EXPERIMENT 9

Time Coincidence Techniques and Absolute Activity Measurements

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EQUIPMENT NEEDED FROM EG&G ORTEC

- ^{60}Co Radioactive Source, 1 to 5 μCi (beta source)
- Two Bins and Power Supplies
- Two 113 Scintillation Preamplifiers
- 142A Preamplifier
- A-015-025-1500 Surface Barrier Detector
- 266 Photomultiplier Tube Base
- Two 551 Timing Single-Channel Analyzers
- 425A Nanosecond Delay
- 428 Detector Bias Supply
- 567 Time-to-Amplitude Converter and SCA
- 556 High Voltage Power Supply
- 480 Pulser
- 418A Universal Coincidence
- Three 875 Counters
- Two 575A Amplifiers
- 719 Timer
- 305 Vacuum Chamber
- 905-3 NaI(Tl) Detector and Photomultiplier
- ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
- Vertical Phototube Stand MPM-9
- Oscilloscope
- Mechanical Vacuum Pump
- Source Kit SK-1G
- ORC-9 Cable Set

Purpose

This experiment will utilize some of the basic instrument configurations for time coincidence studies, including time spectroscopy. It includes a short discussion of typical decay schemes because these include sources of coincident events on which measurements can be made.

Introduction

Time coincidence counting is defined as a method for detecting and identifying radioactive materials and for calibrating their disintegration rates. The absolute activity measurement can be made by counting two or more characteristic radiation events, such as beta and gamma, that occur either together or within a specified time relationship to each other. The isotope that is used in this experiment is ^{60}Co.

Many beta and gamma sources that are used in nuclear training laboratories are produced with nuclear reactors. Typically, a certain stable isotope is placed in the reactor core for a specified time period. The neutron flux in the reactor core could be as much as 10^{14} neutrons per cm^2 per second. This means that 10^{14} thermal neutrons bombard each cm^2 of the sample per second. As a result of the bombardment the sample becomes radioactive.

At thermal neutron energies the most probable neutron reaction is the so-called (n,γ) reaction. A simplified explanation of this reaction is that a neutron from the reactor collides with one of the stable nuclei in the sample and in so doing is absorbed into the nucleus, causing a new nucleus to be formed. The new nucleus is most probably unstable and will get rid of this excess energy by emitting a radioactive particle. For (n,γ) neutron activation the excited nucleus is neutron-rich and the most probable decay mode for a neutron-rich isotope is beta decay. The beta decay is usually followed by gamma emission. In order to see this, consider the simple decay scheme shown in Fig. 9.1.

This decay scheme is really quite simple to understand. It was pointed out earlier that in a decay scheme the energy of excitation of a nucleus is plotted in the vertical direction. The possible energy levels available in the decay are shown as horizontal lines in the figure. We have drawn the lines to the right in Fig. 9.1 to point out the significance of these levels. X_1 decays by beta emission to Y_1. There are two possible modes to this decay, which in the figure are labeled β_0 and β_1. In other words, the excited X_1 nucleus has two possible routes to become de-excited.

In the diagram, C is the zero energy of Y_1. This zero energy is called the ground state of Y_1. Another possible state of Y_1 is the 0.570-MeV state, labeled B in the diagram. The second decay mode for X_1 consists of the emission of a beta particle, β_1, followed promptly by a gamma. Prompt means that the lifetime of the state is very short. These lifetimes usually range from 10^{-8} to 10^{-21} s. The gamma energy is exactly the same as the first excited state of Y_1. In the diagram, it is seen that this energy is 0.570 MeV. In other words, for this decay mode β_1 is emitted to the first excited state of Y_1, which immediately decays to the ground state of Y_1. If the beta spectrum from X_1 is studied as in Experiment 6, the two betas will be observed. However, a (β,γ) coincidence experiment

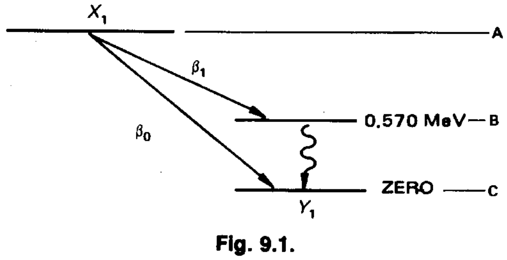

Fig. 9.1.

will quickly show that only β_1 is in coincidence with the 0.570-MeV gamma. This technique will be used later in the experiment to determine the absolute activity of a sample.

