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INTEGRAL EXPERIMENTS I

TAMPER REFLECTION AND DISTRIBUTIONS

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ABSTRACT

The increase of response of 25 and 28 detectors, due to the reflection by various tampers, to neutrons from the D-D source and neutrons from a Ra-B and MsTh-Be source has been measured. The radial distribution in these tampers has been determined. The results permit conclusions as to the relative effectiveness of Pb, Fe, U, WC, C as tamper materials and provide a check on the overall properties as calculated from nuclear constants.

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INTEGRAL EXPERIMENTS I

TAMPER REFLECTION AND DISTRIBUTIONS

Two different methods of predicting the gadget behavior have been rather thoroughly discussed. The "differential" method consists of introducing measured nuclear constants into an adequate theoretical treatment of the behavior; the "integral" method proposes to predict the characteristics from measurements of the over-all effect of these constants in an arrangement as closely analogous to the actual gadget as possible. The former method suffers from the lack of precision in the nuclear constants, particularly in the number and energy of inelastically scattered neutrons and in the low energy part of the fission spectrum, plus whatever inadequacies exist in theory. The latter method is limited by lack of active material or a strong fission source, and the difficulty of exactly duplicating the absorption and scattering properties of active material. A strong fission source in a thin shell of active material can be obtained by the method reported by DeWire in LA-133 but this method is limited to tamper materials which do not appreciably absorb thermal neutrons, and the spectrum is not that of a solid core.

A program of measurements with 25 and 28 fission chambers has been carried out with a number of tamper materials, sources and geometrical arrangements. Here in Part I the results of measurements in tampers with a cavity of 9 cm radius around the source are described. Part II will be devoted to results with a mock U H_3 core filling this cavity, and Part III to measurements with solid U and WC tampers. The theoretical work connected with these measurements will be reported by Group T-3, and a summary of the results of the analysis will be written jointly with this group.

The differential constants and their integral effect as predicted from calculations may be checked by measurements with a source in a cavity in the tamper

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material. If the dimensions are chosen to approximate those of an actual tamper then not only the effect of nuclear constants but also that of geometry will be included. The significance of measurements with a 25 fission chamber is evident, and measurements with a 28 chamber yield information concerning the neutrons above one Mev. The increase of counting rate at the inner surface of the tamper due to its presence and the radial distribution in the tamper can be calculated and measured. The distribution with a 28 detector is particularly sensitive to inelastic scattering below the 28 threshold and is probably the most sensitive method of measuring this factor.

The tampers investigated in integral form were Pb, Fe, C, U and WC. The geometry of the WC tamper will be discussed in the sections on results since it varied according to the experiment. The others were all hollow spheres of outside radius 24 cm and inside radius 9 cm. Radial cylindrical holes 1 inch in diameter passed through the shells to accomodate the detectors. These holes were plugged in front of and behind the detectors which were 1 inch diameter cylinders 1 inch long. 28 and cadmium covered 25 fission detectors of the spiral type developed by Bright were used. The 25 spirals were 55% or 63% material and contained effectively about 15 mg of 25 metal and the 28 spirals between 200 and 350 mg of 28 metal. A count was frequently made with a RaBe source in a standard paraffin geometry. The counting rates in the tamper were divided by the standard geometry count to eliminate the effect of any drift which might have occurred. In each experiment, the source was placed in the center of the tamper and radial distributions measured with both detectors. Using the standardization of the detectors and the 28 data, the 25 data was reduced to pure 25 distribution.

In order to use the d-d source, the spheres were split on a median plane. Three radial holes approximately 5/8" in diameter were cut through the shell in this plane. By means of a chain hoist the tampers could be hung surrounding the target.

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The incident beam of deuterons collimated to 3/16" diameter entered through one hole, striking the face of a cold copper tube cut at 45°. The cooling lead for the ice target was introduced through the second hole. The third served as an exit for protons from the alternate reaction which were counted to monitor the neutron yield. The perturbation of the neutron distribution due to these holes was assumed to be small. Fig. 1 shows a tamper assembly.

It is clear that before the data can be compared with a theory for a point detector, correction must be applied for the perturbation of the neutron density caused by the finite size of the detector.

I. D-D Source

The d-d source was operated at a bombarding voltage of 200 KV. At this energy there is roughly a factor of 2 between the maximum yield per unit solid angle at 0° and 180° and the minimum yield at 90° to the deuteron beam. The energy of the neutrons varies from 3.05 Mev maximum at 0° to 2.09 Mev minimum at 180°. The radial distribution curves for various angles in the tamper differ due to these asymmetrics of the source. For not too large capture, the neutron density along the 90° axis will not fall off as rapidly as for a symmetric source since it receives contributions by scattering from regions of higher density at larger and smaller angles. Conversely, the 0° distribution will fall off more rapidly since it loses more to larger angles than it gains. If the variation of neutron yield were the only contribution factor, one would expect near-symmetry of the distribution with angle around 90°. In this case a solid angle weighting of the counting rate as a function of angle for fixed radius would give an average value corresponding to a symmetric source. However, it is conceivable that the variation of inelastic scattering with energy might cause the counting rate of a 28 detector to vary in a different manner. In this case a simple

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solid angle average would not be a true expression of the situation. However, the variation of scattering cross sections in the energy range may be expected to be small.

Measurements were made in the tamper at 0°, 45°, 90° and 135° to the deuteron beam. An examination of the 28 distributions for those angles shows the following things: the 135° curves lie quite close to the 45° curves both of which are below 0° and above 90° curves. This indicates that the main factor is the yield variation because an energy effect would cause a larger difference between 45° and 135° than between 90° and 135°. On a semi-log plot the 28 curves are nearly straight lines. The 0° curve is generally steepest although there is not much variation in slope between the angles. These features suggest a solid angle average as an adequate summary of the results as a function of radius. The average was obtained by plotting the counting rates against cos θ for the range 0° to 180°. The area under this curve is just twice the average value.

The only WC tamper made available for these experiments had to be built of surface ground blocks of density ≧ 14.8 gms/cc. The specification for cobalt content was ≦ 6% by weight. These blocks were assembled to form a rectangular block of square cross section 14-7/8" on a side and 12-3/4" thick. The cavity was symmetrically placed in the square cross section but was offset along the other axis. The midplane of the cavity along the 12-3/4" axis was 5-55/64 inches from one face and 6-57/64 inches from the other end. Since the cavity was made by offsetting the central blocks, the faces at each end of the 12-3/4" axis were not plane. The central portion of each, 6-3/8" square, protruded from the rest of the surface by 1-7/16" on one end and 11/16" on the other. Square cross section holes were cut for the d-d target assembly and for the detectors. Drawings of one half of the tamper assembly are shown in Figs. 2 and 3. An attempt was made to convert the cavity into a pseudo sphere by filling in the

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corners with 1/2" cubes of WC to approximate a sphere. The radius of the sphere having an equivalent volume was 3.6".

It should be noted that because of the lack of sphericity of the inner and outer surfaces, the shell was of varying thickness, mostly thinner than the other tamper shells. Also complications were present in averaging over the angular asymmetry of the d-d source because angular asymmetry also existed in the geometry. Auxiliary experiments with a natural source showed that a 25 detector was insensitive to the central cavity shape, the mass of tamper present determining its counting rate. The 28 detector was largely sensitive to the thickness of material between it and the source. Hence it also was insensitive to the central cavity shape if suitable plugs were placed in front of it to equalize the path traversed by the direct neutron beam at the various angles measured. This plugging was done for measurements on the d-d source for all angles and for both detectors. The values thus measured were averaged as described previously. Because of the small capture the 25 detector was affected by the irregular outer boundary beginning with smaller radii than the 28 detector. Consequently, the points taken for $r > 6.66"$ could not be averaged to have any meaning for the 25 detector.

Figs. 4 - 9 show, for a detector whose center is a distance r from the source, the ratio of the average counting rate in the presence of the tamper to that for the bare source. This will be called the multiplication, M. The 25 data have been reduced to pure 25 detector as stated previously. The multiplication is just $(nv\bar{\sigma})_{tamper}/(nv\sigma)_{source}$. Here the σ refers to the detector nuclei, the energy (average) and the neutron flux being indicated by the subscript. For 25, except in special cases, $\bar{\sigma}_{tamper} = \sigma_{source}$. For 28 the inelastic scattering may alter the spectrum in the tamper so that $\bar{\sigma}_{tamper}$ differs from σ_{source}. It is of interest to note that this same condition existed when differential measurements were made with a recoil detector whose sensitivity curve, corresponding to a σ curve, was not a square function. In-

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elastic cross section derived from those measurements on the assumption of a square function sensitivity curve might fit only in first approximation to the interpretation of data measured with a 28 detector whose σ curve differs from the recoil sensitivity.

Table I, summarizes M_o, the multiplication for the front of the detector flush with the inner surface of the cavity. A comparison of these values for various tampers of the same size is the beast measure of their relative worth in increasing neutron effectiveness at the inner surface. Differences between tampers might be altered slightly by correction to a point detector on the surface.

