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SLOWING DOWN OF NEUTRONS IN AIR

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ABSTRACT

The total cross sections of nitrogen and oxygen have been measured from 35 Kev to 750 Kev. The slowing-down lengths of neutrons of approximately 450 Kev and 850 Kev has been measured in a large liquid-air bath using cadmium-covered indium and 25 detectors. A discussion is given of the capture of neutrons in air by the nitrogen n-p process, of the effective detection energy for a 25 detector, of the absolute calibration of the source strength from counting rates in the detector, and of the position of the 25 detector least sensitive to primary-neutron energy.

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SLOWING DOWN OF NEUTRONS IN AIR

In order to find the nuclear efficiency of the Trinity test the number of delayed neutrons coming out of the rarefied gadget was measured with a cadmium-covered 25 fission detector. Emergent fast neutrons are scattered and slowed down in the air, diffusing outward from the source. Knowing the scattering cross sections of the nitrogen[1] and oxygen in the air as a function of scattering angle and energy, the neutron distribution at energies considerably lower than that of the source and at not too great distances can be predicted by age theory. For the actual test, serious corrections must be made for moisture in the air[2] and for the effect of the ground[3]. It was thought useful to check the slowing-down lengths $L_S = \sqrt{\tau}$ (τ is the age) computed from the total cross sections, assuming isotropic scattering in the c.g. system, against the observed slowing-down length in liquid air.

The observed differential data are plotted in Figs. 1 and 2. The oxygen cross section is uncertain in the region from epithermal energies to approximately 250 Kev, but is bounded closely enough for present purposes. Energies of less than 1 Mev are of interest here since the spectrum of delayed neutrons from fast excitation of 49 very probably lies in that region; it is hoped to investigate this spectrum soon. Sodium azide, sodium nitrate, and metallic sodium were the scatterers used. The experimental setup was the same as in LA-256. No data were taken on the angular distribution of scattering.

In Table I is presented the slowing-down length in air density .001 grams/cc, oxygen content 20%, as a function of final energy taking 1 Mev as the

1) For total cross section in the region from thermal energies up to 1 Kev, see AM-1211, Rainwater and Havens.

2) Cf. LA-250 by Weisskopf.

3) Cf. LA-257 by Bellman and Marshak.

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primary source of energy[4]. To get the slowing-down length in liquid air of the same composition this must be multiplied by the ratio of densities, which is 870.

Design and construction of the liquid-air tank for the integral experiment and production of the liquid air in Y Building were handled by G.E. Moore and co-workers of group X-4. The dimensions were chosen large enough so that measurements along the axis simulated the infinite medium fairly closely. A butane tank was cut down and rewelded to the desired length, slotted to admit movable neutron detectors, and suspended in a container of thermal insulator, as shown in Fig. 3. The target tube of the long electrostatic generator in W was introduced into a stainless-steel tube welded into the liquid-air tank. The tank was filled with approximately 880 liters of liquid air produced at the rate of 70 liters per hour of continuous running. The composition of the liquid air was determined by a nitrogen vapor pressure thermometer; it was found that the liquid air produced with the present arrangement of the Y Building plant is 27% oxygen instead of the 21% in normal air. It had been anticipated that the losses from the liquid air tank would have to be met mainly with commercial liquid nitrogen because evaporation leaves the liquid air oxygen rich. But the commercial "liquid nitrogen" varied in oxygen content from 5 to 35%, and it proved impossible even with the large quantities available to reduce the oxygen content below 24 ± 1% where it was held throughout the experiment. The heat leak loss of the tank was only 3½ liters per hour.

The neutron intensity was studied primarily along the axis in the forward direction from the target. The neutron source strength was calibrated absolutely

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4) Age theory was used since a more rigorous calculation (based on BM-223 by Marshak) showed that the slowing-down length computed by age theory was low by at most 5% in the energy range considered.

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with a standard RaBe source in a manganese bath constructed by C.M. Turner. Total yields at the four energies used, from the p-n reaction on a 100-Kev-thick lithium target, are given in Table II.

Cadmium-covered indium-foil detectors were placed successively at seven positions out from the target along the axis, and at a few off-axis points. Indium foils were calibrated for absolute sensitivity by the known neutron distribution from a standard RaBe source in the G Building graphite block.

A 25 spiral chamber was built for operation in liquid air and filled with neon gas at 15 atmospheres. This measured the relative sensitivity of a 25 detector as a function of distance from the target and primary neutron energy, but did not give an absolute calibration of counting rate per primary neutron because the effective mass of 25 in the chamber was unknown. One of the sets of 25 plates for use at Trinity was calibrated in the liquid-air bath and has also been compared with a known 25 foil to give its absolute detection efficiency. Table II also gives source strength Q as computed from the indium and 25 data. If the strong forward asymmetry of the source were evident in this data the manganese bath data, which give the total source strength, would show a lower Q than is computed from the data taken in the forward direction. As seen in Table II, a substantial correction had to be made to the computed source strength because of absorption of neutrons by the nitrogen n-p reaction. In the age theory approximation the observed slowing-down density q at a given τ is equal to the predicted q times a factor $e^{-\int_0^\tau (3/\lambda_a \lambda_s) d\tau}$, where λ_a is the mean free path for the absorption process and λ_s the scattering mean free path. In the case of a 1/v absorption and isotropic scattering this gives simply $e^{-2\sigma_a/\xi\sigma_s}$ where σ_a is measured at the energy in question. The nitrogen is assumed to have a 1/v cross section from its thermal value

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of 1.5 ± .2 barns[5] up to where Barschall's data are available. The oxygen is assumed to have a negligibly small capture cross section.

