 25 chamber placed in the front of the thermal column. This gave erratic results for reasons which were never ascertained, while the cellophane foils for successive runs at the same power agreed to within at worst 2 percent. Believing this meant that the boiler was actually constant for each power setting, about 25 Mn foils the size and shape of the cellophane were cut.

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These were used as monitors for individual irradiations by placing them in the front of the source assembly. Here again, when the mask was off, the incident neutron beam was made only 1/20 or 1/10 as strong as with the mask on. This meant that there would be great differences in the counting rates obtained from the Mn monitors.

This difficulty was eliminated as follows: a different Mn foil was used for each irradiation with mask, while the same Mn foil was used for a series of irradiations without the mask. The number of runs in this series was approximately equal to the value of the mask ratio, so that if this series were completed in about one hour, all Mn foils would be equally active.

In order to employ this technique it must be true that all irradiations of the single Mn foil are approximately equal and that saturation is not reached. Then from the following, where A_t = measured activity at end of all bombardments $A_{i1}, A_{i2}, A_{i3} \ldots A_{in}$ = initial activity had each irradiation been on a dead foil; $t_1, t_2, t_3 \ldots t_n$ = time from middle of each bombardment to time of counting; one can find the average initial activity of the series:

$$A_{i1}/e^{\lambda t_1} + A_{i2}/e^{\lambda t_2} + A_{i3}/e^{\lambda t_3} + \text{----} = A_t$$

since all A_i's are equal

$$\overline{A_i} \sum_{1}^{n} 1/e^{\lambda t} = A_t \text{ or } \overline{A_i} = A_t / \sum_{1}^{n} e^{-\lambda t}$$

$$\text{and the mask ratio} = \left[\frac{\text{cellophane activity}}{\overline{A_i}(\text{Mn})}\right]_{\text{no mask}} \Bigg/ \left[\frac{\text{cellophane activity}}{\overline{A_i}\ (\text{Mn})}\right]_{\text{mask}}$$

The actual mask ratios obtained were 22.25 for the 3-1/2" sphere and 10.16 for the 4-1/2" sphere.

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A-4. <u>Determination of Effective Depth of the Source.</u> To determine the number of fissions in the source, from the "source catcher cellophane" it is necessary to know what fraction of these fissions is caught by the cellophane.

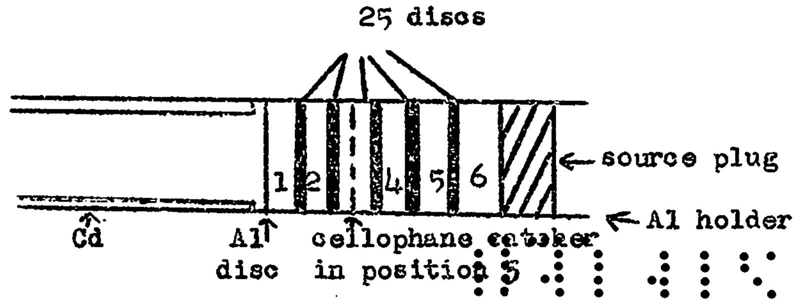
Let the activity of the cellophane be proportional to N_o: then, since the cellophane is on the front surface of the source plug, the total number of fissions in the source is:

$$N_o \int_0^\infty e^{-x/\lambda} dx = N_o \lambda$$

Where x is the distance into the source from the cellophane expressed in gm/cm^2 and λ is the so-called "effective depth". The integral is taken from 0 to ∞ because the depth of penetration of thermal neutrons into the source is so small that the source plug may be considered infinite.

Because of the energy distribution of the incident neutrons, λ is a slowly varying function of x. Since this function was unknown λ had to be determined experimentally.

In place of the solid source plug, five small 25 discs were placed in the source assembly. A cellophane catcher was inserted successively between each disc as shown in sketch below. This whole assembly was irradiated at the end of the Cd cone a short time for each position of the cellophane.



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As the catcher could be changed rapidly, it was possible to hold the boiler at constant power throughout a complete series.

λ was obtained by numerical integration of the experimental curve of I_i/I_o as a function of gms/cm^2 of 25, where I_o is twice the activity of the cellophane at position 1 (since it caught fragments on one side only), and I_i is the activity in any of the other positions.

Fissions originating from the thermal neutron beam produce fast neutrons. A small percentage of these neutrons are captured within the source plug resulting in secondary fissions. Since these secondary fissions should not count as part of the source a correction was made in the experimental curve to eliminate them.

The inaccuracies due to the fact that the cellophane catches some fragments originating a finite distance on each side of it, and due to the thermal leakage out the sides of the source plug, have been neglected since these errors are well within other experimental errors.

The final integration of the corrected experimental curve gave .885 gms/cm^2 for the effective depth in the discs of isotopic constitution 74.01 percent. The effective depth in the source (isotopic constitution 73.7 percent) was therefore .886 gms/cm^2.

