

### Equipment Required

<ul style="list-style-type: none"> <li>• Two <b>113</b> Scintillation Preamplifiers</li> <li>• Two <b>266</b> Photomultiplier Tube Bases</li> <li>• <b>4001A/4002D</b> Bin and Power Supply</li> <li>• <b>414A</b> Fast Coincidence</li> <li>• Two <b>551</b> Timing Single-Channel Analyzers</li> <li>• <b>567</b> Time-to-Amplitude Converter and SCA</li> <li>• Two <b>556</b> High Voltage Power Supplies</li> <li>• <b>480</b> Pulser</li> <li>• <b>994</b> Dual Counter and Timer</li> <li>• Two <b>575A</b> Amplifiers</li> <li>• <b>905-3</b> NaI(Tl) 2 x 2-in. Detector and PM Tube</li> <li>• <b>EASY-MCA-2K</b> System including USB cable and MAESTRO software (other ORTEC MCAs may be substituted).</li> <li>• Two <b>C-36-2</b> RG-59A/U 75-Ω cables, each with two SHV female plugs, 0.61-m (2-ft) length.</li> <li>• Two <b>C-24-1/2</b> RG-62A/U 93-Ω cables, each with BNC plugs, 15-cm (1/2-ft) length.</li> </ul>	<ul style="list-style-type: none"> <li>• Six <b>C-24-4</b> RG-62A/U 93-Ω cables, each with BNC plugs, 1.2-m (4-ft) length.</li> <li>• Two <b>C-24-2</b> RG-62A/U 93-Ω cables, each with BNC plugs, 0.61-m (2-ft) length.</li> <li>• Two <b>C-25-2</b> RG-58A/U 50-Ω cables, each with BNC plugs, 0.61-m (2-ft) length.</li> <li>• <b>TDS3032C</b> Oscilloscope with bandwidth ≥150 MHz</li> <li>• <b>GF-057-M-20*</b> 20-μCi <sup>57</sup>Co source.</li> <li>• <b>5TI200B2/2</b> Thin-Window NaI(Tl) Detector with PM tube (Beryllium window suitable for detecting 14-keV photons)</li> <li>• Personal Computer with USB port and recent, supportable version of the Windows operating system.</li> <li>• Small, flat-blade screwdriver for screwdriver-adjustable controls, or an equivalent potentiometer adjustment tool.</li> </ul> <p><b>Optional Equipment for Experiment 14.3</b></p> <ul style="list-style-type: none"> <li>• <b>GEM-10</b> Coaxial Detector System</li> <li>• <b>SLP-06165P</b> Si(Li) X-Ray Detector System</li> <li>• <b>905-21</b> Fast Plastic Detector with PMT and Base</li> <li>• <b>416A</b> Gate and Delay Generator</li> </ul>
<p>*Sources are available direct from supplier. See the ORTEC website at <a href="http://www.ortec-online.com/Service-Support/Library/Experiments-Radioactive-Source-Suppliers.aspx">www.ortec-online.com/Service-Support/Library/Experiments-Radioactive-Source-Suppliers.aspx</a></p>	

### Purpose

This experiment will use the coincidence method for time correlation to measure the lifetime in the decay scheme of <sup>57</sup>Co.

### Introduction

The measurement of the lifetimes of excited nuclear states constitutes an important experimental technique in nuclear physics. Many nuclear states remain excited for mean lifetimes that are measured easily with the techniques outlined in Experiment 9. The lifetime of a nuclear state is related to its width, (energy), by the uncertainty principle:

$$\Delta E \Delta t = \hbar \quad (1)$$

where

$\Delta E$  = uncertainty in energy associated with a state,

$\Delta t$  = uncertainty in time associated with the state, and

$\hbar = 1.054 \times 10^{-34}$  joules-s is Planck's constant,  $h$ , divided by  $2\pi$ .

In general, for nuclear lifetimes, Eq. (1) becomes

$$\tau = \frac{\hbar}{\Gamma} \quad (2)$$

Where  $\tau$  is the mean life of a level having an energy width  $\Gamma$ . The mean lifetime,  $\tau$ , of the excited state is the *average* time for the nuclei in that state to decay to a lower energy level. The mean lifetime must be distinguished from the half-

# AN34 Experiment 14

## Nuclear Lifetimes and the Coincidence Method

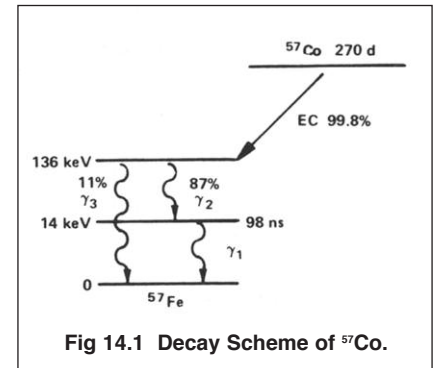
life,  $T_{1/2}$ , of the excited state. The half-life is the time taken for *half* of the nuclei in the excited state to decay to a lower energy level. The term that is most convenient to use depends on the context. The relationship between the two terms is given by equation (3).

$$\tau = \frac{T_{1/2}}{\ln 2} = \frac{T_{1/2}}{0.693} = 1.44 T_{1/2} \quad (3)$$

See reference 2 for details.

