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GAMMA-RAY DISCRIMINATION IN A PROTON-RECOIL PROPORTIONAL COUNTER

by

E. F. Bennett

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E. F. Bennett
Reactor Engineering Division

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TABLE OF CONTENTS

		Page
I.	INTRODUCTION	4
II.	PROPORTIONAL COUNTER	6
III.	THE EFFECT OF STRAGGLING ON THE VOLTAGE PROFILE	7
IV.	EXPERIMENTAL APPARATUS	11
	A. Proportional Counter	11
	B. Electronic Circuitry	12
	1. Differentiating Amplifier and Preamplifier	12
	2. Divider Circuit	15
V.	EXPERIMENTAL RESULTS	15
VI.	CONCLUSION	19
ACKNOWLEDGMENT		20
REFERENCES		21

LIST OF FIGURES

No.	Title	Page
1.	End-on View of a Cylindrical Proportional Counter	6
2.	Preamplifier Circuit Diagram	13
3.	Circuit Diagram for Differentiating Amplifier	14
4.	Differentiating Amplifier Gain versus Width of Input Pulse	15
5.	Pulse-height Spectrum of Protons from the $N^{14}(n,p)C^{14}$ Reaction	16
6.	Gas Multiplication versus Counter Voltage	16
7.	Block Diagram of Arrangement Used to Examine Log Quotient Dependence on Energy	17
8.	Spectrum of Log Quotients Gated by Events in the Interval from 100 to 110 kev	17
9.	Spectrum of Log Quotients Gated by Events in the Interval from 140 to 154 kev	17
10.	Spectrum of Log Quotients Gated by Events in the Interval from 250 to 275 kev	18
11.	Spectrum of Log Quotients Gated by Events in Excess of 80 kev	18
12.	Block Diagram for Normal Operation of Discrimination Circuitry	19
13.	Gated and Ungated Recoil Proton Spectra	19

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A technique for discrimination against gamma-ray background in proton-recoil proportional counters based on changes in the pulse profile is described. The lower useful energy limit of a counter filled with a propane-nitrogen gas mixture and placed in a broad fast-neutron spectrum was extended from 400 kev to 100 kev.

I. INTRODUCTION

When a molecular hydrogen- or hydrocarbon gas-filled proportional counter is exposed to a fast-neutron flux, the resulting ionization spectrum of recoil protons may be used to deduce the energy spectrum of the incident neutrons. The subject matter has been extensively reviewed by Marion and Fowler,(1) for instance.

The detector to be considered here is of the conventional grounded-cylindrical-cathode, fine-wire-anode construction. A neutron may enter isotropically and collide with a proton contained in the filling gas. The resulting ionization will induce a voltage pulse at the anode which will be proportional to the total number of initial ion pairs. By operating the counter at sufficient gas multiplication, the induced voltage may be made substantially in excess of noise in the associated electronic equipment, and so recoil protons of only a few kilovolts of energy can, in principle, be detected with a resolution of 10% or so. Difficulty in extending detector response to the lowest energies may arise from the background of gamma rays which usually accompanies the production and absorption of neutrons.

A degree of freedom of considerable value in dealing with this background is the pressure and nature of the filling gas. It is clear that no more than an amount of gas adequate to stop the most energetic protons expected to arise from the incident neutron spectrum should be used if a reduction in gamma-ray sensitivity is desired. On the other hand, a simple, unambiguous interpretation of the recoil pulse-height spectrum in terms of neutron-energy spectrum is possible only if end effects are negligible and the amount of gas is sufficient to stop nearly all recoil protons. For a

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A degree of freedom of considerable value in dealing with this background is the pressure and nature of the filling gas. It is clear that no more than an amount of gas adequate to stop the most energetic protons expected to arise from the incident neutron spectrum should be used if a reduction in gamma-ray sensitivity is desired. On the other hand, a simple, unambiguous interpretation of the recoil pulse-height spectrum in terms of neutron-energy spectrum is possible only if end effects are negligible and the amount of gas is sufficient to stop nearly all recoil protons. For a neutron spectrum continuous in energy (and it is this kind of spectrum with which the present report is concerned), some compromise gas pressure must be chosen to render end effects negligible, at least for the most populous region of the neutron spectrum. This choice of gas pressure will then determine a threshold energy, below which electrons from gamma-rays converted either in the walls of the counter or in the filling gas will be able to create sufficient ionization to be counted along with proton-recoil events. Below this threshold energy, the counter is valueless as a spectrometer unless a method of discrimination is available. The continued reduction of filling pressure is not a very satisfactory solution to the problem of gamma background if end effects for the higher-energy proton recoils become bothersome. In some instances, a loss in macroscopic cross section accompanying a reduction in filling pressure may not be desirable either.