DISCUSSION OF D-D RESULTS

Because of the cavity and the fact that the shells are of finite thickness, it is not possible to analyze the data quantitatively without applying an exact theory taking account of these effects. However, qualitative conclusions may be drawn from inspection of the multiplication curves.

For all tampers, certain general differences exist between 28 and 25 distributions. 28 multiplication in all tampers reported here is a maximum very near the inner boundary of the shell and falls with increasing radius. 25 multiplication, on the other hand, rises with increasing radius from the inner boundary, reaches a maximum value and falls again as the outer boundary is approached. This is the expected behavior since capture for 25 flux is almost non-existent whereas for 28 flux it is appreciable since inelastic scattering below the 28 threshold is equivalent to capture.

Two things combine to determine the 28 multiplication curve, the scattering mean free path λ_s, and the "capture" mean free path λ_c, due to inelastic scattering. Compared to any standard tamper we may choose, a shorter λ_s will make the curve start higher near the inner boundary and drop more rapidly. A shorter λ_c will cause the curve to start lower and drop off more rapidly. One may say qualitatively, from the

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comparison of the various 28 curves, that Pb has the least inelastic scattering per cc and U the most, excluding WC since its geometry makes interpretation difficult. Also it may be concluded that λ_s for Fe is shorter than λ_s for C. This is in agreement with differential measurements for the primary energy.

The 25 multiplication curve is chiefly determined by the average λ_s for the neutrons detected since λ_c is very large. As already outlined, the curve will rise with increasing r from the inner boundary until leakage from the outer boundary causes it to drop again. The shorter λ_s the higher will be the maximum of the curve. If one temporarily neglects changes in σ_{25}, a comparison of maximum height of different tamper curves gives relative λ_s values. From a knowledge of the variation of λ_s with energy this will serve to estimate the spectra relative to each other in different tampers. Before U is compared it must be recalled that fission in the tamper raises the distribution somewhat. Hence, in order of maximum height for 25 multiplication curves, the tampers are C, U, Fe, Pb again excluding WC. This is the order for λ_s starting with C the shortest and increasing through the list. A comparison of U and C is interesting. From differential measurements λ_s for C is 4.5 cm at 600 Kev and becomes shorter with decreasing energy. λ_s for U is 4.5 cm at 1.5 Mev, 4.0 cm at 600 Kev. Since inelastic scattering requires that a reasonable fraction of the neutrons in U be below the 28 fission threshold the average energy for U is probably well below 1.5 Mev. Consequently for C it is probably near or less than 600 Kev. The results of the comparison between 25 multiplication in WC and U were, at first thought, unexpected. Fission in U due to the primary neutrons may raise the 25 multiplication as much as 20%. Even with this accounted for, WC did not appear as good relative to U as expected. Since the geometry of the WC was so different, interpretation is complicated. It was therefore decided necessary to compare distributions in more identical geometries. This is discussed in a later report.

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TABLE I

Tamper	$M_o(28)$	$M_o(25)$
WC	1.29	4.71
U	1.50	5.4
Pb	2.0	2.4
Fe	1.66	3.2
C	1.52	4.5

II. Ra-B Source

The procedure used in these experiments was the same as that of Section I except that only one radial tamper hole was used for each chamber, i.e. the angular integral was not required on this symmetric source. The centrally located Ra-B source containing 2 curies Ra pressed with amorphous boron was the strongest available source possessing a reasonable approximation to the fission spectrum. Threshold detector activations with this source and a fission spectrum have been compared by Feld as follows:

Reaction		$S^{32}(n,p)$	$F(n,p)$	$Al(n,p)$	$Si^{28}(n,p)$	$P(n,\gamma)$	$Al(n,\gamma)$
Threshold (mev)		.93	1.02	1.95	2.69	0.90	2.39
Relative Activity	Fission	1.00	0.69	0.090	$\leq$ 0.170	< 0.061	0.013
	Ra-B	1.00	0.51	0.058	0.017	0.004	0.003

The average energy for the Ra-B source, as determined by $\overline{r^2}$ distribution measurements in paraffin, is 2.1 Mev.

In order to specify the increase of fission rate due to the tamper, measurements were made with the untamped source. These results followed $1/r^2$, indicating that room background was negligible. Measurements were also made to detect any observable asymmetry of the source, with negative results. Throughout the measurements a "standard geometry" of paraffin and a 200 mc Ra-Be source was used to check the chamber and

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amplifier operation, and particularly to insure the absence of drift between tamped and untamped source measurements.

The results of the measurements are shown in Figs. 10 - 13. The position of the detector was taken as the center of the active volume. The consistency of various runs was within 10%. The distributions have been plotted times r^2 in order to show directly the multiplication, M, of the tamper compared to the untamped source at any radius. Although only three positions were measured they determine a smooth curve on a direct plot of the data from which the r^2F curve shape can be fairly accurately drawn.

DISCUSSION OF Ra-B RESULTS

Considering the results as a whole, the similarity of all curves obtained with this source to those obtained with the D-D is striking. The differences in practically all cases are sufficiently small to be within experimental error. The largest difference appears with the C tamper, both 25 and 28 distributions, and is such as to suggest that the average mean free path is shorter for Ra-B neutrons. The differences in Pb and Fe are probably due to the effect of the complex spectrum of the Ra-B source. There is no essential difference in either 25 or 28 distribution with a U tamper. The apparent differences in WC involve the geometry and must be discussed in more detail.

The curves of Figs. 11 and 13 with angular specifications signify radial distributions perpendicular (0° and 90°) to the side of the essentially square median plane cross section and diagonally (45° and 135°) in this plane. For all these measurements the cavity was cubical, hence even with this spherically symmetric source, an average was required for comparison. This average was obtained by plotting lines of equal density in the median plane and assuming that the radius of the best circle fit to these lines was the appropriate r for the corresponding density. The results of this procedure for both 25 and 28 detectors yielded the average curves shown in the

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figures. The cavity boundary at 10.1 cm is the radius of a sphere of equal volume. It is interesting to note that the equal-density lines for 25 and 28 have the opposite behavior: a 25 equal-density line passes closer to the center at 135° than at 0°; whereas the 28 lines follow more closely the physical shape of the cavity. This method of averaging is admittedly crude, but the cubical geometry makes proper treatment very difficult. The 0° 28 curve has a similar shape to the D-D curve, Fig. 8, and is closely 50% of the 135° curve at all r. The fact that the 0° Ra-B curve is 15% lower than the D-D curve cannot be considered significant.

The similarity of the 45° and 90° 25 distributions in WC (Fig. 3) near the cavity is to be expected if most of the detector response arises from the random neutron current rather than that from the source. The higher value for U at large r is a boundary effect arising from the larger outer radius of the U tamper. This is illustrated in Fig. 11 by the triangles marked "additional WC 90°" which were taken with an additional 2-1/8" of WC on the outer surface in the neighborhood of the detector. There are no differences between U and WC tampers significantly outside of experimental error in the 25 detector response.

III. MsTh-Be Source

A similar set of measurements was made with 500 mc of MsTh in a beryllium sphere of 4 cm outside diameter. This source was placed in the center of the U or WC tamper cavities. The results are shown in Fig. 14.

In this case, the source is very much weaker than any others used, making it difficult to obtain an accurate value of the bare-source counting rate. Two different measurements are indicated by the two horizontal lines of the figure and the ordinates are arbitrary counting rates, standardized as in the other source measurements. In this method of plotting, the error in the bare source does not affect the comparison of the two tamper materials. The counting errors are indicated on the individual curves.

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In contradistinction to D-D and Ra-B results it is immediately evident that for the neutrons of this source (≈ 800 Kev) WC is superior to U as a tamper. The difference is somewhat larger than that to be expected from the absence of 28 fissions in the U. This is consistent with a shorter mean free path in WC for these neutrons as found by differential measurements. The multiplication appears to be less than for either d-d or Ra-B neutrons for both U and WC even considering the uncertainty in the bare-source value. It is possible that the average neutron energy in the tamper may be higher for this source due to the decreased probability for large-energy-loss inelastic scattering.

CONCLUSIONS

The multiplication by various tampers for neutrons from the three different sources is summarized in Table II. It is evident that if C is unacceptable as a tamper due to the low average energy, then WC and U are the best tampers with U perhaps slightly preferable for neutrons approximating the energy of fission neutrons. The distribution curves illustrate the effect of inelastic scattering and mean free path and are consistent with expectations based on differential data.

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TABLE II

Summary of Multiplication Factors

Tamper	D-D neutrons		Ra-B neutrons		MsTh-Be neutrons
	$M_o(28)$	$M_o(25)$	$M_o(28)$	$M_o(25)$	$M_o(25)$*
WC	1.29	4.71	1.12(0°)	4.5	4.5
U	1.50	5.4	1.45	5.1	3.6
Pb	2.0	2.4	1.9	3.0	---
Fe	1.66	3.2	1.8	3.0	---
C	1.52	4.5	1.8	6.2	---

Note: Values of M_o are at r = 9.3 cm for WC
r = 10.3 cm for all others.

*Approximate values, see text.