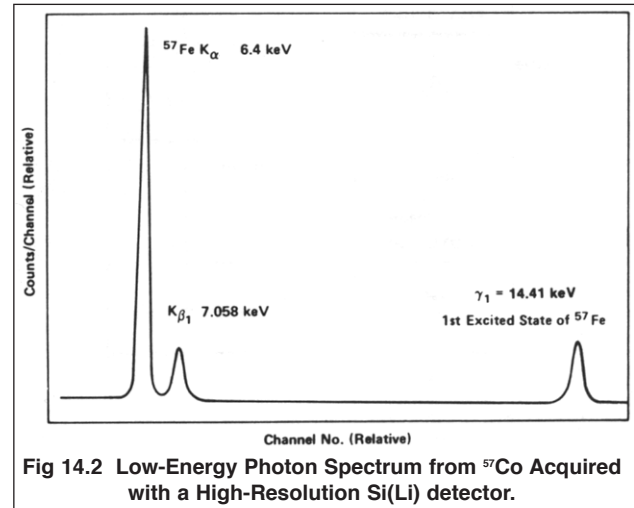
In this experiment, several techniques are outlined for measuring the lifetime of the first excited state of  $^{57}\text{Fe}$ . The accepted value for this half-life is 98 ns, which is well within the measuring capabilities of the coincidence techniques discussed in Experiment 9.

The decay scheme for  $^{57}\text{Co}$  is shown in Fig. 14.1. The decay of this isotope is essentially all by electron capture (EC) to the 136-keV level of  $^{57}\text{Fe}$ . Figure 14.2 shows a high-resolution x-ray spectrum of  $^{57}\text{Co}$ , in which the Fe  $K_{\alpha}$



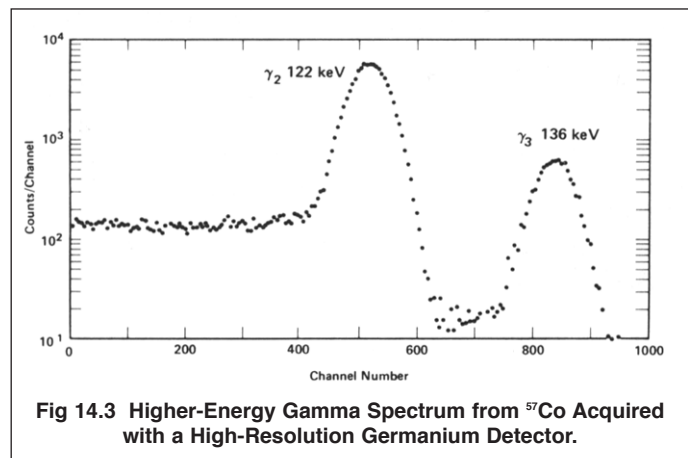
**Fig 14.1** Decay Scheme of  $^{57}\text{Co}$ .

and  $K_{\beta 1}$  x rays resulting from the electron capture are shown. The decay of the 136-keV level of  $^{57}\text{Fe}$  can occur by one of two principal modes: by a 136-keV gamma directly to the ground state, or by branching through the 14-keV level to the ground state. The 136-keV gamma, ( $\gamma_3$ ), branch occurs 11% of the time. The 122-keV gamma, ( $\gamma_2$ ), is 87% abundant. The 14-keV level de-excites most of the time by internal conversion, and less frequently by gamma-ray emission ( $\gamma_1$ ). The ratio of internal conversion to gamma decay, ( $e/\gamma$ ), for this level is  $\sim 9.0$ . The 14-keV gamma, ( $\gamma_1$ ), is also shown in Fig. 14.2. Figure 14.3 shows the higher-energy gamma spectrum of a  $^{57}\text{Co}$  source, revealing peaks from the 122-keV and 136-keV gamma rays. The lifetime of the 14-keV state can be measured by determining the time distribution of coincidence events between  $\gamma_2$  at 122 keV and  $\gamma_1$  at 14.4 keV.



**Fig 14.2** Low-Energy Photon Spectrum from  $^{57}\text{Co}$  Acquired with a High-Resolution Si(Li) detector.

Pragmatically, the best way to do this delayed coincidence experiment is with a time-to-amplitude converter (TAC). In Experiment 9 the TAC was used to indicate pairs of coincident pulses and to measure the variation in their relative times of occurrence. In Experiment 14.1,  $\gamma_2$  will be used to start a time measurement, and  $\gamma_1$  will be used to stop the measurement. Consequently, the output of the TAC will provide a time distribution of the lifetime of the first excited state of  $^{57}\text{Fe}$ , calibrated with known delays as in Experiment 9. In Experiment 14.2 the same information is obtained by measuring the  $\gamma_1$  and  $\gamma_2$  coincidence rate with a fast coincidence circuit as a function of the delay in the  $\gamma_2$  side of the circuit. These techniques can be duplicated in Experiment 14.3 using detectors with different spectral response characteristics.



**Fig 14.3** Higher-Energy Gamma Spectrum from  $^{57}\text{Co}$  Acquired with a High-Resolution Germanium Detector.

### Experiment 14.1. Lifetime Measurement of the 14-keV State in $^{57}\text{Fe}$ Using a Time-to-Amplitude Converter

#### Procedure

1. Set up the electronics as shown in Fig. 14.4. The 905-3 NaI(Tl) detector will be used to detect the  $\gamma_2$  events at 122 keV, and to start a time measurement for each sensed event. The other NaI(Tl) detector, the one with the thin window, will be used to detect the  $\gamma_1$  events at 14.41 keV, and to stop the time measurements. Details for the cable connections and the settings on each module are:

a. Insert the NIM modules into the NIM bin. The cable connections will be convenient if the 556 HV Power Supplies are at opposite ends of the bin, with the 567 TAC and 480 Pulser centered in the bin. The 551 Timing SCAs should be located on either side of the 567/480 pair of modules, and the 575A Amplifiers should be positioned between the SCAs and the HV Power Supplies. This will locate all the electronics for one detector on the left side of the bin, and the electronics supporting the other detector on the right side of the bin. Note that it is not essential to mount the 556 HV Power Supplies in the bin, because they do not draw power from the bin.

