

INSTRUMENTATION FOR INTERNAL SAMPLE LIQUID SCINTILLATION COUNTING

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INTRODUCTION

THE best way to start a discussion of liquid scintillation counting is to look briefly at the equipment used for ordinary gamma scintillation counting. Figure 1 shows a typical gamma spectrometer. The common detection device used in such an instrument is a sodium iodide (thallium activated) crystal, usually canned in metal with a glass window optically coupled to the face of a photomultiplier tube. The radiation to be detected must be of a penetrating

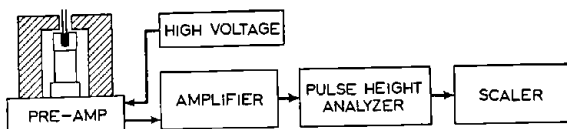


Fig. 1. Typical crystal scintillation spectrometer for gamma-emitting isotopes.

nature in order to get through the metal can and into the crystal. The radiant energy dissipated in the crystal takes the form of heat and light. The light causes emission of photoelectrons from the face of the photomultiplier. These photoelectrons strike the first dynode in the photomultiplier and cause, on the average say, three times as many secondary electrons to be emitted. These go on to the second dynode where they result, on the average, in the emission of approximately three times as many secondary electrons. These in turn go on to the third, fourth, etc., until they are finally collected at the anode. The over-all multiplication or amplification is thus very large. In a typical photomultiplier with ten dynodes using the factor of 3 just cited, it would be 3^{10} or approximately 60,000. If by increasing the high voltage applied to the photomultiplier the average multiplication factor is increased from 3 to 4, the over-all gain goes up to 4^{10} or a little over a million. The amount of gain required for any particular application, and hence the amount of high voltage to be applied, is determined by the average amount of light or the number of photons in the initial pulses.

For an efficient detector like sodium iodide and typical energetic gamma emitters such as iodine-131, cesium-137 and cobalt-60, it is not necessary to apply a very high voltage in order to get an output pulse at the anode that is

adequate for further electronic amplification. In a gamma spectrometer this electronic amplification is usually obtained entirely in the amplifier, with the preamplifier being simply a cathode follower with a gain of 1. The over-all gain in most spectrometers is selected to give output pulses over a 100 V range from the portion of the spectrum being examined. This 100 V span of pulses is then examined in detail by the pulse height analyzer and the desired portion recorded on the scaler. It should be noted that the gain of the photomultiplier is greatly dependent upon the high voltage—it varies roughly as the eighth power of the high voltage. Thus it is essential that an extremely stable high voltage supply be used in order to get the degree of stability desired for good scintillation work.

SINGLE PHOTOMULTIPLIER LIQUID SCINTILLATION COUNTING

To make the simplest type of liquid scintillation instrument for counting nonpenetrating alpha- or beta-emitting isotopes, it is necessary only to replace the sodium iodide crystal with a vessel containing liquid scintillator and an internal sample of radioactivity. This works, but it presents a great many problems.

First of all, the liquid scintillators that are currently available are not nearly as efficient light producers as sodium iodide. Also, the radiant energy is very much less for isotopes generally considered for liquid scintillation counting than it is for the penetrating gamma-emitters previously mentioned. The effect of both of these factors is to reduce greatly the size of the average light pulse, or the number of photons, available at the face of the photomultiplier. Thus it is necessary to use considerably higher gain in order to get output pulses of a suitable size for pulse height analysis and scaling. Most of this extra gain should be obtained in the electronic amplifier rather than by increasing the photomultiplier high voltage to levels that might cause undesirable side effects. The use of high over-all gain brings out an inherent characteristic of the photomultiplier which is of no consequence in ordinary gamma applications. This is the so-called 'dark noise', at least a part of which is known to be a thermal effect.

The material of the photocathode, usually cesium-antimony, is selected for its low work function in order to be an efficient producer of photoelectrons. But because of its low work function it also emits electrons thermionically at low temperature. With the over-all amplification used in ordinary gamma work, thermal pulses are too small to be noticed in comparison to the large gamma pulses. However, at the much higher gains required for internal sample liquid scintillation counting, these pulses are of the same order of magnitude as pulses resulting from the isotope radiation. Hence they constitute

a background count which it would be desirable to eliminate or at least to minimize.

It should be noted, in particular, that this background count originating from the photomultiplier dark noise is not very reproducible as is ordinary background radiation from radioactive sources. It varies considerably without correlation to other obvious factors. This means that any contribution to background from this particular source is a much more serious problem in establishing the true count in the sample than a similar contribution from some radiation source.