A means of discriminating against conversion electrons is suggested by taking note of the relative path length of an electron and a proton of equal ionization. The range of a 100-kev proton in 2 atmos of methane is about $\frac{1}{2}$ mm, for instance, whereas the range of an electron of this energy is about 8 cm. As a consequence, ionization from the recoil proton will be created in the form of a bunch with small spatial extension, whereas the radial projection of ionization from the conversion electron track will, with high probability, occupy a dimension of the order of centimeters. This tendency of the electrons produced by the ionizing track from a converted photon to "straggle" will result in a pulse which rises rather slowly when compared with a pulse containing the same initial number of electrons created at essentially a point. A simultaneous observation of the high-frequency component of the pulse along with its low-frequency amplitude (which is used to indicate the total amount of ionization) will permit rejection of some of the unwanted background pulses.

This approach has much in common with the problem of rejecting gamma-induced pulses in plastic scintillators.(2) The mechanism of gamma rejection in scintillators requires a rather complicated interpretation, not all of which appears well known at present. The rejection mechanism in a proportional counter, on the other hand, is of a very simple nature and may be understood in terms of well-established principles of counter operation.

This report is the second of two (see Reference 7 for first) in which an experimental technique adequate to effect γ-n discrimination in a proportional counter is described. Some experimental results will be included here, the object being to demonstrate the discrimination and not to do accurate spectral measurements.

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II. PROPORTIONAL COUNTER

A few essential details of operation of proportional counters are necessary for the discussion and will be written down in this section. The theory and notation are from Wilkinson.[3]

Figure 1 is an end-on view of a cylindrical proportional counter. The figure is not drawn to scale, the ratio b/a being of the order of 1000 for proportional counters intended to be operated at substantial gas multiplication. An electron created by the passage of an ionizing particle at r will drift under the influence of a field

$$X(\text{volts/cm}) = V/[r \log(b/a)] \tag{1}$$

toward the center electrode (assumed at positive voltage V). The average drift velocity (denoted by v) will depend upon the nature of the filling gas and the ratio of electric field to pressure X/P (volts/cm-mm Hg). Close to the center wire, the electron will be accelerated to energies sufficient to cause ionization in the gas, and an avalanche of secondary electrons will be created for each primary electron. The average increase in electron number is termed the gas multiplication A. It has been verified empirically that the relation

$$\text{Log } A = \text{constant} + \text{constant } (V) \tag{2}$$

holds for operation in the proportional region. Ultimately, space-charge effects will cause a departure from the form of Eq. (2) and, if voltage is increased further, the counter may go over to the Geiger mode of operation if effects such as corona discharge have not already become operative.

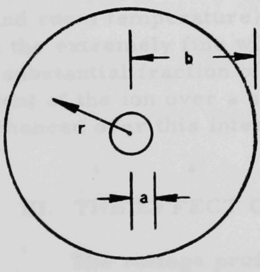

Fig. 1

End-on View of a Cylindrical Proportional Counter

Because the avalanche electrons are created very near the center electrode, they produce only a small induction effect on the electrode. The major part of the pulse arises from motion of the sheath of positive ions away from the wire. An analysis of the voltage profile per electron, E(t), yields the result

$$E(t) = -\frac{e}{C}\,\frac{\log\left[\dfrac{2VKt}{a^2\log(b/a)} + 1\right]}{2\log(b/a)} \tag{3}$$

until a time

$$t = \Big[(b^2 - a^2)\log(b/a)\Big]/2VK \tag{4}$$

when the positive ion is captured at the outer electrode and so $E = -e/C$. Here C is the total anode capacity and K the positive ion mobility. In practice, a finite resistance will shunt the anode capacitance C and this will clip the profile for times of the order of tens of microseconds.

Although the time required to collect the positive ion is quite long, a substantial fraction of the profile will be realized rather quickly. For example, consider $b = 1000$ mils, $a = \frac{1}{2}$ mil, $V = 3000$ volts, and $K = 5$ cm/sec per volt/cm. These parameters will apply to a counter of 2.54 cm radius with a 1-mil-diameter wire containing 2 atmos of methane with A of about 100. The collection time in Eq. (4) works out to be 1000 μsec, but only 0.05 μsec later the voltage profile has risen to 32% of its asymptotic (without clipping) value.

It is perhaps surprising that the rise of the pulse is as rapid as this, considering that it depends upon positive ion and not electron mobilities. The velocity of a heavy ion is proportional to the ratio of field to pressure, X/P:

$$v(\text{ion}) = KX \quad ; \quad K = K_0\, 760/P \quad ,$$

where K_0 is an intrinsic mobility for the gas defined as the velocity of the ion in cm/sec for an applied field of 1 volt/cm at atmospheric pressure (and room temperature). The explanation of the fast rise of the profile lies in the extremely fine wire assumed. Because of the 1/r nature of the field, a substantial fraction of the induced emf will have taken place with movement of the ion over a single wire diameter, and the velocity of the ion is enhanced over this interval because of the strong field.