b. Use the RG-59B/U 75- $\Omega$  cables, with SHV plugs to connect the outputs of 556 HV Power Supplies to the POS HV input on the respective 266 PMT Bases. Check that the controls on the rear panels of the 556 HV Power Supplies are set for POSITIVE POLARITY and INTERNAL CONTROL.

c. Using the 15-cm RG-62A/U 93- $\Omega$  cables, connect the ANODE output of each 266 PMT Base to the INPUT on the respective 113 Preamp. Set the INPUT CAPACITANCE switch on each preamp to 0 pF. This selection implies that the charge integrating capacitance for the PMT output current signal will be circa 50 pF.

d. Using the 1.2-m RG-62A/U 93- $\Omega$  cables, connect the OUTPUT of each 113 Preamp to the INPUT of its respective 575A Amplifier. Check that the SHAPING TIME slide switches accessible through the 575A side panel are all set to 0.5  $\mu\text{s}$  on both amplifiers. Connect the 113 Preamp power cables to the PREAMP POWER connector on the rear panel of their respective 575A Amplifier. Set both 575A INPUT polarities to NEG.

e. Using the 1.2-m RG-62A/U 93- $\Omega$  cables, connect the DIRECT output of the 480 Pulser to the TEST PULSE input on the 113 Preamp that serves the 905-3 NaI(Tl) detector. Connect the ATTENUATED output of the 480 Pulser to the TEST PULSE input on the 113 Preamp that supports the Thin-Window NaI(Tl) detector. Set the polarity switch on the 480 Pulser to NEGATIVE.

f. Using the 0.61-m RG-62A/U 93- $\Omega$  cables, connect the BIPOLAR OUTPUT of each 575A Amplifier to the DC INPUT of its respective 551 Timing SCA. Check that both rear-panel toggle switches are set to the INTERNAL position on each of the 551 SCAs.

g. Use a 0.61-m RG-58A/U 50- $\Omega$  cable to connect the NEGATIVE OUTPUT of the 551 Timing SCA supporting the 905-3 NaI(Tl) detector to the START INPUT of the 567 TAC.

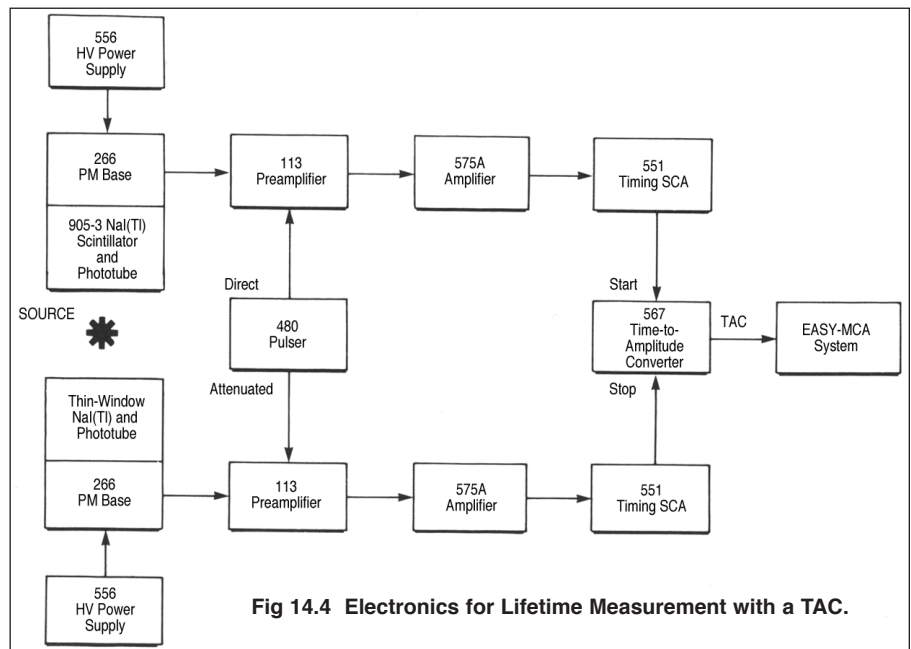


Fig 14.4 Electronics for Lifetime Measurement with a TAC.