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B. INTERPRETATION AND CALCULATIONS

B-1. General Considerations. Throughout this report the multiplication of an undercritical system is defined as the ratio between the total number of neutrons produced in the system to the number of neutrons produced in the source. In the experiments described previously, the source is represented by the fission neutrons emitted by the target button at the center of the sphere when thermal neutrons are absorbed by it. Let ν_T be the ν-value for thermal neutrons and F_s the number of fissions taking place in the source. The number of neutrons emitted by the source is given by

$$\nu_T F_s \tag{1}$$

Let ν_F be the ν-value for the fast neutrons that produce fissions through the mass of the sphere and F_m the number of fissions taking place in the mass of the sphere. The number of neutrons produced in the system is

$$\nu_F F_m \tag{2}$$

The multiplication as defined previously is the ratio of expression (2) to expression (1). In the following we have assumed that $\nu_T = \nu_F$. The multiplication M is given therefore by

$$M = F_m/F_s \tag{3}$$

The multiplication ratio obviously becomes infinite when the system is just critical. Its value can be expressed approximately as a function of the ratio r/r_c of the actual radius of the sphere to the critical radius. In the range of radii over which we have experimented the relationship can be expressed with the following approximate formula:

$$\frac{1}{M} = \frac{1 - r/r_c}{1.86\, r/r_c - .34} \tag{4}$$

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This empirical relationship was obtained by calculating in terms of the Serber theory the critical radii and the multiplication ratio for spheres tamped both with uranium and tungsten carbide tampers. Plotting M versus r/r_e in all these cases one finds that the points lie very closely on a single curve represented analytically by equation (4) for the interval r/r_e from .5 to 1.0.

Four experiments were performed with spheres having diameters of approximately 3.5 and 4.5 inches and with uranium and tungsten carbide tampers. The spheres were assembled out of pieces of not identical isotopic constitution. Also some gaps were left due to the imperfect fitting of the various pieces and of the cavity in the tamper. Proper averages have been taken for density and isotopic constitution. The values used are summarized in Table II.

B-2. Calculations of F_m/F_s. In determining the number of fissions F_m and F_s taking place in the mass of the sphere and in the source, the assumption was made that the activity of the fission recoils is proportional to the number of fissions. Since the fissions produced in the mass are due to the fast neutrons and the fissions in the source are due to thermal neutrons, this assumption may be slightly in error. No attempt was made to correct for this factor.

Let us indicate by M and S the activities of the mass catcher and of the source catcher corrected for cadmium as described in Part A-2. The values found for M/S in the four cases investigated with the source at the center were:

Value		Sphere	Tamper
1.057	for	3-1/2"	U
1.150	"	3-1/2"	WC
.998	"	4-1/2"	U
1.144	"	4-1/2"	WC

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From these values one can calculate the ratio F_m/F_s by the following procedure that we describe in detail for the case of the 3-1/2" sphere and uranium tamper.

Let f be the number of fissions per unit mass. If a catcher of area s is placed in front of the material its activity will be proportional to fs or in case that f varies along the surface of the catcher, by the integral

$$\text{Activity} = \int f\, ds \qquad (5)$$

The proportionality factor can be omitted since it vanishes in taking the ratio.

The number of fissions F_s taking place in the source is given by

$$F_s = f_{\text{surface}} \cdot \text{depth } (\text{gm/cm}^2) \cdot \text{area of source} \qquad (6)$$

where f_{surface} indicates the mean value of f at the surface of the source. The depth is determined by the depth of penetration of thermal neutrons. Its value has been found (see Part A-4) to be .886 gms/cm^2. The activity of the source catcher is given on the other hand by

$$S = \frac{1}{\text{mask ratio}} \cdot f_{\text{surface}} \cdot \text{area of source} \qquad (7)$$

where the mask ratio determined in A-3 is the factor by which the intensity of the source catcher is reduced by the mask placed in front of it. Its values are 22.25 for the 3-1/2" sphere and 10.16 for the 4-1/2" sphere. From (6) and (7) we obtain

$$F_s = \text{mask ratio} \cdot \text{depth} \cdot S = 22.25 \cdot .886 \cdot S = 19.71S \qquad (8)$$

A further correction should be applied in order to take into account the fact that the source loses effectiveness because of the hole that is necessary to lead the thermal neutron beam on to it. The effect of this hole is that some of the neutrons that are emitted by the source in a backward direction

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are completely lost to the system and the rest hit the material at a greater distance from the center than they would in the case of a solid sphere. The loss of effectiveness due to both these happenings has been estimated using the distribution function of the Serber theory and has been found to be .930 for the 3-1/2" sphere and .944 for the 4-1/2" sphere. Introducing such correction factor we find for the effective value of F_s a result .930 times smaller than (8), namely:

$$F_s(\text{effective}) = 19.71 \times .930\ S = 18.33\ S \tag{9}$$

The number of fissions taking place in the mass is given by:

$$F_m = 4\pi\rho \int_0^R f(r)\ r^2 dr \tag{10}$$

The activity of the mass catchers is given on the other hand by:

$$M = 6 \cdot 2\pi \cdot (315/360) \int_0^R (r/R)\ r dr\ f(r) \tag{11}$$

where the factor 6 is due to the fact that the catcher had 6 surfaces collecting recoils. The factor (315/360)r/R represents the fraction of the catcher at the distance r from the center that is not covered by the mask (see description of the mask in Part A-2).

A correction factor must be applied to take into account (a) the fact that the catcher does not reach to the center of the sphere; (b) the fact that the foils placed in front of the catcher had an isotopic ratio slightly different from that of the mass of the sphere; and (c) the fact that the catcher foils had a diameter slightly different from that of the sphere. The correction factor amounts to 1.078. We find

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$$F_m/M = \text{correction factor} \cdot (1/3)(360/315)\rho R$$
$$= 1.078 \cdot (1/3) \cdot (360/315) \cdot 16.92 \cdot 4.484 = 31.17 \qquad (12)$$

From (12) and (9) we obtain finally

$$F_m/F_s = (31.17/18.33)\ M/S = (31.17/18.33)\ 1.057 = 1.797 \qquad (13)$$

A similar calculation can be carried out in the other three cases. The results are summarized in column 5 of Table II.

