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A FAST NEUTRON DETECTOR *

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by

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ABSTRACT

A fast neutron detector with an efficiency of a few percent and the capability of detecting neutrons in the presence of intense gamma-ray backgrounds has been developed. The detector consists of a ZnS and lucite molded cylinder used in conjunction with a 5819 photomultiplier tube. This detector is well suited to experiments requiring "good geometry" and pulse speeds of the order of 0.1 μsec. (auth)

* Research carried out under contract with AEC

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DISCLAIMER

INTRODUCTION

A scintillation detector has been developed which will permit the detection of fast neutrons with moderate efficiency even in the presence of a much stronger background flux of hard gamma-radiation. The detector consists of a uniform dispersion of ZnS grains molded directly into lucite. The lucite serves the dual purpose of supplying the proton recoils which produce the light scintillations in the phosphor, and of transmitting this light to a photomultiplier tube.

Earlier, a fast neutron detector, employing two 931-A photomultiplier tubes in coincidence and in conjunction with a simple ZnS lucite sandwhich, had been used.(1) This detector gave an efficiency of approximately 1.5×10^{-4} with Ra-Be neutrons when operated at a discriminator bias suggested by the authors to give good γ-ray suppression. Employing the newer 5819 photomultiplier tube with its photo cathode area coated with a layer of hardened ZnS and polystyrene dope paste, an efficiency of approximately 5.5×10^{-4} was obtained for Ra-Be neutrons.(2) Again a discriminator was used set to a bias which gave good γ-ray suppression. It should also be mentioned that the efficiency of a detector of the latter type had been raised somewhat by the addition of either $Th\,O_2$ or $U\,O_2\,(NO_3)_2 \cdot 6\,H_2O$ to the ZnS and polystrene dope paste, making possible the detection of the scintillations due to fission produced by fast neutrons.(3)

The present detector was made by molding together a thoroughly blended mixture of ZnS powder(4) and lucite molding powder(5). The two

(1) W.G.Moulton and C.W.Sherwin Rev.Sci.Inst. 20, 766 (1949)
(2) H.Frey Rev.Sci.Inst 21, 886 (1950)
(3) Kuan - Sun and W.E.Shoupp Rev.Sci.Inst 21, 395 (1950)
(4) RCA phosphor number 33-Z-20A
(5) Polychemicals Dept., Du Pont De Nemours Co.

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powders having sensibly the same grain diameters permitted a fairly uniform mixture to be obtained. The molding was carried out at approximately 2000 psi and 120° C.

The molded cylinder or "button" which resulted, was mounted on a 5819 photomultiplier tube with an aluminum reflector and an oil contract between the button and the tube surface. The buttons having high efficiency are rather opague because of the large amounts of ZnS required. The photomultiplier tube anode resistance was 240 KΩ which with a stray shunt capacity of approximately 20 μμfd gave an RC time constant of 5 μsec. In view of the ZnS phosphor light pulse decay characteristics, to be mentioned later, and in view of the nature of photomultiplier tube noise this RC time constant gives an optimum signal to noise ratio as expected. A cathode follower preamp feeding a wide band amplifier was used.

PHOSPHOR CHARACTERISTICS

It seemed advisable to study some of the properties of the ZnS phosphor itself. As is well known, a considerable number of phosphorescent light scintillations are observed to come from ZnS which has previously been exposed to light for some time. With the above circuit constants and a pulse discriminator setting just above the photomultiplier tube noise spectrum, 10^5 pulses per sec were observed 6 minutes after exposure from a button containing 1.5 grams of ZnS which had been exposed for three hours to direct sunlight. One hour after exposure the rate was only 1 per sec. Twenty hours after exposure no rate was detectable either above or well inside the photomultiplier tube noise spectrum. The observed decay of the number of pulses as a function of time could not be fitted with either a simple exponential or power law. In view of the above results it is necessary to keep the neutron detectors of the type discussed here in absolute darkness for at least 20 hours before use to obtain the best signal to "noise" ratio.

The decay character of individual pulses, produced for example, by α-particles on ZnS powder was also found to be complex. An initial "decay time" of the order of 0.1 μsec as well as a longer component of the order of 5 μsec was evident. The integrated light output (voltage developed across an RC circuit with a 25 μsec time constant) reaches one third the total peak value in less than 0.1 μsec. Because of this fast decay time component, a ZnS powder α-particle detector has been successfully used in a coincidence experiment with resolving times as low as 5×10^{-8} sec.

