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(P,N) REACTIONS IN DEUTERIUM, SCANDIUM AND VANADIUM

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ABSTRACT

The thick target yield curves for D(pn)2p, Sc(pn)Ti, V(pn)Cr have been investigated to determine whether the yields are large enough to make these reactions usable neutron sources. The first reaction should give a collimated neutron beam and the latter two reactions should give neutrons of very low energy and high symmetry so far as momentum considerations are concerned. The yield from D(pn)2p appears to be too small at threshold for practical use; Sc(pn)Ti and V(pn)Cr give enough neutrons near threshold to make them appear promising as sources of low energy neutrons.

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(P,N) REACTIONS IN DEUTERIUM, SCANDIUM AND VANADIUM

This is a preliminary report on the thick target neutron yield of the reactions

$$D_1^2(p,n)2p$$
$$Sc_{21}^{45}(p,n)Ti_{22}^{45}$$
$$V_{23}^{51}(p,n)Cr_{24}^{51}.$$

The first of these reactions was investigated with the purpose of finding a highly collimated source of neutrons of fairly high energy. The second two reactions were studied to find a source of very low energy neutrons with good energy resolution and perhaps spherical symmetry. The $Li^7(p,n)Be^7$ reaction used with the electrostatic generators is a very strong source of monoenergetic neutrons in the forward direction over an energy range from about 150 kv to 2 Mev. However, due to the momentum considerations of the proton and light Li^7, the neutrons emitted in the forward direction between the threshold energy of 1.86 Mev and 1.9 Mev are in two energy groups; just at threshold only a single group of 30 kev energy is present. This necessitates observations in the backward direction for neutrons below 150 kev, with a very large decrease in yield if one wishes to use neutrons of energies below about 20 kev. Further difficulties arise in this method of taking data in that the energy resolution at low energies is very poor and a considerable background of epithermals and scattered neutrons is present because of the high forward energy and large yield of these forward neutrons.

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$D_1^2(p,n)2p$

For certain types of experiments it would be desirable to have a source of neutrons which is highly collimated. Momentum considerations show that the reaction $D_1^2(p,n)2p$ should give neutrons of about 370 kev energy in the forward direction just at threshold, assuming that the threshold energy of the protons is about 3.3 Mev. This neutron energy corresponds entirely to the center of gravity motion of D + p and means that all the neutrons emitted say spherically symmetrically in the center of gravity system with zero energy are emitted with 370 kev energy exactly forwards in the laboratory. For somewhat above threshold energy the neutrons spread out into a sharply defined cone within which the energy spread of the neutrons is determined by the proton energy above the reaction threshold. In this three particle emission the energy spread of the neutrons rapidly becomes large above threshold so it is necessary that the yield near threshold be large for the reaction to be useful.

In Fig. 1 is shown the yield of neutrons per proton observed from a thick target of $D_4P_2O_7$ as determined by a long counter, LAMS-66, whose efficiency was measured to be 0.9×10^{-5}. It will be seen that a large background is present down to 2.7 Mev proton energy and that even above the 3.3 Mev threshold for D(p,n)2p there is no marked increase in yield. If one assumes that the threshold is 3.3 Mev and that all the neutrons come from deuterium, then the target is 200 kv thick at 3.5 Mev and from the stopping power of the $D_4P_2O_7$ one calculates that the average cross section at 3.4 Mev is <u>no greater</u> than about $1.7 \times 10^{-29} cm^2$ for D(p,n)2p. If now one