## AN34 Experiment 14 Nuclear Lifetimes and the Coincidence Method

- h. Use a 0.61-m RG-58A/U 50-Ω cable to connect the NEGative OUTput of the 551 Timing SCA supporting the Thin-Window NaI(Tl) detector to the STOP INPUT of the 567 TAC.
  - i. On the 567 TAC, set the toggle switches next to the START and STOP inputs to the ANTI position. Set the STROBE toggle switch to INTernal. Set the TAC inhibit switch to OUT. Choose the 50-ns RANGE and the x10 MULTIPLIER, to achieve a time span of 500 ns.
  - j. Using a 1.2-m RG-62A/U 93-Ω cable, connect the TAC OUTPUT of the 567 TAC to the analog INPUT of the EASY-MCA. Connect the EASY-MCA to the supporting computer using the USB cable. Turn on the ac power to the 4001A/4002D Bin and Power Supply, and turn on the computer.
  - k. Set the High Voltage on each 556 according to the manufacturer's recommended value for the respective NaI(Tl) detector. Then, turn on the 556 HV Power Supplies.
2. Adjust the gain of the 575A Amplifier in the Start circuit in Fig. 14.4 so that the UNIpolar OUTput pulses for the 122-keV gammas from  $^{57}\text{Co}$  are approximately +5V in amplitude, as viewed on an oscilloscope. Check that the FOCUS control on the related 266 PMT base has been adjusted to maximize the above pulse height. If the FOCUS control gets tweaked to maximize the signal, readjust the amplifier gain to achieve the +5V amplitude. For reference, Fig. 14.5 shows a typical spectrum of  $^{57}\text{Co}$  measured at the output of this amplifier. Note that the 122-keV and 136-keV lines are not resolved in the spectrum taken with the NaI(Tl) detector, because NaI(Tl) has much worse energy resolution than exhibited by the HPGe detector employed in Fig. 14.3.
  3. Set the horizontal scale of the oscilloscope to 50  $\mu\text{s}/\text{cm}$  and the vertical scale to 100 mV/cm. With a small, flat-blade screwdriver, adjust the PZ ADJ on the 575A Amplifier to make the pulses on the UNIpolar OUTput return to baseline as quickly as possible without undershooting the baseline between pulses. For further guidance on the Pole-Zero Cancellation adjustment, see Experiment 3 and consult the instruction manual for the amplifier, or the introduction to the amplifier product family on the ORTEC web site at [www.ortec-online.com](http://www.ortec-online.com).
  4. Set the 551 in the 2 x 2-in. NaI(Tl) start channel for a 400-ns delay (0.4  $\mu\text{s}$ ). (With the Delay Range toggle switch in the 0.1–1.1  $\mu\text{sec}$  position, the DELAY dial will read from 0.1 to 1  $\mu\text{s}$ .) Adjust the LOWER-LEVEL control so that the lower-level threshold lies somewhere in the valley between the photopeaks and the Compton edge. (In Fig. 14.5, this is about channel 50, or approximately 2.5V at the amplifier output). Note that the LOWER LEVEL and UPPER LEVEL dials on the 551 SCA are approximately calibrated to read 0 to +10V. Set the UPPER-LEVEL control fully clockwise and select the NORMal mode.
  5. Adjust the gain of the 575A Amplifier in the Stop circuit in Fig 14.4 so that the UNIpolar OUTput pulses for the 14.41-keV gammas from  $^{57}\text{Co}$  are approximately +5V in amplitude. Check that the FOCUS control on the related 266 PMT base has been adjusted to maximize the above pulse height. If the FOCUS control gets tweaked to maximize the signal, readjust the amplifier gain to achieve the +5-V amplitude.

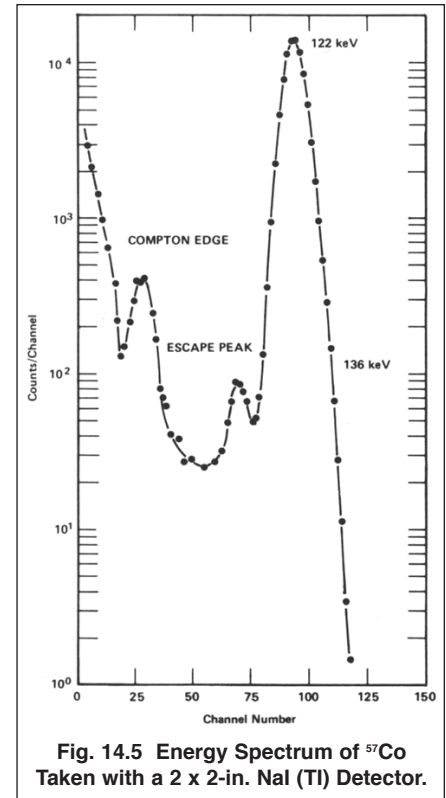


Fig. 14.5 Energy Spectrum of  $^{57}\text{Co}$  Taken with a 2 x 2-in. NaI (TI) Detector.

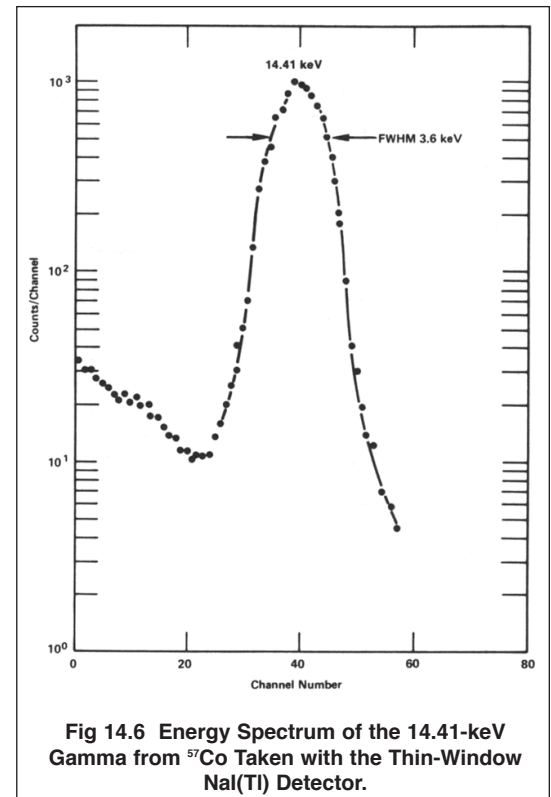


Fig 14.6 Energy Spectrum of the 14.41-keV Gamma from  $^{57}\text{Co}$  Taken with the Thin-Window NaI(Tl) Detector.

