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ENERGY OF INELASTICALLY SCATTERED NEUTRONS IN A LARGE MASS OF TUBALLOY

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ABSTRACT

The experimental data taken on a 35-ton mass of tuballoy metal early in 1944 (CF-1627) have been re-evaluated in the light of our present knowledge of the 28, 25, and 49 constants. The average energy of neutrons which have been degraded by inelastic scattering of 28 is concluded to be 170 ± 30 Kev.

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ENERGY OF INELASTICALLY SCATTERED NEUTRONS

IN A LARGE MASS OF TUBALLOY

Measurements on a 35-ton mass of tuballoy, made at Site X in the early part of 1944 (CF-1627) [1], were interpreted in terms of a two-group theory. These were referred to as the slow and fast neutrons; the fast consists of those neutrons above the fission threshold of 28; the slow consists of all neutrons below the 28 threshold (about 1.2 Mev) and results mainly from inelastic scattering of fission neutrons by the 28. A direct measurement of the average energies of the two groups was also attempted at that time.

The data obtained in the experiment could be consistently interpreted by a two-group theory, using the cross sections and other constants then known to the authors and assuming an energy of about 200 Kev for the slow group.

Since the variation of the cross sections of 28, 25, and 49 with energy are now reasonably well known, it was suggested by E. Teller that the experimental data be re-evaluated, with the object of attempting to find an accurate value for the average energy of the slow group. This energy is of considerable interest, for it tells us to what energy neutrons can be degraded by inelastic scattering of 28 and can lead to some knowledge of the low-lying energy levels of the 28 nucleus.

There are three independent measurements that can be interpreted to give a value of the energy of the slow group:

1. A direct measurement of the slowing-down range in a graphite column.

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1) The experiment was performed at the Clinton Laboratories by a group, headed by L. Slotin, which included J. E. Brolley, R. Scalettar, R. B. Stewart, and the author.

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2. A measurement of the ratio of the fission cross sections of 25 and 49.

3. A measurement of the equilibrium relaxation length of the neutrons in the mass of tuballoy.

In addition, there were measurements of the ratio of radiative capture to fission and of 25 to 28 fission which, though they do not yield a value of the energy of the slow group, shed light on some of the other constants involved.

1. Slowing-down range in graphite- The distribution of indium resonance neutrons in a graphite column, on the bottom of which a beam of neutrons impinged from inside the tuballoy mass, was measured. From an analysis of the curve obtained, the source could be divided into a slow and a fast group. The range of the slow group corresponded to an energy of 170 Kev. Due mainly to the uncertainty in the type and magnitude of the perturbation caused by digging a hole in the mass of tuballoy and placing a graphite column over it, the probable error of this measurement is not larger than about 50 percent.

2. Ratio of 25 to 49 fission - The value of this ratio for the equilibrium distribution of neutrons in the tuballoy mass was found to be 1.04 with a probable error of 20 percent. This error is not due to the accuracy of the measurement - which was far better than this - but rather to the uncertainty in the constitution, weight, uniformity, etc. of the foils that were available to us at the time of the experiment. In Fig. I is plotted the 25 to 49 fission ratio as a function of energy. From this curve and our mean value, we deduce 100 Kev for the average energy of the slow neutrons in the tuballoy. The uncertainty in our experimental value, however, introduces an uncertainty in the energy of a factor of three, so that the energy of the slow group - as deduced from this measurement - may lie anywhere between 30 and 300 Kev.

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3. <u>Relaxation length of the equilibrium neutrons in the tuballoy</u> - The value of 9.6 cms for the equilibrium relaxation length of neutrons in an infinite mass of tuballoy is the most accurately known of all the constants measured in the experiment. The probable error of this measurement is certainly less than 5 percent. From the theoretical considerations discussed in CP-1627, it may be seen that the equilibrium relaxation length is primarily dependent on the product of the transport cross section by the 28 capture cross section for the slow neutrons. Both these cross sections are strongly dependent on energy in the 50 to 300 Kev region, so that the relaxation length should yield a good value for the energy of the slow group.

