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A Liquid Scintillation Counter Using Anticoincidence Shielding

Abstract: A liquid scintillation counter with an active volume of one liter is described. The plastic anticoincidence shield reduces background by about 25 percent in the H^3 and C^{14} region. Photomultiplier noise is effectively eliminated by nanosecond coincidence circuitry. The tunnel diodes used in the coincidence arrangement also act as baseline or window discriminators. Counting efficiency for C^{14} solutions is 85 percent, limited mainly by light collection.

Introduction

This paper describes the development of a large detector, which can be used for assaying radioactivity of bulky samples. Such a counter eliminates chemical processing and allows experiments with short lived isotopes. Because the detector must be β and γ sensitive, the choice is limited to a liquid scintillation system.

Two obstacles were encountered in the design of the system. The first, noise discrimination, resulted from the large size of the detector. As its size is increased, the average number of photons striking the photocathode per nuclear disintegration decreases. A large fraction of true pulses will fall within the noise region. However, noise reduction by pulse height discrimination will decrease the counting efficiency. This problem was overcome by designing a nanosecond coincidence arrangement which limits the tube noise count rate to about one count per hour without sacrificing detection sensitivity.

The second obstacle is the gamma sensitivity of a large liquid scintillation system. To limit the effect of external gamma radiation, the primary detector is surrounded by a plastic scintillator anticoincidence shield. The whole assembly requires shielding by at least 4 inches of steel.

The anticoincidence method can be traced back to H. Geiger.[1] P. R. Bell et al,[2] used a tank filled with a liquid scintillation solution as an anticoincidence shield. More recently plastic scintillators have been used as a matter of convenience. Perkins[3] and Ellet[4] used NaI(T1) as the primary detector; Tanaha[5] and Gat[6] used gas flow counters surrounded by a plastic scintillator.

The efficiency of an anticoincidence shield can be estimated from published data. The shield used by Perkins decreased the background by 50% at the low energy end of the spectrum. For high energy gamma radiation (around 60 Mev) the reduction is much better. Similarly the shield described by Ellet decreased the background by about 50% in the region of 0.2 to 1 Mev. Beyond 1 Mev the reduction increases; below 0.2 Mev the reduction is less than 50%, but precise data are not available. Thus, it appears that an absorbing shield and an anticoincidence shield supplement each other quite well. The absorber is most effective at the low energy end and the anticoincidence arrangement most effective at the high energy end.

Our arrangement differs in the primary detector used. Flow counters are efficient beta detectors and their inherently low gamma sensitivity makes these devices outstanding for low-level counters. However they are unsuitable for our purposes because the sample size is very limited.

Gaseous detectors are inherently noiseless while NaI (Tl) detectors produce pulses which are in general large compared to photomultiplier noise. The low energy end is usually of no interest and is removed by a base-line discriminator.

In this counter the problems are compounded. The inherent gamma sensitivity and large size of the counter make the number of background pulses quite high. Furthermore, background pulses are in general of the same size or even larger than pulses caused by the sample isotope.

The physical layout is shown in Fig. 1. The diameter of the plastic scintillator shield is 14″ and its height, 17″. The cavity is 5″ in diameter and 6″ deep. The top of the shield slides on tracks over the table surface to give access to the primary detector. There is no optical contact between the bottom and top of the shield. Signals are added electrically.

Three EMI 9530B photomultipliers are optically coupled to the main shield. Two EMI 9514S photomultipliers view the top shield. The inner detector photomultipliers are type EMI 6255S. Because an interlock system must be used to protect photomultipliers from accidental exposure, no optical contact exists between the inner detector and these phototubes. Holes are drilled through the shield to accommodate the inner detector photomultipliers.

The plastic scintillator (made by Pilot Chemicals, Watertown, Massachusetts) is a solid solution of p-terphenyl (2-1/2%) and divinyl stilbene (1/40%) in polyvinyl toluene.

Noise reduction

Liquid scintillators produce fast but rather weak flashes of light. The shape of the intensity-time curve is known to some extent but only for the decay part of the curve. The photomultiplier output signal is not a faithful reproduction of the generation and decay of photons in the scintillator. Rather, the rise time of the output signal is determined largely by the dynode structure. The EMI tubes used here have a rise time slightly less than 10 ns. Focussed photomultipliers are reported to have rise times of 2 ns but they appear to be noisier. The duration of the output pulse is largely determined by the circuitry connected to the multiplier anode. By limiting stray capacitance, 10 to 20 ns pulses can be obtained. The range of pulse heights is very large because most of the output pulses represent Compton interaction. Also, a considerable fraction of the true signal falls within the noise region.

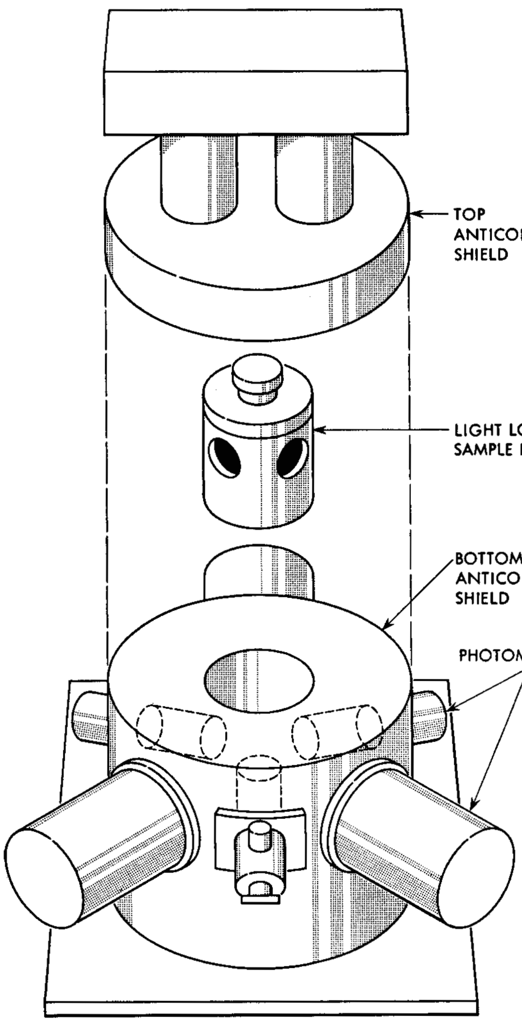


Figure 1 **Physical layout of the liquid scintillation detector and its anticoincidence shield.**

Noise reduction is accomplished by using a coincidence system. If two or more photomultipliers view the same scintillator, true sample pulses will produce coinciding signals at the photomultiplier anodes. The circuit is arranged such that two or more coinciding signals will produce an output but singles do not. Thus, the output of the coincidence circuit represents true signals plus that fraction of random noise pulses that happen to coincide in time. This fraction is not always small compared to the true signal.

Consider two random noise generators producing an average number of pulses N_1 and N_2. After each noise pulse from source 1, a gate is open for a time τ. During this time source 2 will produce $N_2\tau$ pulses. Since this happens on the average N_1 times per second, the count rate from source 2 will be $N_1N_2\tau$. Similarly, source 2 will open the gate after each pulse from 2. Therefore, the coincidence count rate will be $2N_1N_2\tau$.*

If N_1 and N_2 are of the order of 5×10^3 counts per second (cps) and τ is of the order of 1 μs (as encountered in commercial equipment) the coincidence background will be of the order of 50 cps. While the noise count rate is reduced to 1%, the absolute value is still large compared to the true sample rate.