III. THE EFFECT OF STRAGGLING ON THE VOLTAGE PROFILE

The voltage profile induced by the arrival of a single primary electron at the wire at time zero will be approximately given by an expression of the form of Eq. (3) multiplied by A, the gas multiplication. The ionizing particle will be assumed to have created N primary electrons and these will arrive at the wire over some finite time interval. A "straggle function" S(t) will be introduced to represent the distribution of electron arrivals. The first electron will arrive at $t = 0$ and the last at a "straggle time" τ which denotes the total extent in time of the electron burst. The function

$$E(t) = -\frac{e}{C}\,\frac{\log\left[\dfrac{2VKt}{a^2\log(b/a)} + 1\right]}{2\log(b/a)} \qquad (3)$$

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$$v(\text{ion}) = KX \quad ; \quad K = K_0\,760/P$$

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S(t) is zero before and after the interval τ, and is normalized according to the equation

$$\int_0^{\tau} S(t)\, dt = N \quad .$$

The resulting profile U(t) may be expressed as a convolution of E(t) and S(t):

$$U(t) = A \int_0^{\infty} E(t - t')S(t')\, dt' \quad , \tag{7}$$

where E(t) is zero for negative arguments.

Consider, first, that an analysis of the profile is to be made by passing U(t) through filters tuned selectively to certain interesting frequencies. If the interval τ is short, an enhanced amplitude at higher frequencies would be expected relative to the amplitude for long τ (assuming of course that N remains fixed). Denoting by $\overline{U}(\omega)$, $\overline{E}(\omega)$, and $\overline{S}(\omega)$ the Fourier transforms of the resultant profile U(t), the single-electron profile E(t), and the straggle function S(t), it may be readily verified from Eq. (7) that

$$\overline{U}(\omega) = A\,\overline{E}(\omega)\,\overline{S}(\omega) \quad . \tag{8}$$

The existence of $\overline{E}(\omega)$ and $\overline{U}(\omega)$ for all frequencies is assured when clipping of the profile E(t) is permitted, as will always be the case in practice. The output of a filter tuned to the frequency ω will be proportional to the modulus $|\overline{U}(\omega)|$ of the Fourier amplitude $\overline{U}(\omega)$,

$$|\overline{U}(\omega)| = A|\overline{E}(\omega)|\ |\overline{S}(\omega)| \quad . \tag{9}$$

The relative filter output at two different frequencies ω_1 and ω_2,

$$\frac{|\overline{U}(\omega_1)|}{|\overline{U}(\omega_2)|} = \frac{|\overline{S}(\omega_1)|}{|\overline{S}(\omega_2)|} \quad \text{times a constant function of } \omega_1 \text{ and } \omega_2, \tag{10}$$

is seen to be proportional to the ratio of the amplitudes of the corresponding Fourier coefficients of the straggle function. If now the frequency ω_2 is chosen sufficiently low such that $\omega_2\tau << 1$, then it may be verified that

$$|\overline{S}(\omega_2)| \longrightarrow N \qquad \text{(low-frequency approximation).} \tag{11}$$

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is seen to be proportional to the ratio of the amplitudes of the corresponding Fourier coefficients of the straggle function. If now the frequency ω_2 is chosen sufficiently low such that $\omega_2\tau \ll 1$, then it may be verified that

$$|\bar{S}(\omega_2)| \longrightarrow N \quad \text{(low-frequency approximation)}. \tag{11}$$

On the other hand, if the frequency ω_1 is chosen sufficiently high so that $\omega_1 \tau \gg 1$, the corresponding amplitude of the straggle function will be approximately given by

$$|\bar{S}(\omega_1)| \longrightarrow N/\omega_1 \tau \quad \text{(high-frequency approximation).} \tag{12}$$

If the measure of the output of the tuned filters is taken to be the peak of the generated voltage wave form, then the ratio of the peak height from the high-frequency filter to that from the low-frequency filter will be

$$\frac{\text{Peak height from low-frequency filter}}{\text{Peak height from high-frequency filter}} \sim 1/\tau \quad . \tag{13}$$

Equation (13) is a basis for γ-n discrimination since, as has been previously stated, the straggle time may be substantially greater for a conversion-electron track than for a proton track of the same total ionization.

The discussion has been carried through in terms of an analysis of the the profile with filters, but it may also be done on a time rather than a frequency basis, and this is probably more consistent with the kind of electronics that has actually been used.

Sampling the low-frequency content of a pulse is essentially equivalent to sampling the peak height after a sufficiently long time.

A measure of the high-frequency content of a pulse is found in the rate of change of the profile. Differentiation of the profile may be accomplished by a shorted delay line. The output pulse from a shorted delay line differentiating circuit may be written as

$$U'(t) = U(t) - U(t - 1/\sigma) \quad , \tag{14}$$

where the delay (twice the line length) is $1/\sigma$. For sufficiently small $1/\sigma$, a Taylor expansion gives

$$U'(t) = \frac{1}{\sigma}\frac{dU(t)}{dt} = \frac{A}{\sigma}\int_0^\infty \frac{d\,E(t - t')}{dt}\,S(t')\,dt' \quad , \tag{15}$$

where Eq. (7) has been used to make the substitution for U(t). If $1/\sigma$ is much less than τ, the derivative $d\,E(t - t')/dt$ may be replaced by the delta function $\delta(t - t')$. Under these conditions, U(t) will reduce to

$$U'(t) \sim S(t) \quad . \tag{16}$$

It is quite possible that the straggle time could be measured directly by measuring the total extent in time of the derivative, although the conditions under which Eq. (15) reduces to Eq. (16) hold only approximately for

experimentally realizable σ and τ. Fortunately, S(t) for conversion electrons is expected to be smoothly varying and to show no complicated structure, and so the peak value of S(t) may be taken as an approximation to the reciprocal straggle time (the total number of primary electrons being fixed). Use of the peak value of U(t) is much to be desired experimentally. Simple operations upon pulses are conveniently carried out in terms of values of the peak voltage. In the remainder of this note, "differentiation" will refer to the peak voltage of the profile after passing through a shorted delay line. In the time domain, Eq. (13) is

$$\frac{\text{Derivative}}{\text{Asymptotic profile}} \sim 1/\tau \quad . \tag{17}$$