B-3. Calculation of the Critical Mass. The procedure followed in calculating the critical mass is summarized in Table II. The uncorrected critical radius r_e given in column 6 of the table is calculated from the measured values of F_m/F_s given in column 5 and the actual values of the radius given in column 2, making use of formula (4). Three corrections are applied to the critical radius as indicated in columns 7, 8, and 9. The correction to infinite tamper given in column 7 has been calculated with the Serber theory by increasing the effective absorption of the tamper in order to take into account the added loss of neutrons due to the finite size of the tamper. The density and isotopic constitution correction given in columns 8 and 9 have been calculated using the relationship recommended by Oppenheimer

$$\text{critical mass} \sim \rho^{-1.4}\, C^{-1.8} \qquad (14)$$

where C is the fraction of 25 in the active material. This formula can be re-written in terms of the critical radius as follows:

$$\text{critical radius} \sim \rho^{-.8}\, C^{-.6} \qquad (15)$$

The last column of the table gives the critical mass in grams for pure 25 of density 19 in an infinite tamper of uranium or tungsten carbide. There

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is apparently some systematic error in the procedure because the critical mass as calculated from the experiments with the 3-1/2" sphere is slightly lower than the critical mass calculated from experiments with the 4-1/2" sphere for both tampers. We believe, of course, that the measurements with the larger-sized sphere are more reliable. As a conclusion of the experiment we have therefore the following values for the critical mass:

uranium tamper -- 15.8 Kg.

tungsten carbide tamper-- 13.8 Kg.

These values refer to 100 percent 25 of density 19 and to infinite tamper.

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TABLE I.

Data for 3.5 inch 25 sphere in Tu tamper

Run	M	Mx	My	Mxy	S	Sx	Sy	Sxy	$\sqrt{\frac{M^2_{xy}}{S^2_{xy}}}$
				(a) Normal Foils for Mass Catcher, Source at Center					
1.	2640			2662		13280	13910		0.195
2.		2860	2776		14790			15230	0.188
									av. 0.192
Cd.	128			179		-19.2	-64		av. corr. 0.942
				(b) Source at Center					
1.	17220			18170		14400	15370		1.183
2.		17490	18580		13900			15100	1.243
3.	18000			19100		14680			1.218
4.		17380	18790		14720			15300	1.203
5.	18010			19130		15580	15970		1.203
6.		20147	18496		15949			17171	1.167
7.	17914			18803		15340	15360		1.189
8.		18496	17350		14707			15090	1.202
9.	16320			17056		14822	14860		1.124
									av. 1.192
cadmium									av. corr. 0.889
				(c) Source at edge					
1.	10700			10790		19200	20200		0.544
2.		10820	11500		19290			20940	0.555
3.	10720			11170		20040	21210		0.528
									av. 0.542
Cd.	870			940		89	57		av. corr. 0.917

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TABLE I. (Continued)

Run	M	Mx	My	Mxy	S	Sx	Sy	Sxy	$\sqrt{\frac{M^2_{xy}}{S^2_{xy}}}$
(d) Source at R/2									
1.	15090			15700		23220	24190		0.649
2.		14810	15710		22100			23000	0.676
									av. 0.663
Cd.	1241			1350		-38	-166		av. corr. 0.915