For reference, Fig. 14.6 shows a typical spectrum for the 14.41-keV gammas from a thin-window NaI(Tl) detector. The  $^{57}\text{Fe}$   $K\alpha$  and  $K\beta_1$  x-rays that are shown in Fig. 14.2 are not visible in Fig. 14.6 for two reasons. The beryllium window on the front of the scintillator is still thick enough to strongly attenuate the 6.4-keV X-rays. Also, the conversion efficiency of X-ray energy to photoelectrons in the detector is so low that the 6.4-keV X-rays cannot be distinguished from the thermally generated single-electron noise in the photomultiplier tube. Note that the resolution of the spectrum obtained with the thin-window NaI(Tl) detector is 16 times worse than that of the same spectrum taken with the Si(Li) detector.

6. Adjust the Pole-Zero Cancellation on the amplifier in step 5 per the instructions in step 3.
7. Set the 551 in the thin-window NaI(Tl) channel for a 600 ns DELAY. Adjust the LOWER-LEVEL dial so that the lower-level threshold corresponds to the valley in the pulse height spectrum (about channel 20 in Fig. 14.6, or approximately 2.5V at the amplifier output). Set the UPPER-LEVEL control fully clockwise, and select the NORMAL mode of operation.
8. Via the Acquire menu and the ADC tab in the MAESTRO software that operates the EASY-MCA, select the Gate Off option, and adjust the Upper Level discriminator to its maximum value. Adjust the Lower Level discriminator as low as possible without causing excessive counting rate on the noise. Under the Preset tab, clear all data fields, and do the same for the MDA Preset option (if supported). Clearing those fields will default to manual control for starting and stopping spectrum acquisition. Select the analog-to-digital conversion range to be 512 channels for a 0 to +10-V input. Combined with the 500-ns time span on the TAC, this will result in a calibration of approximately 1 ns per channel in the time spectrum. Familiarize yourself with the software controls for setting up, acquiring and erasing spectra.
9. Remove the  $^{57}\text{Co}$  source and turn on the 480 Pulser. Set one x10 attenuator switch On, and the other attenuator switches Off. Adjust the PULSE-HEIGHT dial and the CALIBRATION control as necessary to obtain approximately a 7-V pulse amplitude out of the amplifier in the Start channel. Both amplifiers should have similar output levels within  $\pm 1\text{V}$ . If the amplitudes from the two amplifiers are not similar, select appropriate ATTENUATOR settings on the 480 Pulser to match the pulse amplitudes within  $\pm 1\text{V}$ . Both of the 551 Timing SCAs should now be counting the pulses from the 480, and thus should generate a time measurement with the 567. The time measurement should be  $\sim 200$  ns, the difference in delays between the two circuits.
10. Feed the 567 TAC output to the MCA and accumulate for a period of time long enough to determine the position of the peak. Increase and decrease the delay on the 551 in the Stop channel by 50-ns steps to cover the range from 300 ns to 1000 ns. For each delay setting, determine the peak location on the MCA and record the channel number versus the delay value. At the lower end and the upper end of the delay range, the peaks may fall off the lower or upper end of the spectrum. In that case, terminate the lower or upper range of the settings when the peaks disappear.

### EXERCISE

Plot a curve of delay vs. channel number from your data and determine the calibration in nanoseconds per channel. This technique was outlined in Experiment 9 (Fig 9.9).

11. Turn off the pulse generator and return the  $^{57}\text{Co}$  source to its position as shown in Fig. 14.4. In your table of channel number versus DELAY setting, identify the lowest DELAY setting that still generated a peak in the time spectrum. Add 100 ns to that value, and set the DELAY on the 551 in the stop channel to the resulting number.
12. Accumulate a spectrum in the MCA. Figure 14.7 shows the results of a typical measurement that was made for this experiment. In order to display a smooth graph, groups of ten channels were averaged and plotted. The slope of the delay

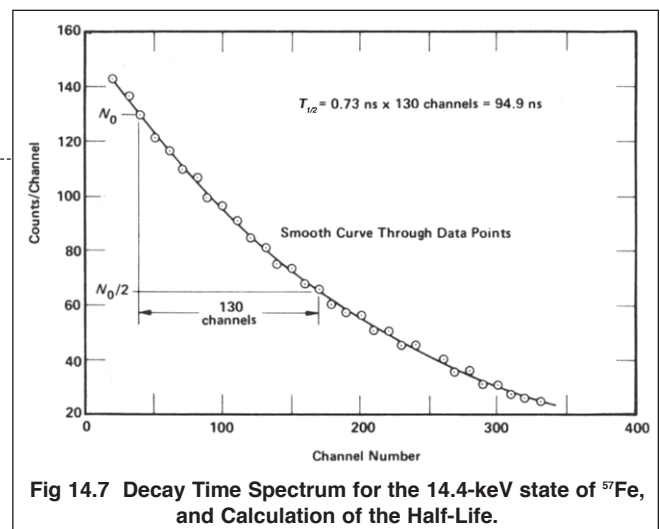


Fig 14.7 Decay Time Spectrum for the 14.4-keV state of  $^{57}\text{Fe}$ , and Calculation of the Half-Life.



vs. channel number for Fig. 14.7 was 0.73 ns/channel. The half-life of the state is therefore the product of the number of channels for half intensity times the 0.73 ns/channel. From the data in Fig 14.7 this product is ~95 ns, which is quite close to the accepted value of 98 ns. The data in Fig 14.7 required a 2-h run. The electronic setup and time calibration also requires ~ 2 h. Therefore the whole experiment should require a 4-h laboratory period.