The 10% agreement between the source strengths computed from the indium and observed with the manganese bath indicates that the anisotropy of the source does not affect materially the intensity at large distances. The 25 absolute calibration agrees within its large experimental error due to low intensities and liquid air leaking into the container.

The solid lines in Figs. 4, 5, 6 and 7 give the counting rate A (in arbitrary units) of indium and 25 detectors at various energies as a function of the distance z (along the axis) from the source. There is an appreciable increase in the indium counting rate near the source, apparently because of excitation of higher energies than the 1.44 ev resonance. This is in qualitative agreement with the fast-excitation data of LA-211, and also the effect has been observed in graphite. Part of the discrepancies between theory and experiment in LA-38 may be due to fast excitation. The fast-excitation effect is considerably stronger for the 25 detector. The dotted lines in Figs. 4, 5, 6 and 7 represent the theoretical curves computed from age theory[6].

The slowing-down length shown with each curve was chosen so that the best fit was obtained with the observed intensity distribution in the bath at a distance greater than one slowing-down length. At such distances the deviations from age theory due to fast excitation become negligible. In obtaining the theoretical curves, an extrapolated end-point of 4 cm was added to all dimensions.

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5) Rainwater and Havens give the total cross section up to 1 Kev as a constant, 9.7 barns, plus a 1/v term (presumably due to absorption) with the thermal value of 3.8 barns. Other measurements give 1.3 to 1.7 barns as the thermal absorption cross section.

6) Cf. BM-744 by Courant.

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For the indium resonance detector the age is measured from the somewhat blurred primary-source energy to the energy of the narrow resonance, and the activity of the detector is proportional to the number of neutrons per cc times the velocity in the energy interval containing the resonance. A detector with a 1/v cross section, as is 25 to a rough first approximation, counts neutrons of all energies weighted according to the neutron density. The observed age for 25 is thus an average of ages from source energy down to many energies, and will change somewhat from place to place as the spectrum of neutrons in the slowing-down medium changes. The mean detection energy for 25 obtained by using its known cross section(i.e. taking account of the deviations from a pure 1/v law)is 20ev in the region in which the data are matched by the theoretical curve. This means nergy corresponds to the energy of a monochromatic resonance detector which would give the same slowing-down length. The mean energy of detection as computed from the ratio of slowing-down lengths for the indium and 25 detectors is 7 ev from the 350-Kev data and 80 ev from the 850-Kev data. The wide discrepancy between these two values is not serious since they are obtained by taking the difference between two very large numbers, namely the ages down to the indium resonance level and to the mean detection energy of 25. It is apparent from the curves that more careful matching would bring these values into better agreement. For the purposes of the Trinity test, the total age is the quantity which determines the neutron intensity and this is very insensitive to the value of the mean detection energy as long as it is below, say, 100 ev. No detailed correction has been made for the intensity and energy anisotropy of the source, but a reasonable guess from the known angular distribution indicates that the effective source energy should be taken as 350 Kev instead of 450, and 850 Kev instead of 950. The observed slowing-down lengths must be shortened by 1.7% to correspond to 20%-oxygen concentration.

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It was of particular importance to locate the 25 detector at Trinity in a position insensitive to the energy of the source neutrons. A region of minimum sensitivity is at such a distance that $\partial q/\partial \tau = 0$; for the infinite medium this is at $r = \sqrt{6\tau}$. This was tested in detail by taking the counting rate in the 25 chamber as a function of distance in this region for four different energies, with the source strength normalized by manganese-bath calibrations. The approximate cross-over points are shown in Fig. 8, along with the expected values in the infinite medium. The finite cylindrical geometry distorts the relative shapes of the curves toward the far end of the bath and brings the theoretical values into better agreement with experiment.

A comparison of the slowing-down length from 350 Kev to 1.44 ev obtained from the liquid-air-bath measurements with the differential value read off from Table I shows that the former is 8% lower than the latter. This is within the accuracy of the measurements, particularly since the differential cross sections are unknown between 1 and 35 Kev.

The ratio of counts, at approximately three slowing-down lengths from the target, for an uncovered indium detector to a cadmium-covered indium detector was 1.36, a qualitative check that the nitrogen capture cross section prevents neutrons from existing much below .2 ev.

The off-axis data are tabulated in Table III. While the off-axis to on-axis ratio is some 20% lower than predicted, the independence of that ratio on z is a check on age theory for the finite cylinder.

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TABLE I

E_{Kev}	τ(cm^2 x 10^{-8}) in air at .001 gm/cm^3
700	0
600	.43
500	.77
400	1.06
350	1.29
300	1.51
200	2.13
100	2.85
40	3.47
20	3.82
10	4.05
4	4.28
1	4.66
.1	5.00
.01	5.43
.00144	5.80
.001	5.86
.0001	6.30

From 350 Kev to 1.44 ev

$$\sqrt{\tau} = \sqrt{(5.80-1.29) \times 10^8} = 2.12 \times 10^4$$

For liquid air

$$\sqrt{\tau} = (2.12 \times 10^4)/870 = 24.4 \text{ cm}$$

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TABLE II

E_n max in Kev	E_n effective	Manganese bath	neutrons x 10^{-8} per microcoulomb			
			Indium		25	
			Uncorrected	Corrected	Uncorrected	Corrected
250		.80				
500	350	1.54	1.1	1.4	.95	1.2
750		1.10				
1000	850	1.00				