(α,γ) Coincidence

In order to understand (α,γ) coincidence, a simple example will be used. Let us assume that we have an alpha source (A) that decays by alpha emission to a stable isotope (B) with the scheme in Fig. 9.2. From the decay scheme it can be seen that 50% of the time (A) goes directly to the ground state of (B) with the emission of an alpha, (α_0), whose 5.5-MeV energy is the difference between (A) and (B). The other 50% of the time, decay is by an (α,γ) branch, which is similar to the (β,γ) branch in the previous example. The decay is by a 5-MeV alpha (α_1) followed immediately by a 0.50-MeV gamma. Thus the α_1 and γ_1 are in coincidence. For this example, every α_1 is followed by a γ_1. Figure 9.3 shows the alpha and gamma spectra for the source as they would have been measured in the previous experiments.

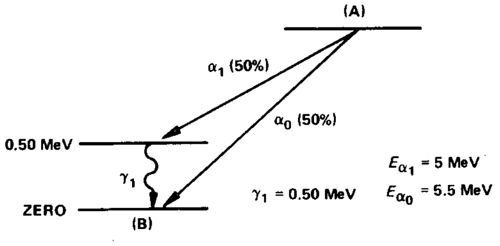

Fig. 9.2.

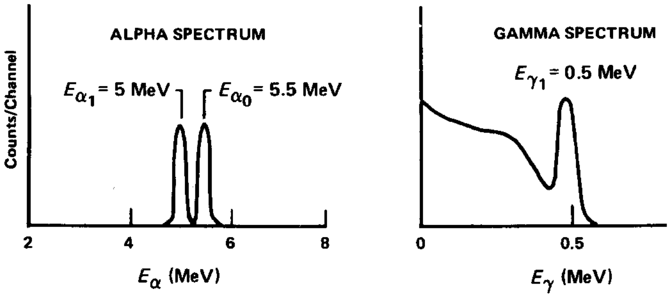

Fig. 9.3.

If the electronics are set up with a surface barrier detector to look at the alphas and with an NaI(Tl) detector to look at the gammas, it will be observed that there are no gammas in coincidence with α_0.

(γ,γ) Coincidence

In all the examples we have shown thus far in this experiment, gamma decay occurs directly to the ground state of the final stable nucleus. It is possible for a nucleus to de-excite with the emission of several gammas. In order to understand this, let us consider the simple decay scheme shown in Fig. 9.4.

In Fig. 9.4 the nucleus (C) decays to the nucleus (D) by beta emission followed by gamma decay. A simple way to look at the decay is as follows: the beta emission of (C) results in the nucleus (D), which is left with an excess energy of excitation of 1.0 MeV. The excited (D) nucleus gives off its energy of excitation by the emission of, first, γ_1, which has an energy of 0.4 MeV, and then promptly by the emission of γ_2, which has an energy of 0.6 MeV. In other words, for every γ_1 we also have a γ_2. For this simple example the gamma spectrum of isotope (C) is shown in Fig. 9.5. Of course, as we pointed out earlier, there would also be a coincidence between the beta particle and either of the gammas. Sometimes an isotope will branch directly to the ground state without going through the intermediate states.

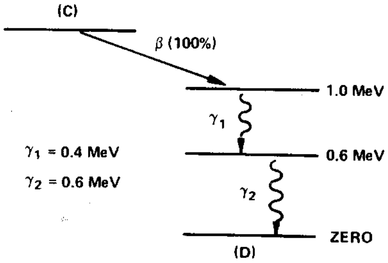

Fig. 9.4.

If this happened in the above example, a gamma of energy 1 MeV would also be seen in the spectrum. These probabilities of gamma decay from a given state to the ground state (stable state) through the intermediate states are called gamma-ray branching ratios.

In later experiments (γ,γ) and (α,γ) coincidence measurements will be made. In this experiment several possible electronic configurations will be considered for coincidence measurements, and a (β,γ) coincidence setup will be used to determine the absolute activity of a sample.

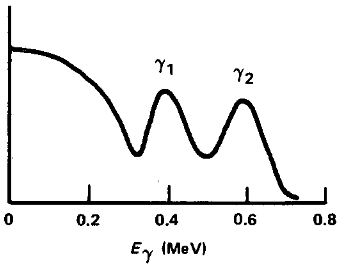

Fig. 9.5.

