BETA-GATED GAMMA COINCIDENCE COUNTING

WITH A PHOSWICH DETECTOR

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SUMMARY

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A special type of phoswich detector system has been evaluated for measurement of radionuclides which decay with emission of time coincident beta and gamma radiation. Background reductions of more than two orders of magnitude have been obtained for the energy region from 500-950 keV. Both NE 102 plastic scintillators and anthracene were evaluated. Advantages and disadvantages of the method are discussed.

INTRODUCTION

A phoswich detector is basically a type of scintillation detector in which two different scintillation materials are viewed by a common photomultiplier tube¹. They have been applied as large surface area detectors for low-background measurement of beta radiation and low energy photons²⁻³. Pulses arising in the two scintillators can be distinguished provided that the inherent decay constants of the scintillators are significantly different, and pulse shape analysis circuitry is commercially available to do this⁴.

This approach works well for measuring beta radiation in the presence of a gamma ray background by use of a thin europium-activated CaF₂

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crystal (decay constant 0.9 usec) coupled to a much thicker thallium activated NaI crystal (decay constant 0.23 usec). However, with this type of detector it is not possible to do beta-gated gamma coincidence counting. This is because the amplitudes of pulses from the $\text{CaF}_2(\text{Eu})$ scintillator due to beta events are much smaller than those from the NaI(Tl) scintillator due to gamma events. Two factors are responsible for this. First, the intrinsic light output of $\text{CaF}_2(\text{Eu})$ is only half that of NaI(Tl)⁵, and second the $\text{CaF}_2(\text{Eu})$ detector is too thin to absorb all of the energy from the beta radiation in most cases. Consequently, if a beta and gamma event occur simultaneously, the shape of the output pulse from the photomultiplier tube will be about the same whether or not the beta event is detected. Therefore conventional rise time discrimination circuitry cannot distinguish a beta-gamma coincidence event from a gamma event alone.

A special type of phoswich detector has been fabricated which does permit distinguishing beta-gamma events from gamma only events. Such a detector has not been commercially available for this purpose to date, and its evaluation will be discussed in this paper.

THE DETECTOR

The gamma detector consists of a hermetically sealed 7.62 cm diameter, 7.62 cm thick NaI(Tl) detector with a window of quartz 3.2 mm thick on the front face and an integral RCA8575 photomultiplier tube. The second scintillator consists of either a thin disk of plastic scintillator or

a thin disk of anthracene, coupled to the quartz window with optical coupling grease (Dow Corning type Q2-3067). Silicone stopcock grease (Dow Corning) is also satisfactory. The detector assembly is shown in Figure 1.

The sample to be counted may either be placed on top of the second scintillator or sandwiched between two pieces of it. A light-tight cap is then placed over the assembly. The detector is surrounded with 10-cm of lead, and a heavy black cloth is placed over the lead cave as an added precaution to prevent stray light from reaching the photomultiplier tube.

ELECTRONICS

A block diagram of the system is shown in figure 2. The circuitry to detect fast pulses from the anthracene or plastic scintillator consists of a simple "T" in the coaxial cable between the anode of the photomultiplier tube and a fast discriminator (Ortec Model 463, 100 MHz), to which a grounded piece of coaxial cable (RG58A) is added. The shorted cable causes an inverted and slightly delayed signal to be added to the original signal. If the signal contains a component with a short decay constant the fast discriminator will be triggered. The discriminator output opens a linear gate (Canberra Model 1451) allowing the amplified dynode signal to proceed to an ADC (Nuclear Data Model 570) for pulse height analysis. If it is desired to monitor the ungated signals simultaneously, as shown in figure 2, the dynode signal from the preamplifier can be split, with one half being amplified and sent to the linear gate, and the other half amplified and sent directly to another ADC, bypassing the linear gate. Use of the second amplifier can be

avoided if the signal is split at the input to the linear gate instead of after the preamplifier. This was not done however because the pulse height at the linear gate output is reduced somewhat relative to its value at the input, and thus the energy calibration for the two ADCs would not be the same.

The spectra were acquired by means of an 8 ADC-input Nuclear Data ND6603 data acquisition system. After acquisition, the spectra were transferred via an RS232 data line to a PDP 11/05 computer system, from which hard copy plots and listings of each spectrum were obtained.

MEASUREMENTS AND RESULTS

Spectra were taken of point sources of ^{137}Cs and ^{134}Cs with the linear gate off, and then with the gate on and at discriminator helipot settings from 0.5 to 4.0, corresponding to anode signal levels of -50 to -400 mV. Figure 3 shows curves of efficiency vs discriminator level for the case of a scintillator "sandwich" composed of two 1.27 cm diam x 0.16 cm thick scintillators of NE102 which were fused together at the edges with a soldering iron. An aliquot of radioactive solution was placed at the center of one scintillator and evaporated to dryness; then the second scintillator was placed on top. Almost all (94.6%) decay events from ^{137}Cs lead to formation of metastable $^{137\text{m}}\text{Ba}$, which decays with a 2.55 minute half-life to stable ^{137}Ba . The other 5.4% of the decay events go directly to the ground state of ^{137}Ba . Thus for ^{137}Cs no time coincident beta-gamma decay events occur. The counting efficiency curve of figure 3 for ^{137}Cs is thus a measure of how well the circuit discriminates against non-coincident decay events, with lower efficiency indicating better

performance. The curve for ^{134}Cs gives an idea of the performance of the system for a typical beta-gamma emitter. The optimum discriminator level appears to be about -250 mV for the case shown in figure 3.