TABLE III

Mean Energy Kev	Distance from source along axis in cm	Fraction of radius off axis	Ratio(on axis/off axis)	
			Experimental	Theoretical
350	22	1/2	.56	.65
		3/4	.35	.39
	52	1/2	.54	.65
850	22	3/4	.33	.39
	52	3/4	.31	.39

[redacted]

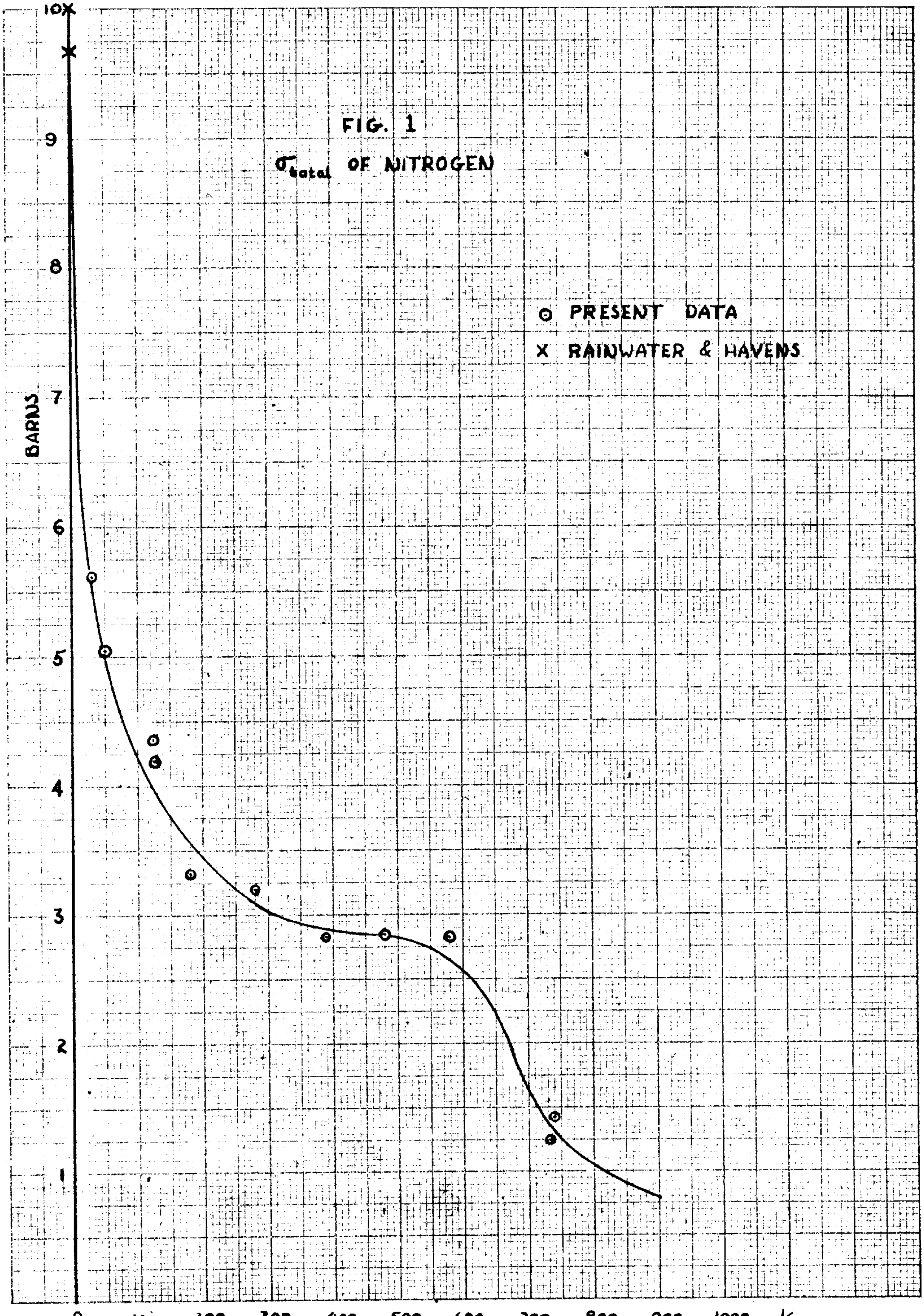