EXPERIMENT 9.1

Simple Fast Coincidence

In the circuit of Fig. 9.6, make the following module settings:

113 Preamplifiers: 0 pF Input Capacitance.

575A Amplifiers: Negative Input, Bipolar Output.

551 Timing Single-Channel Analyzers: Integral mode, Lower Level = 50/1000, Delay 0.5 μs; adjust walk (see manual).

418A Universal Coincidence: Inputs A and B Coinc; C, D, and E Off; Coincidence Requirements 2; Resolving Time maximum, 2 μs.

480 Pulser: Negative Output, Power On, Attenuated Output ~0.5 V (measured with an oscilloscope).

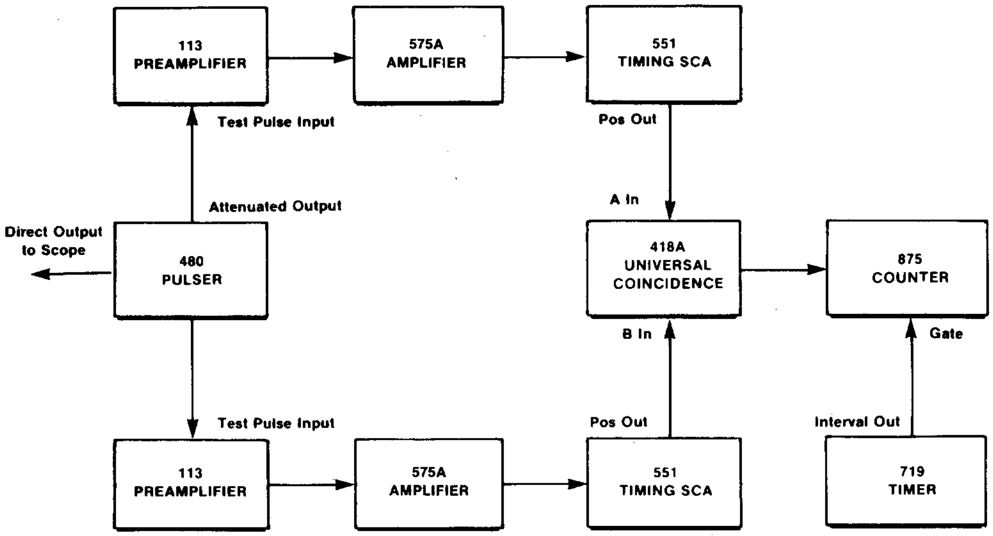

Fig. 9.6. Electronics Interconnections for Experiment 9.1.

Procedure

1. Adjust the gain of each 575A Amplifier so that the output pulse is ~5 V.

2. Set the 719 Timer for a long time (100 s). Vary the delay on either 551 until the maximum counting rate is observed on the 875 Counter. The two branches are now approximately coincident.

3. Clear the counter. Set the timer for 10 s and count. If the maximum counting rate was set properly in step **2**, the counter should read ~600 (60 Hz for 10 s). Change the delay in either 551 by 10 ns (10 dial divisions) and repeat the 10-s count.

EXERCISES

a. Continue changing the delay for enough readings to plot a time coincidence curve similar to that shown in Fig. 9.7.

b. Narrow the resolving time of the 418A to 1 μs and plot the coincidence curve which is similar to Fig. 9.7 (note: take readings every 100 ns).

c. Narrow the resolving time of the 418A to 100 ns and measure the coincidence curve (take readings every 10 ns).

The student should now begin to understand the concept of simple fast time coincidence spectroscopy.

EXPERIMENT 9.2

Fast Coincidence and the Time-to-Amplitude Converter

The 567 Time-to-Amplitude Converter (TAC) can also be used when fast coincidence requirements are needed in an experiment. The TAC basically is a module that gives an output pulse whose amplitude is proportional to the time difference (Δt) between the start and stop input pulses to the converter. It is, therefore, an electronic clock that can be used to measure time differences that are very short (~10 x 10^{-12}s). The TAC will not only indicate that two events are in coincidence but will also tell how the coincidence events are distributed with respect to time. The purpose of this experiment is to study some of the properties of the TAC.