Particles of high specific ionization such as protons and α-particles produce light pulses in ZnS which are comparable to light pulses from NaI under identical conditions. However, electrons of a few Mev energy produce pulses in ZnS just detectable above photomultiplier tube noise (average 5819 at room temperature).

DESIGN CONSIDERATIONS

For a molded button fast neutron detector of the type discussed here, the determination of an optimum ZnS grain size, relative weight of ZnS to lucite, and button thickness depends on the energy of the neutrons to be detected. A neutron energy of approximately 4 Mev (the mean neutron energy of a Po-Be source) was taken as a representative case. The phosphor grain diameter should be no greater and preferrably less than the mean range of the recoil protons in ZnS, which for the case considered is approximately 35 microns. The grain size of the ZnS powder as it comes from the manufacturer ranges from 8 - 25 microns, and hence is directly usable. A study was made of the efficiency as a function of the mean spacing between phosphor grains. In Fig 1, curve a shows the efficiency for detecting Po-Be neutrons as a function of the weight of ZnS for various buttons, each with 3.3 grams of lucite (the buttons were 1 inch in diameter and approximately 1/4 inch in height). It will always be understood that the efficiency is for a flux entering perpendicular to the circular face of the detector. A discriminator was used, set to accept all pulses greater than the photomultiplier tube noise. The predicted efficiency curve b, given for comparison, is based on a simple estimate taking the mean neutron scattering cross section as 2 barns, mean recoil proton range as 60 microns in lucite and a ZnS grain diameter of 16 microns. Using these values the total fraction of the neutron flux scattered by the lucite is estimated to be 6.6 percent. The fraction of the recoil protons thus formed which are detected through scintillations in 500 mg of phosphor, for example, is predicted as 22 percent, giving a total efficiency of 1.4 percent. As expected, the predicted efficiency is higher than the observed efficiency because of the increase of light opacity of the button with increase in the amount of ZnS and the subsequent loss of pulses into the tube noise background. An experiment was run in which the extrapolated maximum pulse height, obtained with a 3.5 Mev α-particle source in contact with a thin layer of ZnS powder dusted directly on the photomultiplier cathode face, was compared with the extrapolated maximum pulse height obtained with the α-particle source in contact with the top face of one of the buttons used above. The light transmission for the entire thickness of button containing 600 mg of ZnS, for example, was thus found to be 7 percent (geometry factors being neglected), this still corresponding, however, to an extrapolated maximum pulse height of approximately 15 times noise. Pulses from the α-particle source were just detectable above noise for the button containing 1500 mg of ZnS.

The above considerations, modified by light geometry factors when greater detector thicknesses are involved, leads to an optimum design of 1.5 grams of ZnS in 10 grams of lucite (a cylinder 1 inch in diameter and 5/8 of an inch in height). While this button has 3.0 times the amount of lucite as the button having the same proportionate weight of ZnS used in the above experiments the efficiency was found to be only 2.3 times as large.

EXPERIMENTAL RESULTS

The integral pulse height spectrum observed with this larger button with various neutron sources is given in Fig 2. The curves show the number of scintillations detected per 10^5 incident neutrons (and the efficiency) as a function of discriminator setting. The absolute neutron flux calibration for the Po-Be source was reliable to within approximately ± 20 percent. Monoenergetic neutrons of 14.2 Mev were obtained using the T(d,n) reaction run with the Brookhaven electrostatic generator. Substantially monoenergetic 0.50 Mev neutrons were obtained with the Li^7 (p,n) reaction. In these two cases the absolute neutron flux was known to ± 5 percent and ± 10 percent respectively. In the pulse height units of Fig 2, the Cs^{137} gamma-ray line (0.66 Mev) in a NaI crystal phosphor mounted on the same photomultiplier tube occurs at 100. Further experiments with the reaction T(p,n) indicated the possibility of detecting neutrons having energies as low as 200 Kev.