FIG. 1

σ_{total} OF NITROGEN

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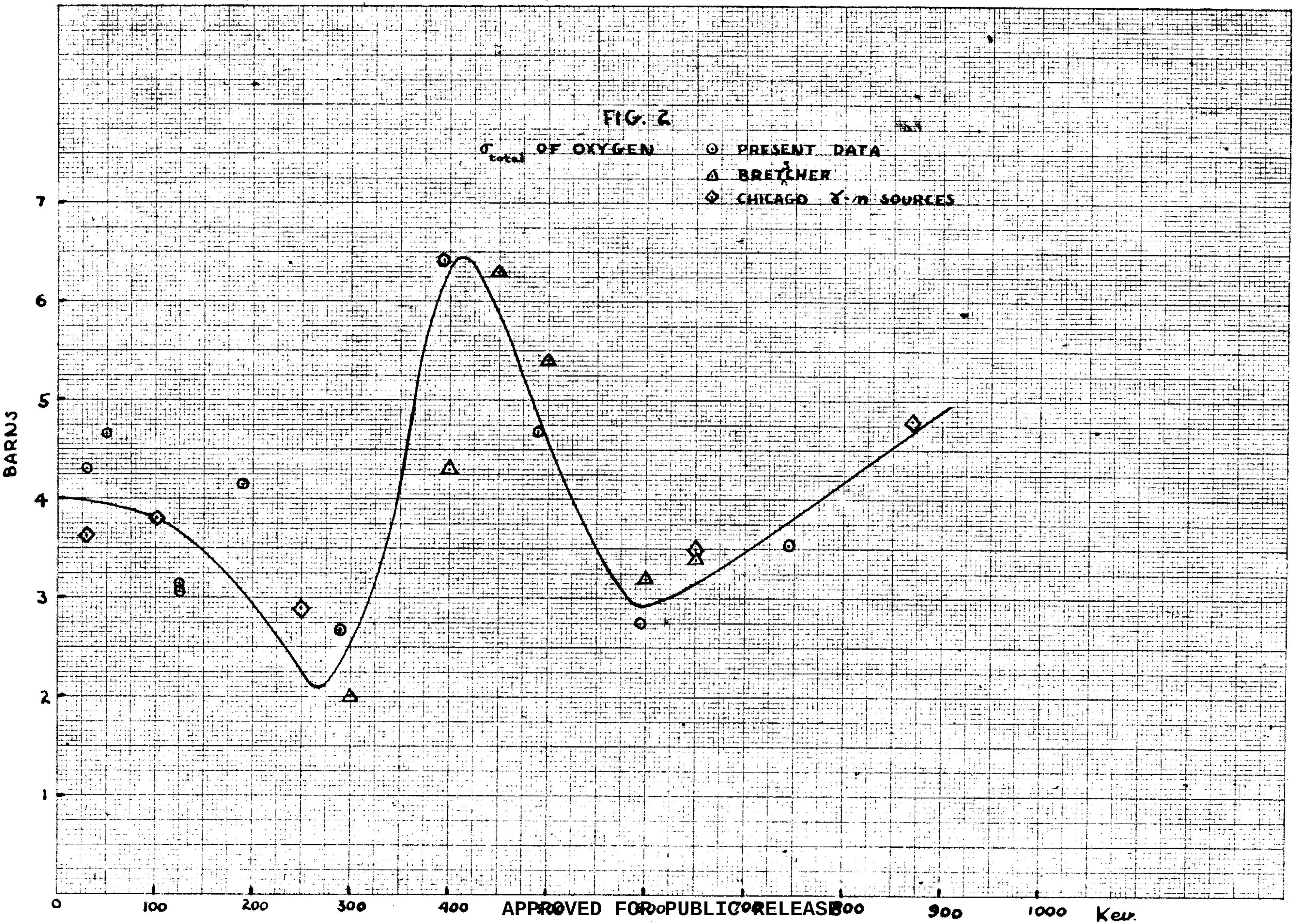
FIG. 2


σ total OF OXYGEN
⊙ PRESENT DATA
△ BRETSCHER
◇ CHICAGO γ-n SOURCES
BARNS
1
2
3
4
5
6
7
0
100
200
300
400
900
1000
Kev.

