Experiment V

Operation and Characteristics of a Solid (External-Sample) Scintillation Counter

The detection of an external source of radiation by means of a scintillation crystal coupled to a photomultiplier tube has been described in Chapter 6. This method of detection differs sharply from that of the ionization-type detectors (G-M, proportional, and the like). It depends on the interaction of radiation with a crystal fluor to emit a number of photons proportional to the radiation energy dissipated. These photons are converted to photoelectrons by the photocathode of the adjacent photomultiplier, and the photoelectrons are then greatly amplified through a dynode chain to produce a pulse. As with the other counting assemblies, a scaler is attached to record the detector pulses. A wide variety of solid scintillation counting assemblies is at present commercially available. The experiment that follows will introduce the reader to a typical counting assembly. **(See Figure V-1).**

A. Functions of the Components of a Solid Scintillation Counter Assembly

1. Power Supply

The d-c voltage supplied to the scintillation detector plays a different role than it does in G-M and proportional detectors. Here it is used to create a stepwise increase of potential on the successive dynodes of the photomultiplier. Note that no voltage is applied to the crystal. Because this potential gradient in the photomultiplier so directly affects the degree of amplification occurring, it is essential that the power supply be both highly stable and well regulated. This point is particularly crucial if pulse height analysis is to be attempted, in which case drift of less than 0.1 per cent per day is desirable. It is usually sufficient to employ a power supply with an output potential adjustable up to 3000 volts to operate most photomultipliers.

2. Scintillation Detector Assembly

The lead shielding and sample support used are normally similar to those found in G-M detector assemblies. Owing to the greater efficiency of the scintillation process for detecting gamma rays, and thus also the cosmic ray background radiation, lead shielding is more essential here.

The detector itself is usually a solid crystal fluor, most commonly of sodium iodide (thallium activated), 1 in. to 3 in. in thickness, encased in a light-tight jacket. In it, some of the energy dissipated by traversing radiation is transformed into photons of visible light. The photons pass through the rear transparent window of the crystal housing and the optical coupling layer into the photomultiplier tube. This tube contains a photocathode surface where the impinging photons cause photoelectrons to be ejected. In turn, these photoelectrons are electrostatically attracted through the series of dynodes and multiplied by secondary electron emission at each successive dynode in the photomultiplier, so that a sharp pulse results at the collecting anode of the tube. The scintillation crystal and photomultiplier tube must be sealed in a light-tight case and the tube further needs to be surrounded