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compares the observed threshold, relative yield as a function of energy and flattening of the yield curve above 3.3 Mev with the observations of DuBridge, Barnes, Buck and Strain[1)] on the reaction $O^{18}(pn)F^{18}$, it appears that most of the neutrons come from this latter reaction. Assuming that the threshold is 2.6 Mev and that the neutrons all come from $O^{18}(pn)F^{18}$ at 2.8 Mev, the average cross section for the reaction at 2.7 Mev is no greater than 2.3×10^{-25} cm^2. This assumes that 200 kv above threshold the neutrons emerge spherically symmetric in laboratory system which is very likely not true so that the correct cross section may be considerably lower than that given above, and would compare favorably with DuBridge, et al's value of about 0.75×10^{-25} cm^2 at 3.55 Mev. This makes it appear that near threshold the yield from D(pn)2p is extremely small and not usable even with a gas target. Changes to a deuterium gas target planned for the near future on the long electrostatic generator will allow a measurement of the thin target yield from D(pn)2p uncomplicated by O^{18} neutrons.

$V_{23}{}^{51}(p,n)Cr_{24}{}^{51}$

The yield of neutrons from this reaction had previously been found quite large[2)] so further studies were made to determine the yield near threshold. Cr^{51} is a negative electron emitter so its threshold is low, about 1.5 Mev proton energy; because of the large mass of the compound nucleus the energy of the neutrons in the laboratory system just at threshold should be about 0.6 kev from the center of gravity motion. Thus for only very small energies above threshold the neutrons already are emitted at all angles, the energy spread with angle is small and the yield as a

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[1)] DuBridge, Barnes, Buck and Strain - Phys. Rev. 53, 447 (1938)

[2)] Unpublished Wisconsin measurements

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function of angle is not strongly concentrated forward due to the center of gravity motion.

In Fig. 2 is plotted the thick target yield curve for this reaction in terms of neutrons detected by the long counter (sensitivity 0.9×10^{-5}) at 51 cm per proton incident on a piece of vanadium metal. If the threshold is at about 1.5 Mev, then at 1.6 Mev the target will be 100 kev thick and the average cross section near 1.6 Mev will be $\overline{\sigma}_{1.6} = 0.8 \times 10^{-27} \mathrm{cm}^2$, if one assumes that the yield in the laboratory system is roughly spherically symmetric.

Since the long electrostatic generator was used in the study of this reaction no very detailed study of the yield just at threshold was made due to the small proton currents available. It appears possible, however, to utilize the larger currents from the short electrostatic generator to accurately locate the threshold and study the yield here in more detail. Even with the present information it is possible to consider a comparison of the Li(pn) and the V(pn) reaction's yields at the same neutron energies, which is the point in question. Thus under typical conditions in short tank, (Li(p,n) source, fission measurements on 5 kv neutrons at 120°, a 5.7 kv target was used and a long counter of 2.1 times the sensitivity of the one used in the present experiment. At a distance of 79 cm from the target 5×10^5 μcouls of protons gave 7761 long counter counts. If this is reduced to the conditions in the present experiment one obtains

$$\frac{\left(\frac{79}{51}\right)^2 \times 7761}{5 \times 10^5 \times 2.1} = 0.0177 \text{ LC counts}/\mu\text{coul}$$

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which is to be compared with the lowest value here obtained of about 0.002 LC counts/μcoul or roughly a factor of 9. Under the experimental conditions of this fission measurement target thickness and angle subtended by the 9/16" foil at 1-1/2" caused the energy from the Li^7(pn)Be^7 to vary from about 2.5 kv to about 7.5 kv across the foil. If one now considers that when one has 5 kv neutrons in the forward direction from a V(p,n) source the neutrons at 90° have 2.5 kev energy it will be seen that the detecting foil can easily be moved close enough to the target for the approximately $\frac{1}{r^2}$ variation in yield to compensate, or better, for the factor of 9 above and still have at least as good an energy resolution as Li(p,n). Another advantage is that no high energy neutrons emerge from the reaction to produce counts from back-scattering and epithermals. Disadvantages are that most of the energy spread will come from target thickness and the necessity for very good energy control of the protons, which, however, seems feasible on the short electrostatic generator.

Thin targets of V_2O_5 have been prepared by Corporal Miller which will be used to study the reaction yield near threshold more carefully on the short tank, and to determine the proton energy at which the neutrons are no longer monoenergetic.