It is evident that remarks made in this section are of a very qualitative nature intended to indicate the basis for the method of γ-n discrimination to be used here. The straggle function may assume a variety of shapes depending on where the conversion electron arises and on the path taken by it in stopping. The function S(t) and its duration τ are also dependent upon the nature of the filling gas and the counter voltage. It is clear that the straggle time τ is greatest for those electrons having a track making a large angle with the axis of the counter and least for those events in which the track is roughly parallel to the counter axis.

Even for a proton recoil track extending over a fraction of a millimeter, the straggle time would be large if there existed a tendency for the electron bunch to diffuse apart as it drifts to the center wire. This effect will set a lower limit on τ and may be estimated. If the electron bunch (assumed to be initially concentrated at a point) is assumed to move under the influence of a fixed field X for a distance d, the mean-square displacement of the electrons from the center of gravity will be given by

$$\delta^2 = 0.036(\eta/X)d \quad , \tag{18}$$

where η is the mean energy of agitation of the electrons relative to their thermal equilibrium value (see Reference 3, p. 37). The value of η is strongly dependent upon the type of gas and on the ratio X/P. For molecular gases, such as hydrogen and nitrogen, η will not exceed about 10 over a substantial radial extent of the counter. The field in a cylindrical counter geometry varies as 1/r and so Eq. (18) is not directly applicable, but, by splitting the radial dimension into segments and taking appropriate averages of η and X for each segment, it may be verified that δ is negligibly small for a molecular gas, even for an electron bunch that originates near the counter wall. Since a molecular gas will necessarily be present in any proton-recoil counter, the conclusion may be drawn that diffusion effects will not contribute significantly to straggle times, although the theory used is admittedly crude.

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As an example of the order of magnitude of τ for a conversion electron and for a recoil proton, consider a counter ($a = \frac{1}{2}$ mil, $b = 1000$ mils, $V = 3000$ volts) filled with 2 atmos of methane. The drift velocity of electrons in methane is known[4] and may be crudely expressed as a function of X/P by

$$\frac{dr}{dt} = v = 16.5 \frac{\text{cm}/\mu\text{sec}}{\text{volts/cm/mm Hg}} \frac{X}{P} \quad . \tag{19}$$

If Eq. (1) is substituted for X and the result is integrated, it will be seen that the time required for an electron created at $r = x_0$ cm to drift to the wire is

$$t(\mu\text{sec}) = 0.1\, x_0^2 \quad . \tag{20}$$

If, for example, the radial projection of a conversion-electron track extends from 1.0 to 2.0 cm, the straggle time will be about 0.3 μsec. The straggle time for a recoil proton with a track of 0.05-cm radial projection and created at $x_0 = 2$ cm will be about 0.002 μsec. The ratio of straggle times for the 2 events is then about 150 and, according to Eq. (17), this is the expected relative value of the ratio of slope to asymptotic pulse height for the 2 events. One reason that it is not easy to observe this large discrepancy in τ indicated by the example lies in limitations of available electronics. In order to differentiate in 0.002 μsec, a follow-up amplifier with a large gain-bandwidth product would be necessary, and this may not be consistent with an adequate signal-to-noise ratio.. The differentiating amplifier employed in these experiments was actually suitable for a differentiating time $1/\sigma$ of about 0.050 μsec, and if this number is used in place of the value of 0.002 μsec calculated for the example, a rather more modest value of 6 is arrived at as the ratio of peak derivatives for the 2 events.

It is to be noted, however, that methane is an extremely fast gas (high electron drift velocity) when compared with other filling candidates, such as hydrogen. Use of a slow gas like hydrogen, with drift velocities substantially less than the values given by Eq. (19), may permit improved discrimination in those cases for which amplifier limitations restrict differentiating times to about 0.050 μsec.

IV. EXPERIMENTAL APPARATUS

A. Proportional Counter

The counter was constructed from a stainless steel tube, of 5.08-cm OD with 0.080-cm wall thickness. Provision for access at one end was made by use of a flange with an aluminum "O" ring. Kovar seals with glass insulation extending 1.27 cm into the counter interior were used at both ends.