The most obvious solution is to make τ of the order of nanoseconds rather than microseconds. This is possible because the photomultiplier output pulses are in the ns region; however this solution was not attainable until the advent of fast transistors and tunnel diodes.

There are alternate means of reducing tube noise: 1) Detector and phototubes can be cooled in a freezer to reduce thermionic emission, but this makes the freezer an integral part of the equipment. 2) Photomultipliers can be operated at low accelerating voltage. This reduces only the noise from the dynode structure, not the photocathode noise. To obtain enough gain, an elaborate amplifier is necessary. The gain-bandwidth product of a multistage linear amplifier with reasonable overload characteristics severely limits the rise time. One commercial amplifier produces pulses with a rise time of 0.2μs. Since the coincidence time must be appreciably larger than the rise time, the advantage is largely lost. 3) By discriminating small pulses, tube noise is reduced but only by sacrificing the true sample pulses below the discriminator setting.

* An expression for accidental triples is derived in the same way, $N_c = 3\, N_1N_2N_3\tau^2$.

Coincidence circuits

A coincidence circuit adds pulses if they overlap in time. Thus coinciding pulses will be larger than singles and a discriminator can be used to reject singles but pass coinciding signals. The pulses appearing at the coincidence point must therefore be of the same height. However, photomultipliers as used here produce pulses from well below 50 mv to over 3 v. A nonlinear device must be used between the phototubes and the coincidence point for pulse normalization. Tunnel diodes are superior in this aspect to transistors. While simple diode adders or delay line adders operating in the nanosecond region can be built using high speed transistors and diodes, it was found that the linear region of such circuits extends too far to be useful for soft beta emitters[15]. However, tunnel diode circuits operating as low level triggers can be overdriven. The extent to which this occurs will now be discussed.

Figure 2 shows a simple tunnel diode coincidence circuit built and used early in the development. It is discussed here to show the principle of operation.

The signal is developed across the 50 ohm resistors which form the anode load resistors of the photomultipliers. The photocathodes (not shown) are at high negative voltage (1.5 to 2.0 kv). The input signal is a negative pulse; thus the tunnel diodes are grounded at their anodes. The forward bias is adjusted with R_6 and R_7. A 1.5 v dry cell is an adequate supply.

Tunnel diode theory need not be discussed here. It will be sufficient to recall that the operation of tunnel diode switching circuits depends largely on the choice of the load line. If the load line intersects the $I(V)$ characteristic at only one point, below V_p the diode will reset to its quiescent point after the pulse has passed. If the load line intersects both stable branches, the diode must be reset after each pulse.

Since the circuit is required to trigger from random pulses, the reset pulse must be derived from the tunnel diode output pulse. This can be achieved by using the pulse reflected at the grounded end of a delay line (Sommers[16], Rabson[17]) or by producing a reset pulse which is delayed and fed back (Sugarman[18]). The time needed to produce the reset pulse determines the width of the output signal (0.7 μs in Ref. 17, 5 ns in Ref. 18). The pulses produced in this way depend less on the input trigger, but this advantage is offset by the added complexity. The self resetting circuit is used here. Circuitry of the same philosophy is described in Refs. 19, 20, and 21.

Returning to Fig. 2, as the signal increases the voltage across the tunnel diode to slightly beyond V_p, the diode switches. Thus the quiescent point determines the minimum signal height needed to produce an output and R_6

Figure 2 **Tunnel diode coincidence circuit.**

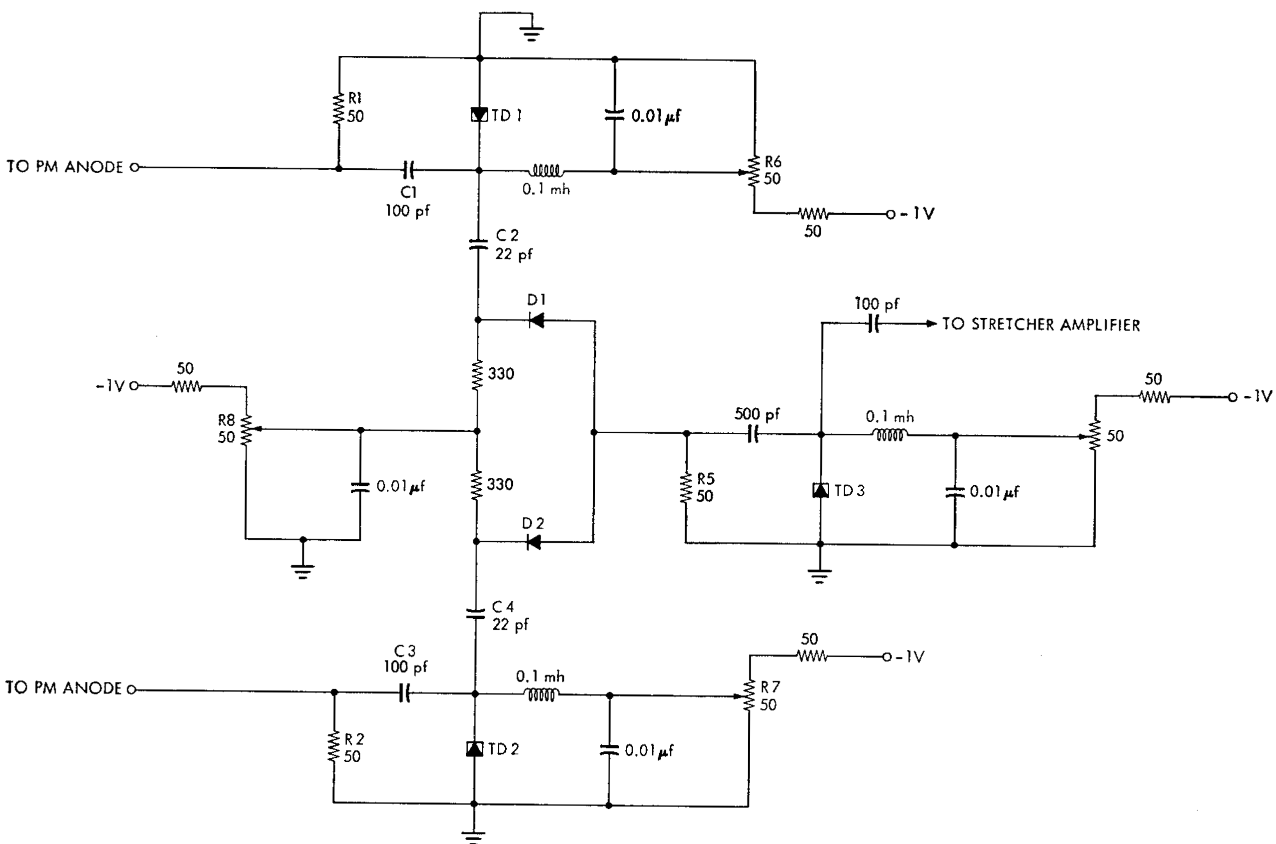


Table 1 **Noise count rates as function of high voltage EMI 9514S tubes (Nos. 5712 and 5722). Tubes dark-adapted and cooled to —30°C for 1 day.**

High Voltage		*Counts per Minute*			*Calculated Coincidence Time in Seconds*
Tap	*Volts*	*Tube No.* 5712	*Tube No.* 5722	*Coincidence (5 min. counts)*	
6	1820	66,000	61,000	30.2	3.7×10^{-9}
5	1750	30,500	36,200	13.2	4.7×10^{-9}
4	1650	24,500	25,300	5.6	4.5×10^{-9}
3	1500	16,900	16,000	2.1	3.7×10^{-9}
2	1500	10,500	9,200	0.3	...
1	1420	4,900	2,700	0	...

and R_7 can be used as base-line discriminators. This is very useful in determining the shape of the pulse spectrum.