$Sc_{21}^{45}(p,n)Ti_{22}^{45}$

Since protons on vanadium gave a very low yield near threshold due to the high barrier for 1.5 Mev protons, the reaction $Sc_{21}^{45}(pn)Ti_{22}^{45}$ was considered for the following reasons: It is a single isotope, the product nucleus is a positron emitter such that the threshold should be near 3.0 Mev proton energy, the barrier is slightly lower due to the lower charge, and the

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mass is still sufficiently high to give low energy neutrons near threshold, i.e., 1.4 kv at threshold. The principal reason for choosing scandium is that at the high threshold energy the protons are up to about 50 per cent of the top of the 6 Mev barrier making the barrier penetration roughly 100 times as large at threshold as for the V(pn) reaction. This would make it appear a much better source of low energy neutrons than vanadium.

The targets were made by heating scandium oxalate on quartz in an oxygen flame to form fairly uniform fused Sc_2O_3 on the surface. Measurements of the yield in the forward direction were made with the same long counter previously used at 50 cm. The yield curves shown in Fig. 3 were obtained with the LC at 50 cm and with fission foil L9B at 1.6 cm. It will be seen that the long counter data has a rather slowly decreasing yield down to 2.6 Mev, whereas the fission foil shows a sharp threshold at about 2.95 Mev. It seems very likely that O^{18}(pn) is causing the tail in the long counter measurements since it is approximately uniformly sensitive to the high energy neutrons from O^{18} and to the low energy ones from Sc; in the fission foil measurements, however, the Sc neutrons are much more heavily weighted than the fast ones from O^{18}, thus giving a more nearly correct value for the threshold and shape of the yield curve of Sc. Background measurements with the proton beam falling on a quartz plate indicate that the low energy tail is due to O^{18} but that at 3.05 Mev proton energy the oxygen yield is only about 5 per cent of the observed yield from Sc_2O_3. The yield from Sc_2O_3 is about 17 times that for metallic vanadium; reducing this to Sc metal, the yield is roughly 40 times the yield from vanadium and the cross section about 3×10^{-26} cm^2 at 3.05 Mev proton energy. Thin targets of

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ScF_3 on Ta have been prepared by Corporal Miller which will allow more accurate determination of the cross section without confusion by the neutrons from O^{18}.

The use of Sc as a target material for low energy neutrons depends in part upon being able to obtain thin targets with a maximum amount of metal and no oxygen, upon obtaining good energy control of the long electrostatic generator and upon a study of energy distribution of the emerging neutrons up to the first excitation level above threshold. It should be possible to determine the bombarding energy at which the neutrons are no longer monoenergetic by observing the ratio of fissions to hydrogen recoils as a function of energy; the appearance of a slow group should give rise to a marked change in ratio if its intensity is at all appreciable compared to the main group.

The large cross section of $O^{18}(pn)F^{18}$ would make it appear interesting as a target material if it were not for its low abundance (about 0.5 per cent). The energy of the neutrons at threshold in this case is about 6 kv and they are likely to remain monoenergetic over a larger energy interval than from the heavier elements Sc and V. A rough comparison of (p,n) cross sections gives