In the circuit of Fig. 9.8, make the following module settings:

113 Preamplifiers: 0 pF Input Capacitance.
575A Amplifiers: Negative Input, Bipolar Output.
551 Timing Single-Channel analyzer on Start Side: Integral mode, Lower Level = 50/1000, Delay 100 ns; adjust walk (see manual).
551 Timing Single-Channel Analyzer on Start Side: Integral mode, Lower Level = 50/1000, Delay 100 ns; adjust walk (see manual).
480 Pulser: Negative Output, Power On, Attenuated Output ~0.5 V (measured with an oscilloscope).
567 Time-to-Amplitude Converter: 0.2 μs; single-channel controls not used.
425A Delay: 32 ns In, all others Out.

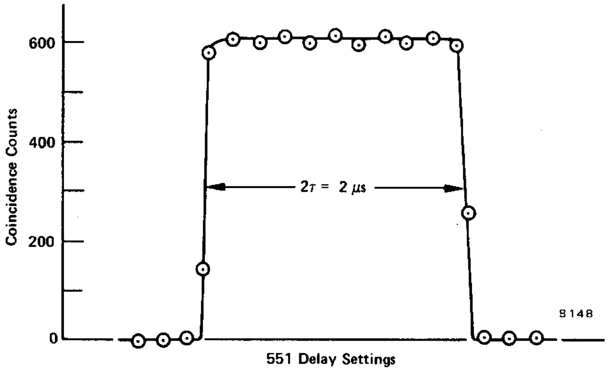

Fig. 9.7. Typical Time Coincidence Curve.

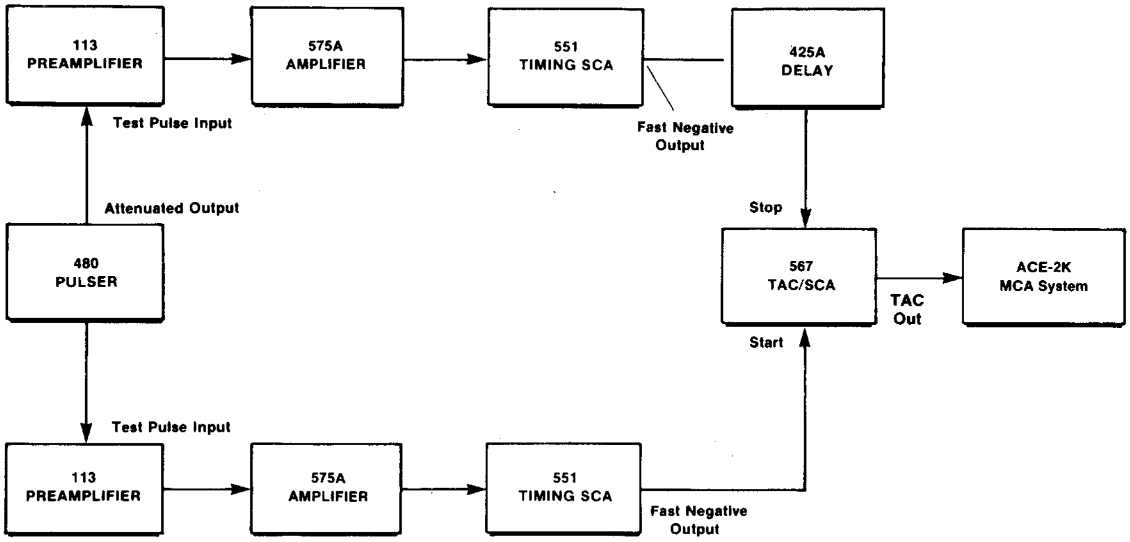

Fig. 9.8. Electronics Interconnections for Experiment 9.2.

Procedure

1. Adjust the gain of each 575A Amplifier so that its Bipolar Output has an amplitude of ~5 V.

2. Accumulate a spectrum in the analyzer. A single isolated group of signals should be observed above midscale on the analyzer display.

3. Set the 1, 2, 4, 8, and 16 ns switches of the 425A Delay unit all at In. This should move the position where signals are being accumulated in the analyzer display, and they should accumulate in the upper quarter of the display. Record the channel number of the peak.

4. Switch the 16-ns switch to Out and observe the movement of the peak in the analyzer. Record the new peak position.

5. Set all the switches in the 425A Delay module at Out, for 0 delay. Record the channel number of the peak in Table 9.1.