13. Measure the half-life in the decay-time spectrum you obtained for the 14.4-keV state. Compare your result to the accepted value.

**EXPERIMENT 14.2. Lifetime Measurement of the 14-keV State in <sup>57</sup>Fe Using the Delayed Coincidence Method**

This experiment is identical to Experiment 14.1 except for the instruments that are employed to measure the lifetime. Where the TAC and MCA were used to make the measurements in the previous experiment, a fast coincidence circuit with controllable resolving time, plus a counter and a timer will be employed in this experiment. The 414A Fast Coincidence module will be configured to convert the 500-ns wide pulses from the 551 Timing SCAs to standard 100-ns wide pulses. When those 100-ns logic pulses overlap, the 414A generates an output logic pulse that will be counted by the 994 Dual Counter and Timer. When the delays from both detectors through to the 414A inputs are identical, the counting rate at the output of the 414A represents the counting rate for prompt decay of the 14.4-keV state. By increasing the delay of the logic signal from the 905-3 NaI(Tl) detector, which is sensing the 122-keV gamma-ray, the counting rate for delayed decay of the 14.4-keV state can be profiled. As seen in experiment 14.1, this profile should be an exponential decrease in counting rate when plotted against delay time. The half-life of the 14.4-keV state can be calculated by measuring the delay time needed to reduce the counting rate by a factor of 2.

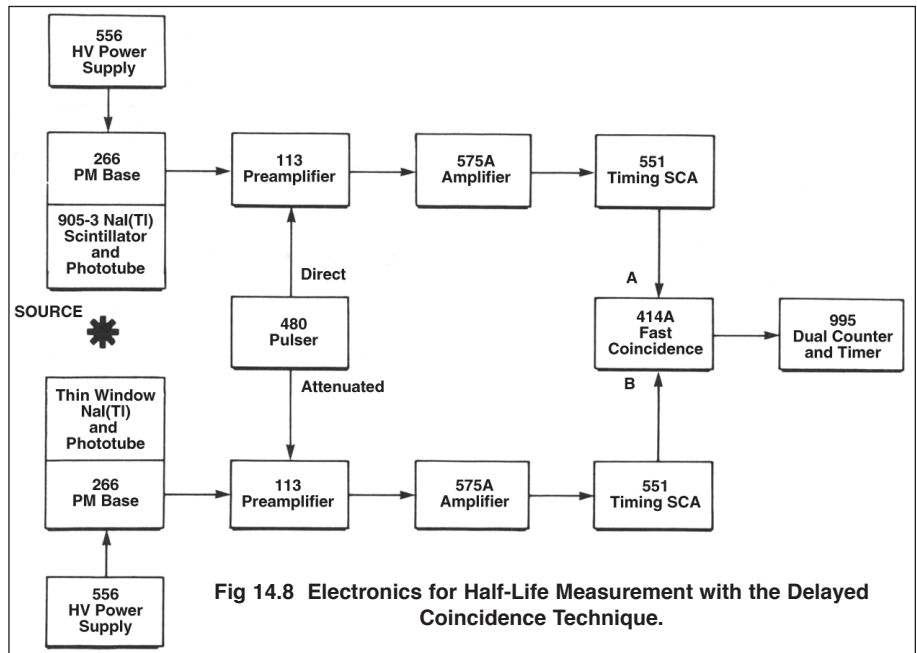
**Procedure**

1. Starting with the Setup defined by steps 1 through 7 of Experiment 14.1, turn off power to the NIM Bin, and replace the 567 TAC with a 414A Fast Coincidence and a 994 Dual Counter and Timer. Modules can be shifted right or left in the bin to accommodate the required extra bin slots. Alternatively, the 994 can be inserted at either end of the bin. The EASY-MCA will not be used for the following measurements. The resulting setup is illustrated in Fig 14.8. The adjustments and settings on the modules are the same as in Experiment 14.1. Additional details for the 414A and 994 are:

- a. Connect the POSitive OUTput of the 551 SCA serving the 905-3 NaI(Tl) detector to COINCidence INPUT A on the 414A.

- b. Connect the POSitive OUTput of the 551 SCA serving the Thin-Window NaI(Tl) detector to COINCidence INPUT B on the 414A.

- c. Connect one of the two OUTPUTs of the 414A to the IN B input of the 994 Dual Counter and Timer. Confirm with your laboratory manager that both INPUT POLARITY jumpers on the 994 printed circuit board have been set to “P” for positive input polarity, the A COUNTER/TIMER jumper has been set to “Timer”, and the B COUNTER/TIMER