As the diode switches it can be regarded as a current generator driving a load. In this circuit the output pulse is about 300 mv with a rise time 3 to 4 ns. The width is determined by the inductance. The output signals were differentiated by C_2R_5 and C_4R_5 respectively. The diodes D_1 and D_2 determine the flow of information. The diodes are forward biased such that an output pulse from TD 1 cannot trigger TD 2 and vice versa. To take full advantage of the sharp rising tunnel diode pulse, fast diodes must be used; otherwise the rise time of the sum signal across R_5 will be determined by the coupling diodes rather than by the tunnel diodes. The dc bias at TD 3 largely determines the coincidence time. For this circuit a single pulse will produce about 8 mv at TD 3. Coinciding pulses produce about 15 mv. Thus if the bias is adjusted to accept only 15 mv pulses, full overlap is needed to produce an output.

In Table 1 the noise count rate and the chance coincidence count rate for two photomultipliers are listed. To determine the single rates one can either bypass TD 3 or adjust its bias until it triggers from singles. The calculated coincidence time (4 ns) agrees quite well with the value determined using artificial delay. In this test the signal from a suitable pulse generator is coupled to the two inputs using cables of different lengths. One determines the difference in length needed to reduce the count rate to near zero, and from the known propagation velocity of the cable the delay is calculated. Using the same photomultipliers, a counting arrangement was made by placing a small vial filled with scintillator solution between the tubes. The light collecting efficiency was poor but background and C^{14} spectra could be obtained. The counting efficiency for C^{14} was 40%.

In general, it is not possible to group the components around the photomultiplier base. Connecting cables must be used but then (Fig. 2) the cable becomes part of the tunnel diode load and a considerable part of the tunnel diode pulse appears across it. In newer circuits an *npn* high-speed transistor is used between each photomultiplier anode and tunnel diode. The transistor is operated in the common emitter configuration and biased sufficiently to accept most of the spectrum of pulses. For large pulses however, the transistor cuts off; this puts an upper limit on the pulse at the tunnel diode. The base-collector junction prevents the tunnel diode pulse from reaching the cable.

Figure 3 shows a triple coincidence circuit as used with the counter. Positive high voltage is applied to the photomultiplier structure so that the photocathode is at ground potential. This tends to reduce noise. In most applications the emitter resistor is not bypassed. Emitter feedback makes the circuit linear up to 0.8 v input. For soft beta emitters it is advantageous to bypass the emitter resistor. In the grounded emitter configuration the gain is increased about twofold, but input signals larger than 0.3 v overload the device.

The tunnel diode circuit forms the collector load impedance. It may be represented by a 10 ohm resistance shunted by a 10 pf capacitance. The time constant of the coupling network is so short that the response is limited essentially to the leading edge of the photomultiplier signal. The *RC* coupling networks between the input tunnel diodes and the coincidence tunnel diode replace the diodes used in Fig. 2. The input tunnel diodes produce pulses 10 ns wide with a height of 200 mv and rise time of 2 to 3 ns. The coupling network differentiates these pulses again with an attenuation of about 13:1. The crosstalk between two input tunnel diodes through the coincidence tunnel diode is attenuated more than 100:1. This represents the ultimate performance using coupling diodes; however, the resistive network simplifies the circuit and avoids increasing the rise time as discussed previously.

The coincidence tunnel diode may be biased such that it requires three completely overlapping inputs to produce an output. The resolving time is then about 2 ns. Alternative bias settings are discussed below. L_2 is chosen to produce pulses of the desired width (refer to anticoincidence circuit). The variable bias supply is a temperature stabilized emitter follower. The output impedance is constant at any setting of the bias. Thus the slope of the load line does not change. The arrangement is fully discussed elsewhere.[22] The same temperature stabilization scheme is used for the input transistors.

Block diagram

Coincidence units can be combined in a number of ways, two of which are shown in Fig. 4. In the integral discriminator mode (Fig. 4a) the A units are connected to the detector photomultipliers and the B inputs to the anticoincidence shield. The detector coincidence stage A and the two shield coincidence stages B_1 and B_2 are connected to the anticoincidence unit C. This unit produces an