$$D(pn)2p < 2 \times 10^{-29} cm^2$$

$$V^{51}(pn)Cr^{51} \sim 10^{-27}\ cm^2$$

$$Sc^{45}(pn)Ti^{45}\ \ 3 \times 10^{-26} cm^2$$

$$O^{18}(pn)F^{18} \sim 10^{-25}\ cm^2$$

$$Li^7(p,n)Be^7\ \ 3 \times 10^{-25} cm^2$$

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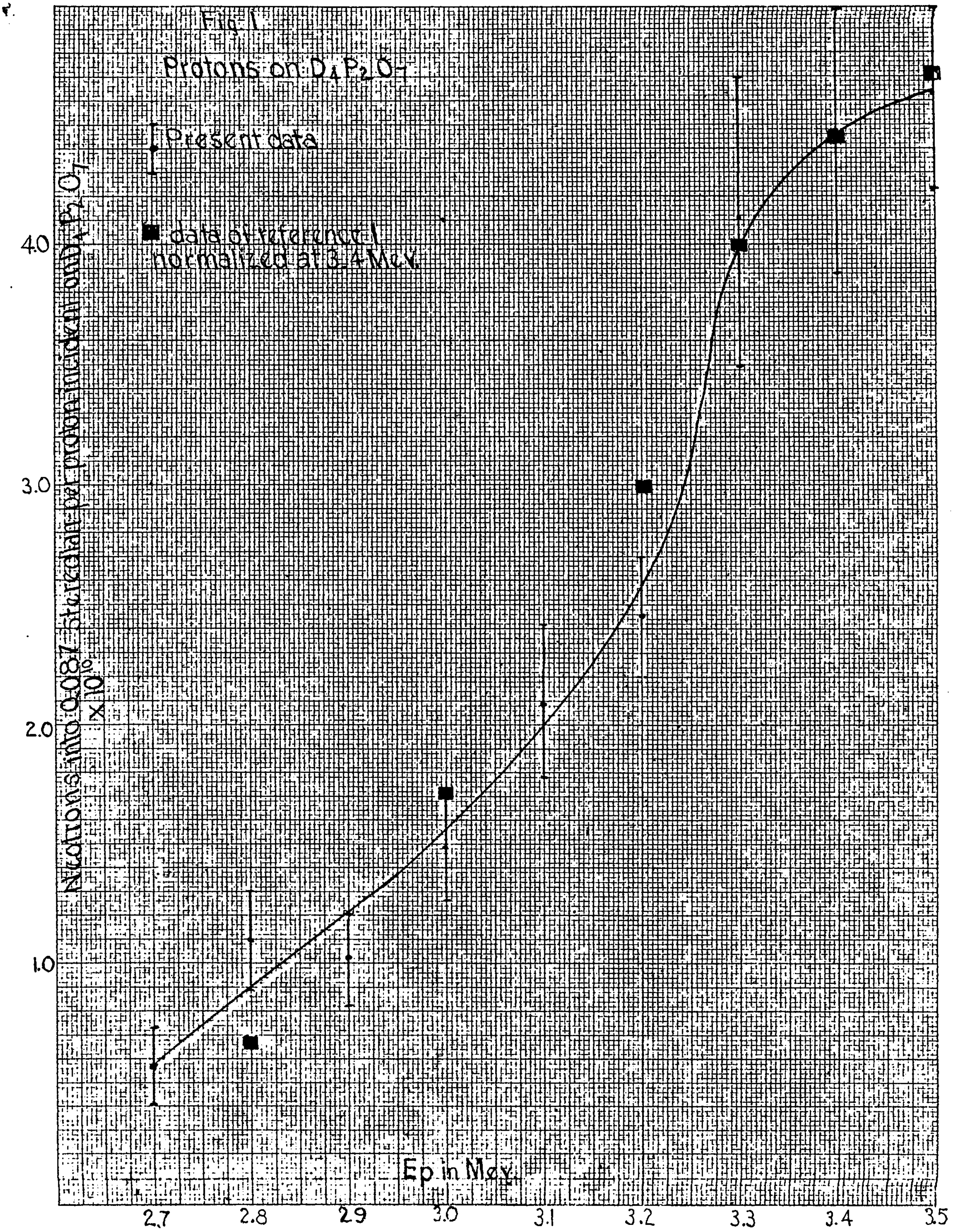
Fig 1
Protons on $D_4P_2O_7$
Present data
data of reference 1 normalized at 3.4 Mev.
Neutrons into 0.087 steradian per proton incident on $D_4P_2O_7$ $\times 10^{10}$
1.0
2.0
3.0
4.0
Ep in Mev.
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5