As an example of the order of magnitude of τ for a conversion electron and for a recoil proton, consider a counter ($a = \frac{1}{2}$ mil, $b = 1000$ mils, $V = 2000$ volts) filled with 2 atmos of methane. The drift velocity of electrons in methane is known[4] and may be crudely expressed* as a function of X/P by

$$\frac{dr}{dt} = v = 16.5 \frac{\text{cm}/\mu\text{sec}}{\text{volts/cm/mm Hg}} \frac{X}{P} \qquad (19)$$

If Eq. (4) is substituted for X and the result is integrated, it will be seen that the time required for an electron created at $r = x_0$ cm to drift to the wire is

$$t(\mu\text{sec}) = 0.1\, x_0^2 \qquad (20)$$

If, for example, the radial projection of a conversion-electron track extends from 1.0 to 2.0 cm, the straggle time will be about 0.3 μsec. The straggle time for a recoil proton with a track of 0.05-cm radial projection and created at $x_0 = 2$ cm will be about 0.002 μsec. The ratio of straggle times for the 2 events is then about 150 and, according to Eq. (17), this is the expected relative value of the ratio of slope to asymptotic pulse height for the 2 events. One reason that it is not easy to observe this large discrepancy in τ indicated by the example lies in limitations of available electronics. In order to differentiate in 0.002 μsec, a follow-up amplifier with a large gain-bandwidth product would be necessary, and this may not be consistent with an adequate signal-to-noise ratio. The differentiating amplifier employed in these experiments was actually suitable for a differentiating time (τ of about 0.050 μsec), and if this number is used in place of the value of 0.002 μsec calculated for the example, a rather more modest value of 6 is arrived at as the ratio of peak derivatives for the 2 events.

It is to be noted, however, that methane is an extremely fast gas (high electron drift velocity) when compared with other filling candidates, such as hydrogen. Use of a slow gas like hydrogen, with drift velocities substantially less than the values given by Eq. (19), may permit improved discrimination in those cases for which amplifier limitations restrict differentiating times to about 0.050 μsec.

IV. EXPERIMENTAL APPARATUS

A. Proportional Counter

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Hypodermic needles positioned the center wire and defined the effective counting volume, which was 17.8 cm long. A soft stainless steel wire of 1-mil diameter was used.[5] The Kovar seals and stainless wire were soft soldered to the counter body, and care was taken to keep wire and counter interior clean.

A mixture of 1 atmos N_2 plus 1 atmos C_3H_8 (propane) was used in the experimental work described here. Nitrogen was added in order to calibrate the counter by exposure to a well-thermalized neutron flux, which will produce protons of 560-kev energy via the $N^{14}(n,p)C^{14}$ reaction. No special purification techniques were used in filling the counter, and this may account for the rather poor resolution (18%) for the observed line.

B. Electronic Circuitry

Voltage pulses from the counter are fed to a preamplifier and the output of the preamplifier fed to a slow amplifier and a differentiating amplifier. The fall time (9 μsec) of the slow amplifier is set sufficiently large to permit the entire profile to form, regardless of the origin of the pulse and magnitude of straggle time, before substantial attenuation due to the finite clipping time constant can occur. An Argonne model A-61 B was used for the slow amplifier. The design exhibits rapid recovery from overload pulses.

Pulses proportional to the derivative of the profile and pulses proportional to the peak of the profile (with allowance for the finite clipping time in the slow amplifier) are compared in a pulse-division circuit, and if the "quotient" is indicative of a proton recoil rather than a conversion electron, the analyzer gate is switched on and the pulse from the slow amplifier sorted.

1. Differentiating Amplifier and Preamplifier

The preamplifier and differentiating amplifier are modifications of an Argonne design for high-speed counting.[6] The design uses feedback stages and, as a consequence, has good stability features. Complete circuit diagrams of the preamplifier and differentiating amplifier are given in Figs. 2 and 3. The preamplifier has a gain of about 30 and a frequency response essentially flat between about 10 kc and 20 Mc. Pulses are differentiated by a section of shorted RG114/U delay line following the input cathode follower of the differentiating amplifier. The output impedance of the cathode follower has approximately the correct termination impedance for the line. Exact termination is not important since the pulse is to be stretched later. The first 2 stages in the amplifier have a gain of 75 and 50, respectively. The maximum linear output from the second stage is about 20 volts, and at this point the pulse is stretched to a decay time of about 2 μsec. The third stage is an output stage which is slow (rise time of

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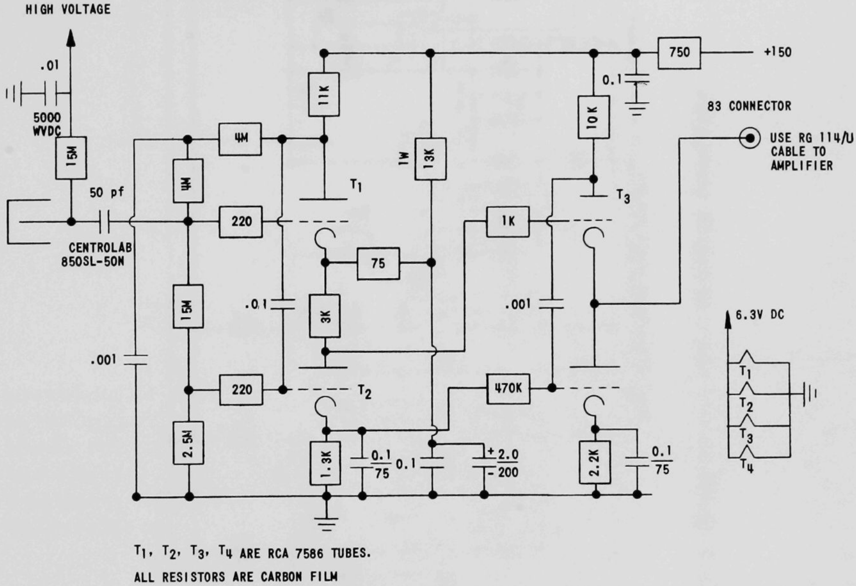