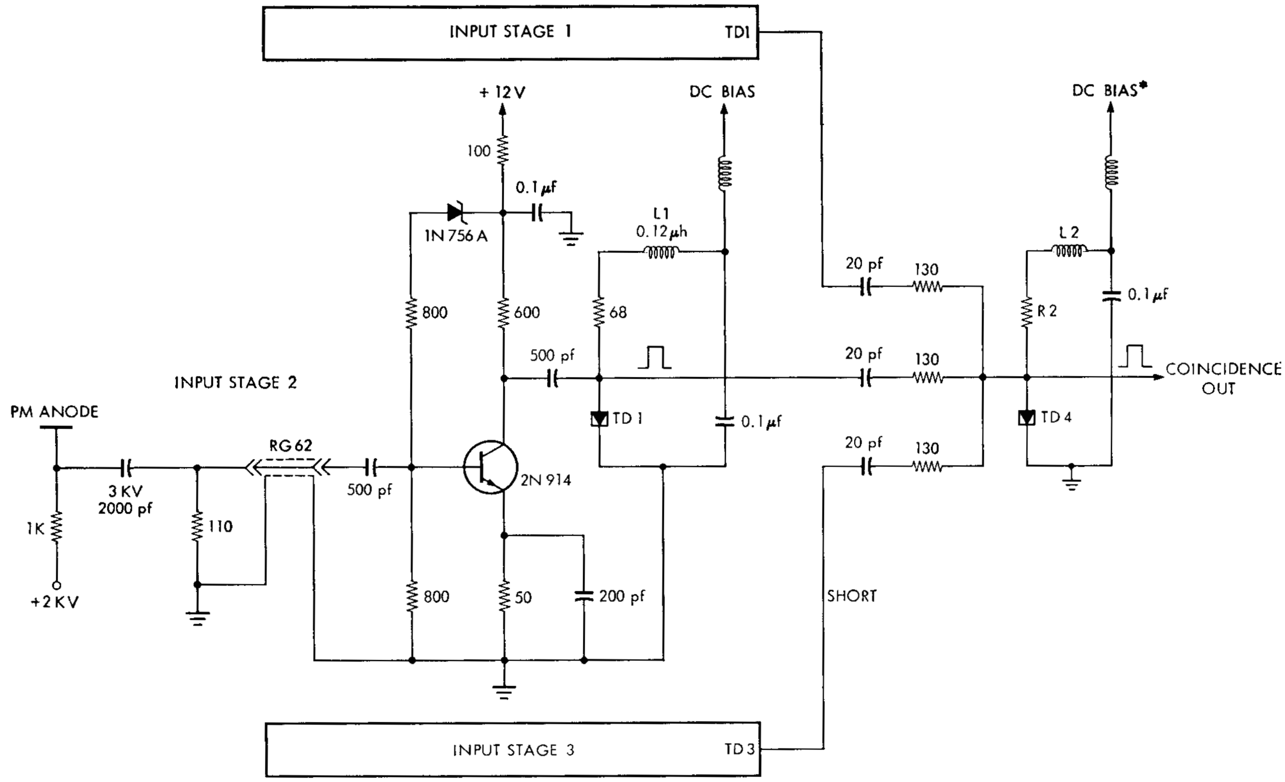
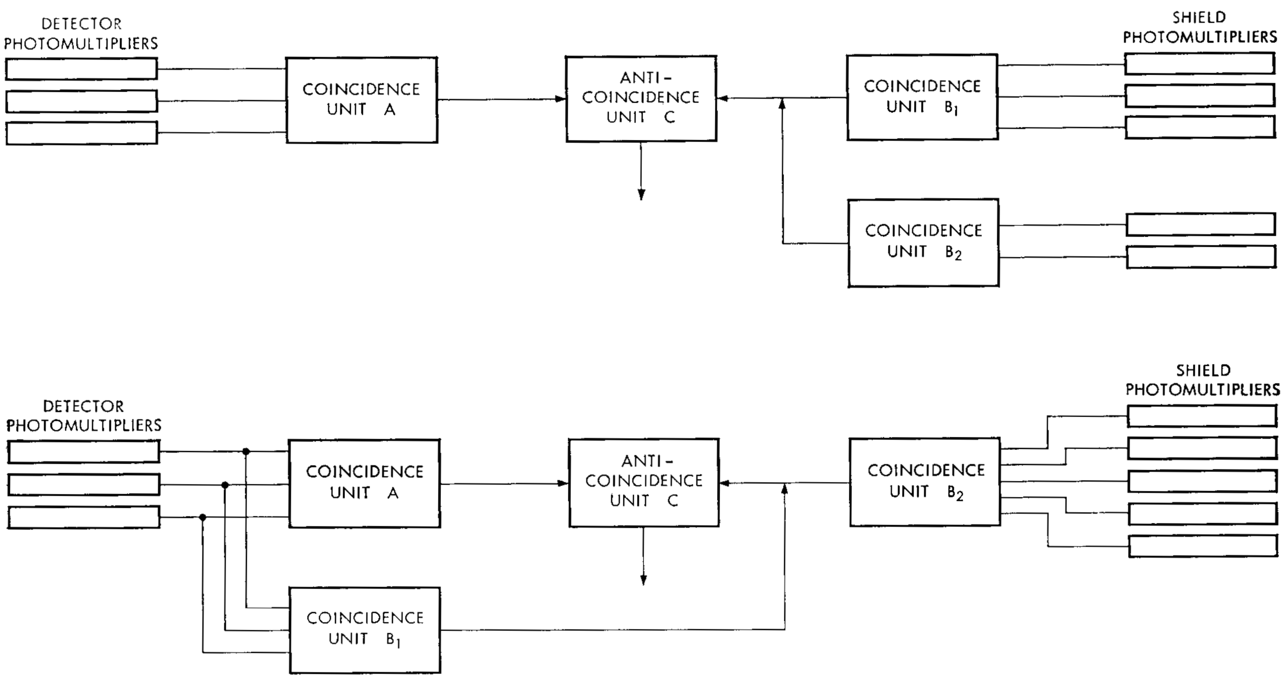


Figure 3 **Photomultiplier and pulse shaping circuit.** *Photomultiplier output pulse as measured on base of 2N914: $T_R = 10$ ns; $T_W = 10 - 20$ ns; height is variable. Tunnel diode output pulse at anode IN3128: $T_R = 2$ ns; $T_W = 10$ ns; height is about 200 mv. Three of these circuits are combined at the coincidence tunnel diode. Values of R_2L_2 selected for desired pulse width.*

Figure 4 **Block diagrams for two possible combinations.**
Top: Integral discriminator mode. Bottom: Differential discriminator mode.



output only from an A trigger if at that time there is no B_1 or B_2 signal. Thus an output is produced from detector signals larger than a predetermined value if there is no shield signal. In the differential discriminator mode, the A inputs and three of the B_1 inputs are connected to the inner detector photomultiplier (A_1 and B_1 to PM 1 etc.). The shield photomultipliers are summed at the input of the B_2 coincidence unit. The bias of the B_1 unit is adjusted so it triggers only from signals larger than A. Thus only pulses in the "window" between A and B are recorded, provided there is no shield signal at that time.

Anticoincidence circuit

The anticoincidence circuit must produce an output from a trigger at input 1 only if at that time input 2 is not triggered. The inputs must not be interchangeable.

The circuit logic is provided by T_2 and T_3 in Fig. 5. Amplifiers T_1 and T_4 isolate the preceding tunnel diode circuits. The output pulse of the detector coincidence tunnel diode is increased to 0.3 μs. This width is required by the scaler circuits following the anticoincidence network. The input network impedance of T_1 is high and its effect on the tunnel diode circuitry negligible. The T_1 collector output pulse is clipped to 0.6 v and delayed 0.3 μs.

T_4 is connected to the coincidence tunnel diodes in the B units. The tunnel diode pulses are increased to 1 μs. The output of T_4 is clipped to 1.5 v. In the absence of a pulse from T_4, the base of T_3 is held at −2.8 v by the bias network; the base of T_2 is at −2.6 v. Thus, emitter follower T_3 is on but T_2 is off. The 0.6 v pulse from T_1 is sufficient to turn on T_2, producing an output pulse 0.6 v high and 0.3 μs wide. A pulse from T_4 will increase the reverse bias of T_2 to about 1.5 v for the duration of this pulse. During this time the detector cannot turn on T_2. A pulse from T_4 merely clips T_2 further and will not produce an output. The delay line assures proper operation of the circuit. As an example, if an external radiation pulse is registered both in the shield and in the detector, the pulses at T_1 and T_4 coincide. The delay of the detector signal assures that T_2 will be in the cutoff region when the signal arrives.

Although the circuit is not extremely fast, it can be tolerated because the expected count rates are low. All transistors operate as switches and temperature compensation is not necessary. The remaining circuitry consists of scaler and timer decades and a control circuit.