Fig. 2 is a plot of the 28 transport cross section vs. energy. The curve is not the same as that given in LA-140. It is rather a combination of measurements of the total 28 cross section recently made at the Argonne Laboratories for low energies and the Los Alamos measurements for high energies. It has been shown by V. Weisskopf to be consistent with both the Argonne and the Los Alamos measurements, when account is taken of the forward scattering by 28 of neutrons above about 200 Kev.

In Fig. 3 is plotted the latest values for the 28 capture cross section vs. energy, from the measurements of Linenberger and Segrè. In addition to the above-discussed cross sections, the fission cross section of 25 as given in LA-140 and the following cross sections for the fast group were used:

$\sigma_f(28)$ = .45 barns

$\sigma_{inelastic}(28)$ = 2.4 barns [2)]

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2) This value is not the actual inelastic scattering cross section but a fictitious number chosen to fit a two-group approximation. More detailed considerations show that the data are consistant with the presently accepted values of the 28 inelastic scattering cross section.

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$\sigma_{tr}(28)$ = 4.5 barns - for the fast group

$\nu_{25} = \nu_{28}$ = 2.5 barns, of which 75 percent are emitted fast and the rest slow.

The expressions developed in CF-1627 were used to calculate the value of $(2/3N^2)$ $(1/L^2)$ as a function of energy. (N is 10^{-24} times the number of T atoms per cm^3 for a density of 18.9 ; L is the relaxation length.) The results of this calculation are plotted in Fig. 4. As stated above, L is primarily a function of the product of the 28 transport and capture cross sections with the other constants entering only as corrections.

From this plot (Fig. 4) we obtain a value of 170 Kev for the energy of the slow neutrons in the tuballoy mass. This value is accurate to about 5 percent if the cross sections used are that good. However, V. Weisskopf suspects, on theoretical grounds, that the 25 fission cross section may be somewhat high in the 100-Kev region. This would lower the above energy rather slightly and raise the energy as obtained by the 25 to 49 fission ratio so as to bring the two into better agreement.

4. Other measurements - The ratio of capture to fission in the tuballoy is rather insensitive to energy; the measured ratio is in good agreement with a slow-neutron energy of between 150 and 200 Kev.

The experimental value of the ratio of 25 to 28 fission in tuballoy was 336 with a probable error of about 20 percent, due again to the uncertainties in the foils used. In Fig. 5 is plotted this ratio as a function of energy. The value of the ratio at 170 Kev is 270, which agrees with the experimental value to within the experimental error. Again, a lower value of the 25 fission cross section would make the agreement better.

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From the theory presented in CF-1627, it may be seen that the ratio depends directly on the following ratio of fast-neutron constants:

$$\frac{\sigma_{inelastic}(28)}{\sigma_f(28)\ \nu_{25}}$$

The uncertainty in this ratio can easily explain the difference between the theoretical and experimental values. For instance, if we should take

$$\sigma_{inelastic}(28) = 2.5 \text{ barns}$$

and

$$\sigma_f(28) = .40 \text{ barns},$$

the agreement would be almost perfect.

The above considerations lead to consistent values for the energy of the slow-neutron group in an infinite mass of tuballoy. In view of these considerations, this energy can be stated with some confidence to have a value of 170 ± 30 Kev.