Fig. 2. Preamplifier Circuit Diagram

A test pulser was used to introduce rectangular pulses of fixed height and duration ranging from 0.012 to 0.102 μsec into the differentiating amplifier (with delay line stub removed). The peak height of the output pulse was observed as a function of input pulse width and the results are plotted in Fig. 4.

A length of 24 ft of RG114/U (total delay of 0.057 μsec) was used for differentiation in the experiments reported here.

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T_1, T_2, T_3, T_4 ARE RCA 7586 TUBES.
ALL RESISTORS ARE CARBON FILM

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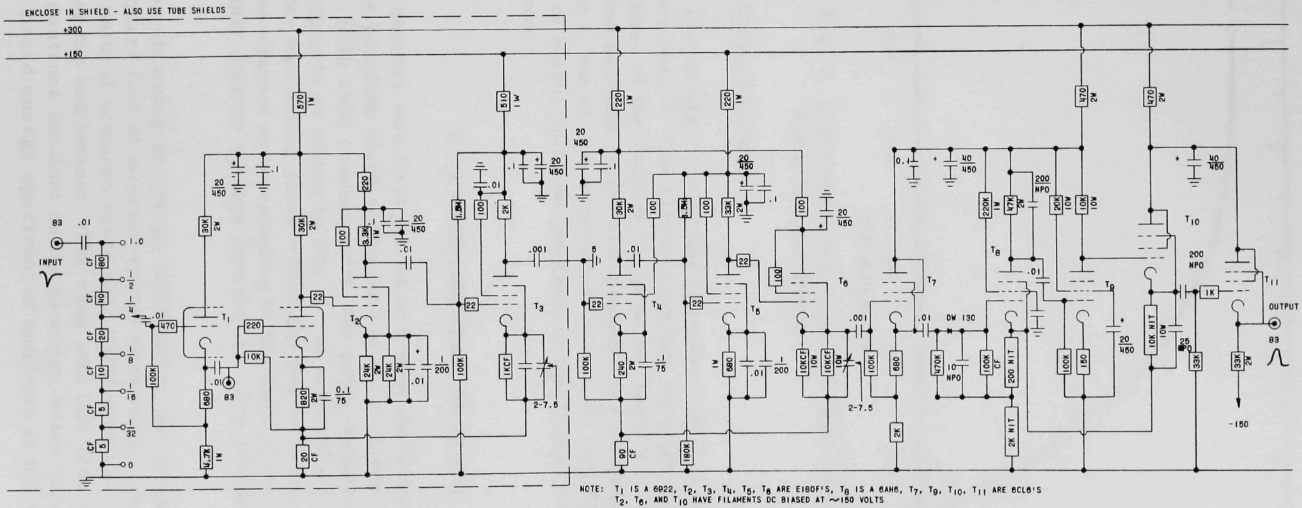

Fig. 3. Circuit Diagram for Differentiating Amplifier

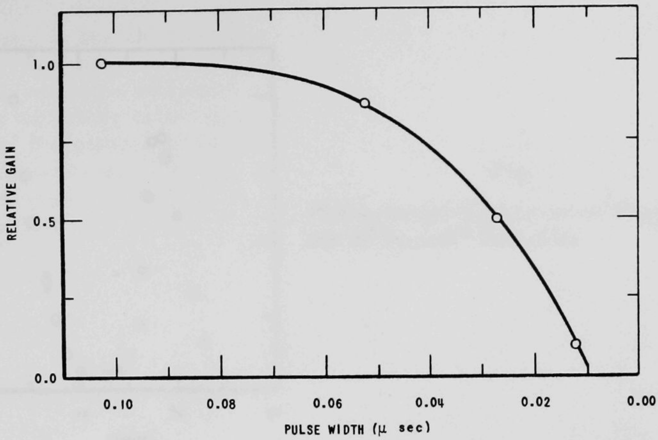

Fig. 4. Differentiating-amplifier Gain versus Width of Input Pulse

2. Divider Circuit

The divider circuit has been described in detail in the report preceding this one.(7) The circuit develops an output pulse proportional to the logarithm of the ratio of the peak voltages of 2 input pulses. A linear relation between output and quotient may be obtained, as discussed in Reference 7, but in this experiment it was not required; the logarithmic dependence of output pulse on the ratio of input pulses was adequate for discrimination.

V. EXPERIMENTAL RESULTS

The counter was first placed in a well thermalized neutron flux from a large graphite block at the face of the Argonne Thermal Source Reactor.(8) With 2550 counter volts, the pulse-height spectrum of 560-kev protons is as shown in Fig. 5. In order to check that operation of the counter was taking place within the proportional region, the logarithm of the channel corresponding to the peak of the distribution was plotted against counter voltage (see Eq. 2). The results are given in Fig. 6.