Alternative circuits

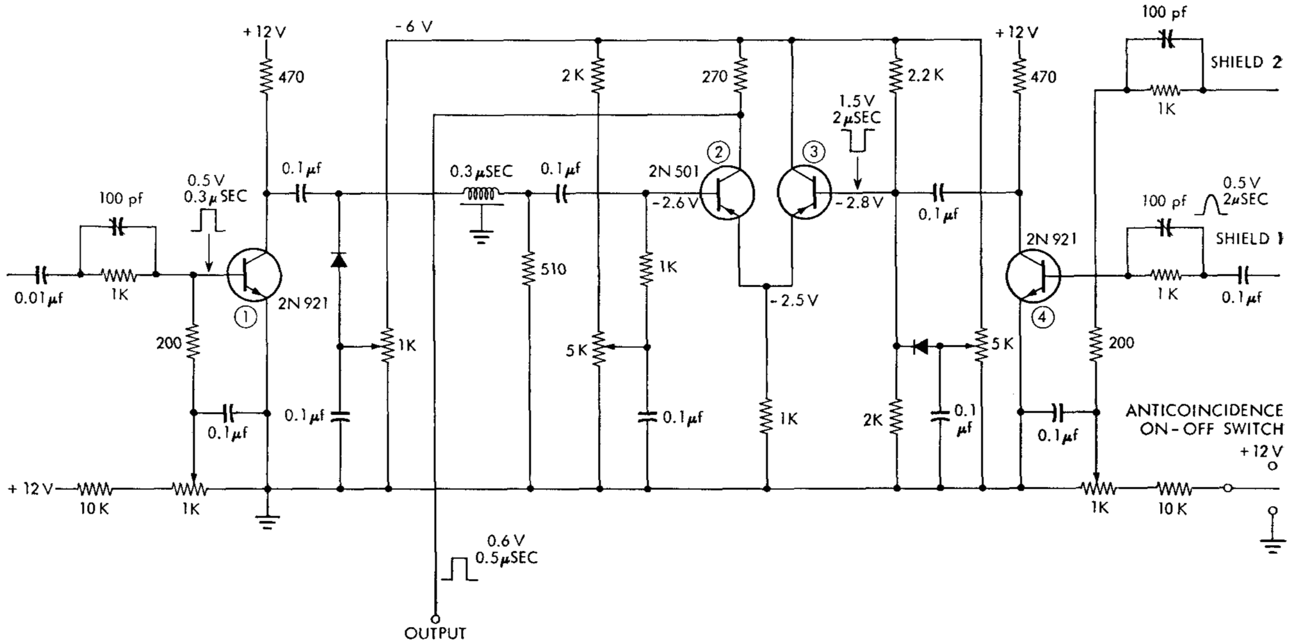
Coincidence units of shorter resolving time can be built easily. By replacing the IN 3128 devices used in Fig. 3 by the faster IN 3129 tunnel diodes and changing the dc load resistance to 15 Ω, coincidence times slightly less than 1 ns can be obtained. However, the counting efficiency of such arrangements is appreciably lower. The input sensitivity of the 3129 units is lower, but most of the decrease in counting efficiency is caused by the loss of true coincidences which happen to produce unequal photomultiplier pulses.

Pulse shapes

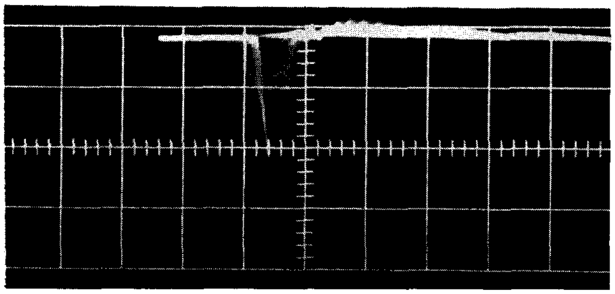
Figures 6-8 illustrate pulse shapes at key points in the system. A Tektronix 585 oscilloscope and a Tektronix 561 sampling scope were used. The rise time of the 585 oscilloscope (3 ns) is too slow for displaying tunnel diode pulses, but the 585 can be used to show other features.

The rise time of photomultiplier pulses, measured at the base of the input transistor is about 10 ns. Figures 6a and 6b show the envelope of all photomultiplier pulses

Figure 5 **Anticoincidence circuit.**



(a)



(b)

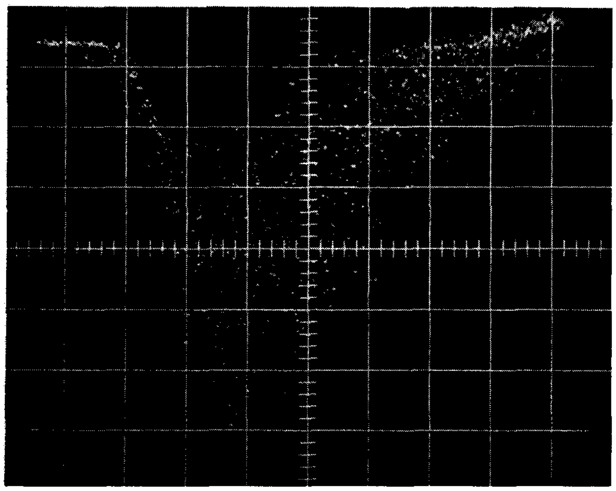


Figure 6 **EMI 6255S photomultiplier signal (tube No. 5637)**
a: Internally triggered; photomultiplier noise pulses only; 585 scope; 50 ns/div; 100 mv/div.
b: Trigger from coincidence tunnel diode. The sample is outside the inner detector. Envelope of all signal pulses exceeds bias setting. 561 scope; 10 ns/div; 20 mv/div; 10:1 cathode follower probe.

exceeding the bias setting of the input tunnel diodes (200 mv in this case). To construct a single pulse the trigger must be taken off at the anticoincidence output; the instrument is in the differential discriminator mode.

The rise time of tunnel diode pulses using a signal generator as pulse source is about 2 ns (Fig. 7a). The timing of the tunnel diodes can be checked as illustrated in Fig. 7b. Figure 7c shows the rise time of the tunnel diodes triggered from the photomultiplier signal; the rise time is about 3 ns in this single display. Notice in Fig. 7d the sharp leading edge while the trailing edge is diffused. The tunnel diode triggers abruptly, but the width of the pulse depends on the height of the triggering pulse if this trigger overdrives the diode. The height of the tunnel diode pulse is nearly constant. The transistors acts as a limiter for large input signals.

Figure 8 shows the coincidence tunnel diode output pulse for the detector and the shield unit. Figure 8c is included to show the timing of the anticoincidence unit. A fraction of the detector pulse appears at the common-emitter junction. The large pulse is the veto pulse.

Calibration

The dc bias of the coincidence tunnel diode may be adjusted to produce an output from single inputs. This feature can be used in obtaining the integral pulse height distribution of noise pulses from individual photo multipliers. In normal operation the dc bias is adjusted such that the noise count rate of three photomultipliers is essentially zero. It is difficult to measure very low count rates precisely. Counting times are long and accidental pulses may be introduced via the power line or by direct radiation. To eliminate power line disturbances, the unit was operated from storage batteries. Average noise count rate was below 1 count per hour and it is not certain that these counts represent three coinciding photomultiplier noise pulses.

Calibration curves are obtained by plotting input signal versus dc bias of the variable supply; a Tektronic 110 generator and a 585 scope were used. Figure 9 shows two calibration curves for a triple coincidence unit. In the grounded emitter configuration the input sensitivity is 40 mv, but beyond 250 mv the transistor cuts off. With the commonly used emitter feedback configuration, the input sensitivity is 120 mv, but the range extends to 0.8 v. For tritium the higher gain arrangement is preferred (see the following section).

The calibration as obtained with a signal generator and triple coincidence input is affected little by the dc bias setting of the coincidence tunnel diode. However the counting efficiency decreases markedly as the coincidence tunnel diode dc bias is decreased. The required overlap of the three inputs is greater and some true pulses are rejected. Because the purpose of the circuit is to eliminate photomultiplier noise, an optimum bias setting is found just below the level required to reduce coincidence noise to zero. If minimum resolving time is required the dc bias of the coincidence tunnel diode is adjusted just above the level needed to produce an output from three coinciding inputs. The resolving time is now about 2 ns. The background is lower but the counting efficiency is decreased. The difference between the two levels depends on the device, but is of the order of 5 to 10 mv.