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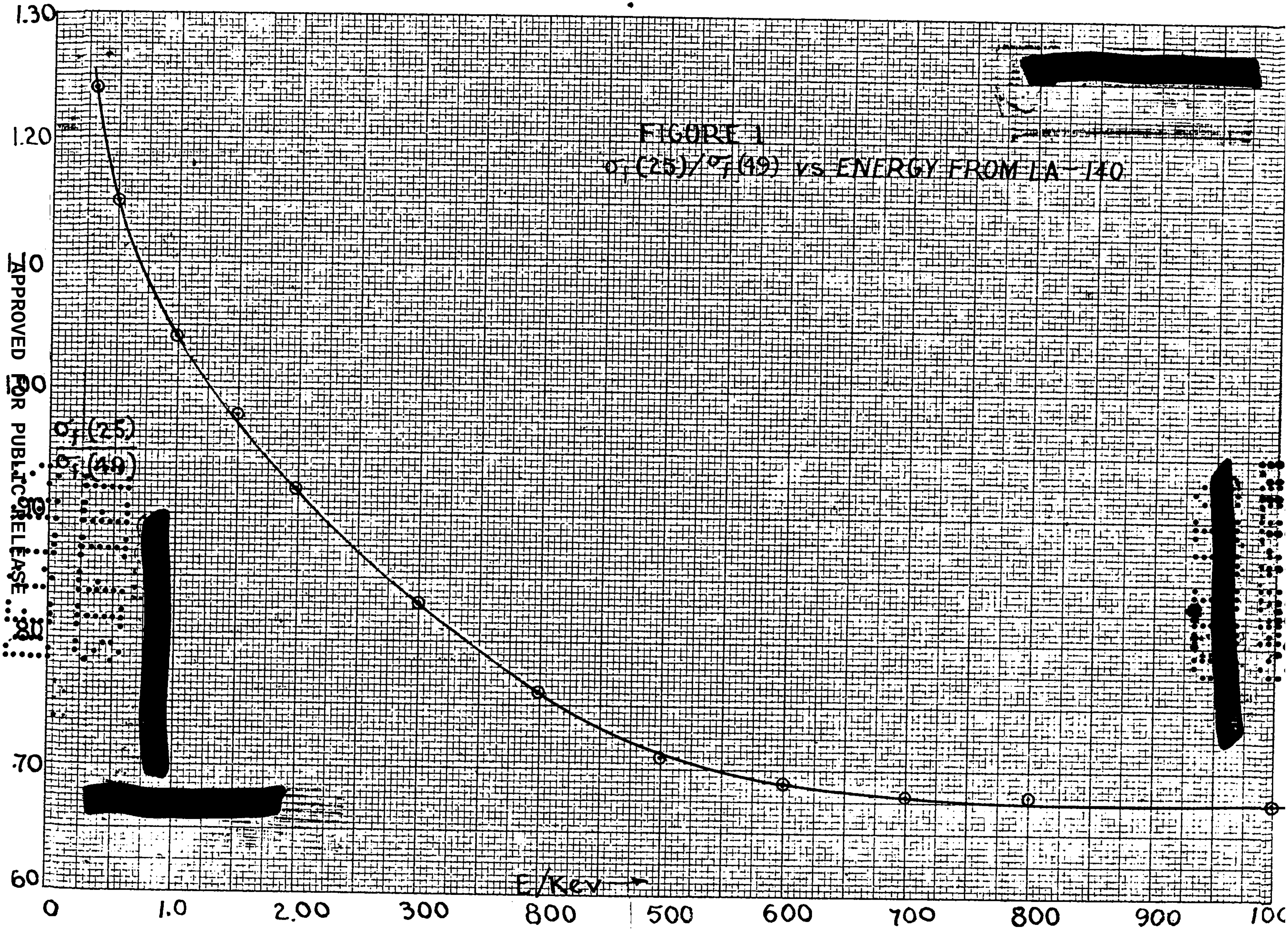