After obtaining an energy calibration, the counter was shifted to a cave (1 square foot of interior space) consisting of a front wall of 3-in.-thick natural uranium brick with about a foot of hydrogenous moderator on sides top and bottom. The rear was left open for access. A flux of thermal neutrons incident on the uranium-brick face caused the formation of a broad energy spectrum of neutrons in the interior of the cave.

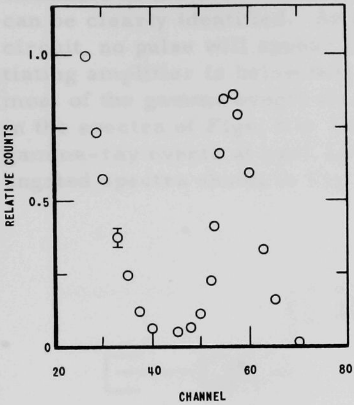

Fig. 5

Pulse-height Spectrum of Protons from the $N^{14}(n,p)C^{14}$ Reaction

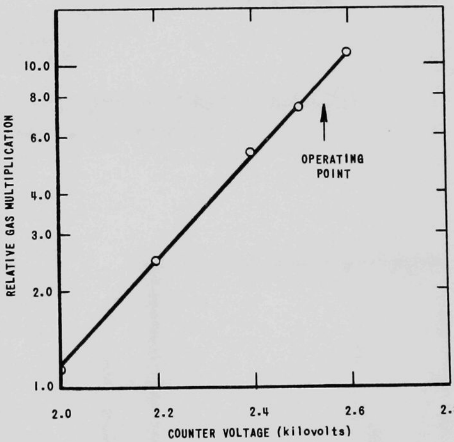

Fig. 6

Gas Multiplication versus Counter Voltage

A pulse-height spectrum from the counter placed within the converter is shown in Fig. 13 (curve marked "ungated"). The rapid rise below 400 kev is due both to gamma background and to recoil protons.

The system was first operated in the mode given by the block diagram in Fig. 7. A fixed-energy window from the slow amplifier was selected and events falling in this window developed a gating pulse (of 22-μsec duration) which was fed to the delayed external gate input of a 99-channel analyzer. A 3.5-μsec delay of the differentiating-amplifier output is introduced before division. This will permit development of the slow amplifier output pulse before division commences (see discussion in Reference 7). "Quotient" pulses from the divider are amplified and sorted. In Figs. 8, 9, and 10 are shown spectra of "log quotients" when

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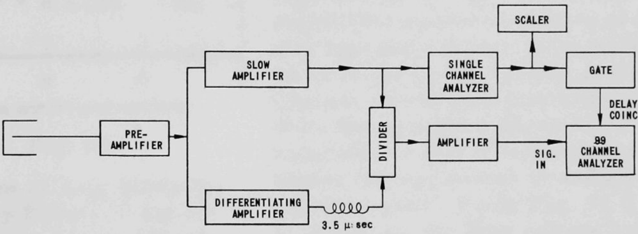

Fig. 7. Block Diagram of Arrangement Used to Examine Log Quotient Dependence on Energy

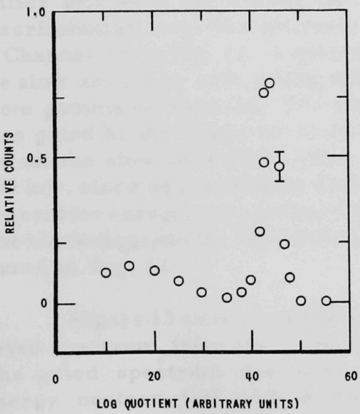

Fig. 8

Spectrum of Log Quotients Gated by Events in the Interval from 100 to 110 kev

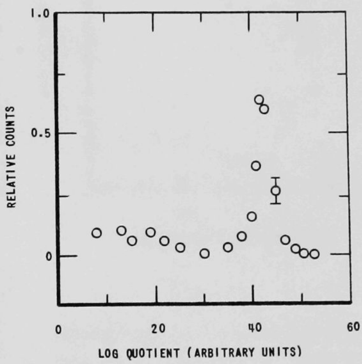

Fig. 9.

Spectrum of Log Quotients Gated by Events in the Interval from 140 to 154 kev

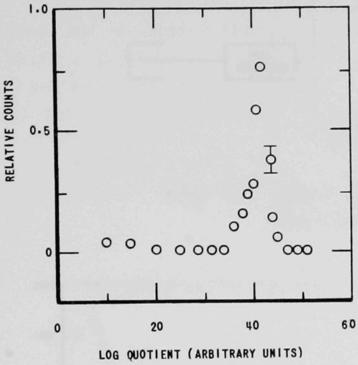

Fig. 10

Spectrum of Log Quotients Gated by Events in the Interval from 250 to 275 kev

Figure 11 shows a spectrum of "log quotients" gated by all events from the slow amplifier in excess of 80 kev. The spill-over of gamma events into the neutron channels arises primarily from two causes. The lowest energy (80 kev) contains such an adverse γ-n ratio that the high-energy tail of the electron distribution is becoming significant relative to the neutron peak. Also, high-energy proton recoils will produce a significant spatial extension of the tracks so that log quotients for these events will not be as large as for recoils of lower energy. Gamma conversion electrons are absent from the spectrum above about 400 kev, however, so that it is not necessary for higher-energy events to satisfy the divider requirements. From Fig. 11 it is possible to ascertain the bias voltage required to exclude all but a few gamma events.