Table 9.1

Stop Signal Delay (ns)	Peak Location (Channel No.)	Stop Signal Delay (ns)	Peak Location (Channel No.)
0		35	
5		40	
10		45	
15		50	
20		55	
25		60	
30		65	

EXERCISES

a. Use the 425A Delay module to increase the Stop signal delay in 5-ns steps and fill in the peak location channel numbers in Table 9.1.

b. Plot the data from Table 9.1 on linear graph paper. The plot should be similar to that in Fig. 9.9.

c. Determine the slope of your calibration curve.

d. Determine the time resolution for your system. This is defined as δT in the formula

$$\delta T = (\mathrm{FWHM})\frac{\delta D}{\delta\,\mathrm{ch}}, \qquad (1)$$

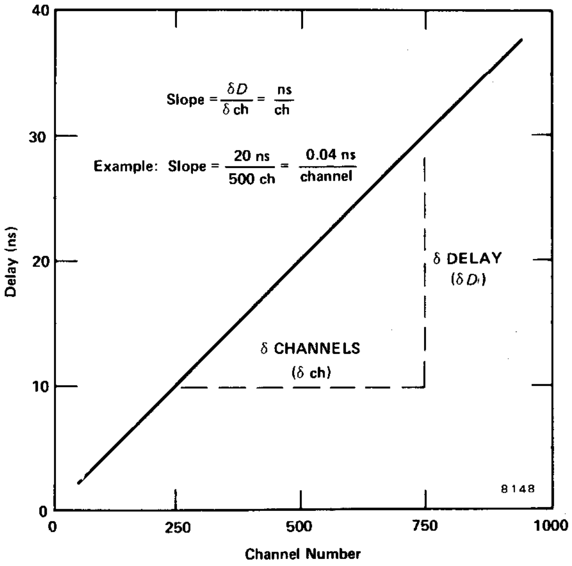

Fig. 9.9. Typical Delay vs Pulse-Height Curve.

where the (FWHM) factor is the number of channels across the half-height of the spectrum as defined earlier.

6. Switch the 567 TAC range to 400 ns. The TAC now has a full-scale output range that corresponds to 0–0.4 μs. Change the Delay on the Start 551 to 0.1 μs. Adjust the Delay in the Stop 551 until the TAC output is being stored in the upper quarter of the analyzer. Record the position of the peak.

7. Decrease the Delay in the Stop 551 by 100 ns (100 dial divisions). Record the new location of the peak.

EXERCISE

e. Continue to change the values of Delay in the Stop 551 and record the resulting channel locations. Use enough settings to establish a delay vs pulse-height curve for this new range of the TAC and calculate its measured resolution.

EXPERIMENT 9.3

Determination of Absolute Activity by the Coincidence Method

Introduction

Some of the coincidence techniques that were outlined above will now be used to determine the absolute activity of a ^{60}Co sample. The method consists of counting in the following order:

1. the gamma spectrum for the sample as in Experiment 3,
2. the beta spectrum as in Experiment 6,
3. the (β,γ) coincidence for the sample.

From step **1** the gamma counting rate, R_γ, is determined:

$$R_\gamma = A_0 \epsilon_\gamma \,, \tag{2}$$

where A_0 is the true disintegration rate of the sample and ϵ_γ is the efficiency of the NaI(Tl) detector.

From step **2** the same information is determined for the betas:

$$R_\beta = A_0 \epsilon_\beta , \tag{3}$$

where ϵ_β is the efficiency of the beta detector.

The coincidence counting rate measured in step **3** would be

$$R_c = A_0 \epsilon_\gamma \epsilon_\beta \,. \tag{4}$$

From Eqs. (2), (3), and (4) A_0 is given by

$$A_0 = \frac{R_\gamma R_\beta}{R_c} \,. \tag{5}$$

The purpose of the experiment is to determine A_0 for the ^{60}Co sample.