FIGURE 1
$\sigma_f(25)/\sigma_f(49)$ vs ENERGY FROM LA-140

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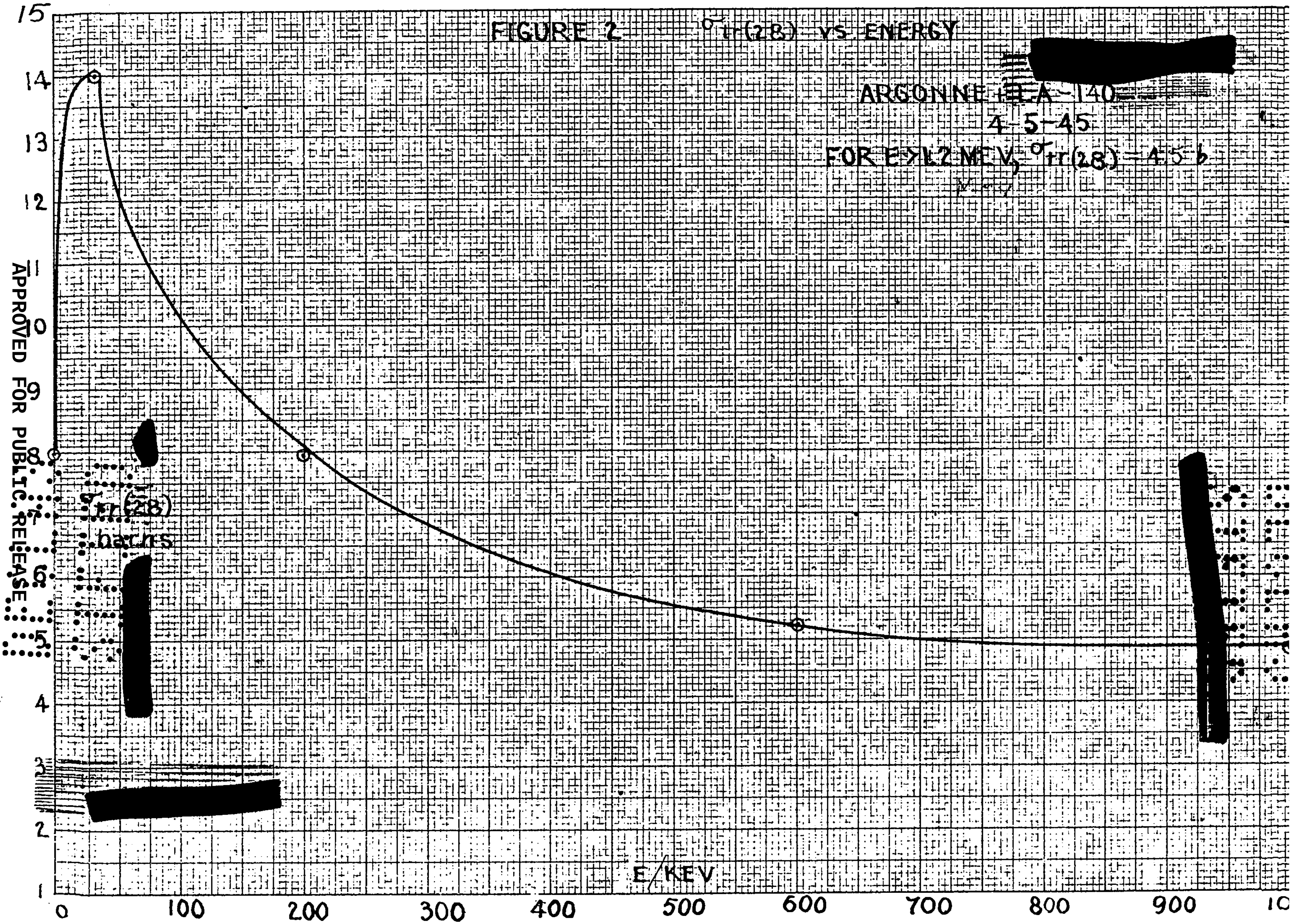