The sensitivity of this large button to gamma-rays of various energies is shown in Fig 3. For convenience, the pulse height unit is the same as in Fig 2 and the curves have been normalized to 10^5 incident quanta. The 17.6 Mev gammas* were from the $Li^7(p,\gamma)$ reaction, the 2.9 Mev gammas from the radioactive decay of Ru^{106} and the 1.2 Mev gammas** from the radioactive decay of Co^{60}. The photomultiplier tube noise spectrum per 1/2 minute runs is also given. The absolute gamma-ray flux calibrations are ± 2, ± 30, ± 10 percent respectively.

The Ru^{106} curve was not continued below a bias setting of 8 since a marked increase in slope occurs at this point indicating a substantial

* actually a mixture of 70 percent 17.6 Mev and 30 percent 14.6 Mev gamma-rays.

** mean energy of the two Co^{60} gammas.

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contribution to the count rate from the 1.5 Mev and lower energy gamma components of this source.

The neutron spectra of Fig 2 for the Po-Be source and the $Li^7(p,n)$ reaction were measured in the presence of gamma-ray backgrounds. Fig 4 has been included partly to demonstrate that in the latter case the background represented a completely negligible correction, and partly to give an example of a typical case in which both low energy neutrons and energetic gammas are present. Fig 4 shows the separate contribution of the 5819 tube noise, the 17.6 Mev gamma-rays, and the 0.50 Mev neutrons to the scintillation pulse height spectrum observed when Li is bombarded with 2.35 Mev protons (thick target, forward direction). The pulse height unit is again the same as in Fig 2 and 3.

To determine the separate contribution of the hard gamma-rays it was first necessary to obtain their yield as a function of bombarding proton energy. For this purpose a NaI detector was used with a discriminator set to accept pulses greater than those corresponding to 10 Mev scintillation events, and thereby preferentially detecting only the hard gamma-rays. The relative yield of hard gammas was thus obtained for a range of proton energies from the 0.44 Mev p,γ resonance through the 1.89 Mev p,n threshold up to 2.35 Mev. The pulse height spectrum for the hard gamma-radiation on the ZnS, lucite detector was obtained at a proton energy of 1.70 Mev (below the p,n threshold). A simple normalization then resulted in the spectrum shown in Fig. 4. The tube noise is for the length of time of an average run.

CONCLUSIONS

Table I, based on a comparison of Figs 1 and 2, shows the efficiencies attainable under various background conditions. It is assumed that the total background rate is equal to the total neutron rate to be detected.

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TABLE I

Background Limitation	Discriminator Setting	Percent efficiency at indicated neutron energies		
		14.2 Mev	$\sim$ 4 Mev	0.50 Mev
Tube noise	10	8.0	2.5	0.70
$E_\gamma \lesssim 3$ Mev	15	6.8	1.7	0.28
$E_\gamma \lesssim 17$ Mev	30	4.0	0.86	0.12

An inspection of Table I shows that the efficiencies attainable with the present detector are substantially greater than those hitherto obtained for ZnS recoil detectors. Techniques designed to suppress the large gamma-ray sensitivity of such scintillation phosphors as KI to permit the detection of neutron induced recoil protons in the presence of gamma-ray backgrounds ~~here~~ have given neutron detection efficiencies not far below those obtained here,[6] but the success of the gamma sensitivity suppression is considerably less than with the present detector.

(6) G.N. Harding Nature 167, 437 (1951)

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Figure Captions

Fig 1. Variation of detector efficiency with weight of ZnS in 3.3 grams of lucite. Curve a observed, curve b estimated prediction, for Po-Be source.

Fig 2. Integral pulse height spectrum and efficiency as a function of discriminator setting for various neutrons sources. Detector contained 1.5 grams of ZnS in 10 grams of lucite.

Fig 3. Integral pulse height spectrum and efficiency as a function of discriminator setting for various gamma-ray sources. These curves are for the same detector used in obtaining the experimental results shown in Fig 2. The discriminator units are the same as those of Fig 2. The 5819 photomultiplier tube noise spectrum per 1/2 minute is also given for comparison, room temperature.

Fig 4. The separate integral spectrum contributions of tube noise, 17.6 Mev gamma-rays, and 0.50 Mev neutrons when Li is bombarded with 2.35 Mev protons (thick target, forward direction). These curves are for the same detector used in obtaining the experimental results shown in Figs 2 and 3.