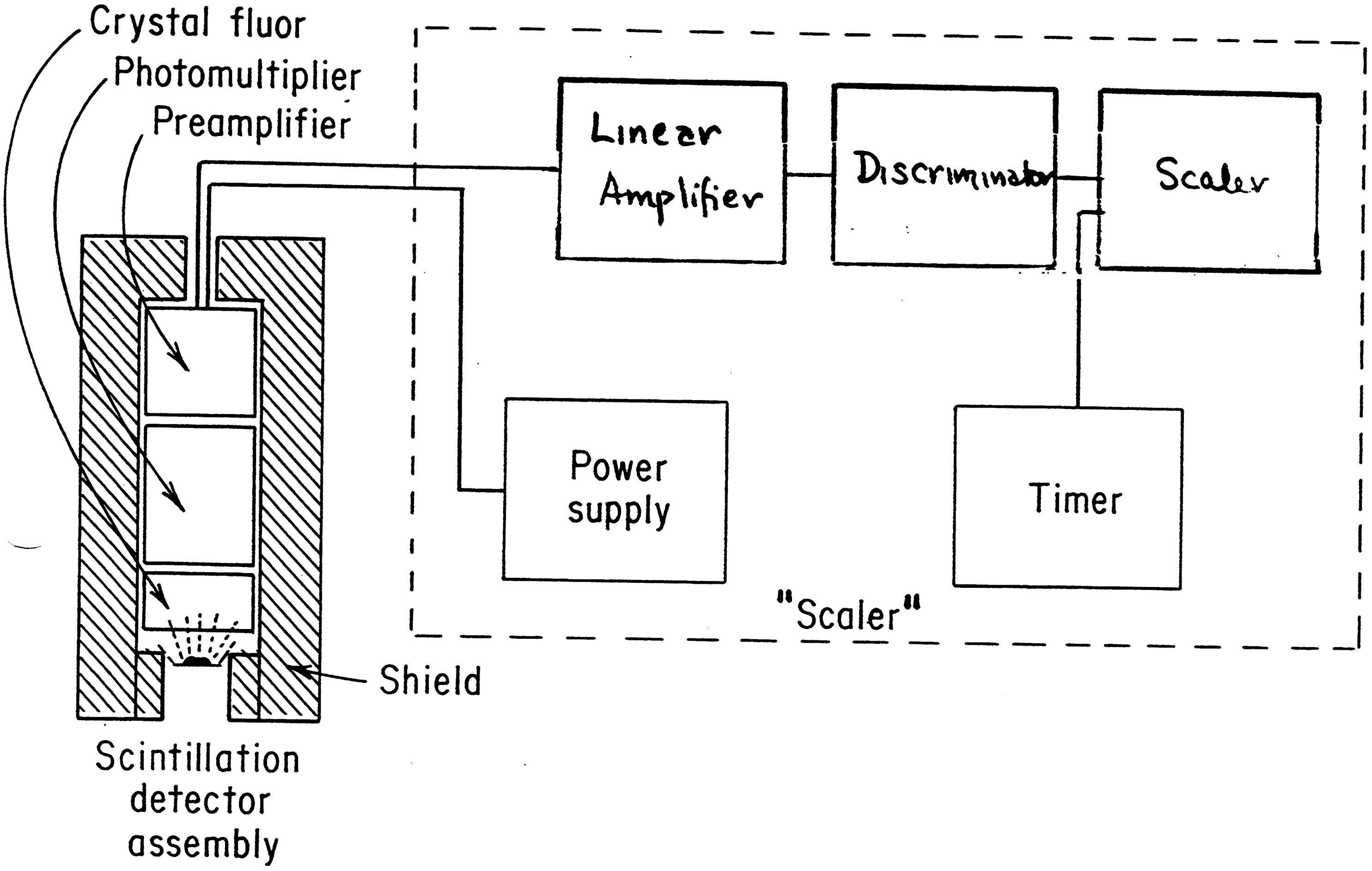

Figure V-1. Block diagram of an external-sample scintillation counter assembly.

by a shield of Mu metal to avoid disturbance by external magnetic fields. (Consult Chapter 6 for further details of the scintillation process.)

For improved detection efficiency, a well scintillation crystal (usually 3 in. in thickness) may be employed (see). Well detectors, as they are called, are particularly suited for assay of liquid samples containing gamma emitters. Scintillation well detectors are also available commercially with automatic sample-changing equipment.

A preamplifier (of the "cathode follower type") is commonly attached directly to the photomultiplier tube base. This serves the dual purpose of "shaping" pulses and amplifying them sufficiently to reach the scaler through the connecting cable. The gain setting of this preamplifier is adjustable in some models.

3. Linear Amplifier and Pulse Height Selectors

The amplifier must be linear, in that it preserves the original relative pulse heights although amplifying them. Furthermore, the amplifier must be capable of handling a wide range of pulse heights. All these requisites, coupled with a necessarily high degree of stability, make this a component to be selected with care.

Pulse height selector circuits are used to reject certain pulse heights coming from the preamplifier. In integral counting all pulse heights below a selected level ("low gate") are rejected by a discriminator and only those above the discrimator setting pass on to the scaler. This allows low photomultiplier "noise" pulses to be rejected in favor of the larger pulse heights resulting from sample radiation. This discriminator level may be varied as the occasion demands.

In single channel counting, a single channel analyzer is used. This device only puts out a standard output pulse when the pulses entering the unit fall within a certain voltage range. (See Chapter 4 for a detailed discussion of single channel analyzers.) The lower voltage level is called the lower level or baseline while the upper end of the acceptable voltage range is called the upper level. The voltage difference between the upper and lower levels is called the window width. In single-channel counting, one counts the number of pulses from the detector that fall within some preset range of pulse heights (corresponding to a range of energies). Since the single channel analyzer can be used to "straddle" a photopeak in a γ-ray spectrum, the sample-to-background ratio can be improved when counting a single radionuclide. (See discussion of single channel counting in Chapter 7.)

4. Scaler and Timer

These components are no different from those described for G-M and proportional counters and are commonly grouped together with the power supply as a "scaler". Note that, as in the case of the proportional counter, a high scaling factor is necessary to take advantage of the very short resolving time of the scintillation detector.

B. Operation of a Solid (External-Sample) Scintillation Counting Assembly

1. General Instructions

Here again, as with the other counting assemblies previously described, it is important to become familiar with the manufacturer's specific operating instructions before attempting to use the counter.