One approach toward the avoidance of the thermal effect is to cool the photomultiplier to extremely low temperature as with liquid nitrogen. Another is to try to maximize the light output by using only pure samples of more energetic isotopes and to handle each sample with special precautions such as flushing the oxygen out and sealing the vial. Neither of these approaches is very practical for routine tracer studies.

There are many other problems encountered in trying to do liquid scintillation counting with a single photomultiplier setup. Phosphorescence of the sample vessels and of the glass in the photomultiplier tube itself is probably one of the more serious. Even without the thermal effects, this problem of phosphorescence is enough to make it impractical to do typical tritium tracer work or counting of carbon-14 samples with compounds or systems that have quenching or color effects. And perhaps it should be emphasized here that these effects are present in a great many of the practical counting systems that people wish to use. It certainly would not be at all unusual for some common carbon-14 sample to cause light loss in the order of 50% from that which could be obtained with a pure carbon-14 system.

Even for samples of carbon compounds that cause no quenching and have no color effects, it may be necessary to use special individually calibrated quartz vessels that have been flamed and dark adapted. For routine, practical counting we consider procedures of this sort to be entirely unsatisfactory. And certainly we do not believe that equipment having this sort of limitation would be commercially acceptable. A person who builds such an apparatus for himself might well be content to work within these restrictions, but our experience with people who purchase instruments is that they definitely would not be satisfied with the kind of performance that can be obtained today with single photomultiplier liquid scintillation equipment.

PHOTOMULTIPLIERS

In the course of our work we have had occasion to examine many hundreds of photomultipliers. Primarily we have been concerned with the Du Mont type 6292 because we have found it to be the most satisfactory tube that is currently available for our purposes. However, we have examined many other

photomultipliers, such as the RCA 5819, RCA 6342, RCA 6810, Du Mont 6467, and a few others. In an effort to get some kind of insight into this dark noise characteristic of photomultipliers, we have made a special detailed study of a group of twenty-four 6292's. (The rough work sheets shown at the Conference are omitted from this publication.) About half of the tubes were selected as being representative of acceptable quiet tubes that might be used in Tri-Carb spectrometers, and the other half were selected as more or less typical reject tubes, with the noisiest tubes eliminated from the study because it would have been impossible to follow their very high noise rates for more than a few high voltage taps.

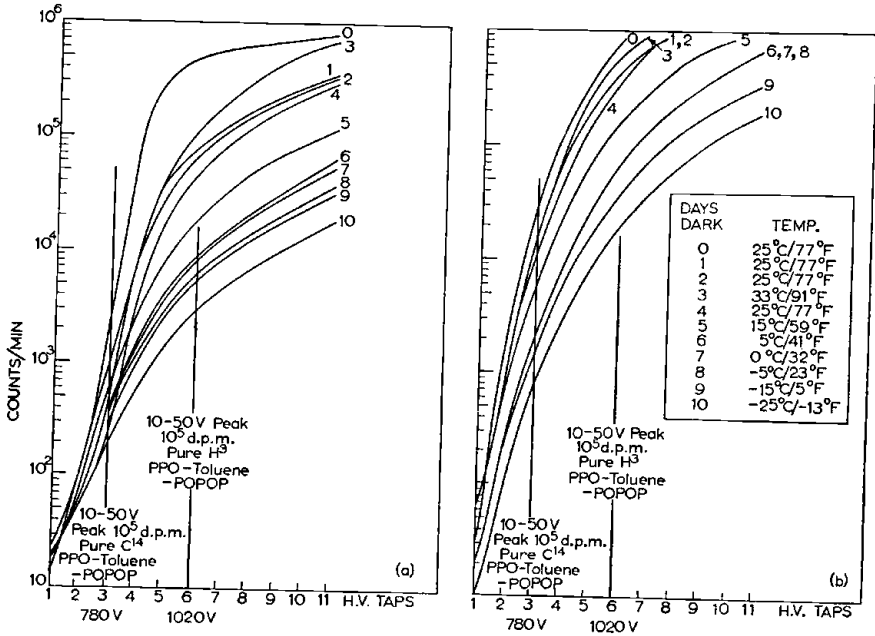


Fig. 2. Semi-log plots of the 'dark noise' of two Type 6292 DuMont Photomultipliers. (a) Typical 'quiet' tube, Serial No. 4724. (b) Typical 'noisy' tube, Serial No. 2431.