Background and spectra

Figure 10 shows noise spectra for the detector photomultiplier tubes. Noise count rates of individual tubes can differ by as much as a factor of 5. A correlation was observed between noise count rate and sensitivity, noisier tubes being more sensitive. The number of tubes tested was small and the correlation may not hold in general. However if this assumption is valid, the usual selection criterion for photomultipliers should be changed. Tubes should be selected for high sensitivity rather than low noise. The coincidence circuit will eliminate the noise.

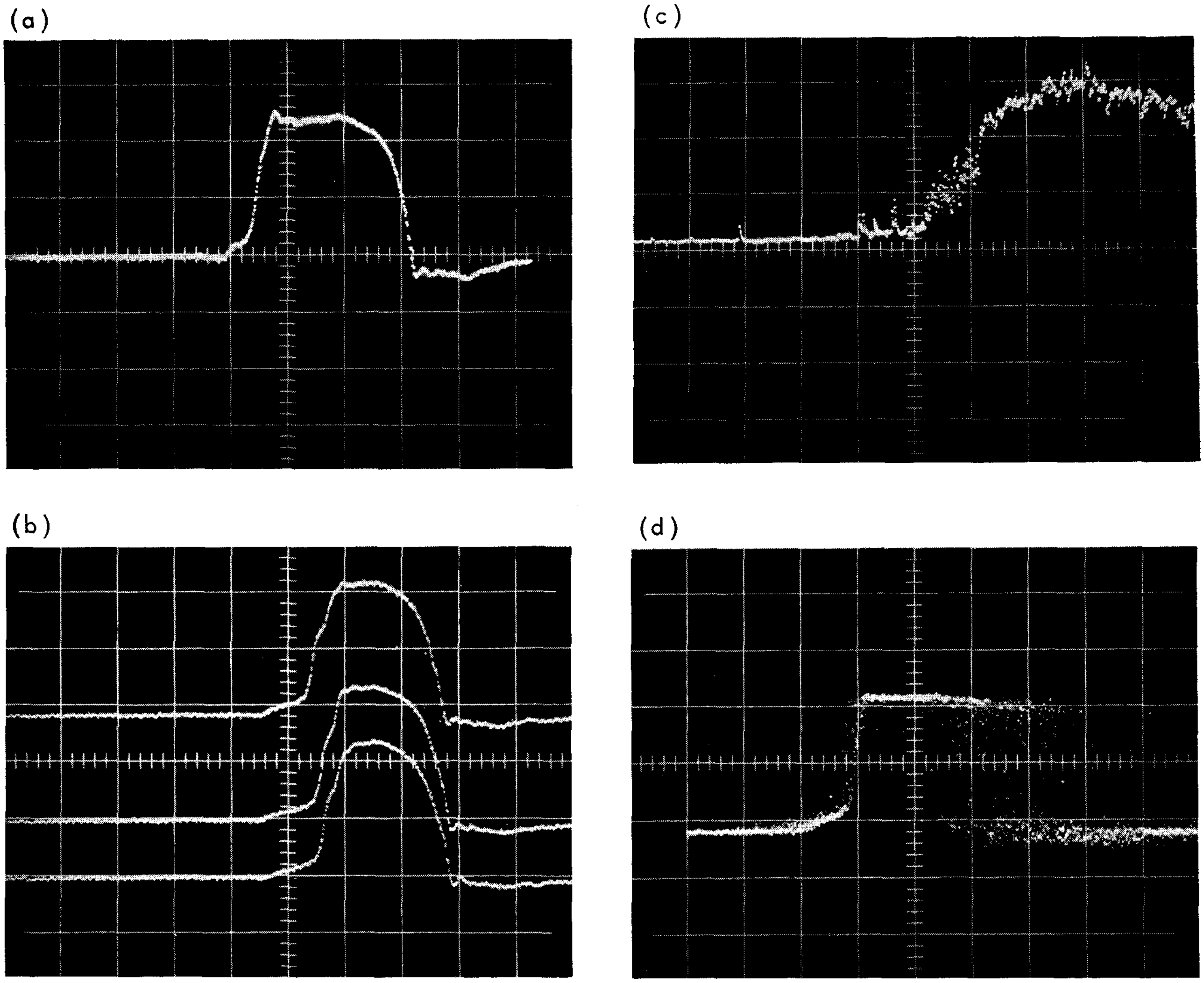


Figure 7 **Tunnel diode output pulses.**

a: Signal at tunnel diode No. 70. Trigger from tunnel diode No. 72 is passed through 500Ω resistor; measurements made using signal generator source. 5 ns/div; 20 mv/div; 10:1 cathode follower probe.

b: Trigger from coincidence tunnel diode; triple exposure; single display for each of the three input tunnel diodes. 5 ns/div; 20 mv/div; 10:1 cathode follower probe.

c: Internal trigger shows rise time of tunnel diode triggered from photomultiplier signal. 2 ns/div; 20 mv/div; 10:1 attenuator.

d: Trigger at coincidence tunnel diode. Tunnel diode pulse shows sharp leading edge and diffuse trailing edge. 10 ns/div; 20 mv/div; 10:1 cathode follower probe.

Figures 11a and 11c illustrate the background count rates for a 1 liter vial, a 500 ml vial and a 20 ml vial, the last type used with a light pipe. The upper level discriminator and the anti-coincidence shield were turned off and external shielding was not used. The graphs are reproduced here to indicate the shape of the background spectrum. The volume of the large container is nearly 50 times that of the small vial, but the background shows only a 6-fold increase.

Counting efficiences for C^{14}, SrY^{90} and H^3 are plotted in Fig. 12. 20 ml counting vials were used. Table 2 lists the observed counting efficiencies for the larger vials. To enable comparison of the data for hard beta emitters and for H^3, the input transistors were operated as grounded emitters in all cases. The SrY^{90} source can be regarded as a point source. The sample was evaporated on a glass surface and has 2π geometry. The counting efficiency decreases very slowly with signal height; most pulses are large and therefore the loss of light in a large vial does not change the counting efficiency. The C^{14} and H^3 samples are homogenous solutions. The counting efficiency of C^{14} in a small vial is quite high because most of the light can