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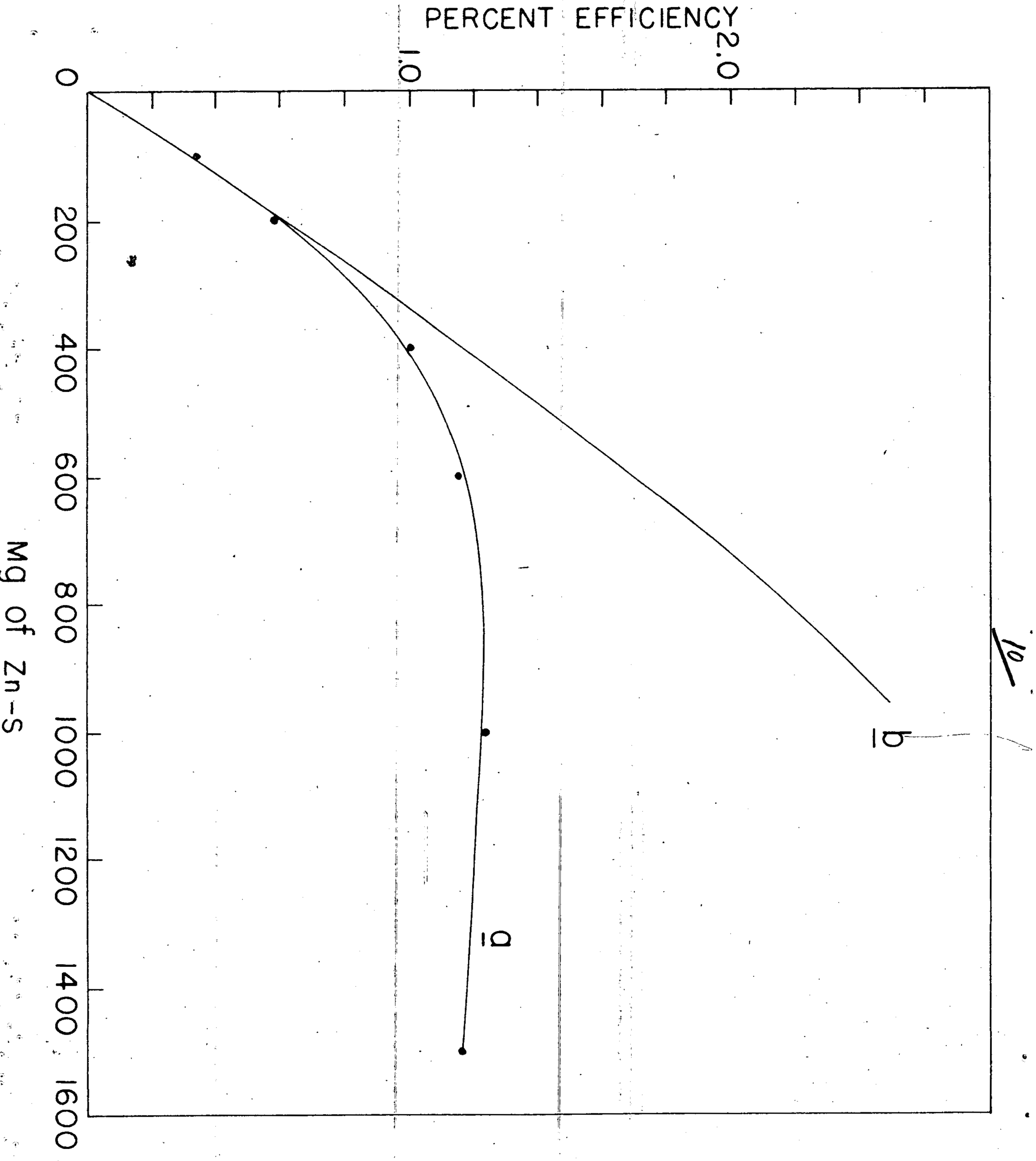
PERCENT EFFICIENCY
1.0
2.0
0
200
400
600
800
1000
1200
1400
1600
Mg of Zn-S
a
b
10