The analyzer may then be gated by the upper-level discriminator on the amplifier following the divider circuit. The discriminator level was set corresponding to Channel 33 in Fig. 11. A spectrum from the slow amplifier with gating will be free from gamma background. The analyzer is also gated by the upper-level discriminator on the slow amplifier, which is set at 400 kev, since no conversion electrons are present for energies in excess of that value. The block diagram for this arrangement is shown in Fig. 12.

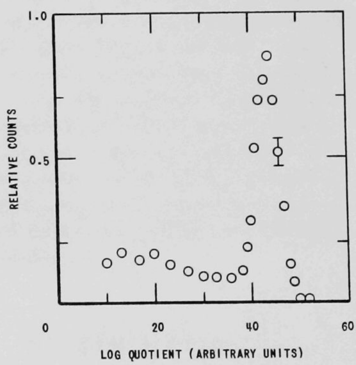

Fig. 11

Spectrum of Log Quotients Gated by Events in Excess of 80 kev

Figure 13 shows a gated and an ungated spectrum from the slow amplifier. The gated spectrum has a broad, high-energy neutron tail with a rising low-energy component. This is consistent with the converter arrangement required to produce the fast neutrons. No attempt at good statistics on the gated curve was made.

As can be seen from the figure, useful information would not be possible without discrimination below about 400 kev. The γ-n discrimination technique described here has, in this case, extended the low-energy limit of the detector from about 400 kev to about 100 kev.

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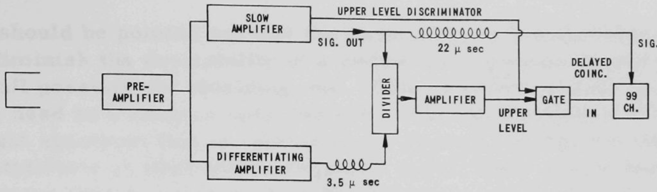

Fig. 12. Block Diagram for Normal Operation of Discrimination Circuitry

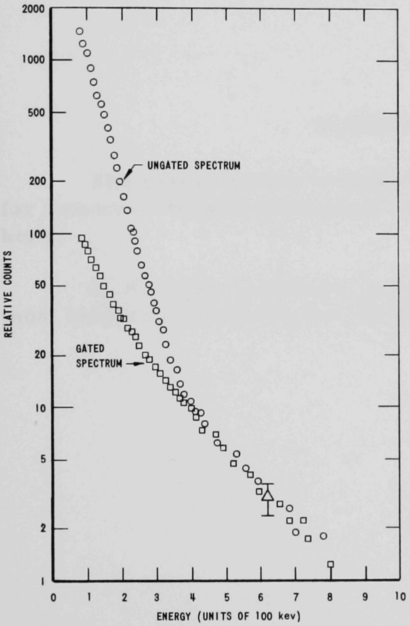

Fig. 13. Gated and Ungated Recoil Proton Spectra

Even without use of the device in extending the low-energy range of the detector, it would have value in determining that energy in excess of which a negligible conversion-electron background is found. Recoil counters have been operated in the presence of intense gamma background, in which case this background is treated as noise. A device of the type described could be used to determine at what energy this noise component is acceptably less than proton recoils. The divider would, in this case, be unnecessary. The decision as to gamma background is not very easily made by inspection of the pulse-height distribution alone, since both proton-recoil and gamma-background events may tend to become more numerous at low energies.

VI. CONCLUSION

Although γ-n discrimination has been shown to be practicable for a propane-nitrogen gas mixture, it is pertinent to ask whether or not this mixture is particularly well suited to exaggerate the difference in straggle times for electrons and protons. A gas having a slower electron-drift velocity would permit a longer differentiating time, which could be accomplished with an amplifier of lower gain-bandwidth product. The extent to which the initial point-electron burst from a recoil proton disperses limits the potential γ-n resolving power and this dispersion should be held to a minimum. Additional information on optimum gas mixtures would be desirable.

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It should be pointed out that the possibility of γ-n discrimination does not diminish the desirability of a reduction in gamma background, if this is at all possible, by shielding, etc. When a proton-recoil proportional counter is used as a neutron spectrometer, it is the derivative of the recoil pulse-height spectrum that is related to the neutron-energy spectrum. Acceptable statistics on derivatives require a great many counts and a proportionally longer time to accumulate if the detector spends part of its time rejecting unwanted events.

ACKNOWLEDGMENT

The author wishes to thank S. G. Kaufmann and K. G. A. Porges for numerous helpful discussions on various aspects of the work reported here.

E. F. Groh, C. Kotora, and the D-316 shop personnel have been most helpful in designing and constructing much of the apparatus required.

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