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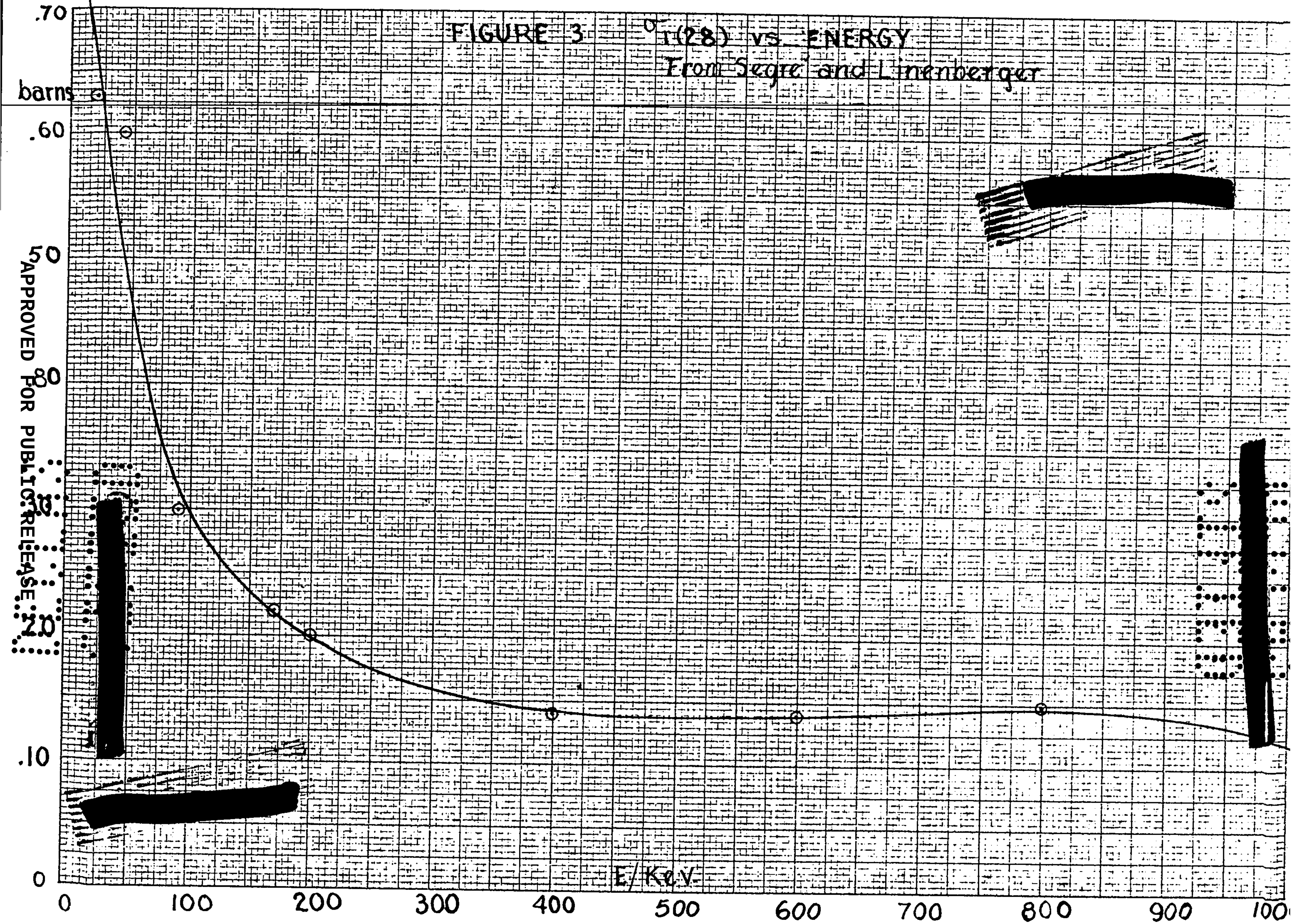