Averages for 25 sphere measurements

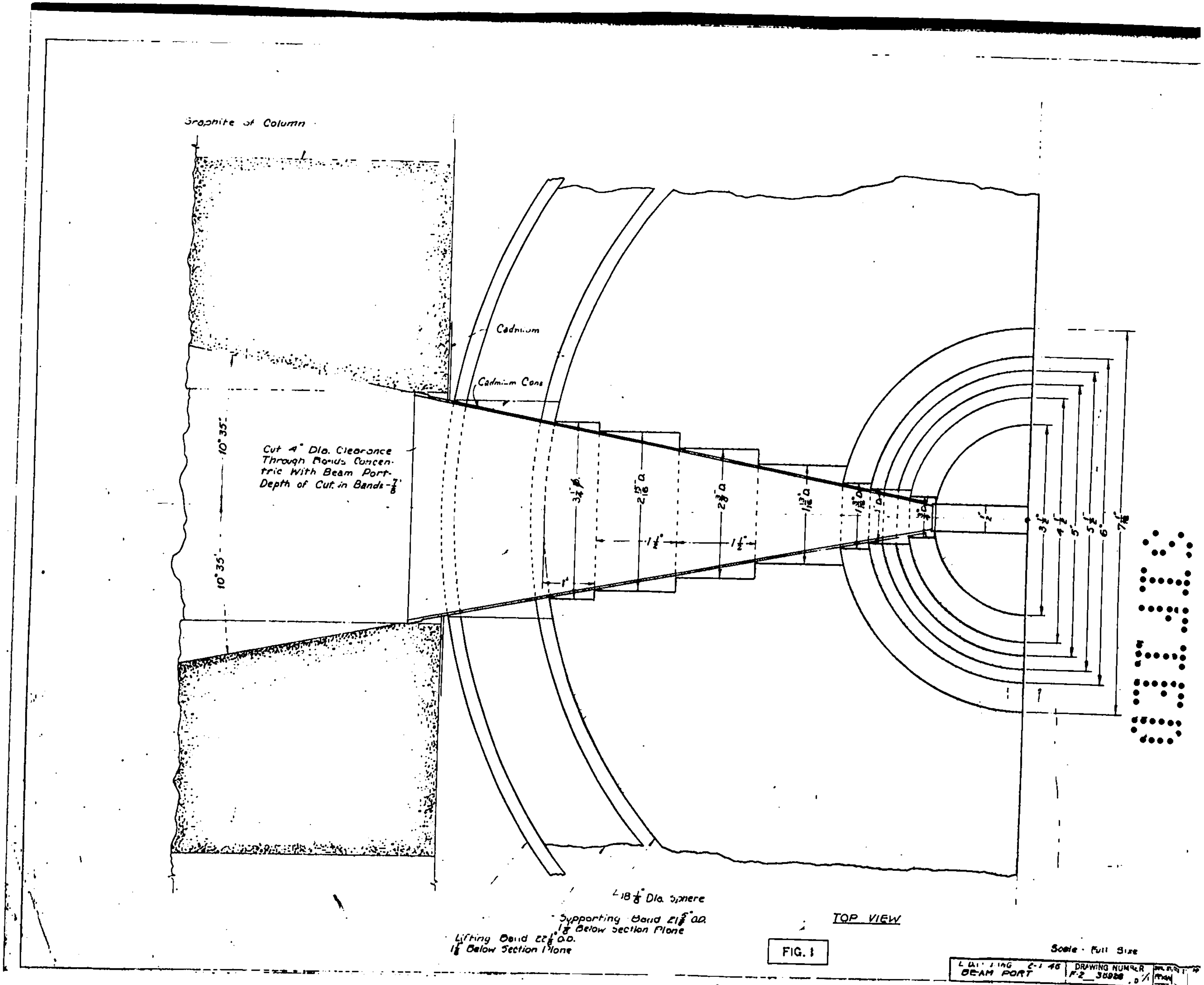
Tamper	Core	M/S	S	Catchers	Cd. correction	Cd. corrected
Tu	3.5"	1.192	center	25	.887	1.057
Tu	3.5"	0.542	R	25	.917	0.497
Tu	3.5"	0.663	R/2	25	.915	0.607
Tu	3.5"	0.192	center	normal	.942	0.181
WC	3.5"	1.176	center	25	.975	1.150
WC	3.5"	0.581	R	25		
WC	3.5"	0.688	R/2	25	.977	0.672
WC	3.5"	0.198	center	normal	.942	0.187
WC	4.5"	1.219	center	25	.938	1.144
WC	4.5"	0.582	R	25	.910	0.530
Tu	4.5"	1.276	center	25	.776	0.998

[redacted]

TABLE II.

Sphere and Tamper	Actual Radius	Density	Percent 25	F_m/F_s	Uncorrected r_c	Corr. to ∞ Tamper	Corr. to Normal Density 19	Corr. to 100 25	Corrected r_c	Critical Mass
3-1/2" U	4.484 cm	16.92	73.9	1.797	7.67	.985	.911	.834	5.74	15,050
4-1/2" U	5.76 cm	17.1	76.7	4.53	7.56	.985	.919	.853	5.84	15,850
3-1/2" WC	4.484 cm	16.92	73.9	1.956	7.45	.970	.911	.834	5.49	13,200
4-1/2" WC	5.76 cm	17.1	76.7	5.19	7.34	.970	.919	.853	5.58	13,800

[redacted]