The effect of scintillator area vs background counting rate was studied by counting two scintillators which were each 0.16 cm thick and with diameters of 1.27, 1.90, 5.08 and 7.62 cm. The two scintillators were fused together, and white tape was placed on one side. The discriminator level was fixed at -200 mV and a shorted piece of RG58A cable 91 cm long was used as the delay line. Counting intervals were 1000 minutes. The results are shown in figure 4.

The effect of discriminator level on background counting rate is shown in figure 5. A disk of NE102 plastic scintillator 1.27 cm in diameter and 3.2 mm thick was used, and 1000 minute counts were taken with the gate off, and with the discriminator at -100, -200 and -300 mV. A 91 cm delay line was again used.

Similar studies were also made in which anthracene crystals 1.6 mm thick and 1.27 cm in diameter were used. For this case a delay line 9.14 m long was used. The delay line length was chosen such that the signal would be delayed about twice as long as the time constant of the scintillator, which for anthracene is 30 nsec⁶. Curves of counting efficiency vs discriminator level for ^{137}Cs and ^{134}Cs with use of anthracene as the second scintillator are shown in figure 5. In figure 6, gated and ungated background spectra are shown for the case of anthracene, with the discriminator at -250 mV.

DISCUSSION

As can be seen from figures 4 and 7, a large reduction in background counting rate is obtainable by use of this gating method in the energy region below 1000 keV. From figure 5 it is also apparent that the amount of background reduction achieved is very dependent upon the setting of the discriminator. Optimum discriminator values correspond to signals from the detector anode of -200 to -250 mV. Discriminator values corresponding to larger (more negative) signals lead to a reduced counting efficiency for beta-gamma events, and the benefits of a further reduced background are more than offset by the greater loss in efficiency.

For the case of anthracene, with a point source of ^{134}Cs and a discriminator value corresponding to -250 mV, the background in the region from 500 to 950 keV is reduced from 61.3 ± 0.2 cpm in the ungated mode to 0.54 ± 0.02 cpm in the gated mode, a factor of 114. The counting efficiency for ^{134}Cs is reduced from 23 percent to 5.9 percent, a factor of 3.9. If we assume that a "figure of merit" for this detector can be related to $E/B^{1/2}$ where E is the counting efficiency and B the background counting rate, then a factor of 2.7 improvement is obtainable by gating. For the case of the plastic scintillator NE 102, and for a discriminator value corresponding to -200 mV, the background is reduced from 61.3 ± 0.2 cpm to 0.105 ± 0.010 cpm and the efficiency from 23 percent to 3.1 percent. The benefit obtained from gating in this case is a factor of 3.3.

As can be seen from figure 4, if the discriminator level is fixed, then the gated background above a certain energy does not vary with the diameter of the second scintillator. This is because large signals from the NaI(Tl) detector cause the linear gate to open. At the low energy end of the gated

spectrum on the other hand the counting rate increases as the diameter of the second scintillator is increased. These events are due either to pulses arising only in the second scintillator or in both scintillators. This means that beta events not in coincidence with gamma events may also be included in the gated spectrum. Whether or not this occurs depends on the amount of energy deposited in the second scintillator and on the discriminator level.

Due to light from the second scintillator adding to that generated in the NaI(Tl) detector, the ungated spectrum at low energies contains more counts than are obtained if the second scintillator is not present. This effect is more pronounced for the case of anthracene because of its greater light output relative to NE102.

CONCLUSIONS

Advantages of this method for beta-gated coincidence counting include:

1) the background may be reduced by more than two orders of magnitude for gamma energies below 1 MeV 2) the approach is relatively inexpensive 3) only a few standard electronic modules are required and 4) conventional ungated spectra may be acquired simultaneously. Disadvantages include:

1) the counting efficiency for beta-gated events is low 2) counting events due to non-coincident beta pulses of sufficient amplitude are included in the gated spectrum 3) non-coincident gamma events above a certain energy are always included in the gated spectrum 4) complete discrimination against non-coincident gamma events of any energy is not obtained and 5) the low energy

part of the ungated spectrum includes counts due to the second scintillator as well as NaI(Tl).

ACKNOWLEDGMENTS

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Figure 2.

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Fig. 3

FIG. 4

FIG 5

SCINTILLATOR ANTHRACENE
 SIZE 12.7 mm dia x 3.2 mm
 DELAY LINE 914 cm

FIG. 7

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