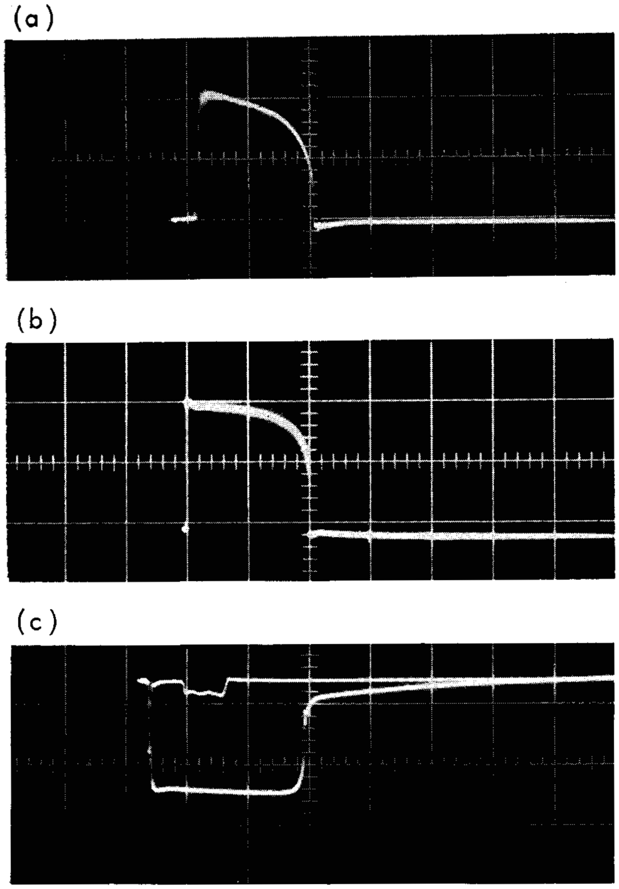
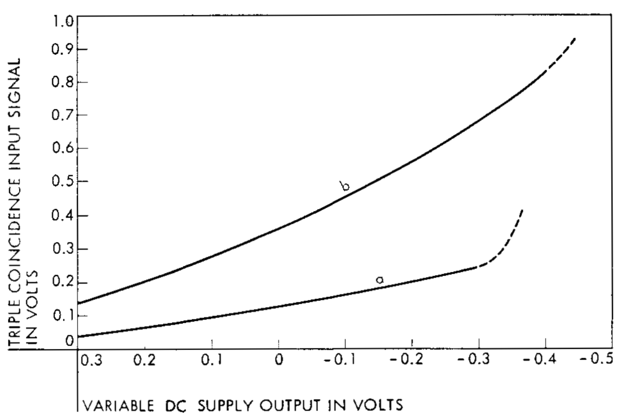


Figure 8 **Pulses from coincidence units.**
a: Detector coincidence tunnel diode output pulse. 0.2 μs/div; 200 mv/div.
b: Shield coincidence tunnel diode output pulse. μs/div; 200 mv/div.
c: Timing of anticoincidence unit. Trigger at collector of T_1 in Fig. 6. Signal at common emitters T_2, T_3. 0.5 μs/div; 1v/div.

Figure 9 **Calibration curves.**
a: Grounded emitter.
b: Emitter resistor not bypassed.



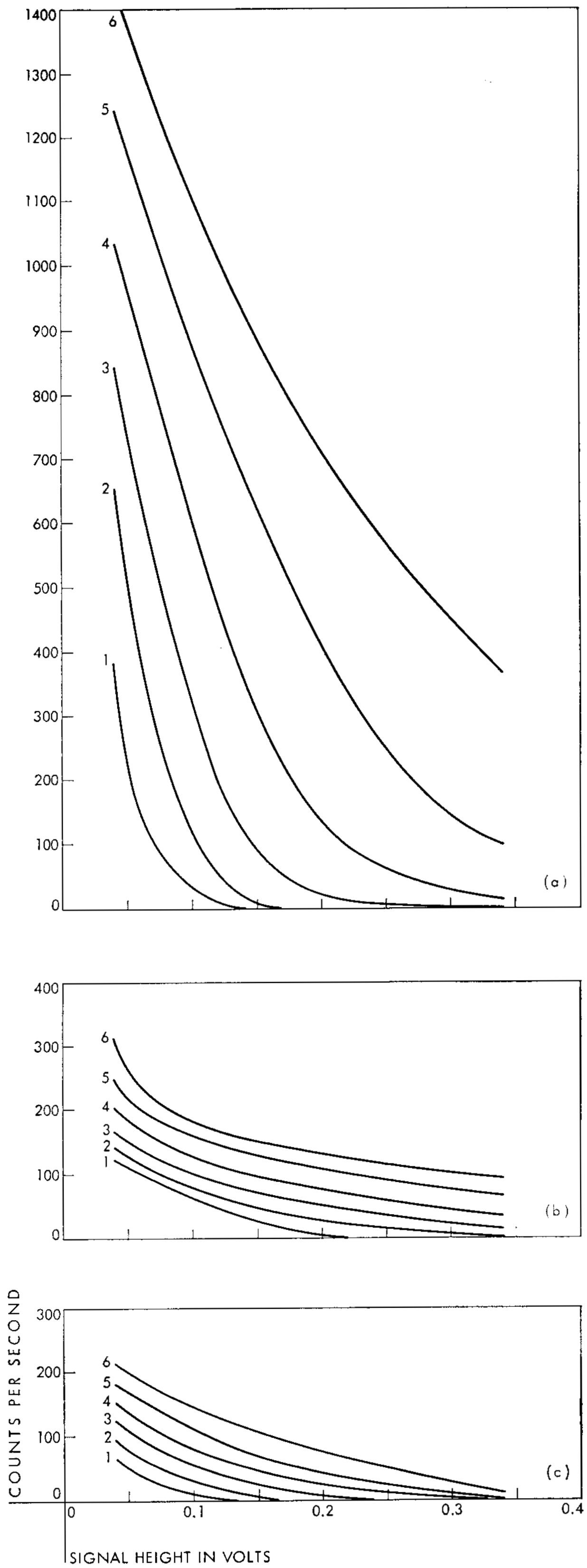


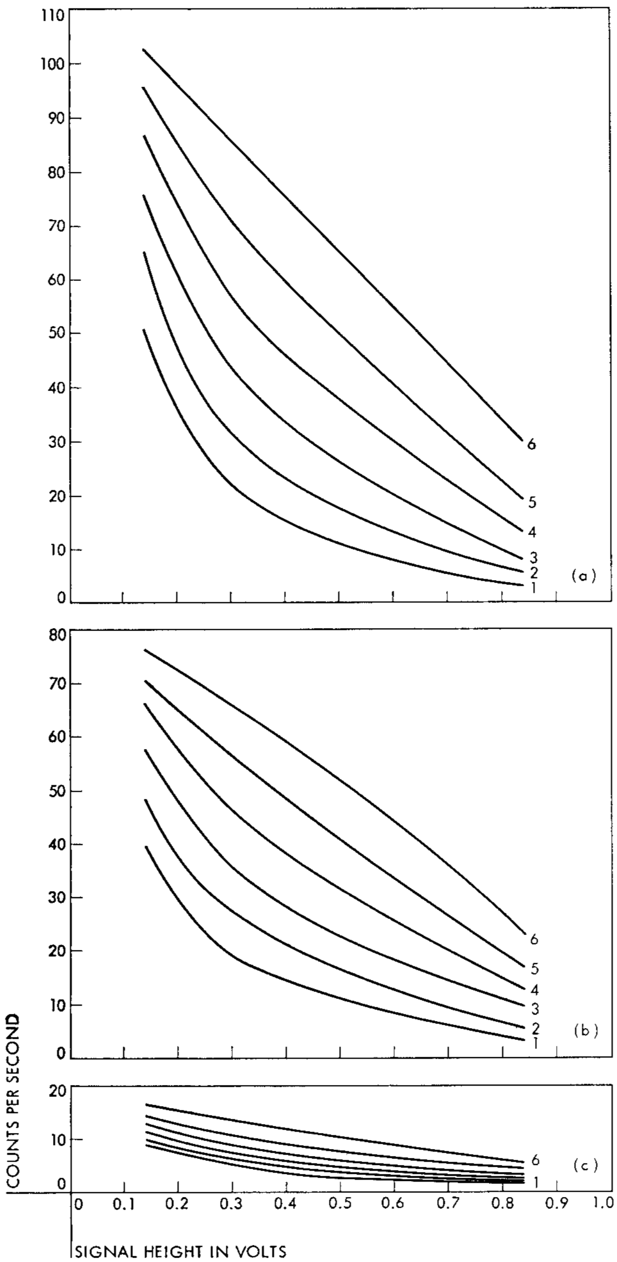
Figure 10 **Integral tube noise spectra for three EMI type 6255S photomultipliers.**

be collected. However, compared to SrY^{90} the number of large pulses is far smaller and therefore the loss of light in large containers causes a decrease in counting efficiency. For tritium the effect is even more pronounced. Figure 13 illustrates the effect of the anti-coincidence shield. The background at the low energy and (∽10 kev) is reduced by 35%.