TOP VIEW

FIG. 1

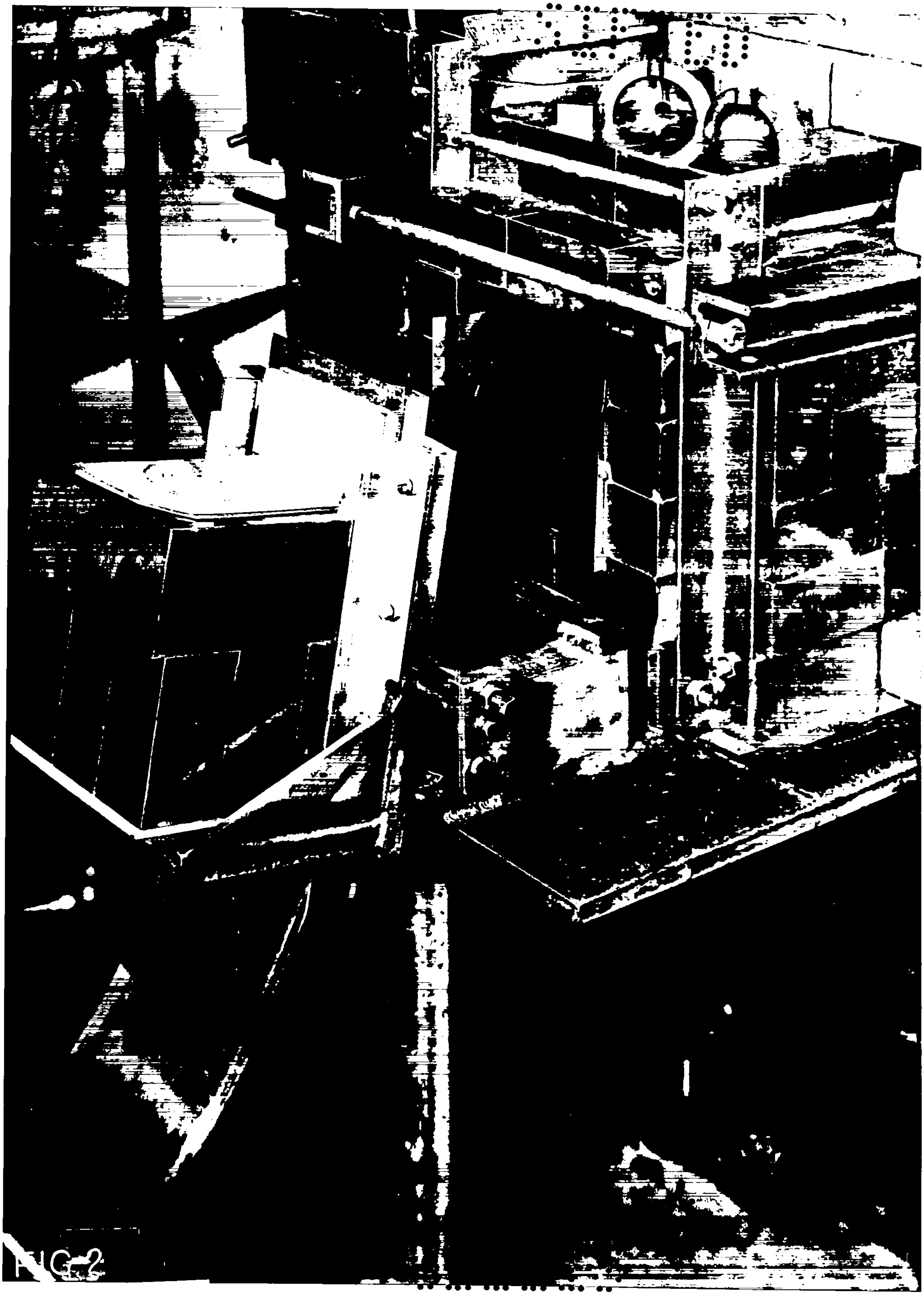


FIG. 2

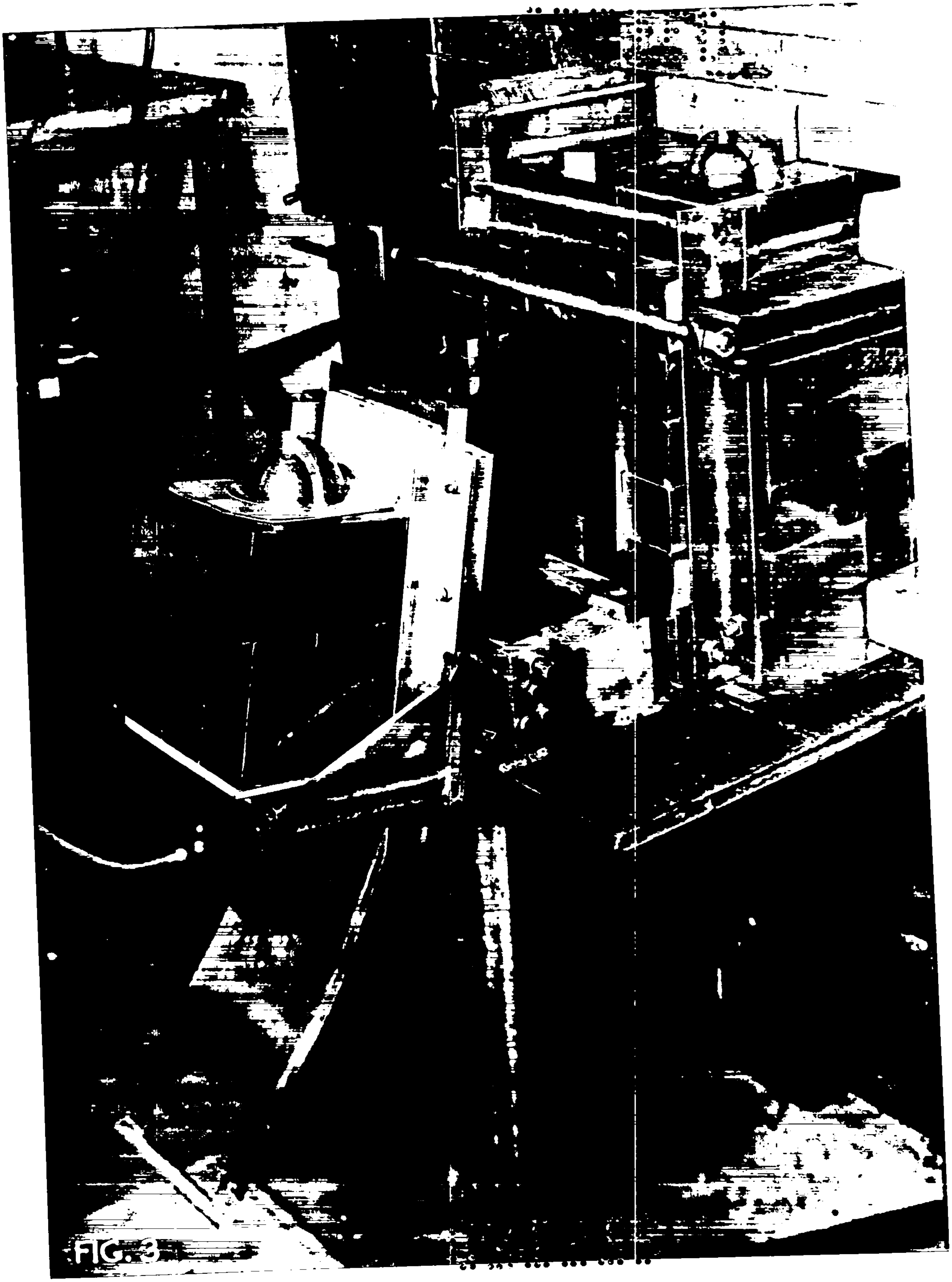


FIG. 3