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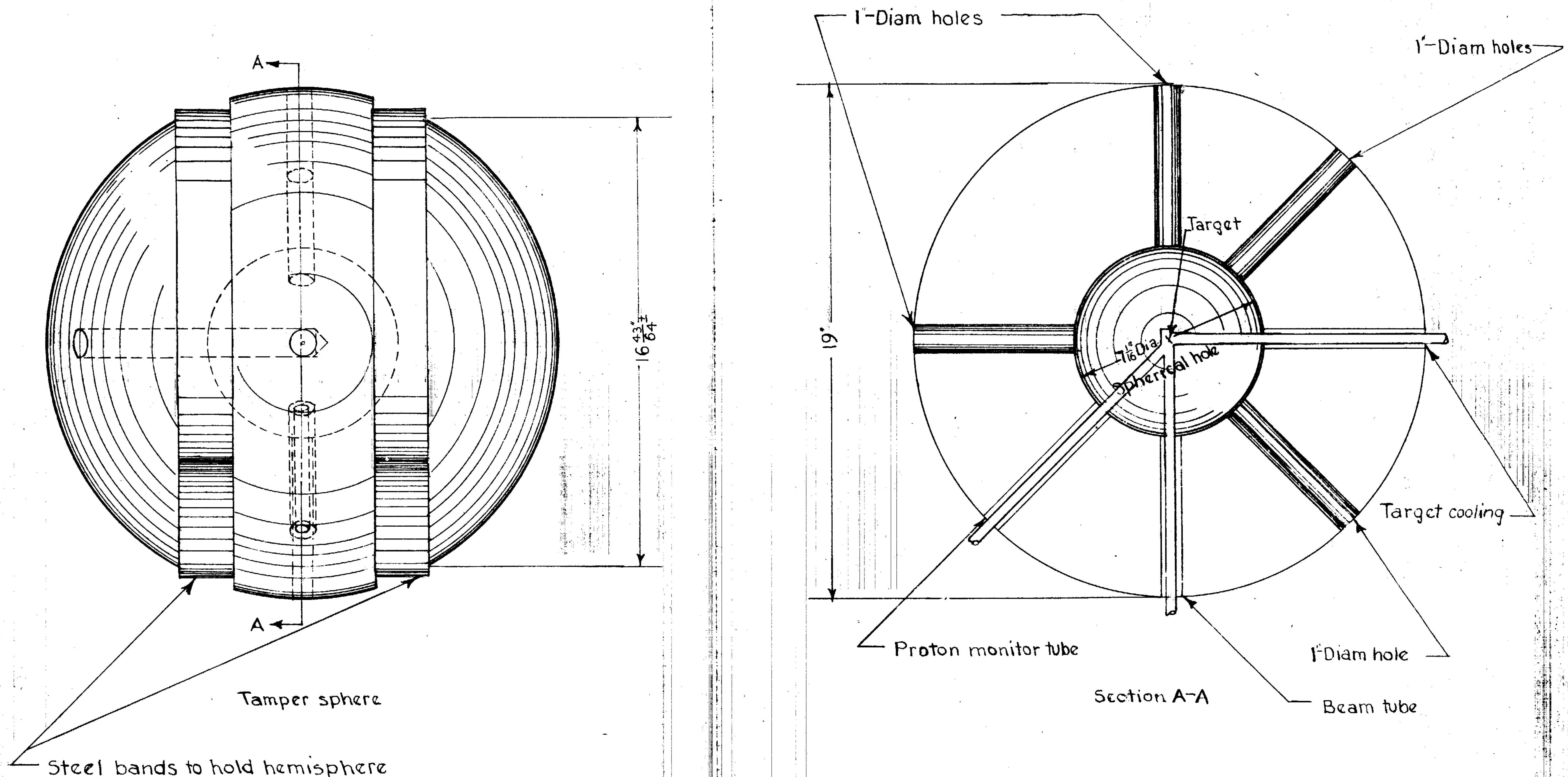
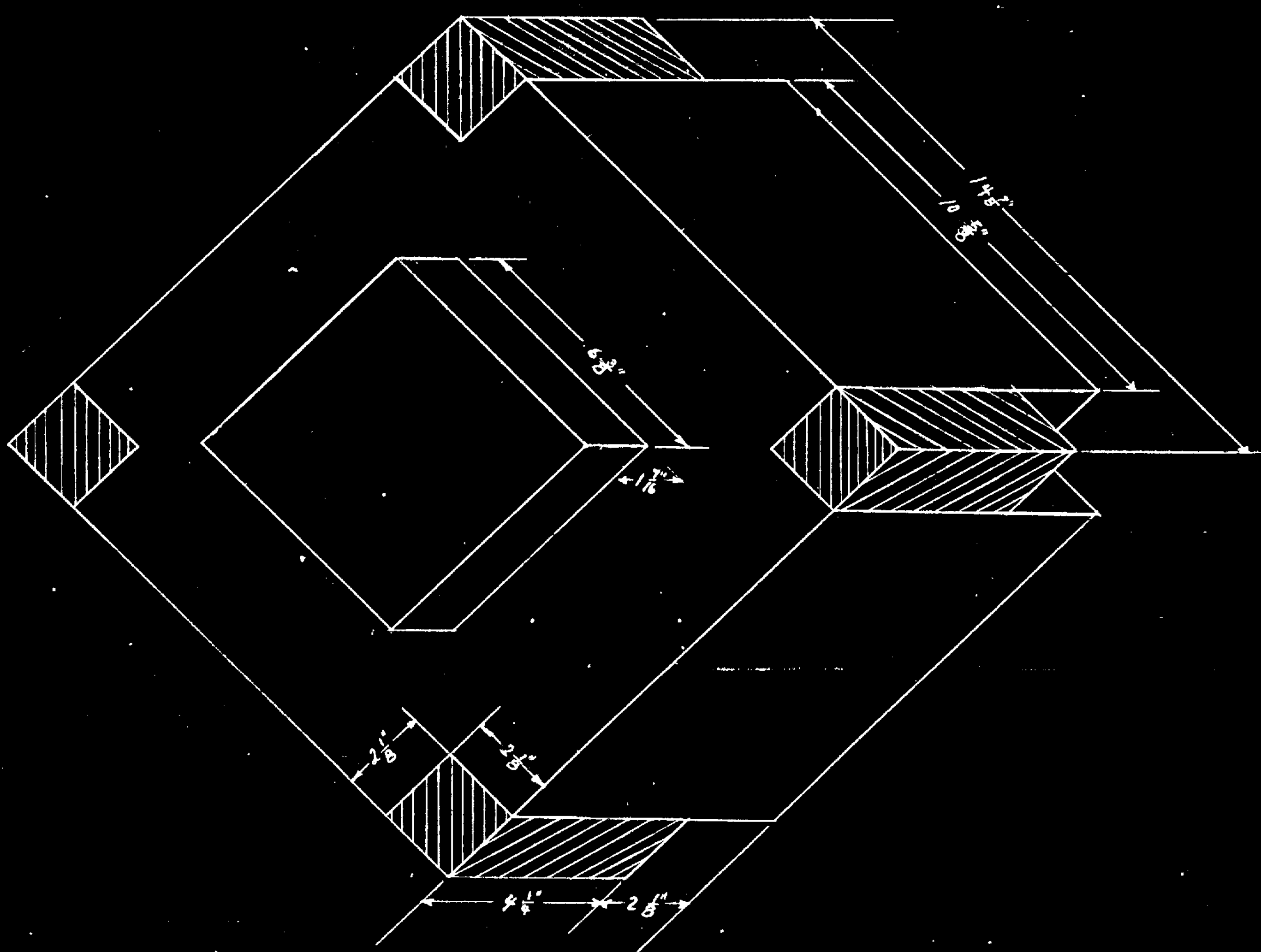


FIGURE 1

Scale 1/4"