FIG. 1

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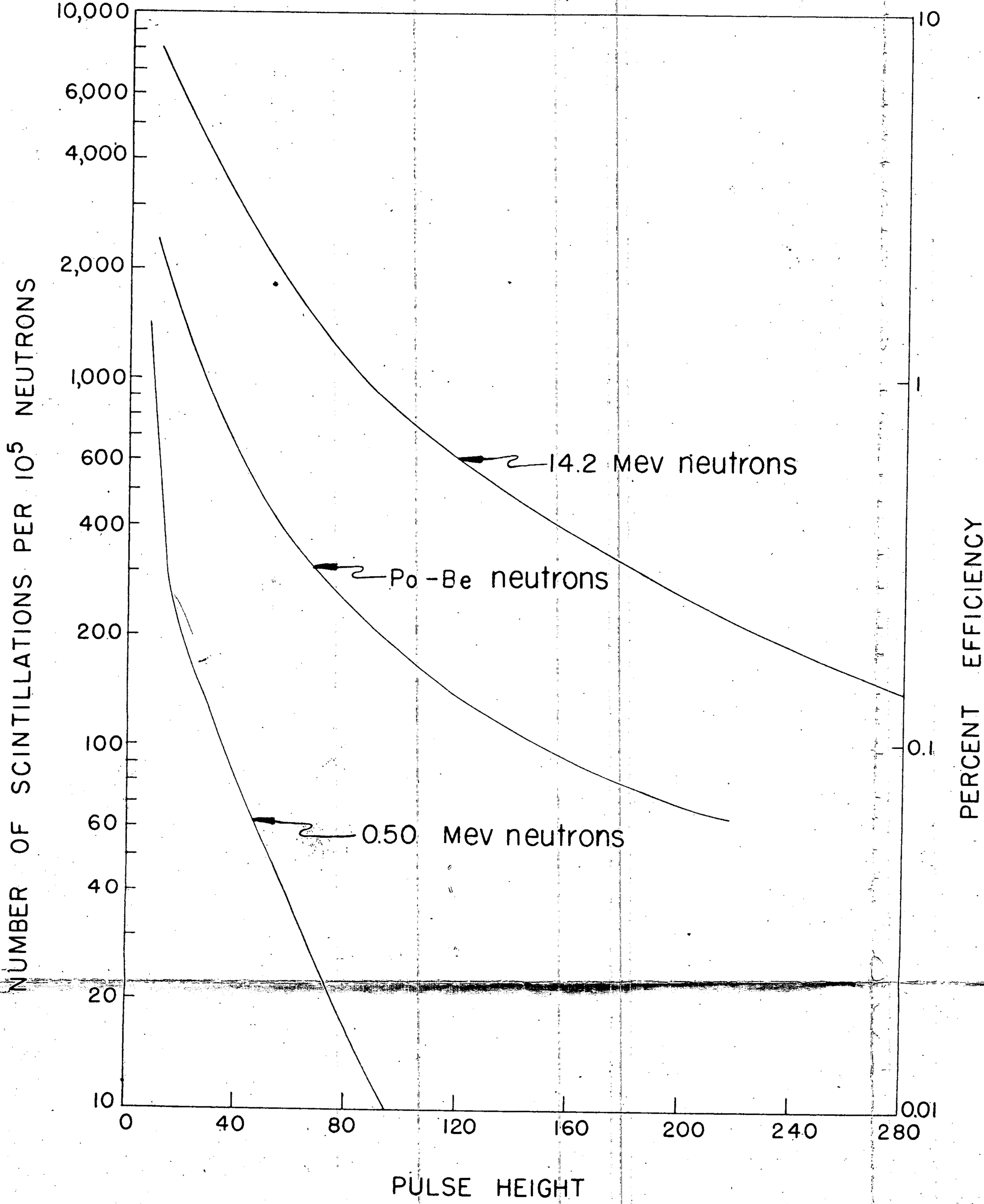

10,000
6,000
4,000
2,000
1,000
600
400
200
100
60
40
20
10
10
1
0.1
0.01
0
40
80
120
160
200
240
280
NUMBER OF SCINTILLATIONS PER 10^5 NEUTRONS
PERCENT EFFICIENCY
PULSE HEIGHT
14.2 Mev neutrons
Po-Be neutrons
0.50 Mev neutrons