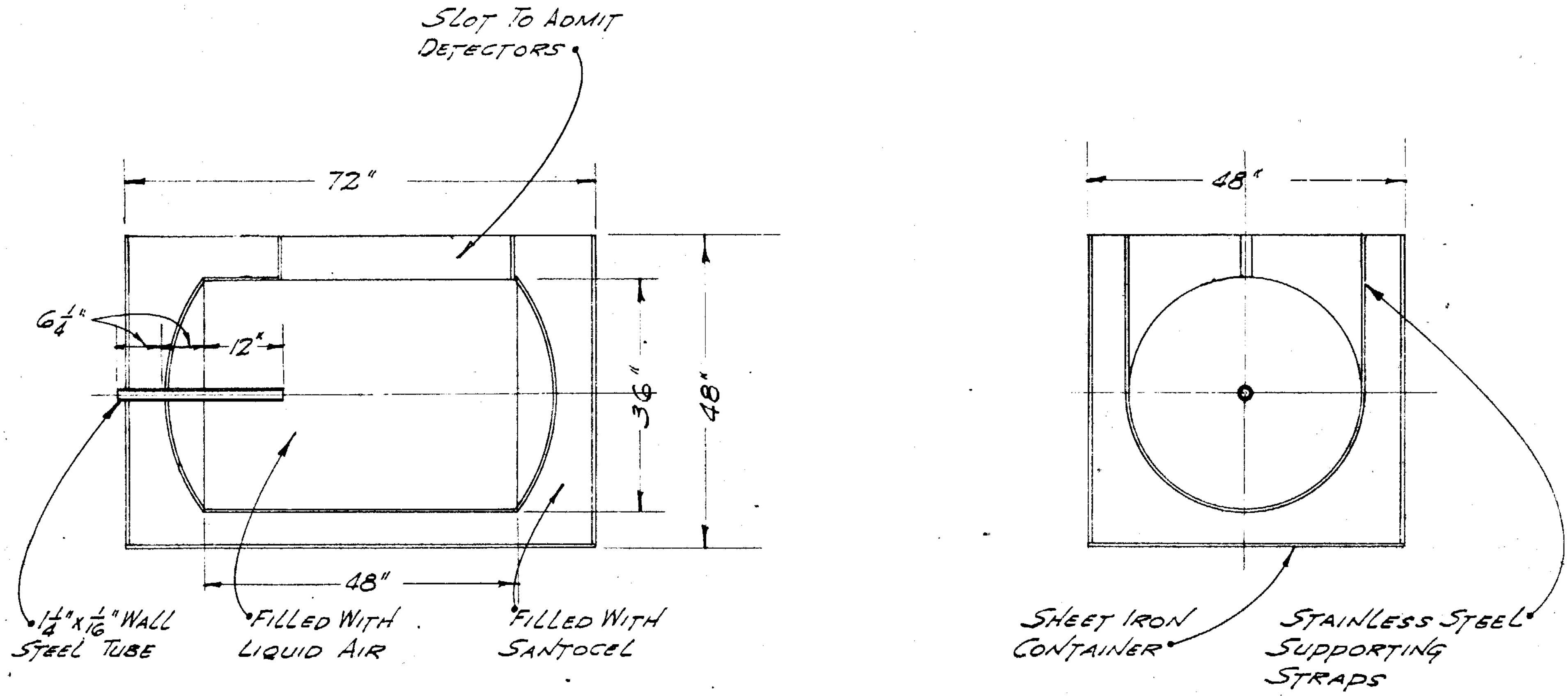

SLOT TO ADMIT DETECTORS
72"
$6\frac{1}{4}$"
12"
36"
48"
48"
$1\frac{1}{4}$" x $\frac{1}{16}$" WALL STEEL TUBE
FILLED WITH LIQUID AIR
FILLED WITH SANTOCEL
48"
SHEET IRON CONTAINER
STAINLESS STEEL SUPPORTING STRAPS

FIG. 3

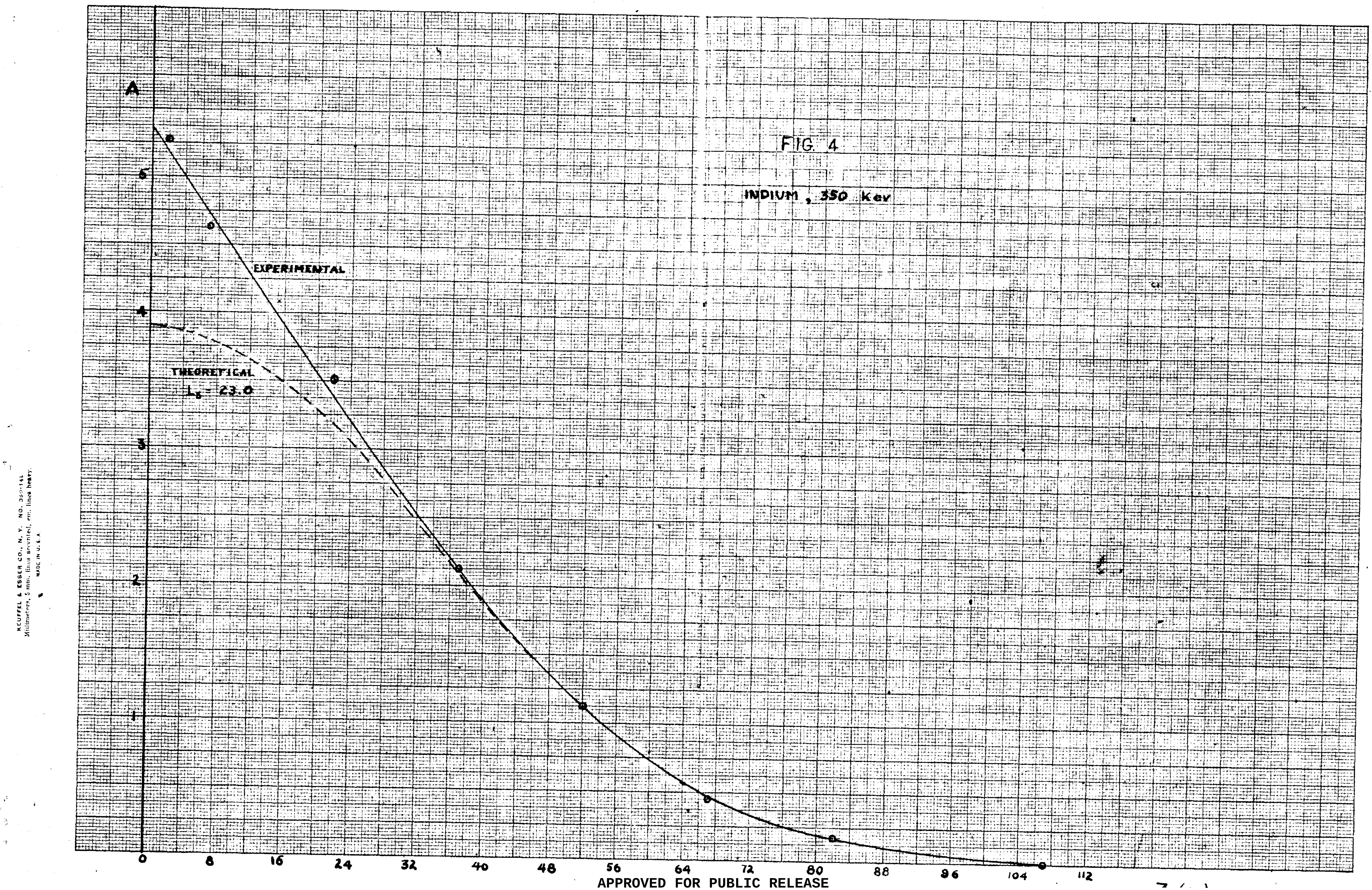


FIG 4
INDIUM, 350 Kev
EXPERIMENTAL
THEORETICAL
L_s = 23.0
A
5
4
3
2
1
0
8
16
24
32
40
48
56
64
72
80
88
96
104
112
KEUFFEL & ESSER CO., N. Y. NO. 359-14L
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U.S.A.