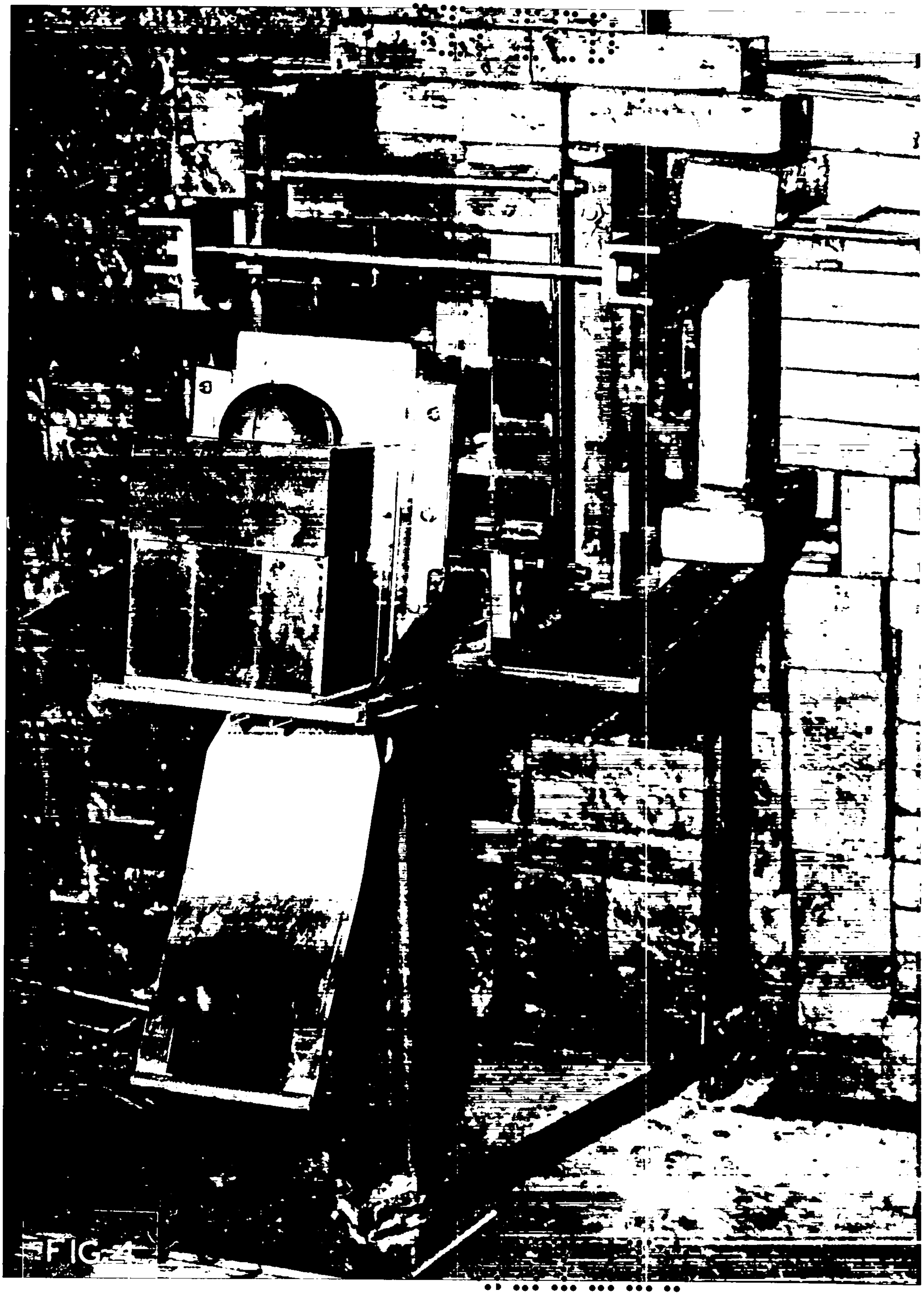


FIG 4

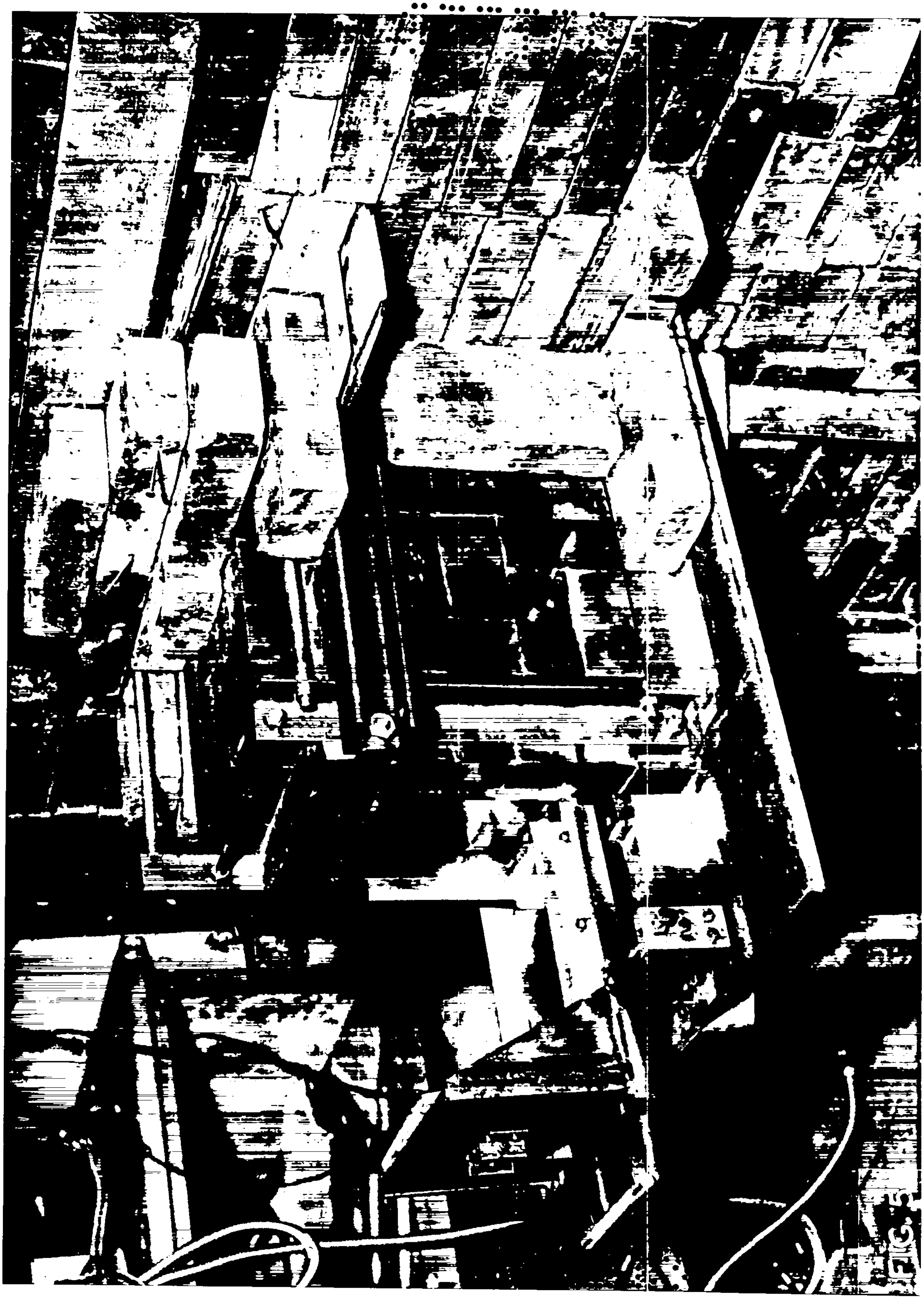


FIG. 5

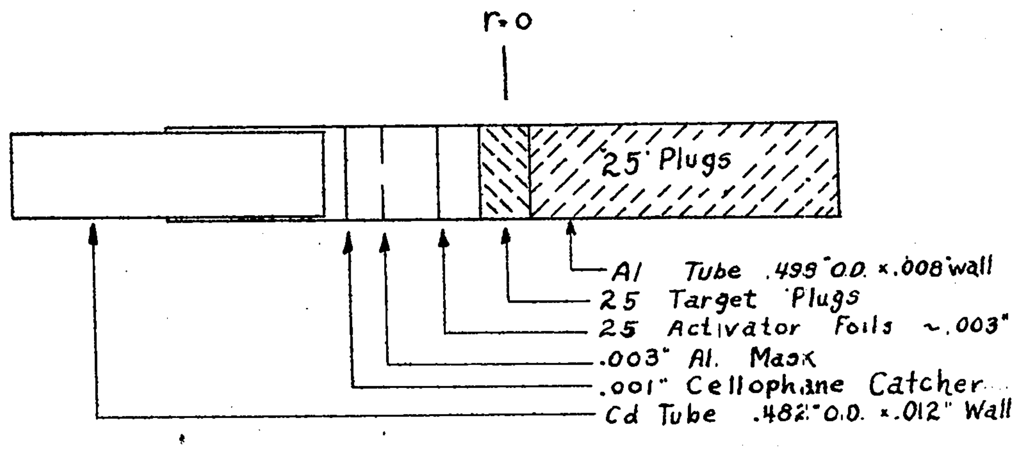


Fig. 6 - A Source Assembly
Parts separated to show detail, Cd tube is pushed in flush with Al. tube.