FIG. 2

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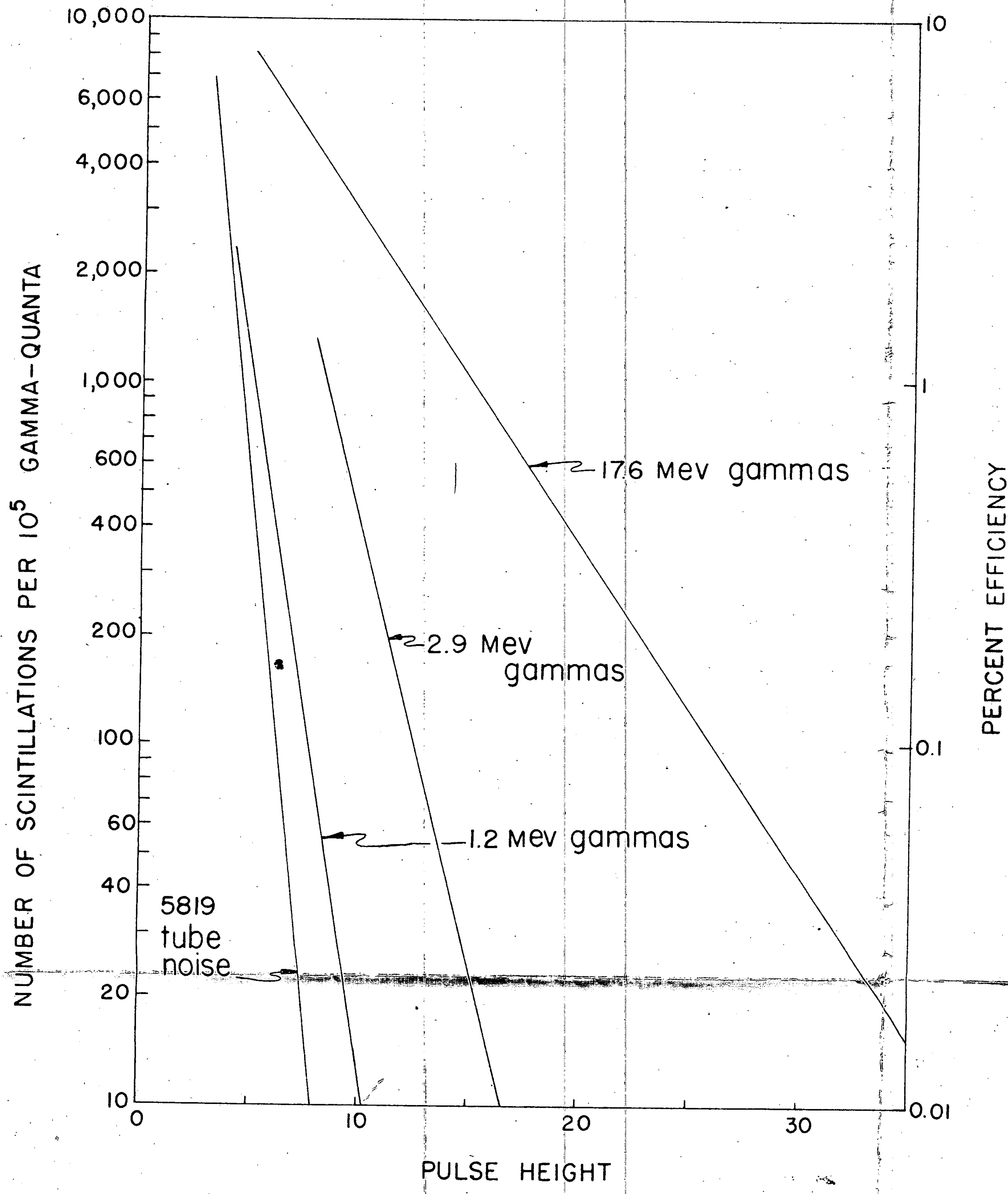
10,000
6,000
4,000
2,000
1,000
600
400
200
100
60
40
20
10
NUMBER OF SCINTILLATIONS PER 10^5 GAMMA-QUANTA
10
1
0.1
0.01
PERCENT EFFICIENCY
0
10
20
30
PULSE HEIGHT
17.6 Mev gammas
2.9 Mev gammas
1.2 Mev gammas
5819 tube noise