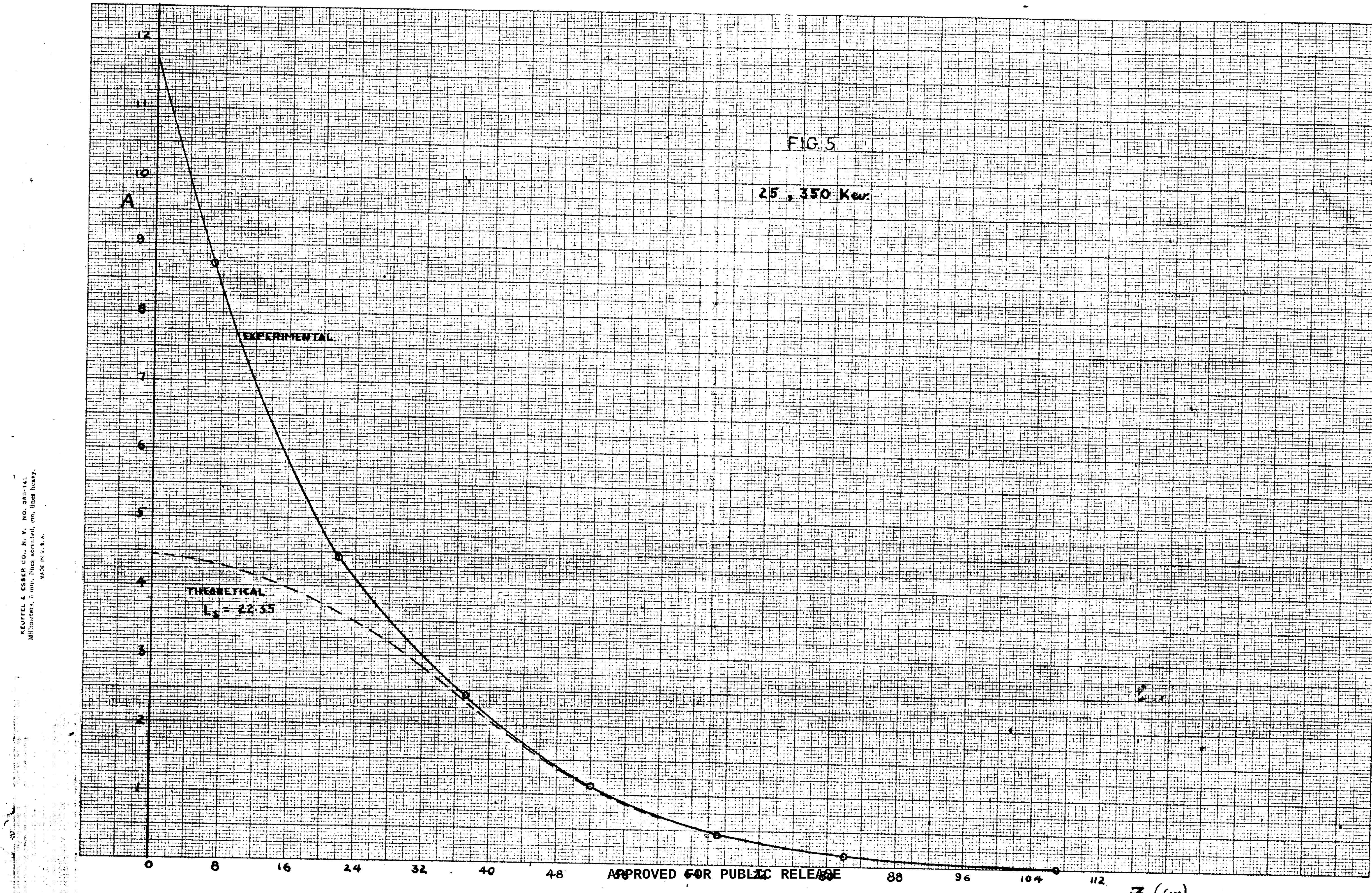


FIG 5
25 , 350 Kev.
A
12
11
10
9
8
7
6
5
4
3
2
1
0
8
16
24
32
40
48
88
96
104
112
EXPERIMENTAL
THEORETICAL
L_s = 22.35
KEUFFEL & ESSER CO., N. Y. NO. 359-14
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U.S.A.