**Fig 14.8 Electronics for Half-Life Measurement with the Delayed Coincidence Technique.**

- jumper has been set to “Counter.” This is necessary for counter A to display the elapsed time, and counter B to show the counts accumulated from the 414A output.
- d. Turn on power to the NIM Bin.
  - e. On the 414A, set the INPUT CONTROLS toggle switches to IN for inputs A and B. Set the toggle switches for the C and D inputs to the OUT position. Unlock the RESOLVING TIME dial by moving the black lever above the dial from right of center to left of center. Set the dial to 100 ns. Lock the dial by moving the black lever to the right of center.
2. Set the delays for both 551 SCAs to 400 ns.
  3. Remove the <sup>57</sup>Co source and turn on the 480 Pulser. If step 9 of Experiment 14.1 has not already been implemented, duplicate that step as follows. Set one X10 attenuator switch On and the other attenuator switches Off. Adjust the PULSE-HEIGHT dial and the CAL control as necessary to obtain approximately a 7-V pulse amplitude out of the amplifier in the Start channel. Both amplifiers should have similar output levels within  $\pm 1V$ . If the amplitudes from the two amplifiers are not similar, select appropriate ATTENUATOR settings on the 480 Pulser to match the pulse amplitudes within  $\pm 1V$ . Both of the 551 Timing SCAs should now be counting the pulses from the 480.
  4. For the purpose of setting up the controls on the 994, temporarily flip the B input toggle switch on the 414A to the OUT position. This feeds the counting rate from the 905-3 NaI(Tl) detector directly through the 414A to the 994 counter input.
  5. Set up the 994 Dual Counter Timer as follows:
    - a. Push the STOP button to ensure the 994 is not counting. Then push the RESET button to erase any events previously accumulated in either counter.
    - b. Press the TIME BASE push-button repeatedly until the LEDs indicate the 0.01-SEC time base is selected.
    - c. Turn the DWELL control to its full clockwise limit. This will ensure the contents of the 994 are displayed for 10 seconds before the module erases the contents and starts a new data acquisition cycle.
    - d. Press the DISPLAY push-button repeatedly until the LEDs indicate that the PRESET mode has been selected for the display.
    - e. Press the PRESET SELECT push-button repeatedly, until the value of the M digit is displayed. Press the PRESET ADVANCE push-button repeatedly until the value of the M digit is zero.
    - f. With the PRESET SELECT push-button, select the N digit for display. Using the PRESET ADVANCE push-button select a value of 1 for N.
    - g. Press the PRESET SELECT push-button to display the P digit. With the PRESET ADVANCE push-button, select a value of 2 for P. This sets the counting interval to  $MN \times 10^P \times 0.01 \text{ s} = 01 \times 10^2 \times 0.01 \text{ s} = 1 \text{ second}$ .
    - h. Press the DISPLAY push-button repeatedly until the LED indicates counter A has been selected. This is counting the time in 0.01-second increments. Press the COUNT pushbutton and confirm that counter A starts at zero, accumulates 100 counts (1 second), pauses for 10 seconds, resets, and repeats the cycle. The DWELL control can be adjusted to achieve a pause for display that varies from 1 to 10 seconds. Select a DWELL period that is convenient. If the DWELL control is turned far enough in the counterclockwise direction a faint click may be heard as the OFF switch is activated. This turns off the dwell/recycle feature, requiring the counter to be manually stopped with the STOP button, reset with the RESET push-button, and started with the COUNT button. Return the DWELL control to a clockwise position to enable the recycle mode for the next step.
    - i. Press the DISPLAY push-button to select counter B. If the THRESHOLD ADJUSTment for the IN B is properly adjusted, counter B should start with zero counts, accumulate up to 60 counts, pause for display, then reset and repeat the cycle. Note that the 60 counts is based on the 480 Pulser generating periodic output pulses at the same rate as the ac power line frequency (60 Hz). If your ac line frequency is different, substitute the appropriate number.
    - j. If the condition in step (i) is not achieved, use a flat-blade screwdriver to turn the B THRESH ADJUST clockwise several full turns, and then continue turning until counter B stops accumulating events. Next, turn it counterclockwise until counter B barely begins to count its input pulses. Finally, turn the B THRESH ADJUST an

additional 6 turns counterclockwise. This will set the threshold at approximately +2.5V for counting the +5-V pulses from the 414A.

6. On the 414A set both the A and B toggle switches to the IN position. While observing the recycling counting on the B display of the 994, adjust the delay on the SCA feeding the B input of the 414A. Increase and/or decrease the delay from its initial 400-ns setting to find the delay that maximizes the counting rate. The resulting value should be fairly close to 400 ns, i.e., essentially the same delay as in the SCA feeding the A input on the 414A. Lock the dial at the final setting. The counting rate should be approximately 60 counts/s, for a 60-Hz ac line frequency controlling the 480 Pulser rate.
7. Turn off the 480 Pulser and replace the <sup>57</sup>Co source in its operating position. Set the preset counting period on the 994 to 600 seconds (10 minutes). Turn the DWELL control on the 994 fully counterclockwise to disable the recycle mode. Manually reset the counter and start the counting. Stop the counter after sufficient counts have been accumulated to crudely estimate the counting rate.
8. Based on the result in step 7, estimate how long the preset counting interval must be to obtain reasonable statistics on the 994 Counter B. If the number of counts recorded in the preset time is N, the estimated percent uncertainty in the counts is

$$\sigma\% = \frac{\sigma \times 100\%}{N} = \frac{\sqrt{N}}{N} \times 100\% = \frac{100\%}{\sqrt{N}} \quad (4)$$

Where  $\sigma = \text{SQRT}(N)$  is the estimated standard deviation for N. Equation (4) shows that 10,000 counts are required to achieve an estimated percent standard deviation of 1%. Set the preset time on the 994 to achieve between 5,000 and 10,000 counts in this initial data point. Do not set a preset time longer than 600 seconds, to avoid prolonging the experiment beyond an additional 2 hours. Record the initial counting rate and keep the preset time constant throughout the remainder of this experiment.

9. Increase the delay for the 551 in the A channel by 20 ns and repeat the measurement. Continue for delay increases by 40, 60, 80, 100, 120, 140, 160, and 180 ns.