I fig 2

ASSEMBLY NUMBER ONE



Shaded areas denote iron plugs
Scale 1/2

FIG. 2

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ASSEMBLY NUMBER ONE ~ FACE

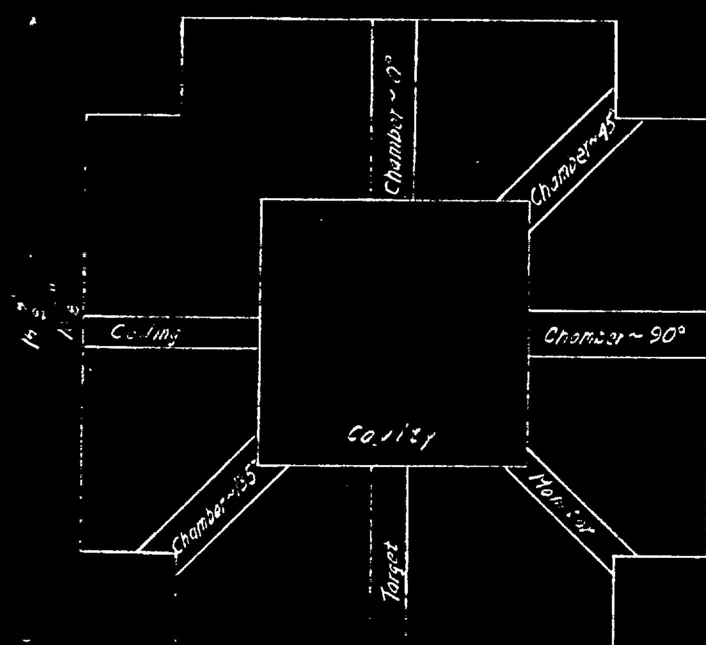
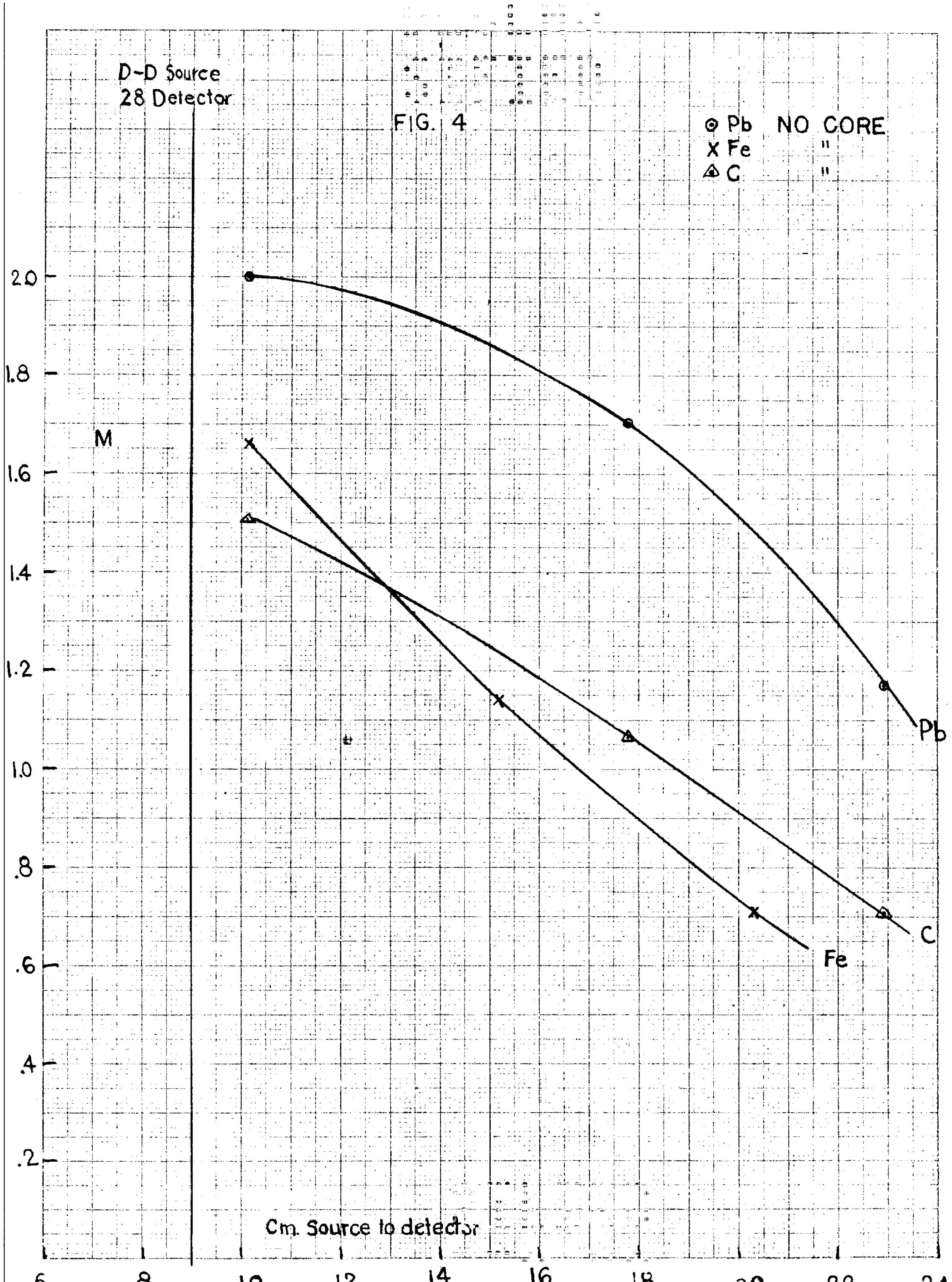


FIG. 3

LEGEND
Cooling Slot ~ 3/4" × 3/4"
Target Slot ~ 3/4" × 3/4"
Monitor Slot ~ 5/8" × 5/8"
Chamber Slots ~ 1 1/2" × 1 1/2"
Cavity ~ 6 3/8" × 5 3/8" × 3 11/16"
Scale 1/2

SIFIED
DECLAS



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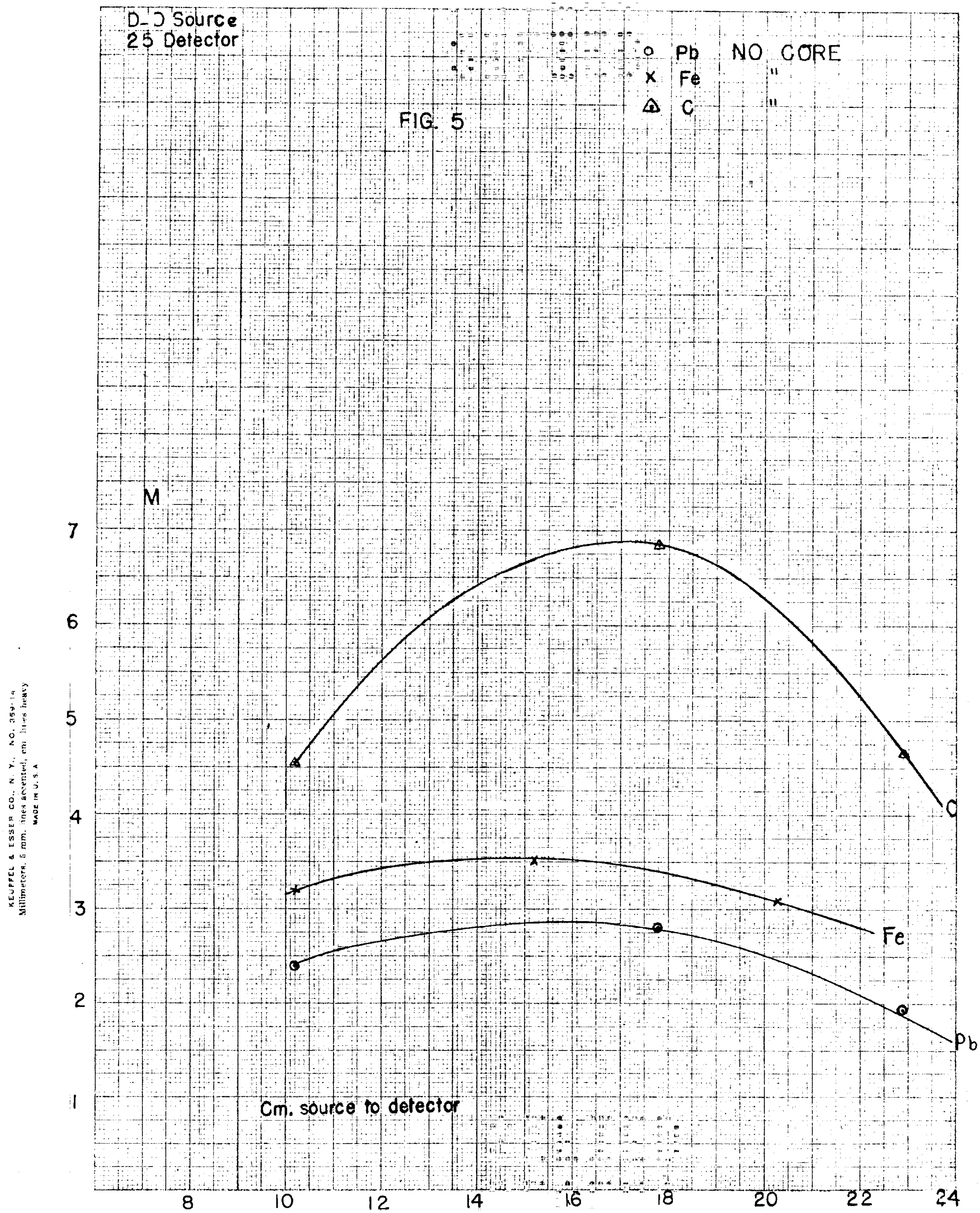
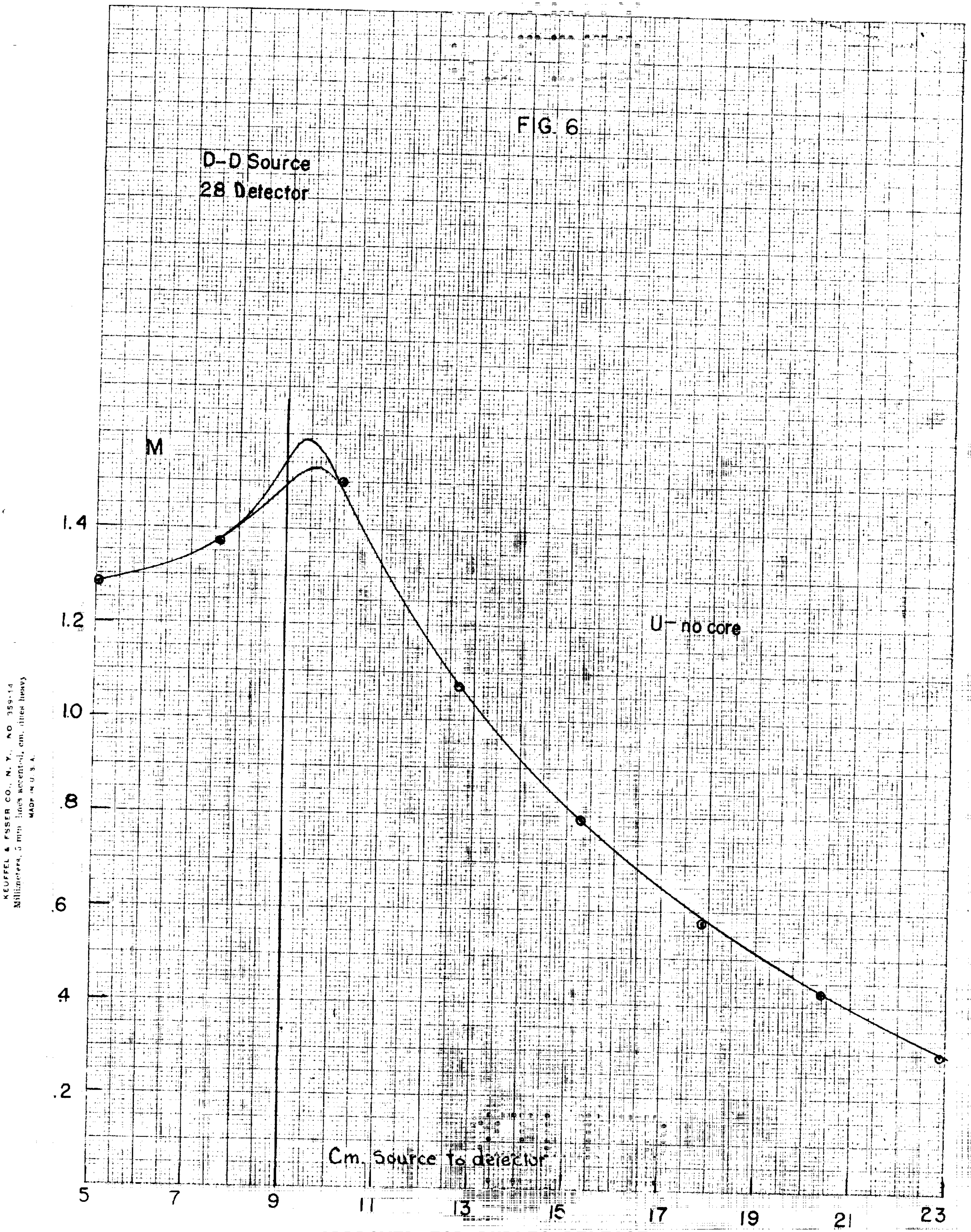