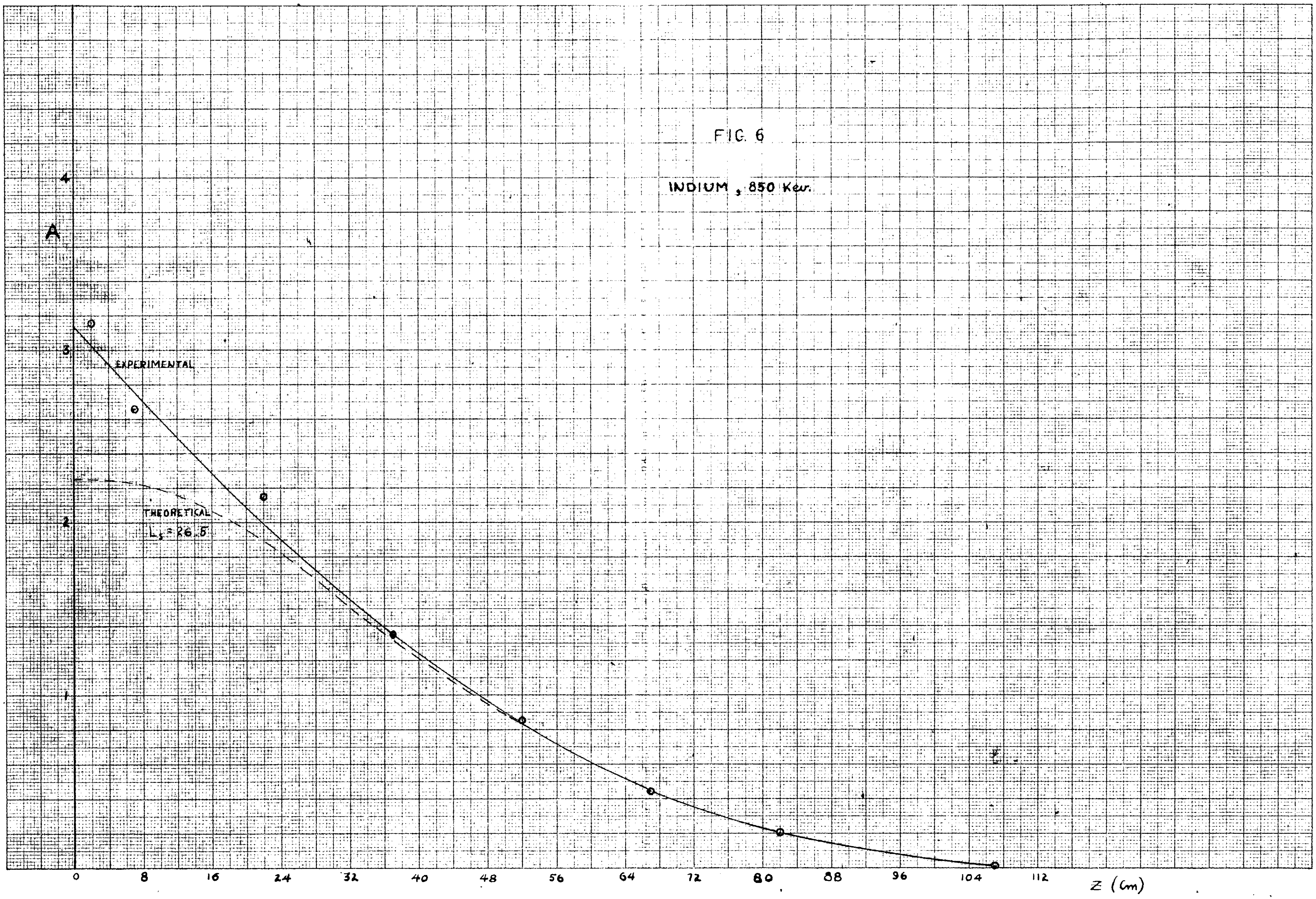


FIG. 6
INDIUM, 850 Kev.
A
4
3
2
1
EXPERIMENTAL
THEORETICAL
$L_s = 26.5$
0
8
16
24
32
40
48
56
64
72
80
88
96
104
112
Z (cm)