### EXERCISE

Plot the counting rate as a function of delay change. The curve should be similar to that in Fig 14.7. From these data determine the half-life of the 14-keV state of <sup>57</sup>Fe as in Experiment 14.1. Compare the result to the accepted value of 98 ns.

The calibration uncertainty of the 551 delay is about  $\pm 2\%$  of the delay range. That implies at least a  $\pm 2\%$  uncertainty in the time measured for the half-life. Compare the deviation of your result from the accepted value to the errors you would expect from a) the 551 delay calibration and b) the counting statistics in equation (4).

### Experiment 14.3. Alternate Detectors to Substitute with the Electronics in Experiments 14.1 and 14.2

#### Purpose

In Experiments 14.1 and 14.2 the lifetime coincidence measurements are made between two NaI (TI) detectors that are suitable for the task. There are alternate detectors that can be employed with essentially the same electronics. These candidates can have advantages in offering better energy resolution, or in familiarizing the experimenter with a different detector technology.

Typically, the semiconductor detectors require amplifiers with longer shaping time constants to deliver their improved energy resolution. If the experiment incorporates a detector employing a short shaping time constant with a detector needing a much longer shaping time constant, a 416A Gate and Delay Generator will be required to extend the delay of the Timing SCA output serving the shorter shaping time constant.



### The Start Side (the 122-keV Gamma)

An HPGe detector could be used for the 122-keV gamma. Figure 14.3 shows a typical output spectrum for a germanium detector. For this measurement an SCA could be set to span the 122-keV peak. Other points with regard to HPGe detectors are covered in Experiment 7. Additional information with regard to time measurements and germanium detectors can be obtained from ORTEC. See application note AN42, Principles and Applications of Timing Spectroscopy in the library of application notes on the ORTEC web site at [www.ortec-online.com](http://www.ortec-online.com).

An organic (plastic) scintillator such as KL-236, NE-102, or Pilot B could be used to detect the 122-keV gammas. Figure 14.9 shows a spectrum of  $^{57}\text{Co}$  obtained with an organic scintillator. Because of the exceptionally low average atomic number of the materials in the scintillator, the spectrum consists of a Compton continuum with no photopeaks. The line marked “E-LEVEL” is the recommended setting for the lower level threshold of the 551 Timing SCA with this scintillator.

The organic scintillator has the advantage of being considerably faster than NaI(Tl), and hence better time resolution can be obtained. Figure 14.10 shows a typical output pulse from a fast plastic scintillation detector. The anode signal has been fed to the oscilloscope on a 50- $\Omega$  coaxial cable, and terminated in 50  $\Omega$  at the oscilloscope input.

### The Stop Side (the 14-keV Gamma)

A Si(Li) detector could be used for the stop pulse. Figure 14.2 shows an output pulse-height spectrum for  $^{57}\text{Co}$  that was taken with one of these high-resolution devices. Si(Li) detectors also have good timing characteristics. Other features of these detectors are discussed in Experiment 8.

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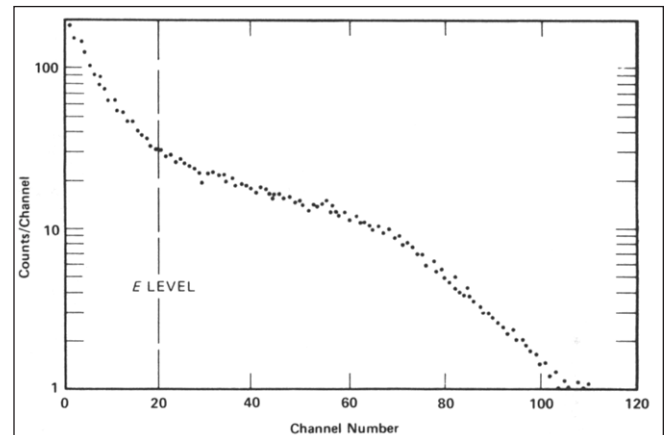


Fig 14.9 Spectrum of  $^{57}\text{Co}$  Obtained with an Organic Scintillator.

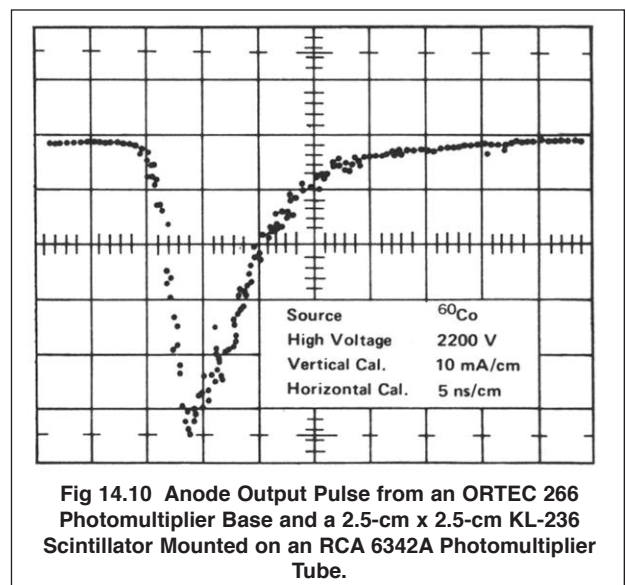


Fig 14.10 Anode Output Pulse from an ORTEC 266 Photomultiplier Base and a 2.5-cm x 2.5-cm KL-236 Scintillator Mounted on an RCA 6342A Photomultiplier Tube.





Specifications subject to change  
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