D-D Source
25 Detector
o Pb NO CORE
x Fe "
△ C "
FIG. 5
M
7
6
5
4
3
2
1
C
Fe
Pb
Cm. source to detector
8
10
12
14
16
18
20
22
24
KEUFFEL & ESSER CO., N. Y. NO. 359-14
Millimeters, 5 mm. lines accented, cm. lines heavy
MADE IN U. S. A.

FIG 6



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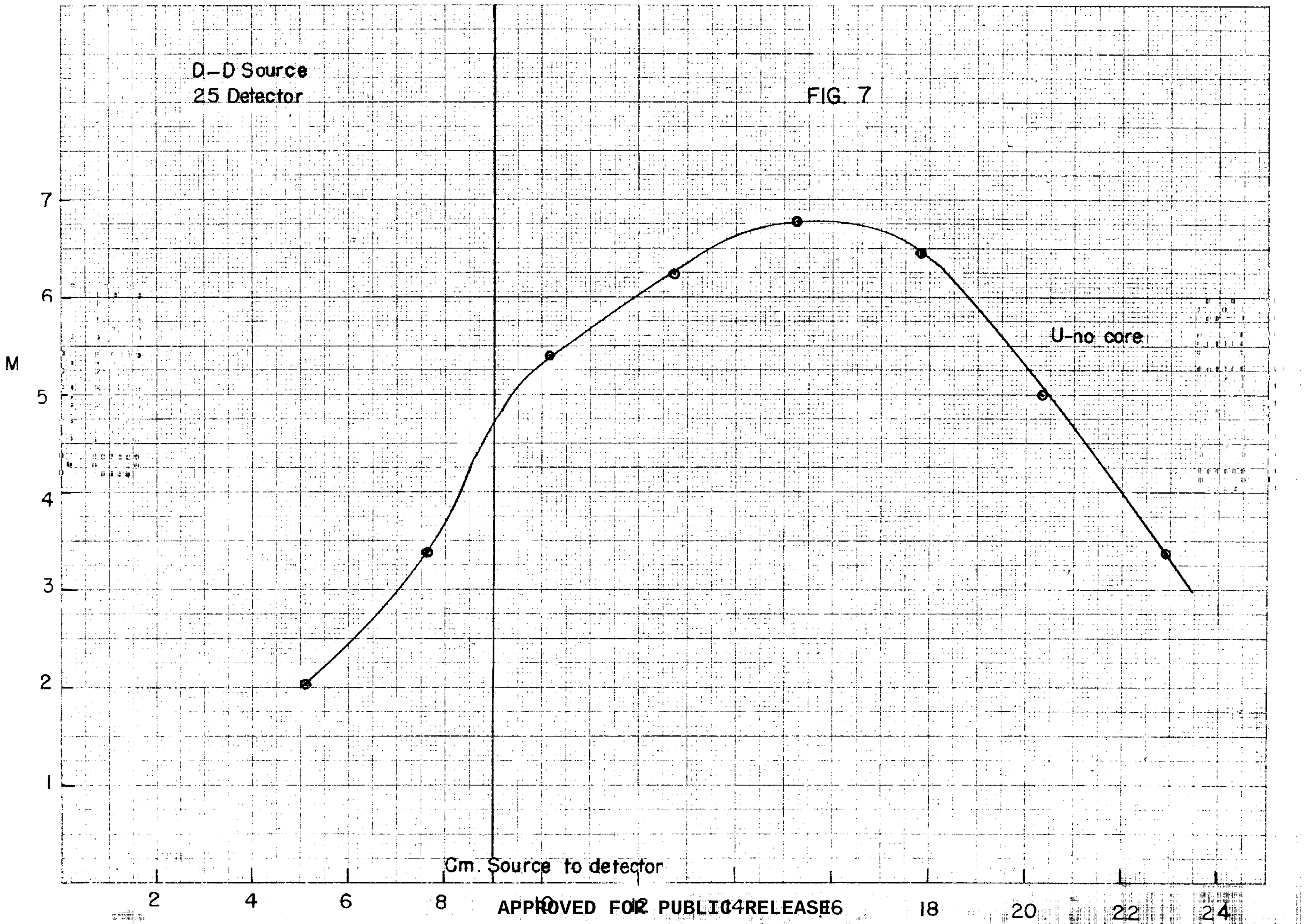
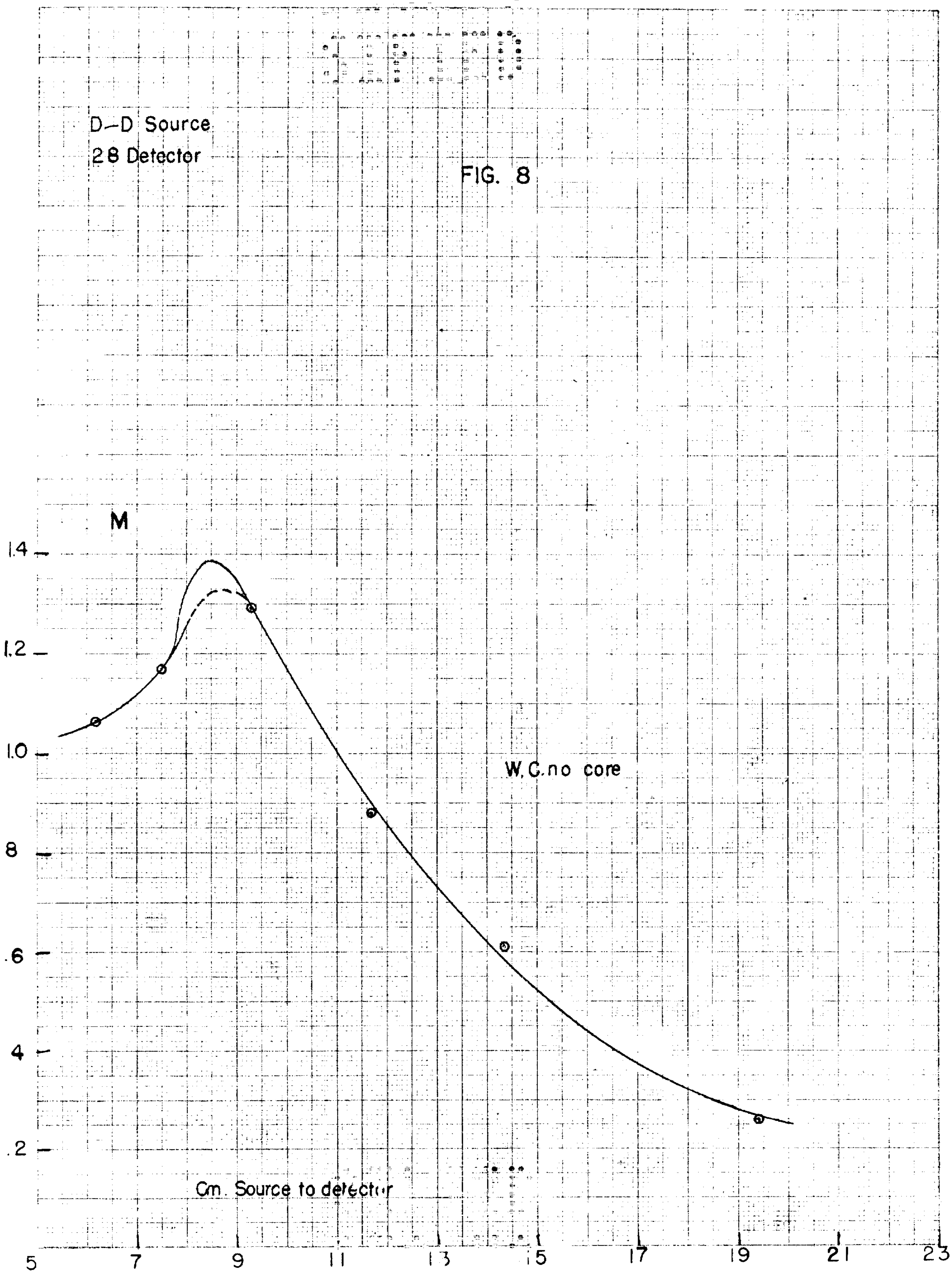