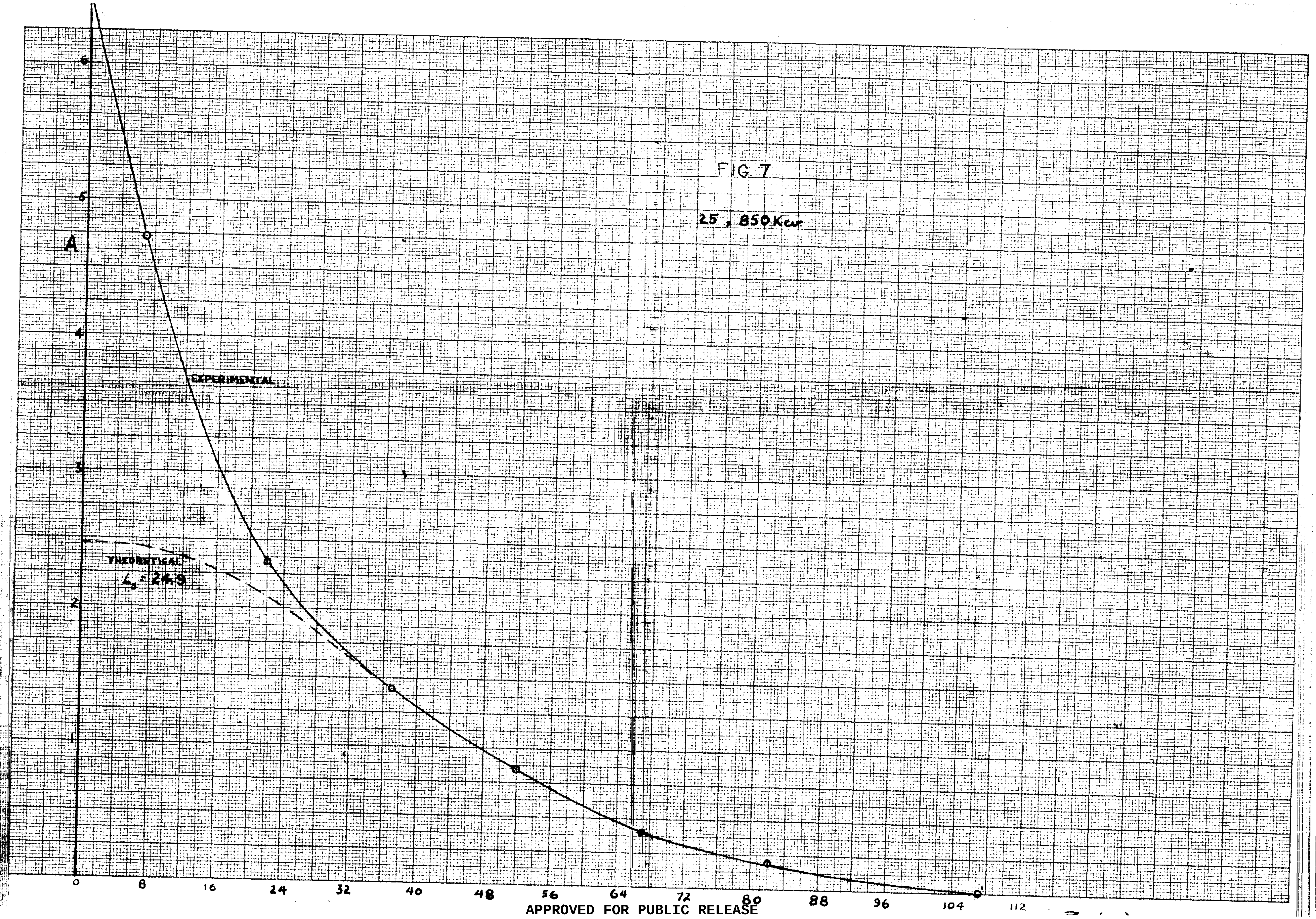


FIG 7
25, 850Kcv
A
EXPERIMENTAL
THEORETICAL
L_s = 24.9
0
8
16
24
32
40
48
56
64
72
80
88
96
104
112
1
2
3
4
5
6

APPROXIMATE CROSS OVER POINTS

MAXIMUM NEUTRON ENERGY	EXPERIMENTAL CROSS OVER POINTS (Cm)	THEORETICAL CROSS OVER POINTS (INFINITE MEDIUM) (Cm)
250 - 500 Kev.	46	49
500 - 750 Kev.	60	57
750 - 1000 Kev.	79	61

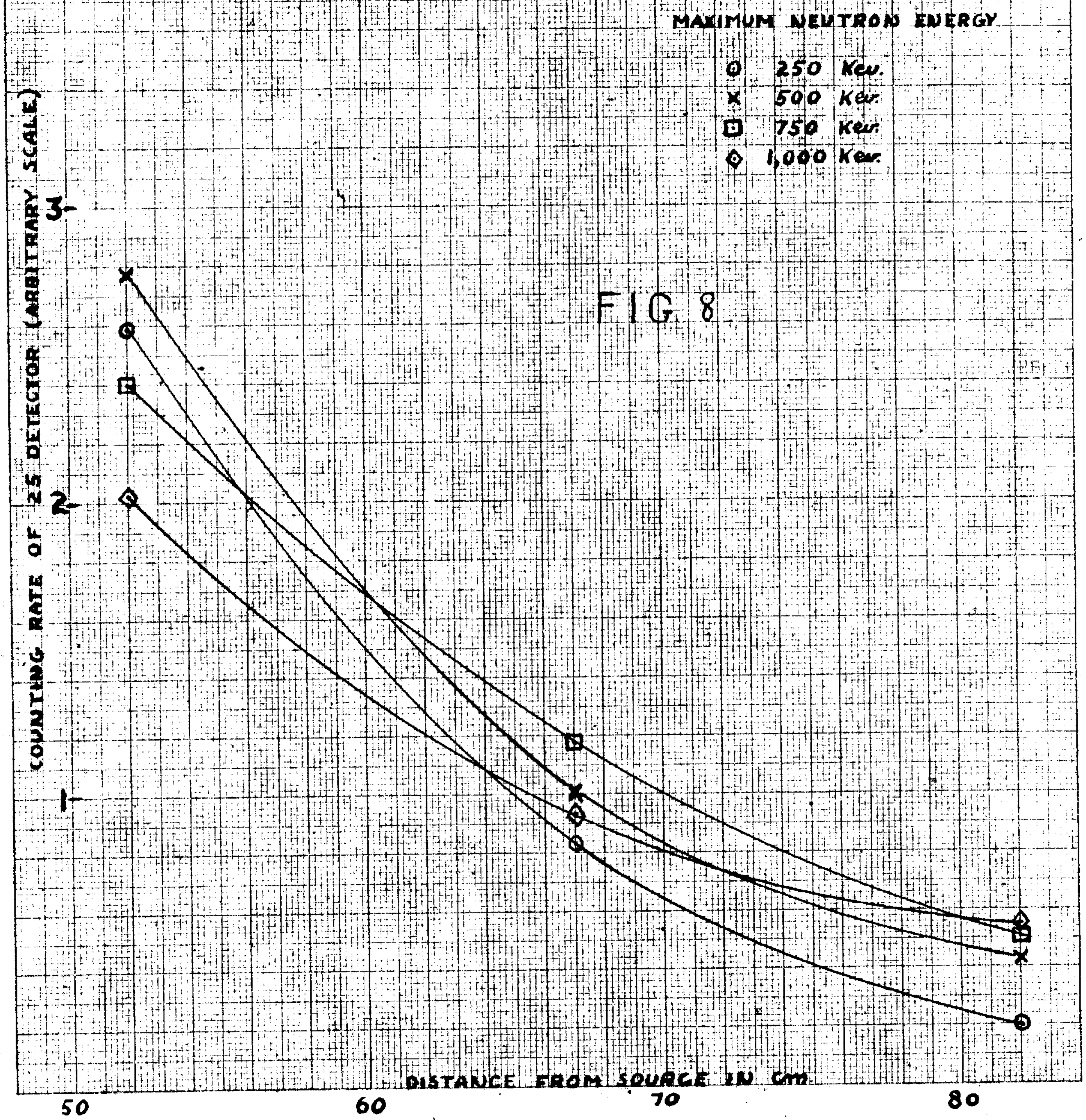


FIG 8

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