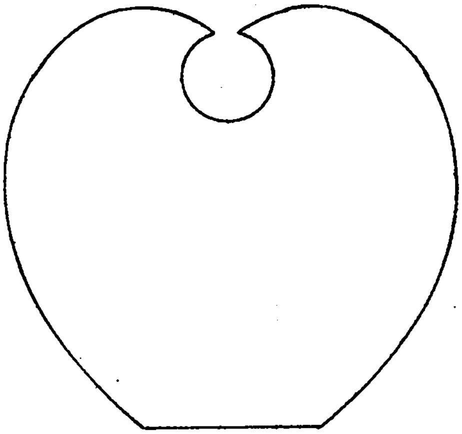


Fig. 6 - B
"r²" Mask For
3½" Sphere

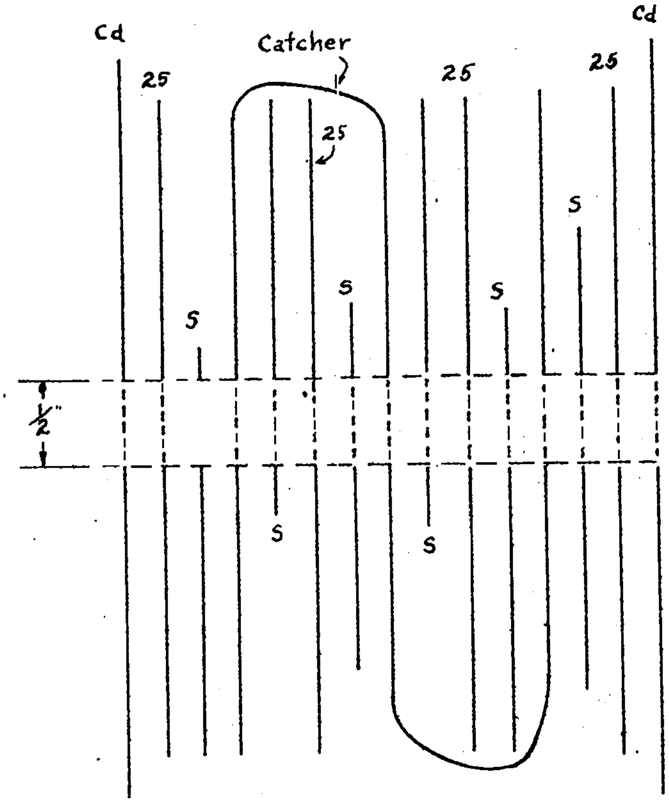
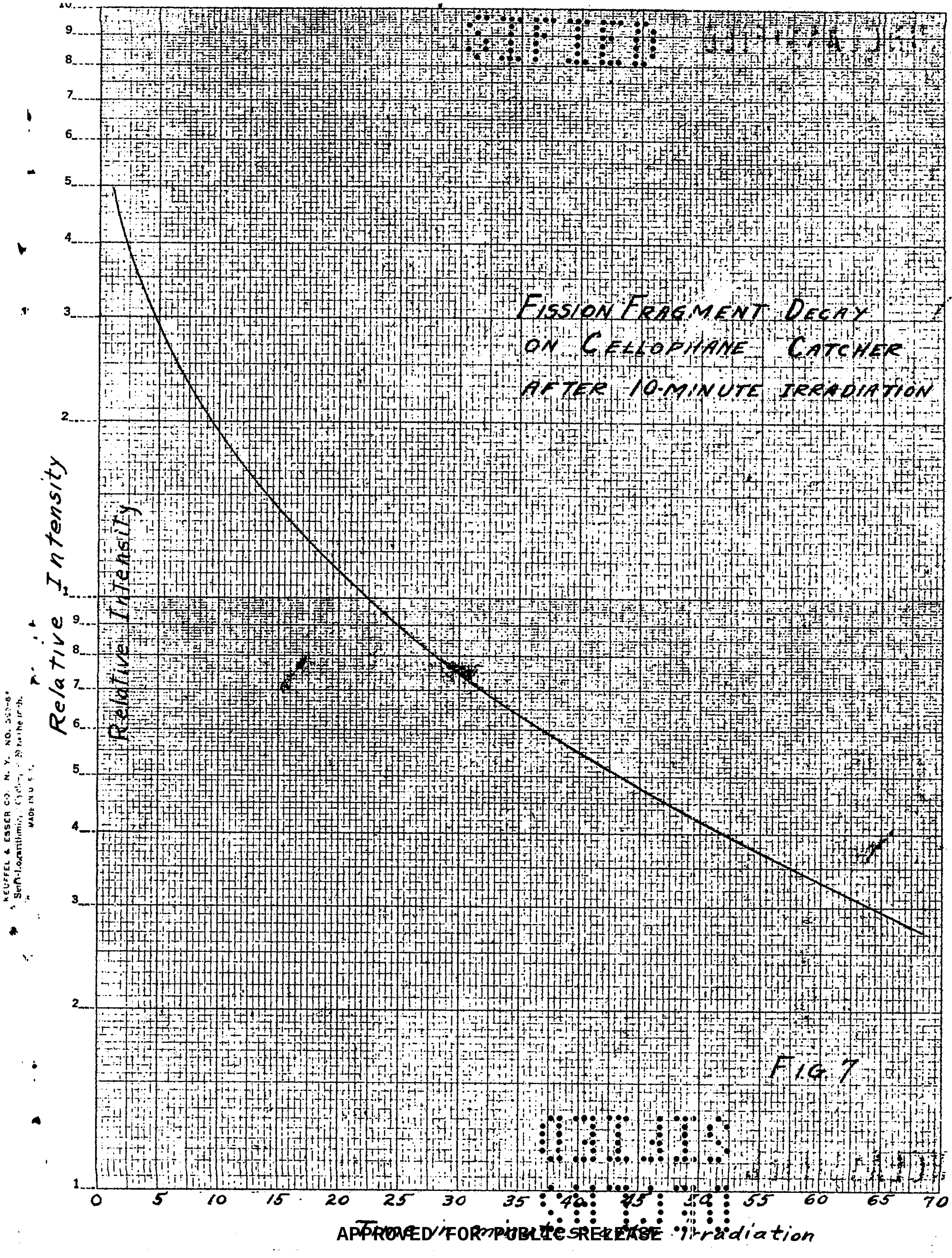


Fig. 6 - c Mass Catcher Assembly



FISSION FRAGMENT DECAY
ON CELLOPHANE CATCHER
AFTER 10-MINUTE IRRADIATION

FIG. 7

[redacted]