D-D Source
25 Detector
FIG. 7
M
7
6
5
4
3
2
1
U-no core
Cm. Source to detector
2
4
6
8
10
12
14
16
18
20
22
24



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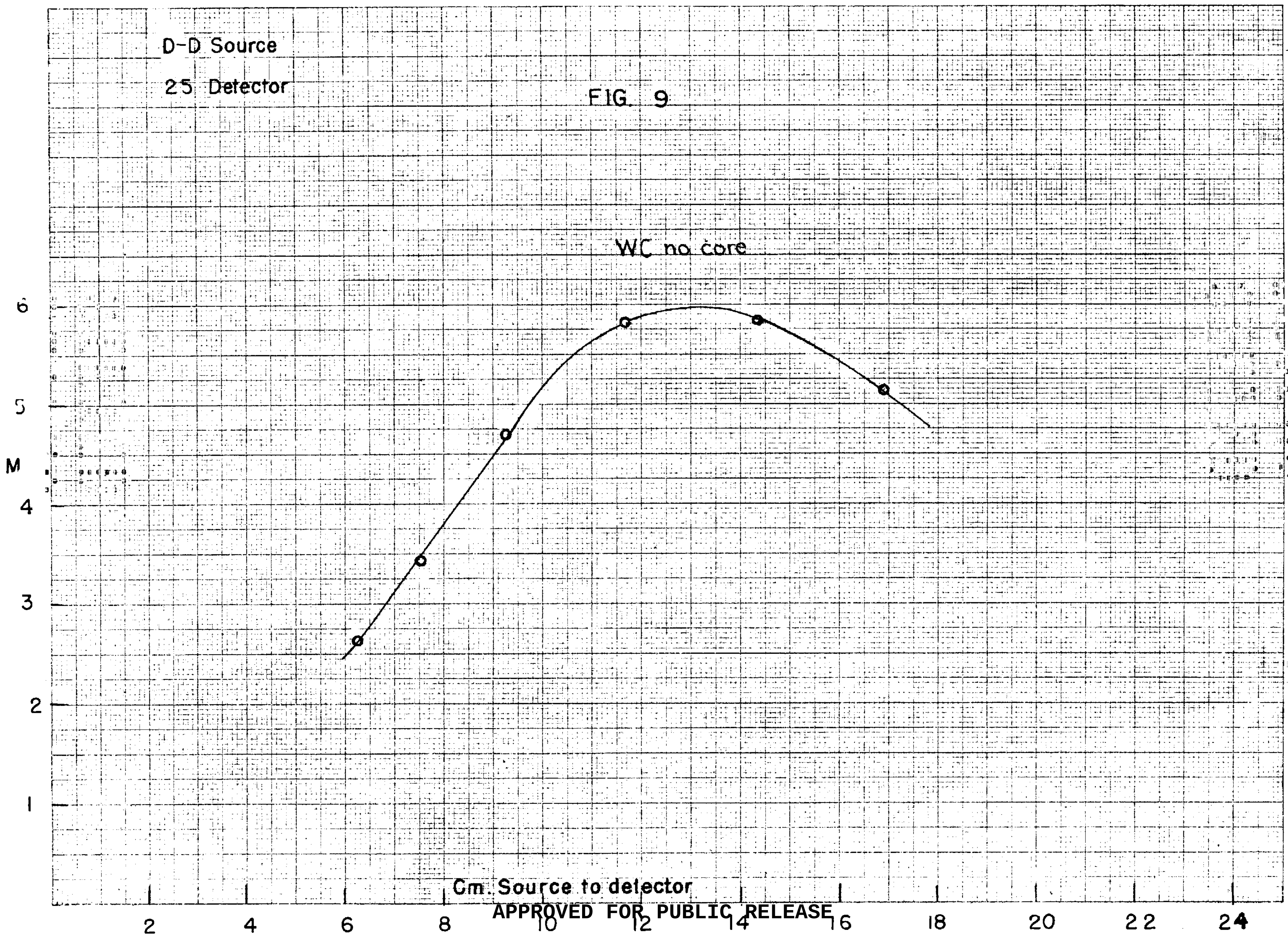

D-D Source
25 Detector
FIG. 9
WC no core
M
6
5
4
3
2
1
Cm. Source to detector
2
4
6
8
10
12
14
16
18
20
22
24