FIG. 3

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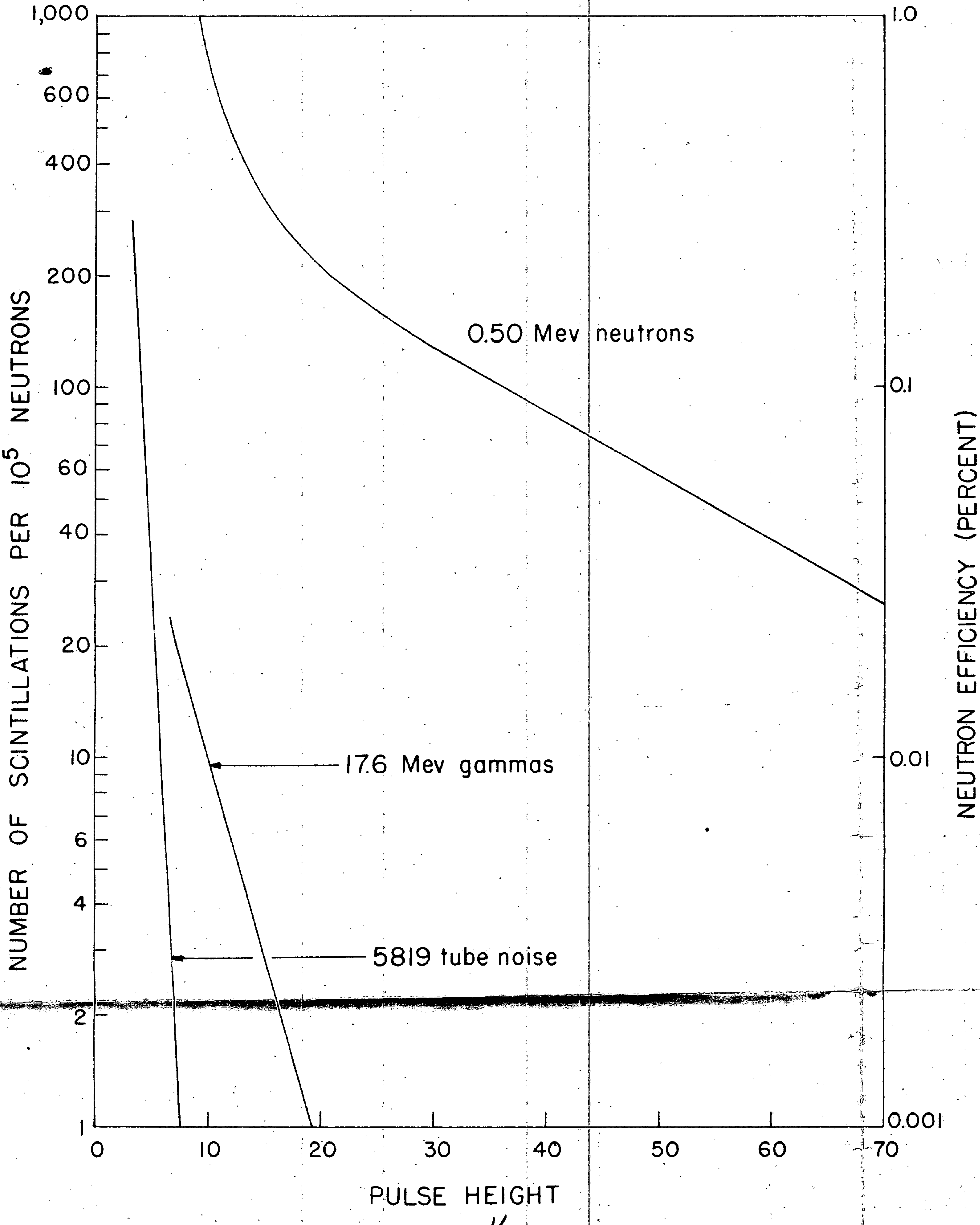
1,000
600
400
200
100
60
40
20
10
6
4
2
1
NUMBER OF SCINTILLATIONS PER 10^5 NEUTRONS
1.0
0.1
0.01
0.001
NEUTRON EFFICIENCY (PERCENT)
0.50 Mev neutrons
17.6 Mev gammas
5819 tube noise
0
10
20
30
40
50
60
70
PULSE HEIGHT

FIG. 4

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