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STOPPING POWER OF VARIOUS SUBSTANCES FOR FISSION FRAGMENTS

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ABSTRACT

The relative stopping power of collodion, aluminum, copper silver and gold for fission fragments has been measured. The results are similar to those for alpha particles of 4.5 Mev.

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STOPPING POWER OF VARIOUS SUBSTANCES FOR FISSION FRAGMENTS

Several investigations, both experimental and theoretical, concerned with the passage of uranium fission fragments through matter have been published in the past few years.(1) Although these studies cover the subject generally, they do not seem to have especially investigated the relative stopping powers of various substances for fission fragments. Relative stopping powers are often a matter of importance in experimental investigations, e.g. for determining thickness corrections. We have thought it worth while to make a special study of it.

Catcher-Foil Activity Experiment

Two types of experiments have been performed. In the first type a thin (0.085 mg/cm^2) layer of U_3O_8 enriched in U^{238}, and deposited on a platinum disc was covered with various thicknesses of aluminum foil. On top of the aluminum foil we placed a thick celluloid foil. The whole system was irradiated with neutrons and the activity due to the recoiling fission fragments collected in the celluloid foil was measured.

The decay curves of this activity do not show any significant variation in their form as a function of the thickness of aluminum interposed. The observations were always made nine hours after the end of the irradiation.

In Figure 1 we show the result of these experiments.

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(1) See e.g. W. E. Lamb, Phys. Rev., 58, 696 (1940) which includes also a bibliography and J. Knipp and E. Teller, Phys. Rev., 59, 659 (1941).

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If the fission fragments had all the same range one would expect that the curve of Figure 1 would be a straight line. This is easily seen by considering the fission fragments emitted by an element of area dS in the active surface (Figure 2).

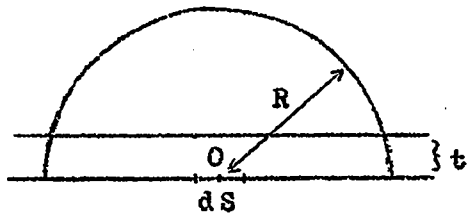

Figure 2

The end points of their trajectories in air lie with uniform density on the surface of a sphere of radius R (range of the fission fragments). By covering the source with a substance of thickness t such that, after traversing it normally, the residual range is reduced from R to R - t, the number of fission fragments emerging in air is also reduced in the same ratio and hence the activity collected is $A = b(R - t)$, where b is a coefficient depending upon the conditions of irradiation, etc.

The curve of Figure 1 is not a straight line because the fission fragments do not have all the same range. Each range represented gives a straight line and what is observed is the composite curve. The large scattering of the fission fragments has also probably a considerable influence. From Figure 1 one may try to determine a mean range and an [redacted]

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extrapolated range in aluminum, these being respectively, 2.2 and 3.9 mg/cm^2. It is however obvious that such a procedure is considerably arbitrary since the fission fragments do not have a uniform range.

Ionization-Chamber Experiment

In the second series of experiments the same thin foil of U_3O_8 was covered with the absorbers and introduced into an ionization chamber filled with nitrogen. The depth of the ionization chamber was 1.0 cm and electrons were collected. The ionization chamber was connected to a linear amplifier whose amplification and bias were kept constant.

The apparatus was tested with polonium covered with aluminum or gold foils and in Figure 3 we show the results of these test runs. Because of the homogeneity in energy of the Po alphas, we should this time really expect that the number of pulses registered, N, varies according to $N = c^{-}(R - t)$, in which again c depends on the bias, strength of the source, etc. Figure 3 shows the linear dependence of N on t, and by comparing the slopes of the two curves, for aluminum and gold, we find that the relative mass stopping power is 2.45. This is in excellent agreement with the accepted value of 2.45.(2)

In the runs with uranium fission fragments we obtain the curves given in Figure 4. Five types of absorbers were used: aluminum, copper, silver, gold and also collodion (approximately $C_{12}H_{17}O_{16}N_3$), which should not differ very much in its stopping properties from air. In Table I we summarize the results. Of each pair of numbers in the Table, the upper

(2) See e.g. Livingston and Bethe, Rev. Mod. Phys., 9, 272, (1937).