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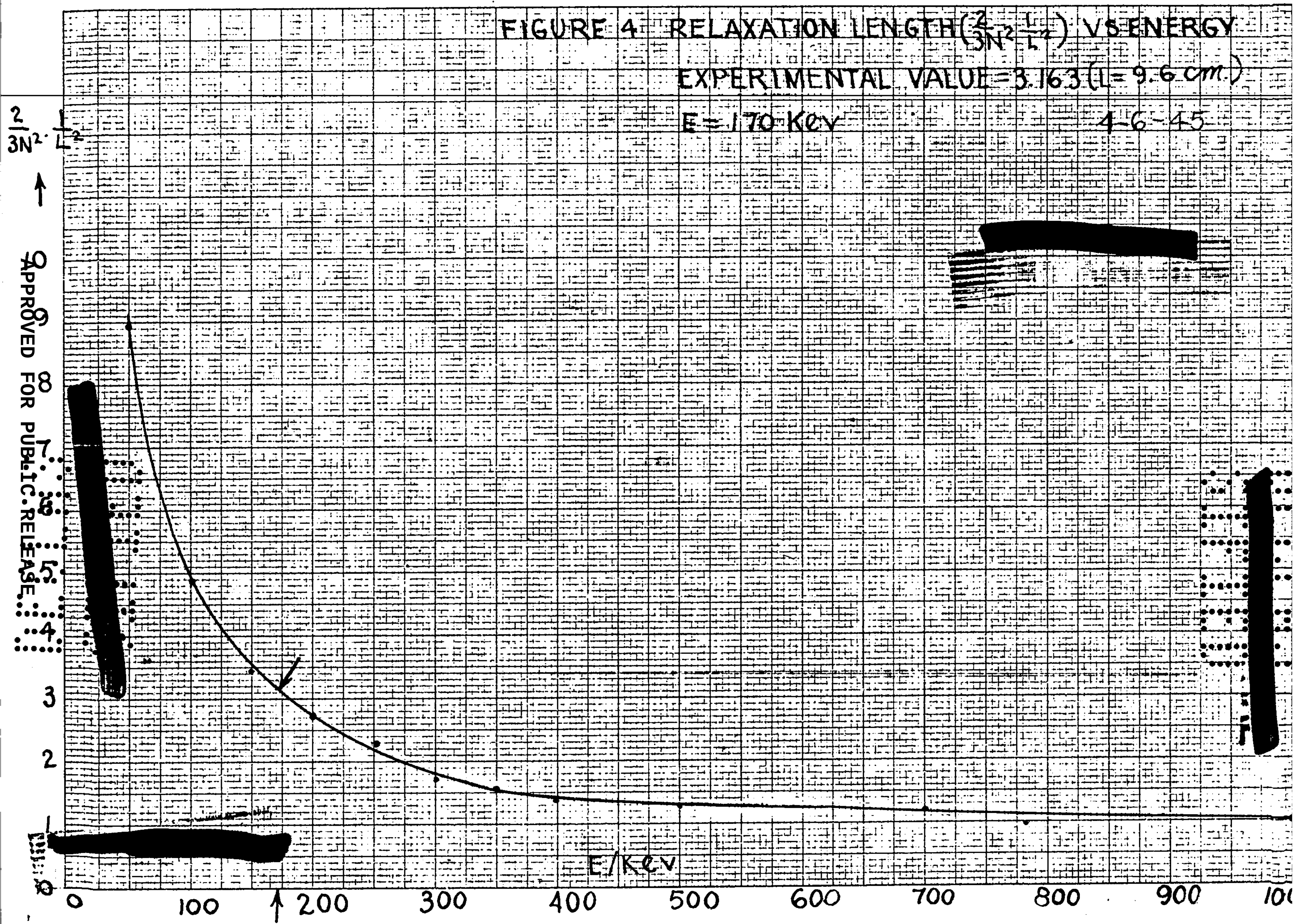
FIGURE 4 RELAXATION LENGTH$(\frac{2}{3N^2}\cdot\frac{1}{L^2})$ VS ENERGY
EXPERIMENTAL VALUE = 3.163 (L = 9.6 cm.)
E = 170 Kev
4-6-45