Discussion

The simplification introduced by the use of tunnel diodes is apparent. Photomultiplier tube noise is eliminated with-

Figure 11 **Background count rates for 1 liter vial, 500 ml vial and 20 ml vial.**



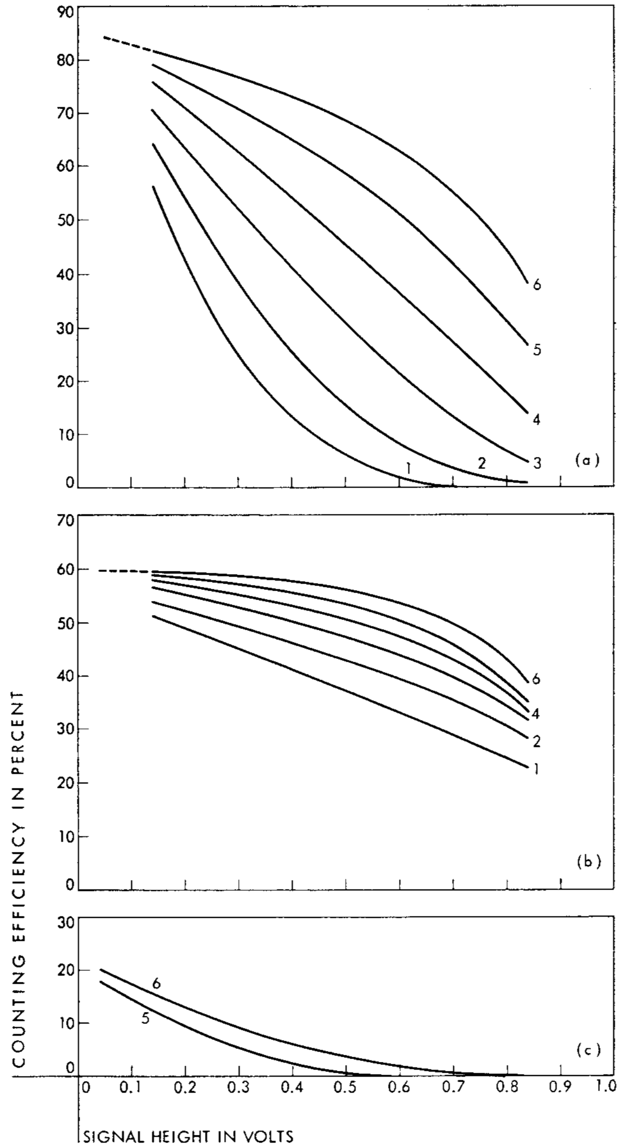


Figure 12 **Counting efficiency for C^{14} SrY^{90} and H^3.**
a: Benzoic acid — C^{14} solution.
b: 10 SrY^{90} Cl_2 evaporated in vial.
c: Tritiated toluene.

Table 2 **Counting efficiences for Sr^{90}, C^{14} and H^3 Transistor in grounded-emitter configuration. HV at 6. Bias: 300 mv.**

	20 *ml Vial*[1]	500 *ml Vial*	1l *Vial*
SrY^{90}	59%[2]	64% (Ref. 3)	58% (Ref. 3)
C^{14} (Ref. 4)	84%	36%	26%
H^3 (Ref. 5)	29%	1.4%	0.5%

[1] 20 ml vial used with light pipe.
[2] 10λ of a standard solution evaporated in 20 ml vial.
[3] 10λ of a standard solution evaporated on microscope slide sample suspended in geometrical center. 2π geometry.
[4] Benzoic acid C^{14} dissolved in scintillator.
[5] Tritiated toluene mixed with scintillator.

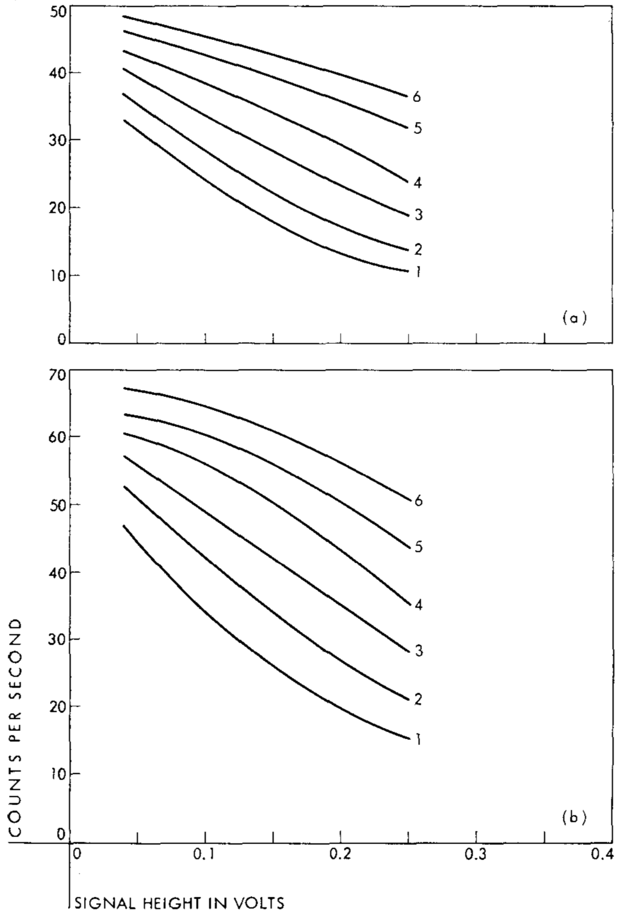


Figure 13 **Background 500 ml vial shows the effect of anticoincidence shield.**
a: Anticoincidence circuit on.
b: Anticoincidence circuit off.

out decreasing the input sensitivity. Although overloading does occur, pulse pile up is not noticeable because of the high speed of the circuit. The dynamic range of the discriminator is about a factor of 5, which is not always sufficient for a complete beta spectrum. A 10:1 constant impedance attenuation could be incorporated in the input circuit if an investigation of the high energy of the spectrum is desired. For routine counting, however, the attenuator would not be used. The gain of the circuit is sufficient, even for 150 kev C^{14}. For H^3 an increase in gain would probably increase the counting efficiency somewhat. Self absorption of the emitted light drastically reduces the counting efficiency for soft beta emitters in large containers. Thus improvements in the optical part of the system are needed more than an increase in gain of the electronic circuit. Schemes for increasing the light collecting efficiency have been proposed (Shurcliff,[24] Garwin[23]), but the practical problems in realizing such systems remain. The anticoincidence shield could be increased without adding much to the overall cost but again the light collecting problem should receive primary attention.

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