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one is the thickness necessary to stop a certain fraction of the fission fragments and the lower one is its ratio to the thickness of aluminum having the same stopping power. These ratios do not vary much as a function of the thickness employed, and inasmuch as we are willing to consider them constant we may speak of a stopping power.

In Table II we report the mass stopping power and the atomic stopping power and for comparison the similar number for 4.66 Mev of α-particles.

It must be borne in mind that in this experiment counts were registered only if the fission fragments spent enough residual range in the ionization chamber. We can have a rough estimate of this quantity by comparing the range in aluminum measured in the foil-activity experiments, (3.7 mg/cm^2), with that measured in the chamber experiments, approximately 2.9 mg/cm^2. It thus appears that the fission fragment has to spend approximately a residual range of 0.8 mg/cm^2 of aluminum in the chamber in order to be registered on our apparatus. If we increase the bias so as to count only larger pulses, the apparent stopping power of the various substances increases, as to be expected, but we have observed that the ratios between the stopping powers of various substances stay practically constant. To give at least a qualitative idea of the magnitude of this effect we point out that in taking the data of Figure 4 a bias of 10 millivolts was used, whose position with respect to the plateau for fission fragments can be seen in Figure 5. If we use a bias of 20 millivolts, i.e. twice the previous one, we obtain a figure similar to

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TABLE I

Fraction of fission fragments absorbed in layer	Thickness of layer in mg/cm^2				
	Collodion	Al	Cu	Ag	Au
.0					
.10	0.11 1.6	0.18	0.28 0.64	0.33 0.55	0.60 0.30
.20	0.22 1.64	0.36	0.56 0.64	0.68 0.53	1.16 0.31
.30	0.32 1.69	0.54	0.82 0.66	0.98 0.55	1.68 0.32
.40	0.42 1.72	0.72	1.10 0.66	1.30 0.55	2.20 0.33
.50	0.54 1.67	0.90	1.36 0.66	1.62 0.55	2.78 0.34
.60	0.64 1.72	1.10	1.66 0.66	1.96 0.56	3.34 0.33
.70	0.74 1.84	1.36	2.0 0.68	2.33 0.58	3.94 0.35
.80	0.91 1.78	1.63	2.34 0.69	2.75 0.59	4.65 0.35
.90	1.23 1.67	2.06	2.85 0.72	3.39 0.61	5.7 0.36
1.00	(2.10) (1.38)	(2.90)	(4.10) (0.71)	(4.80) (0.60)	(9.0) (0.42)

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TABLE II.

	Mass Stopping power		Atomic Stopping power	
	α(4.66 Mev)	f	α(4.66 Mev)	f
Collodion	1.38	1.70	----	----
Aluminum	1	1	1	1
Copper	0.69	0.66	1.59	1.52
Silver	0.51	0.55	2.04	2.20
Gold	0.36	0.34	2.62	2.48

Figure 4 but with all the abscissae divided by approximately 2. The quantitative features of this effect are of course dependent upon the ionization chamber construction, the absolute value of the bias etc., and are not simple to analyse.

We can obtain the end points of the various absorption curves by adding to the last thickness of Table I the quantity 0.8 mg/cm^2 divided by the mass stopping power relative to aluminum. This gives:

Collodion	Al	Cu	Ag	Au	U	U_3O_8	
2.6	3.7	5.2	6.1	11.14	(12.6)	(10.0)	mg/cm^2

These numbers are a little uncertain because both the apparent end points of Figure 4 and the stopping power at the end of the range are not precisely known. We have given also the calculated values for uranium and

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U_3O_8 because they are particularly important.

The atomic stopping power S as a function of Z can roughly be represented by the formula[3]

$$S = a Z^{\frac{1}{2}}$$

Silver and collodion depart from this formula considerably. The reason for collodion is most probably the presence of hydrogen which is expected to be anomalous, and the reason for silver is not known. It is quite possible that the different degree of homogeneity of the thickness of the foils affects the precision of the measurements.