$\frac{2}{3N^2}\cdot\frac{1}{L^2}$
9
8
7
6
5
4
3
2
1
0
E/Kev
0
100
200
300
400
500
600
700
800
900
1000
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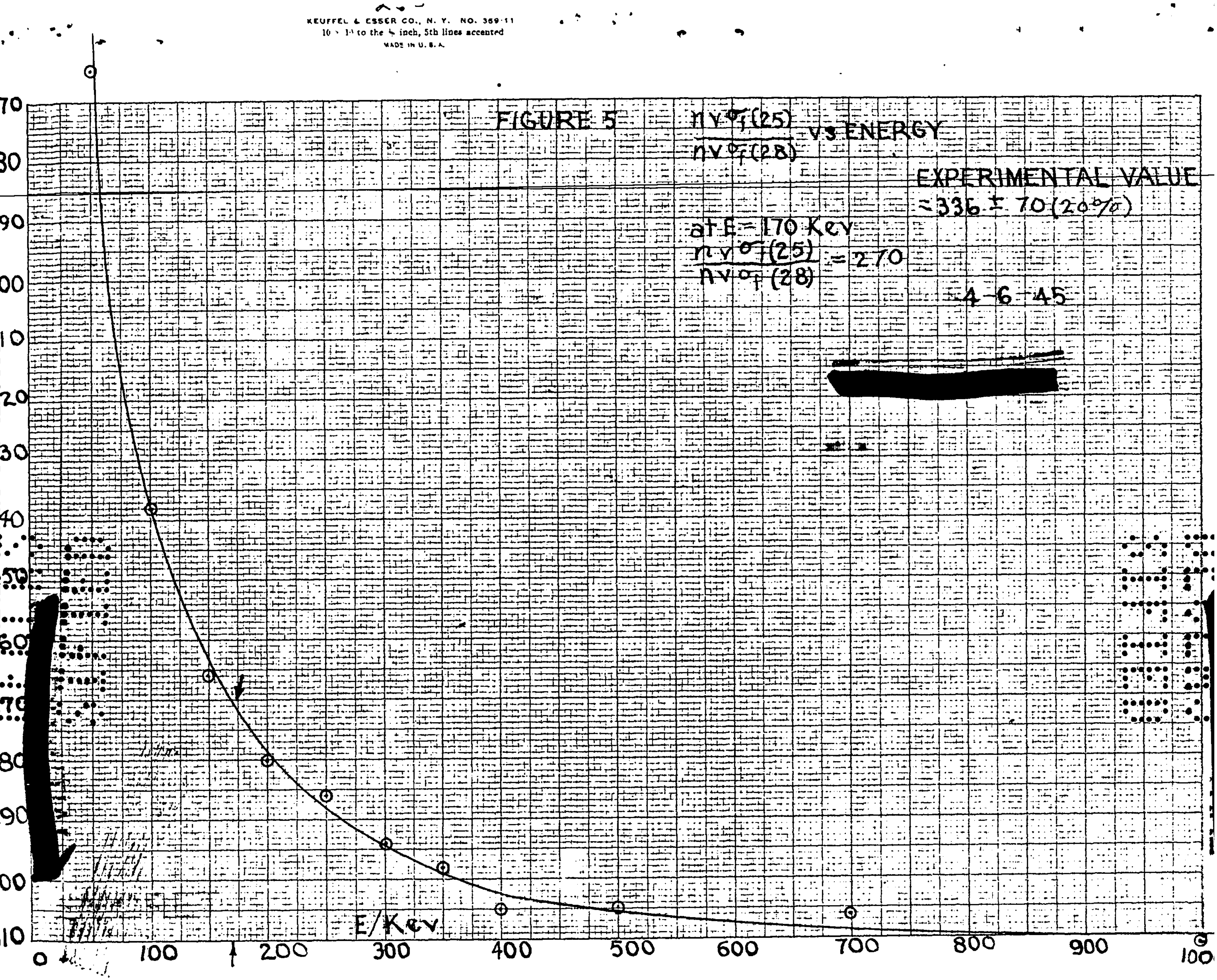

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