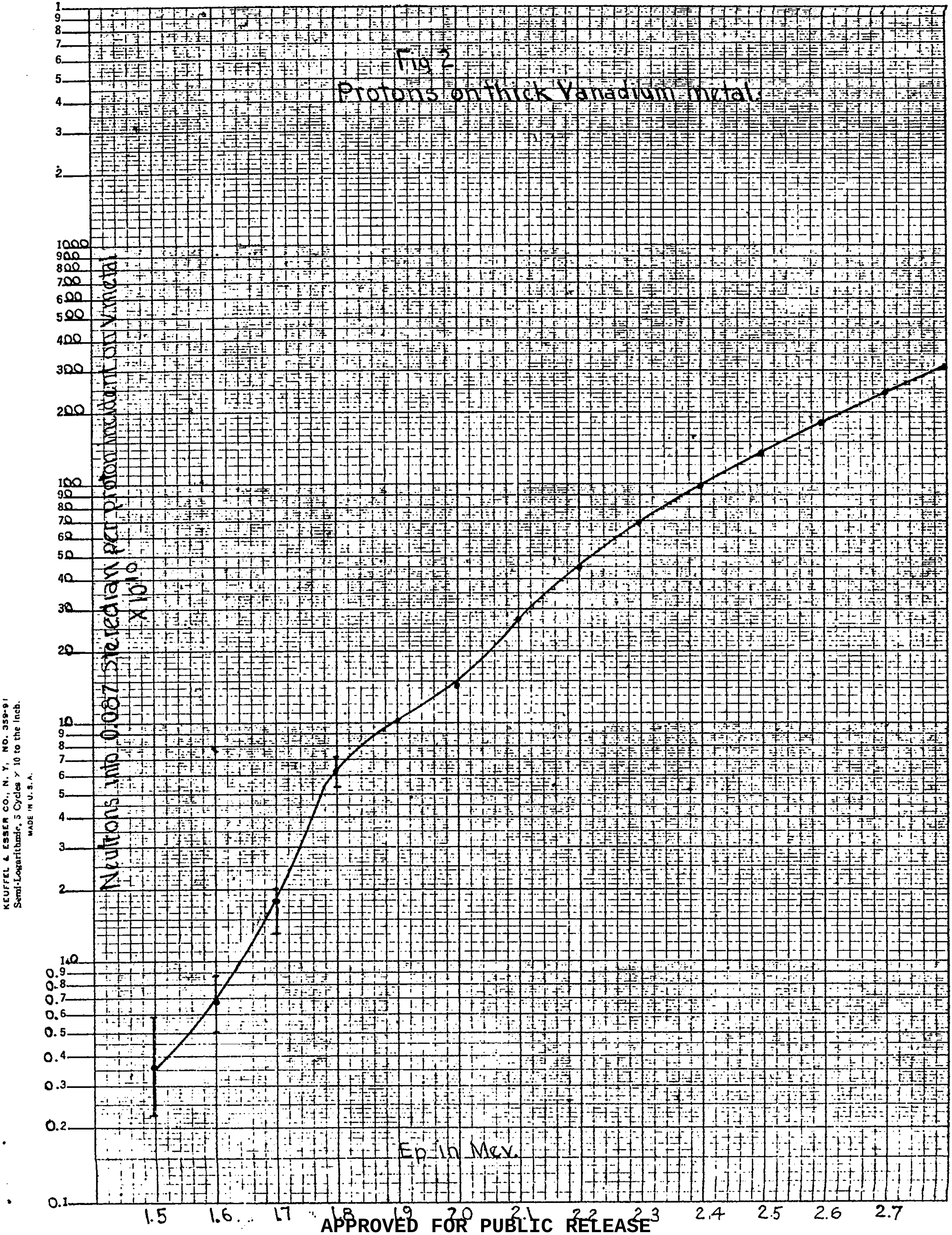

Fig 2

Protons on thick Vanadium metal.