A further check, of practical interest, on these measurements is afforded by the following experiment. A thick piece of uranium foil of 1 cm^2 surface is placed against a celluloid foil and exposed to neutrons. The recoil activity is then measured and compared to the recoil activity collected on celluloid from a mass m of uranium spread as thin foil, and exposed to the same neutron flux. We find by experiment that 1 cm^2 of thick uranium is equivalent to 4.7 mg of thin uranium.

This relation can be calculated also by multiplying the abscissae in Figure 1 by the relative mass stopping power of aluminum with respect to uranium (3.4) and integrating the curve. In this way we find that 1 cm^2 of thick uranium should give as many active recoil atoms as 4.6 mg of thin uranium in agreement with the experiment quoted above.

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(3) Cf. Rutherford, Chadwick and Ellis - Radiation from Radioactive Substance , page 99 and following.

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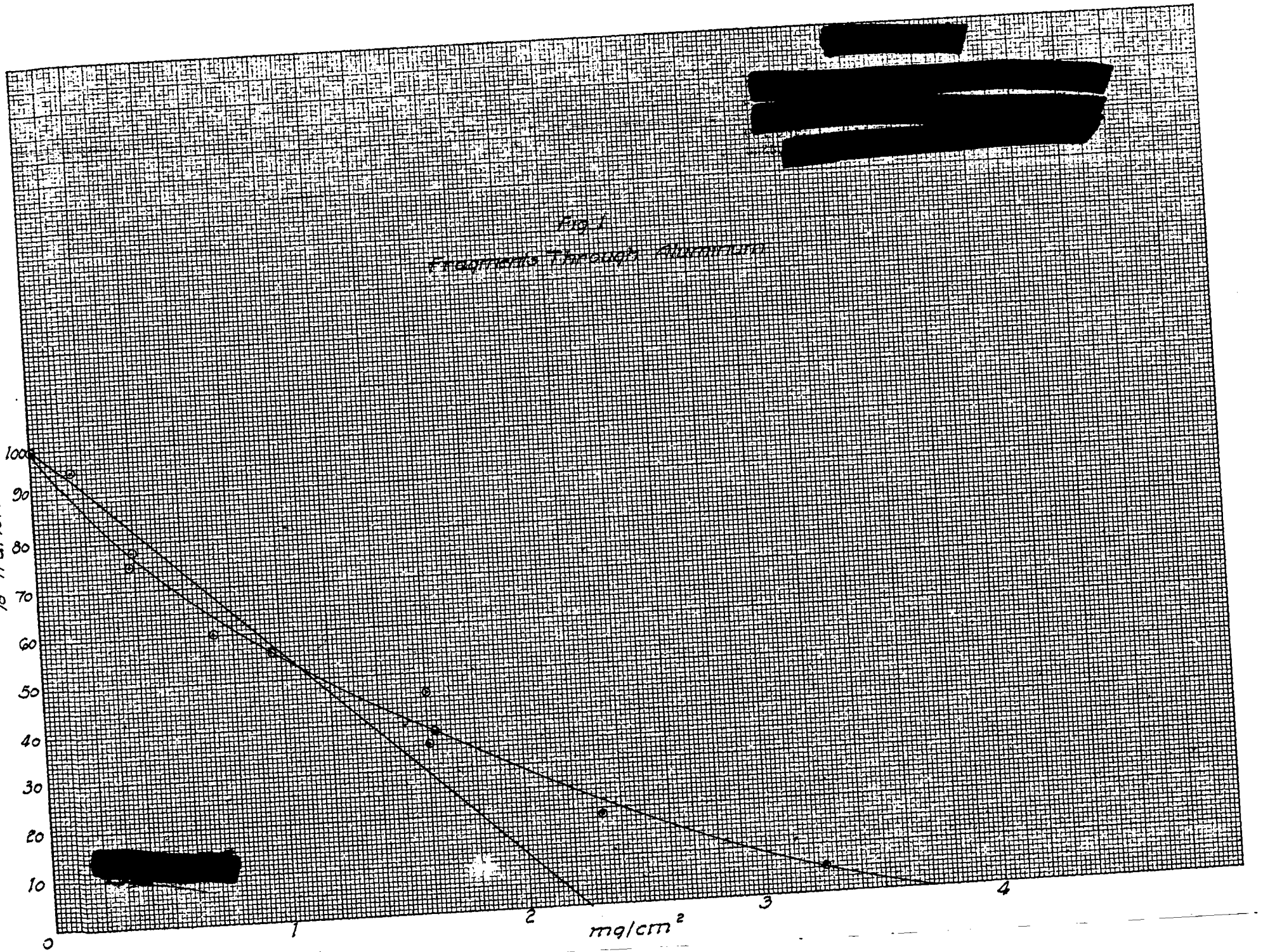
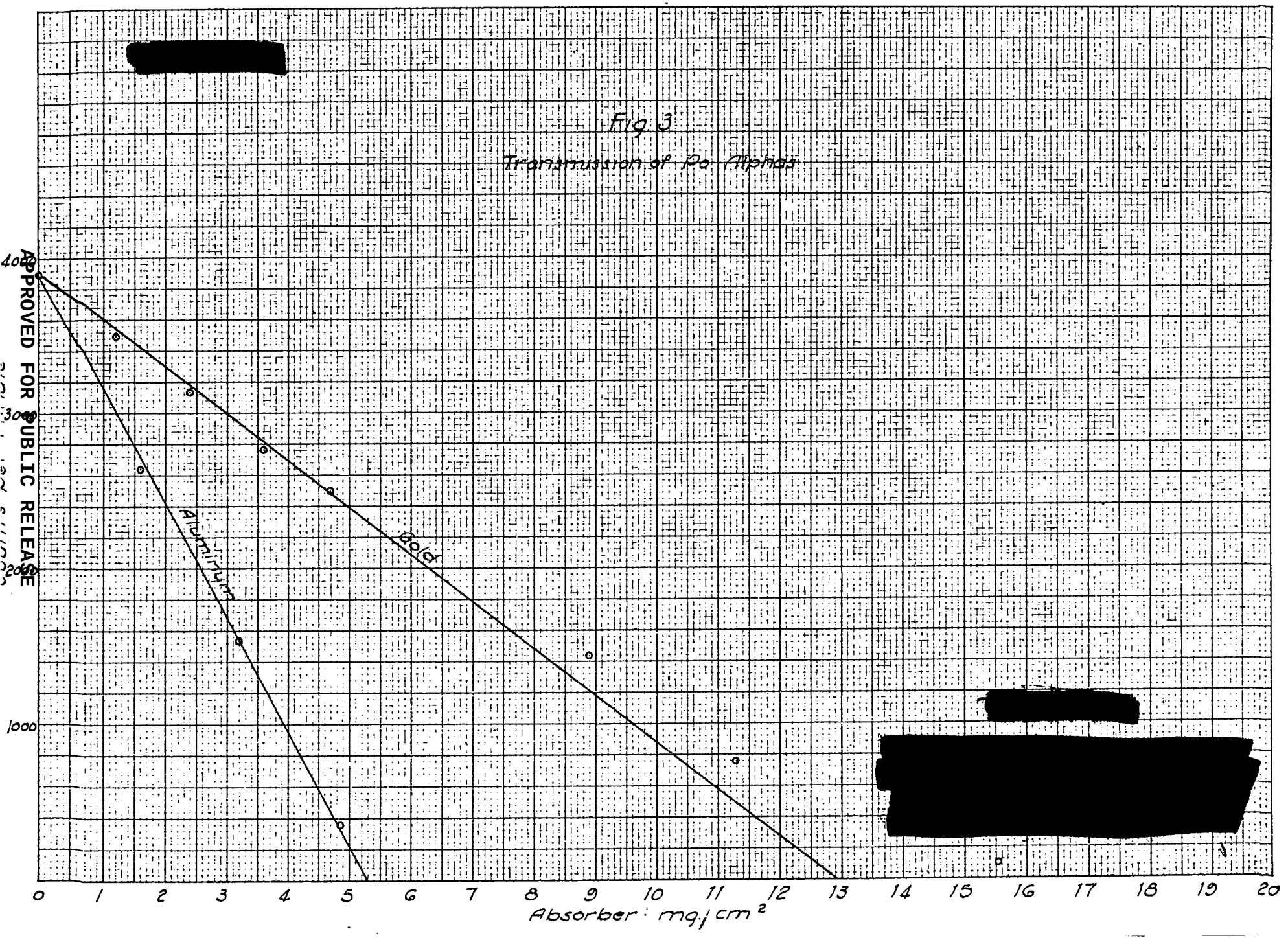