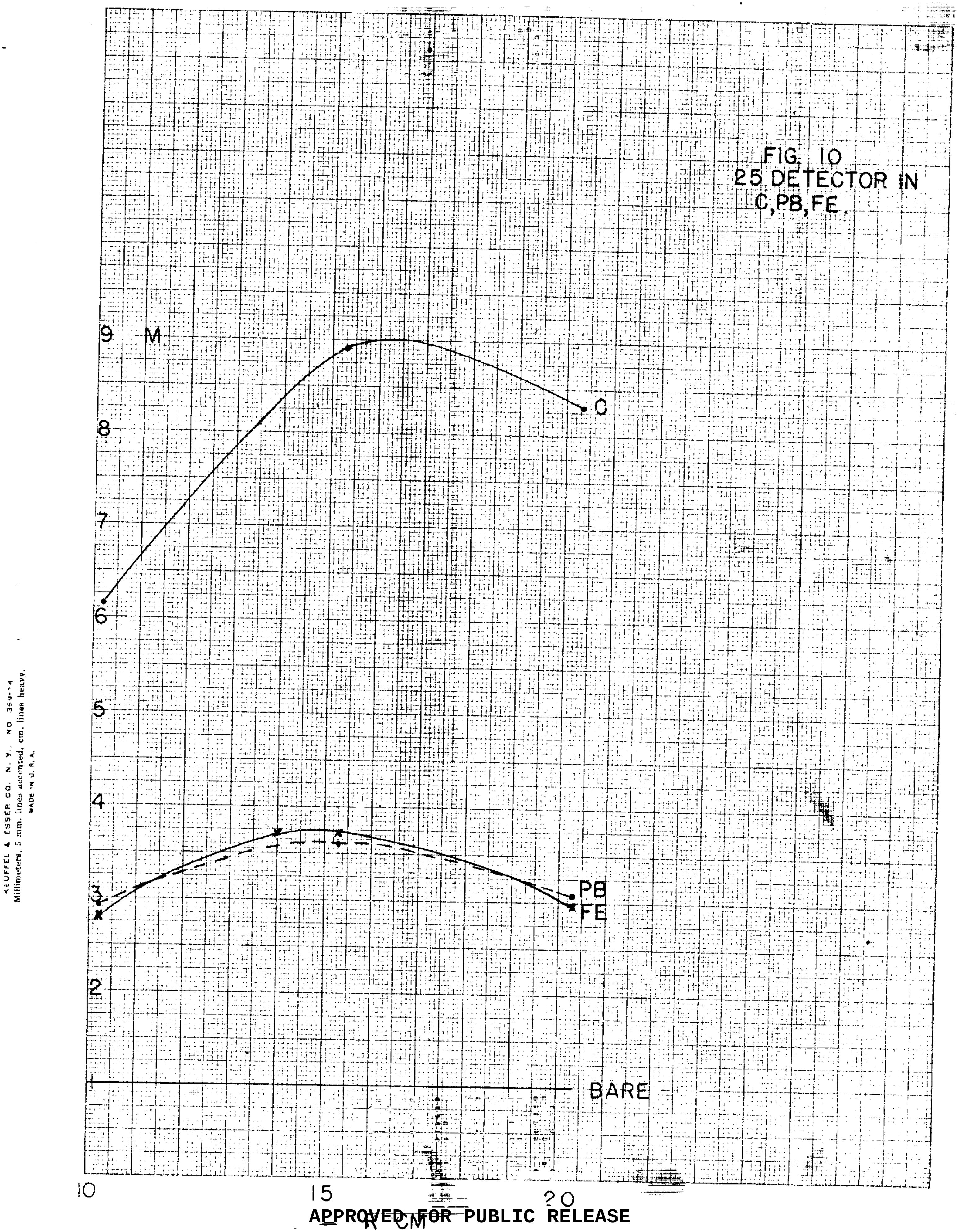


FIG. 10
25 DETECTOR IN
C, PB, FE
M
9
8
7
6
5
4
3
2
1
C
PB
FE
BARE
10
15
20
R CM
KEUFFEL & ESSER CO. N. Y. NO 359-14
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U.S.A.

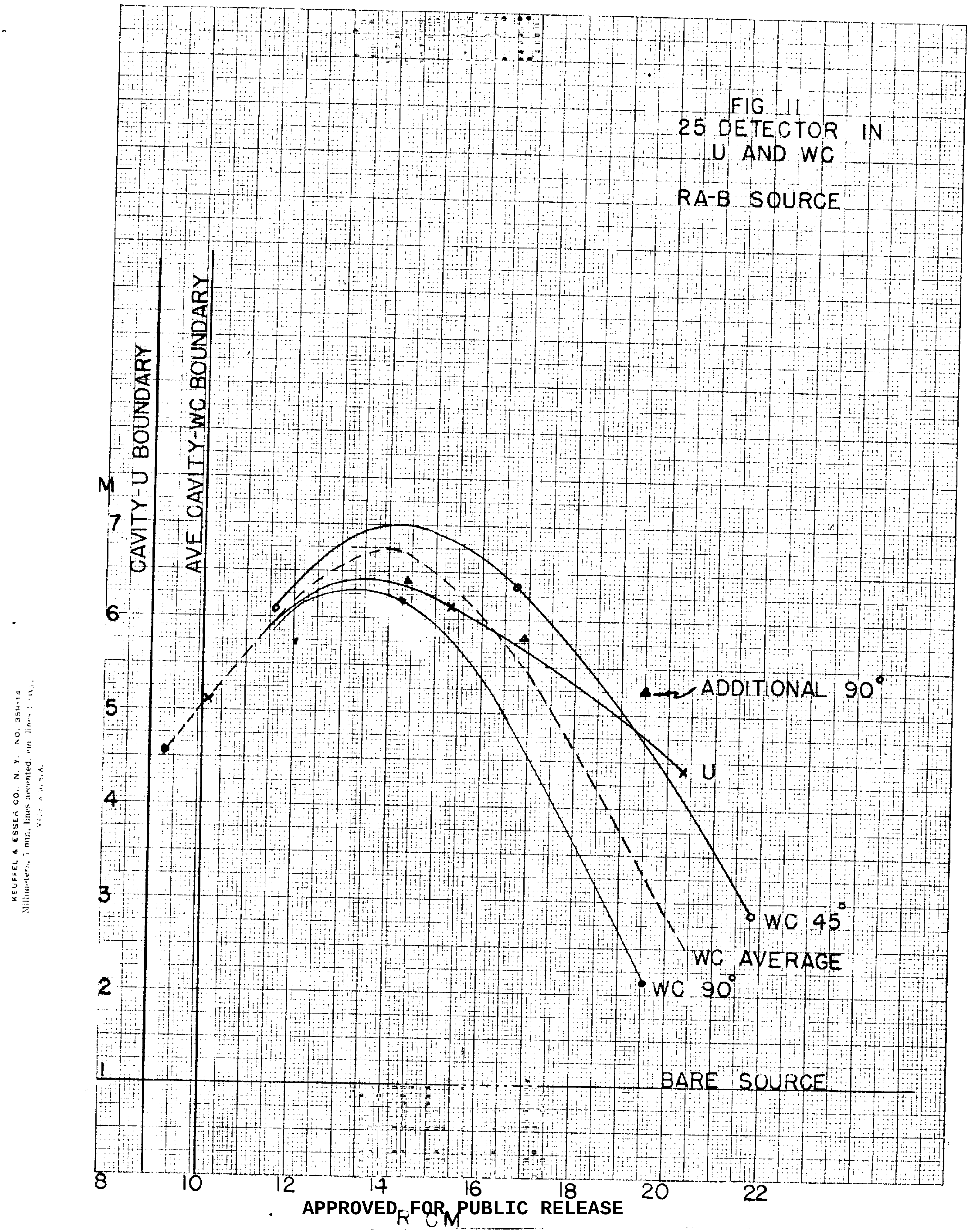


FIG 11
25 DETECTOR IN
U AND WC
RA-B SOURCE
CAVITY-U BOUNDARY
AVE CAVITY-WC BOUNDARY
M
7
6
5
4
3
2
1
ADDITIONAL 90°
U
WC 45°
WC AVERAGE
WC 90°
BARE SOURCE
8
10
12
14
16
18
20
22
R CM
KEUFFEL & ESSER CO., N. Y. NO. 359-14
Millimeters, 5 mm. lines accented, cm. lines heavy.
Made in U.S.A.