Be particularly careful in handling the scintillation crystal and photomultiplier tube, if these are not already mounted in a fixed position. Both are extremely fragile and quite costly to replace. Photomultiplier tubes with focusing-type dynodes can be damaged by even moderate jarring. The photocathode in the photomultiplier is extremely light-sensitive and must never be exposed to normal room light with high potential applied to the tube or irreparable damage will occur. In addition, excessive d-c potentials applied to the tube can also produce permanent damage.

2. Scintillation Plateau Curves and Operating Voltages

Selecting optimal operating conditions for the scintillation counter is more complex than for the G-M counter. Unlike the situation with G-M counters, as the potential applied to the photomultiplier tube is increased, the background and "noise" count rates increase sharply. At very high potentials, they may even exceed the sample count rate. Furthermore, adjustments of the amplifier gain setting will lead to considerable alteration in the plateau characteristics of a counter. These characteristics also vary with different radioisotopes. Thus, there is not a "best" set of operating conditions for all applications of the scintillation counter.

If a pulse height selector is available with the detector assembly, the setting of the discriminator or single channel analyzer introduces another consideration. Since gamma rays have discrete energies, it is possible to set the window of the single channel analyzer at the site of the peak of the gamma spectrum (single channel counting). Such action will result in good detection efficiency of the gamma rays, while enjoying low background counting rates (see). The site of the window setting is naturally dependent on the nature of the gamma emitter and can be determined by crude scanning of the entire gamma spectrum. On the other hand, it is also possible to leave the window open (integral counting) , that is, cover nearly the entire pulse range, so long as the low-level discriminator is set to prevent undesirable noise pulses being recorded. This simplified procedure is particularly suitable for counting samples with a reasonably high counting rate.

Procedure:

1. With the high-voltage control in the "off" position, and the window settings wide open, turn the power switch on and allow approximately 10 min for the circuits to come to stability before proceeding. Insert a suitable gamma-emitting sample (^{137}Cs or ^{60}Co) into a fixed geometrical position in the sample support or crystal well and do not move it during the operations that follow.

2. Set the amplifier at a low gain position (this corresponds to high "attenuation" for some models). Turn the high-voltage and scaler count switches to "on" and raise the potential slowly until the scaler begins to record pulses. Collect a minimum of 3000 counts and record count rate and photomultiplier potential in Table V-1. Successively, at 50-volt increments, make such count rate determinations and record the data. The counting rate will rise rapidly and then level off somewhat on a "plateau." Discontinue counting when a second rapid increase in counting rate is observed.

In no case should the potential be advanced beyond the limit specified by the photomultiplier tube manufacturer.

3. Remove the radioactive source from the counter and repeat the measurements recording the data in Table V-1. Collect 3000 counts or count for at least 5 minutes at each voltage setting. This will give one the background rate at each high voltage setting.

4. Subtract the background counting rate (B) from the (sample + background) rate to obtain the net sample rate (S) at each value of the applied voltage.

5. To determine the best voltage for operation of the phototube at this amplifier gain, calculate a value of (net sample rate)^2/(background rate) for each applied voltage and enter the results in Table V-1. Plot this ratio vs. applied voltage. The optimum operating voltage will correspond to the maximum value of this ratio of S^2/B.

$(S^2/B)_{max}$ = ______, Optimum Operating Potential ______v. at low gain.

6. Repeat the above procedure (steps 2-5) for a medium and high gain setting (or alternatively, medium and low "attenuation") of the amplifier using the same sample and geometry. Report the results below

$(S^2/B)_{max}$ = ______. Optimum Operating Voltage ______v. medium gain

$(S^2/B)_{max}$ = ______. Optimum Operating Voltage ______v. high gain

7. Pick the amplifier gain that gives the maximum value of (S^2/B).

Amplifier Gain ____________

Optimum Operating Voltage ____________v.

Table V-1

	Sample + Background			Background				
Applied Voltage	Total Counts	Counting Time	Count Rate	Total Counts	Counting Time	Count **Rate** (B)	Net Count **Rate** (S)	S^2/B

Of course, this choice strictly applies only to the γ-emitting radionuclide used here and will vary somewhat for other γ-emitters. Similar procedures can also be used to determine the optimum gain setting and high voltage in single channel counting.