Fig 1
Fragments Through Aluminum



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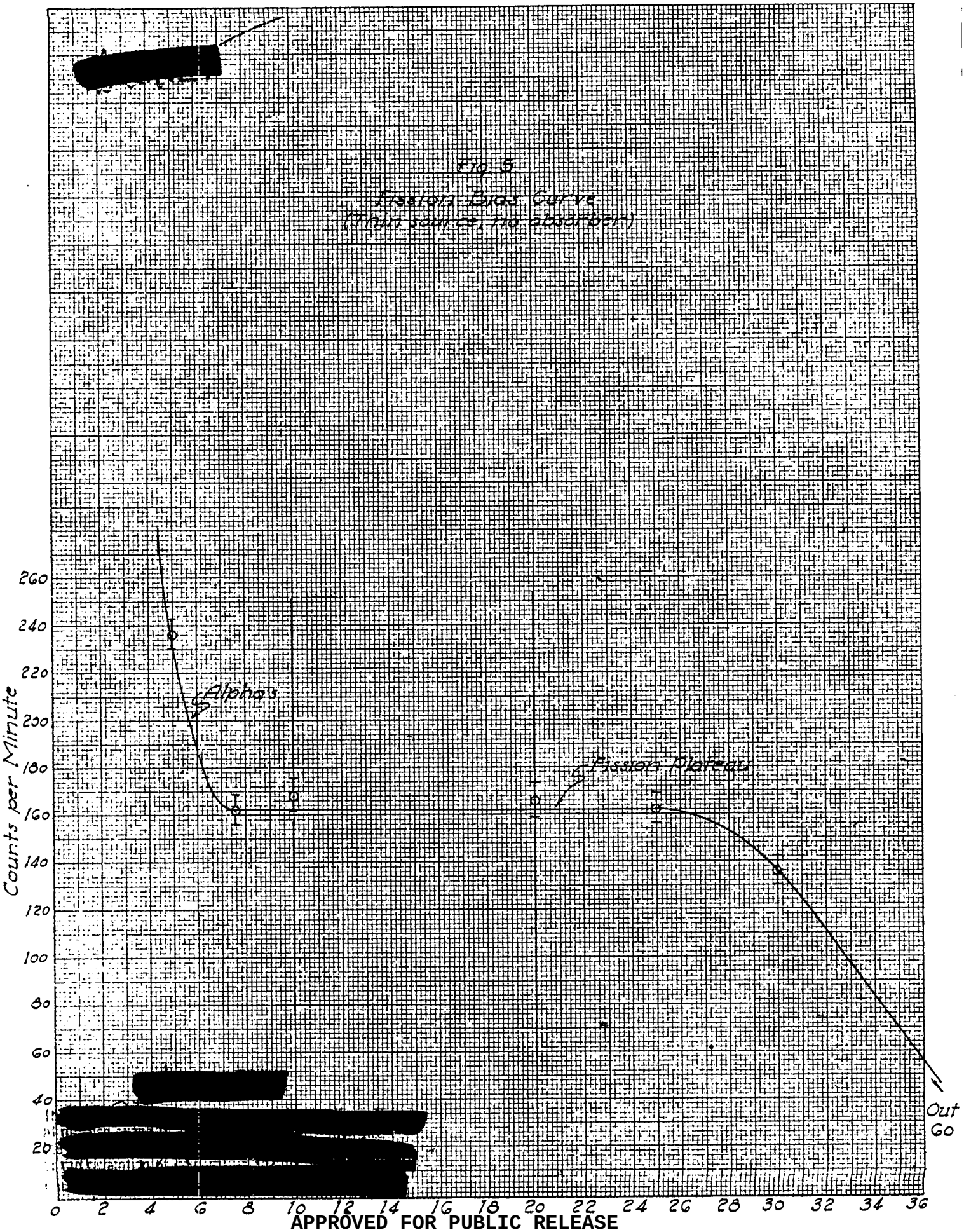