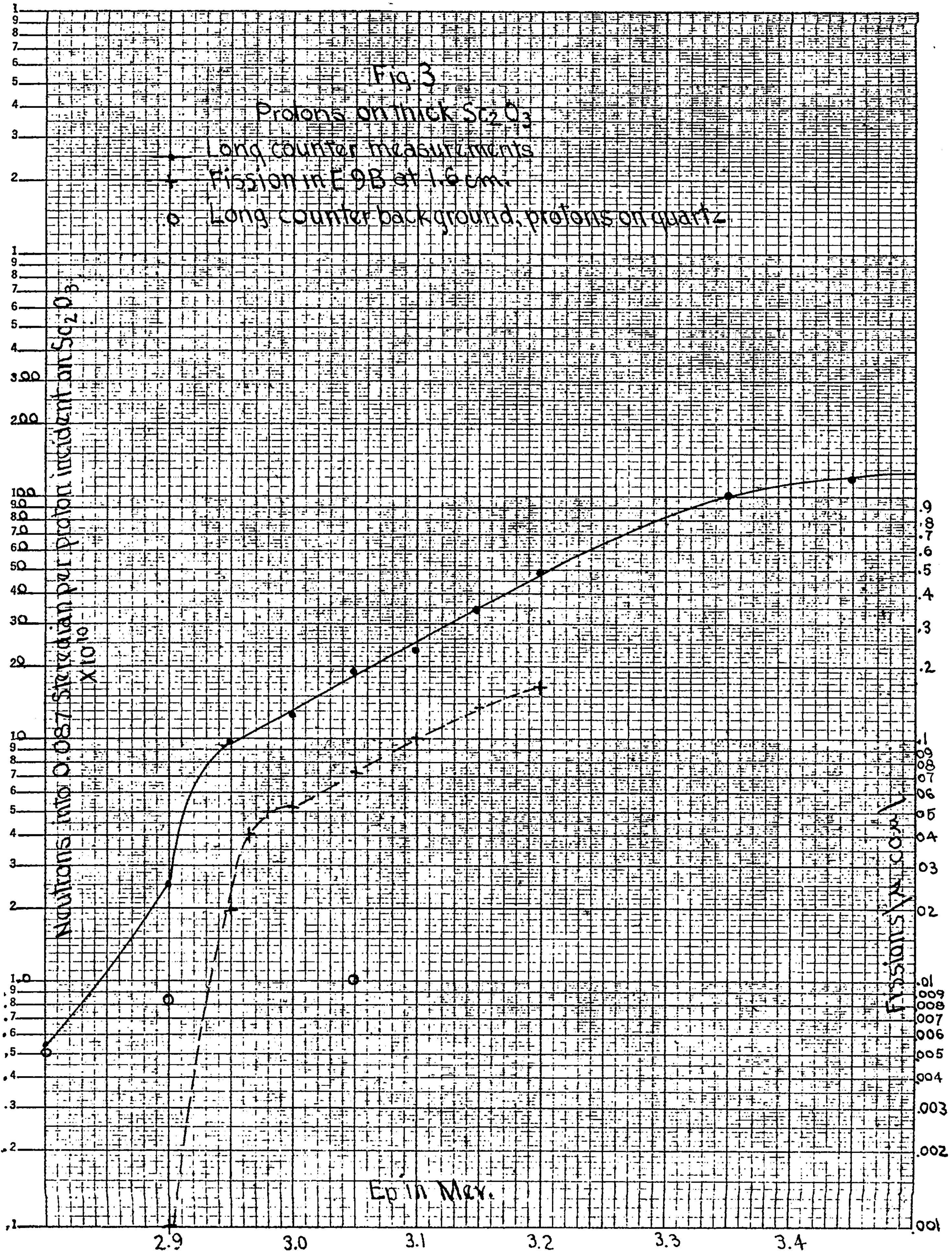

Fig. 3

Protons on thick Sc_2O_3