3. Effect of Sample Volume in a Well Type Scintillation Counter

When a sample is placed near a radiation detector, any changes in sample position or size will affect the relative geometry of the sample and the detector. Since the radiation intensity falls off as $1/r^2$ where r is the sample to detector distance, changes in volume for liquid samples can cause large changes in count rate for the same activity especially when r is small. One way to lessen such effects is the use of a well crystal for scintillation count. In such a detector a hole is drilled in a solid NaI(Tl) crystal to form a well. The sample (usually a liquid in a sealed vial) is placed in this well. Now modest cha in sample volume (provided the total volume is small) will not affect the count rate significantly. This can be demonstrated as shown below:

Procedure:

1. Prepare a sample of 0.5 ml volume of ~ 0.1N HCl solution containing ~ 5000-10000 cpm of either ^{22}Na or ^{137}Cs.

2. Place the sample in the well of a well type scintillation counter. With the high voltage and amplifier gain properly set for this isotope take a 2 minute count of the sample. Record the count rate in Table V-2.

3. Increase the solution volume by 0.5 ml using inactive HCl. Repeat the count rate measurement recording the result in Table V-2. Repeat this

procedure until the solution volume is ~10 ml.

Table V-2

Solution Volume	Total Counts	Counting Time	Count Rate

4. Plot the count rate as a function of solution volume. Your results should resemble Figure 6-14.

4. Detection Efficiency of the Scintillation Counter for Different Gamma Energies

Because of the highly penetrating nature of γ -radiation and the many interactions with matter that may occur, the efficiency of a scintillation counter for the detection of γ -rays is rarely unity. In fact, as discussed in Chapter 6, it can be considerably below unity and decreases with increasing γ -ray energy (see Figure 6-13). In this section, we wish to explore this effect.

Procedure:

1. Secure three calibrated γ-ray sources (such as ^{57}Co, ^{137}Cs and ^{60}Co) of varying γ-ray energy from your instructor. Using the optimal operating voltage and amplifier gain selected in Section 2 of this experiment, determine the net count rate due to each source. Be sure each source is placed in exactly the same position with respect to the detector when it is being counted. Record the data in Table V-3.

Table V-3

Source	Source Strength (γpm)	Eγ(MeV)	Total Counts	Counting Time	Count Rate (cpm)	Bkg	Net Count Rate
^{57}Co		0.122					
^{137}Cs		0.662					
^{60}Co		1.17 1.33					

2. Calculate the detection efficiency of your scintillation counter for each of the above sources, using equation V-1 below and record this information in Table V-4.

$$\text{Efficiency} = \frac{\text{Net Count Rate (cpm)}}{\text{Source Strength } (\gamma\,\text{pm})}$$

Table V-4

Source	E_γ (MeV)	Efficiency

3. Plot the log of the counting efficiency vs. the log of the gamma ray energy, E_γ, on log-log paper. Your data should resemble that shown in Figure 6-13. You should now be able to see that as E_γ increases, the detection efficiency decreased steeply. (In using the efficiency data you have now obtained for your counter, be sure to realize that it only applies for the voltage, amplifier gain and sample geometry conditions employed in this experiment.)

5. Gamma Detection Efficiency of the G-M Counter

As discussed in Chapter 5, the G-M counter is a notoriously poor detector for γ-rays. Just how poor the G-M counter is relative to the scintillation counter will now be demonstrated.

Procedure:

1. Select one of the calibrated sources used in Section 4 and present

it to a G-M detector, maintaining a sample-to-detector geometry as close as possible to that used with the scintillation detector. If the G-M tube is not equipped with a beta shield, some type of metal absorber sufficient to keep sample beta radiation from entering the detector should be interposed. Determine the net gamma counting rate for the sample and, as in Section 4, calculate the relative detection efficiency of the counter for gamma rays. A rough comparison of the gamma efficiency of the two counters can be obtained by examining this value and the value calculated in Section 4 for the same source.

Net Gamma Counting Rate ___________cpm
Detection Efficiency G-M Counter________

$$\frac{\text{Gamma Efficiency Scintillation Counter}}{\text{Gamma Efficiency G-M Counter}} =$$

C. Summary

The operating characteristics of the external scintillation counter examined in this experiment are quite in contrast to those of the G-M counter. First, the plateau length, slope, and potential vary with amplifier gain and gamma energy of the sample. One must select an optimal operating potential with each of these variables in mind. Secondly, the much higher background count rate of the scintillation counter and the tendency for this background level to rise sharply with increasing photomultiplier potential somewhat offsets the value of its greater gamma ray detection efficiency. Thirdly, although the G-M counter is quite highly efficient for detecting beta particles, it has a rather low gamma efficiency. In addition, the gamma efficiency of the external scintillation counter is dependent on the energy of the gamma radiation.