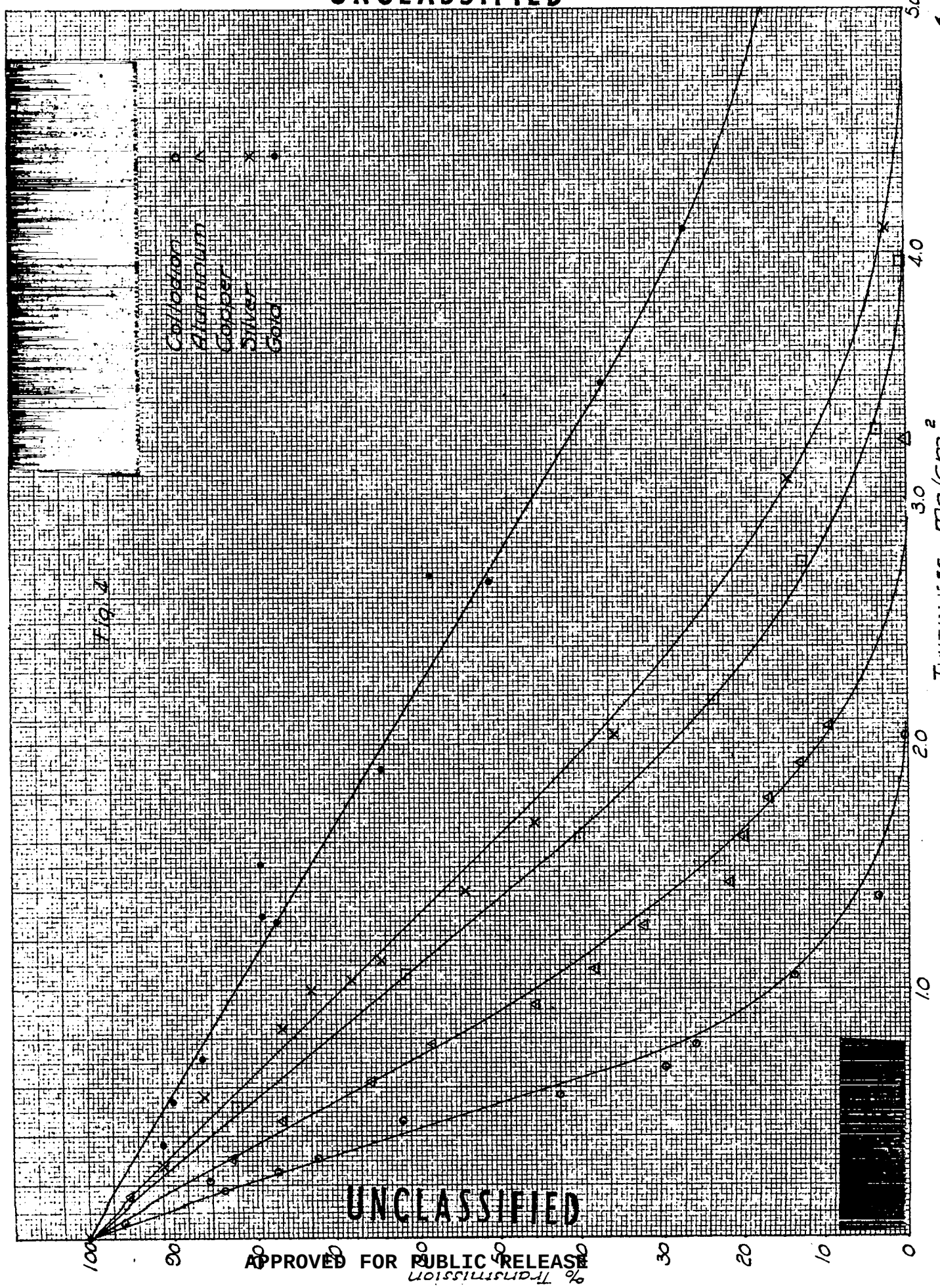

LA-64