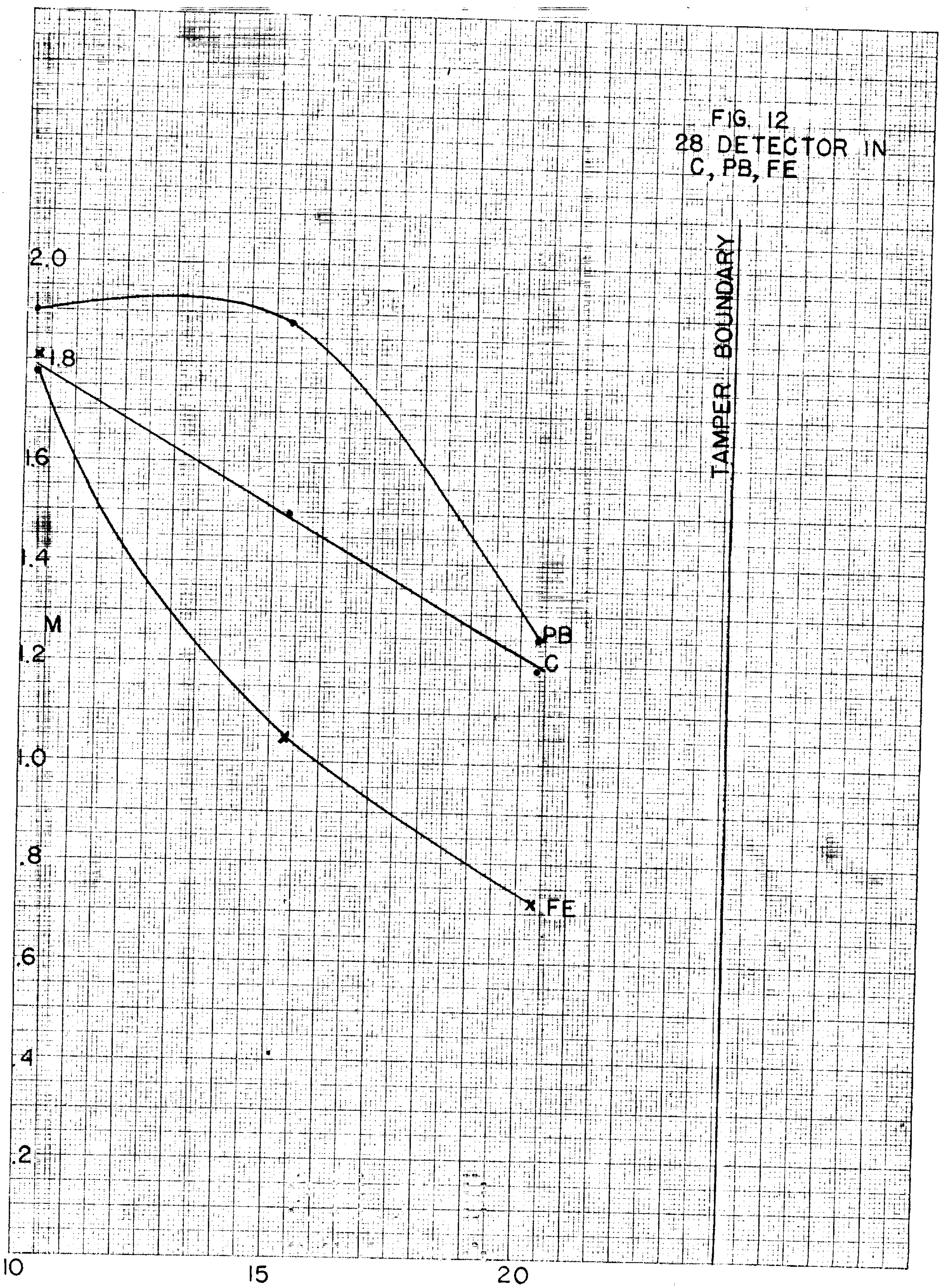
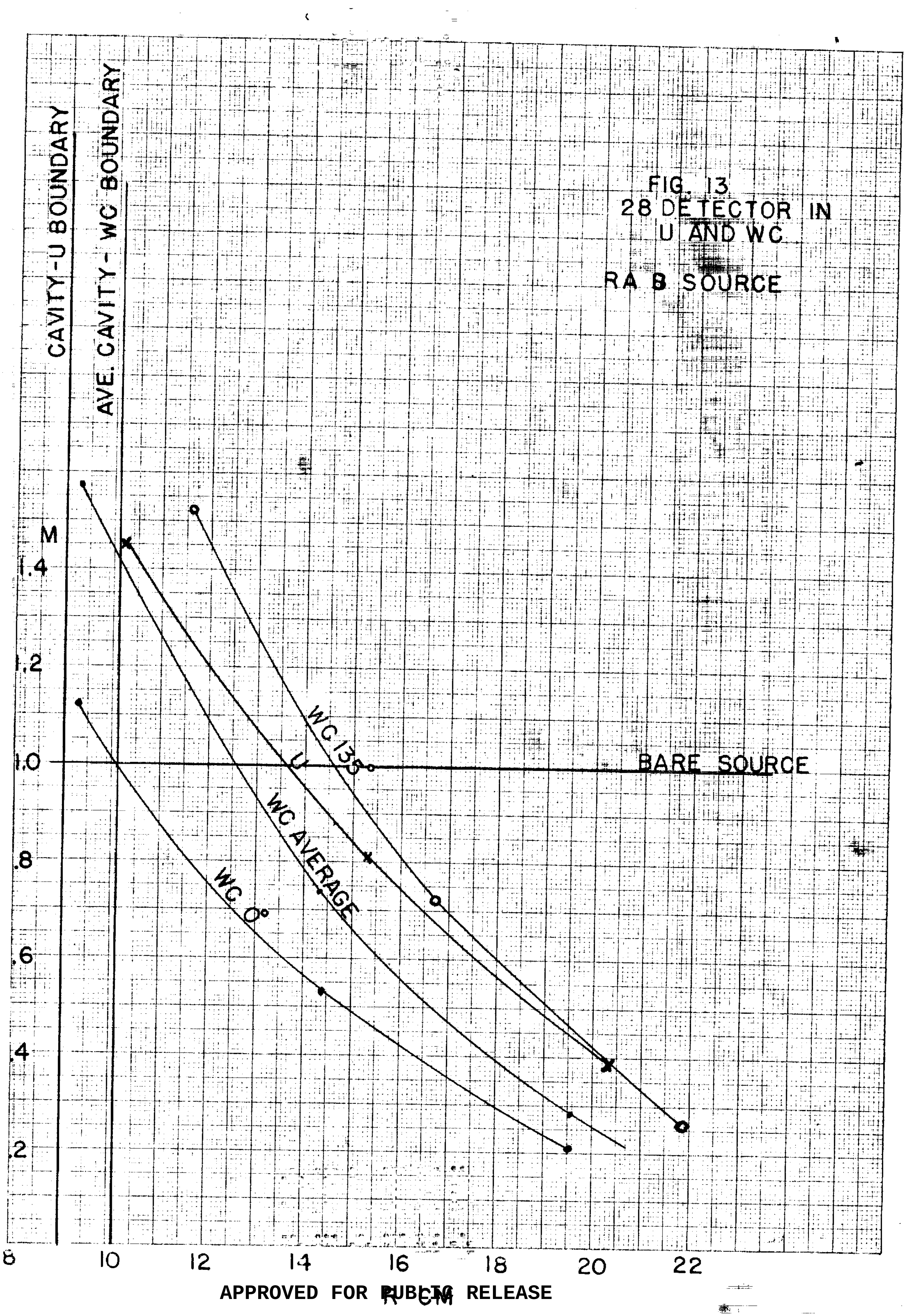


FIG. 12
28 DETECTOR IN
C, PB, FE
TAMPER BOUNDARY
2.0
1.8
1.6
1.4
M
1.2
1.0
.8
.6
.4
.2
PB
C
FE
10
15
20
R CM



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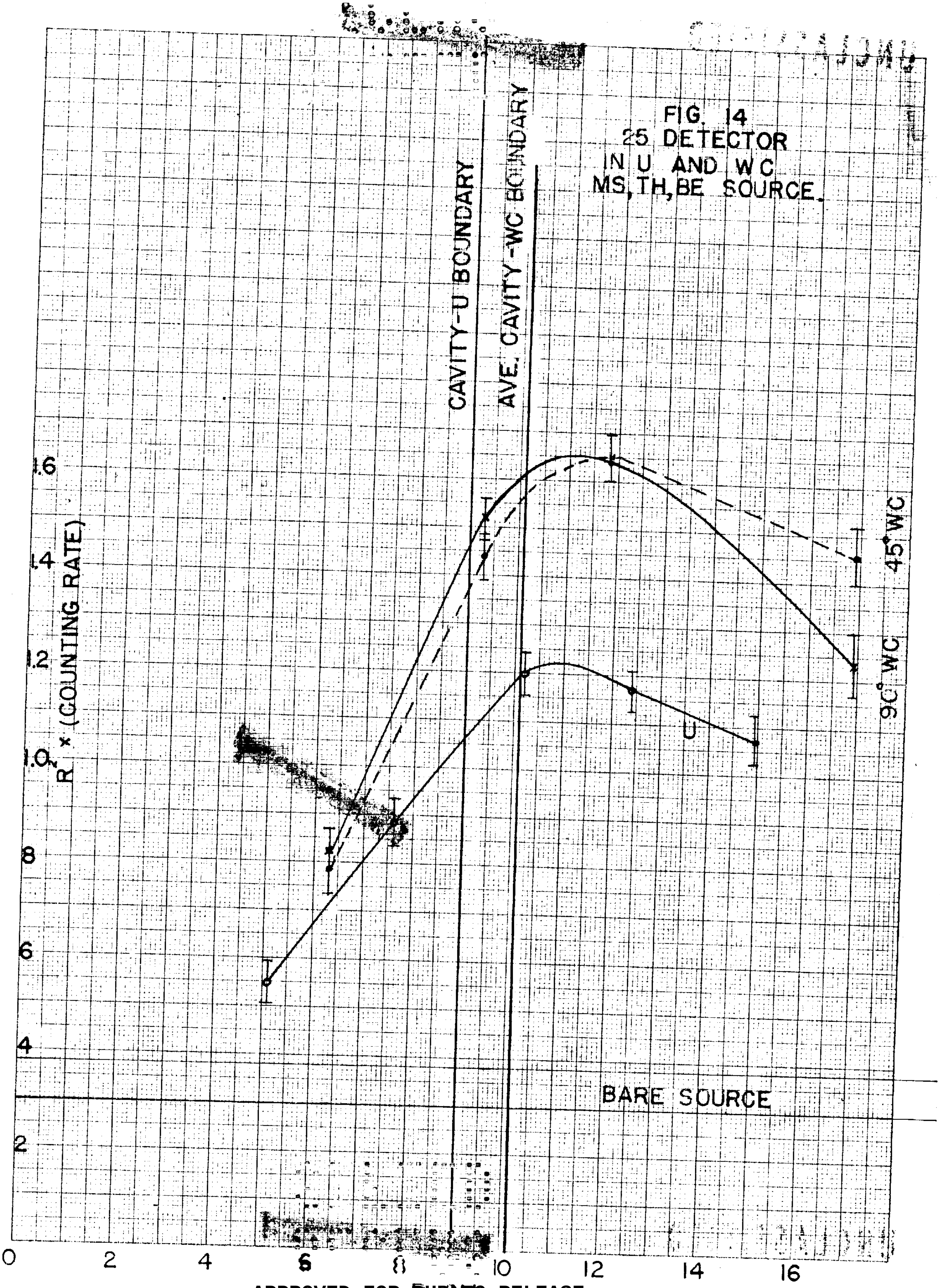
FIG. 14
25 DETECTOR
IN U AND WC
MS,TH,BE SOURCE.
CAVITY-U BOUNDARY
AVE. CAVITY-WC BOUNDARY
R × (COUNTING RATE)
1.6
1.4
1.2
1.0
8
6
4
2
45° WC
90° WC
U
BARE SOURCE
0
2
4
6
8
10
12
14
16