In the circuit of Fig. 9.10, make the following settings on the modules:

113 Preamplifier: 0 pF Input Capacitance.
575A Amplifier (from 113): Negative Input, Bipolar Output.

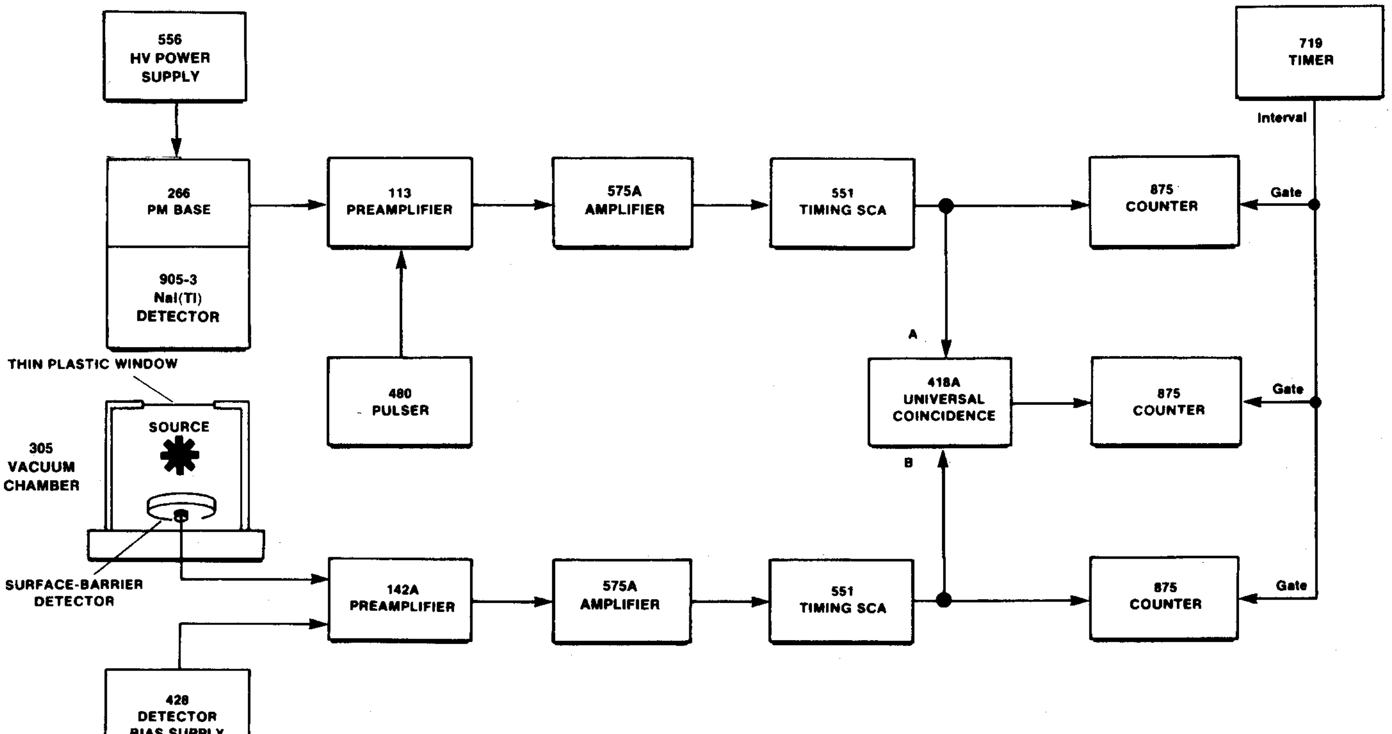

Fig. 9.10. Electronics Interconnections for Experiment 9.3.

575A Amplifier (from 142A): Positive Input, Bipolar Output.
551 Timing Single-Channel Analyzers: Integral mode, Lower Level N 40/1000, Delay minimum.
418A Universal Coincidence: Coincidence Requirements 2, Resolving Time maximum, 2 μs, Switch A Coinc, Switch B Coinc, Switches C, D, and E Off.

Turn on the mechanical vacuum pump.

Procedure

1. Adjust the 556 high voltage to the polarity and value recommended for the phototube.

2. Adjust the gain of the 575A Amplifier on the 113 side of the circuit so that the 1.33-MeV gammas from the ^{60}Co source are ~6 V at the Bipolar output.

3. Raise the 428 Bias Supply voltage gradually to the value recommended for the surface barrier detector.

4. Adjust the gain of the 575A Amplifier on the 142A side of the circuit so that the maximum pulse amplitude from the beta continuum is ~7 V.

5. All three 875 Counters should be counting.

6. Stop the 719 Timer and clear all counters to zero.

7. Start counting in all three counters by starting the 719. Count for a time interval long enough to accumulate ~600 counts in the R_c counter (for the coincidence events).

EXERCISE

Calculate A_0 from Eq. (5). How does your value compare with the value indicated for the sample, considering its current rate of decay?

References

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