Figure 2 shows a typical quiet tube on the left and a typical noisy one on the right. These were representative of the two groups of the twenty-four tubes studied—not the quietest of the quiet nor the noisiest of the noisy. The vertical scale is cpm of dark noise on a five-cycle log plot from 10 to 1,000,000, and the horizontal is photomultiplier high voltage in tap settings with reference voltages shown.

The procedure followed in this experiment on these tubes was to set them all photocathode-up exposed to room light at room temperature for 24 hr. Each tube was then taken individually, sealed in a light-tight can, and immediately operated for a plot of dark noise vs. high voltage. The top or

zero curves show these data. Then after one day with the tubes stored dark at room temperature, the entire group was run again. The data from this run are shown by curves marked 1 which, it should be noted, are not the second curves down, but rather the ones below that or the third curves from the top. Then after another 24 hr, again at room temperature, the process was repeated once more. These data, after two days, are shown by the curves marked 2. In the case of the quiet tube this curve lies just below 1; in the case of the noisier tube, it is coincident with curve 1. At this point it appeared that they were leveling off, and the rest of the experiment—which was to study temperature effects—was begun. The temperature of the tubes, still in the dark, was raised to 33°C which was considered a warm room temperature (91°F). The data are shown by the curves marked 3. In both cases they are above curves 1 and 2 but below the initial zero curve. Having taken the data at 33°C the tubes were returned to room temperature and after another 24 hr a run was made as shown on the curves marked 4, which in both cases—the quiet tube and the noisy tube—lie slightly below the room temperature curves previously taken. The temperature was then lowered to 15°C, 24 hr

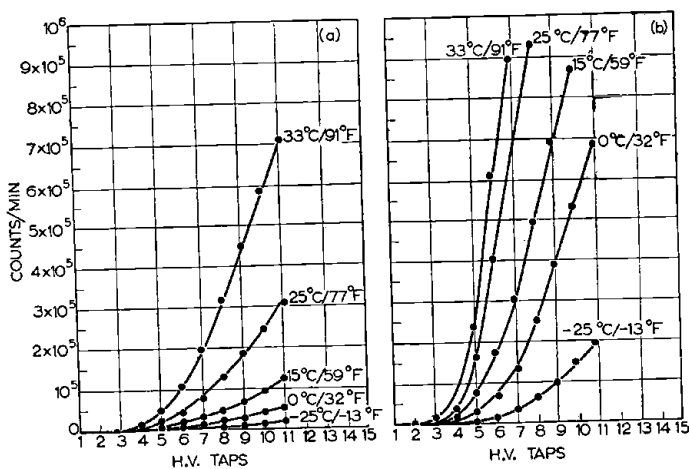


Fig. 3. Linear plots of the main temperature data from Fig. 2 showing the difference between typical 'quiet' (a) and 'noisy' (b) tubes.

elapsed and the data shown in the curves marked 5 were taken. In both cases this makes a significant difference in the noise rate. Next the temperature was lowered to 5°C, and after another 24 hr, the data obtained for the curves marked 6. This procedure was repeated successively, each time with a 24 hr wait, and the curves marked 7 show the data for 0°, 8 show -5°, 9 show -15° and finally 10 show -25°C.

As reference marks, two vertical lines are shown in each plot. The one on the left, at tap 3 or 780 V, is the location of the 10-50 V peak (discussed

later) for a pure carbon-14 sample dissolved in toluene, PPO and POPOP. The one on the right, at tap 6 or 1020 V, shows the location of the 10–50 V peak for a pure tritium sample in the same solvent system. The height of the lines indicates the absolute counting efficiencies with 100,000 disintegrations/min in each sample. This shows that both tubes had efficiencies of slightly over 50 per cent in the 10–50 V window for carbon-14 and between 15 and 20 per cent in the 10–50 V window for tritium. It should be emphasized that these are five-cycle semilog plots used for the sake of showing complete detail over the range of 10–1,000,000 counts/min.

For a more graphic illustration Fig. 3 shows linear plots of the same data. Here the first few days of dark adaption have been eliminated, and only the temperature effects are shown. Since it is difficult to visualize the extension, on the noisy tube, of the upper curves to heights way above the top of the plot, perhaps the best comparison can be made from the 0° curves for both tubes.

Still another way of showing the data is presented in Fig. 4. Here at one high voltage tap, No. 6, the tritium operating point for both of these tubes, the dark noise has been plotted against temperature. It is of particular

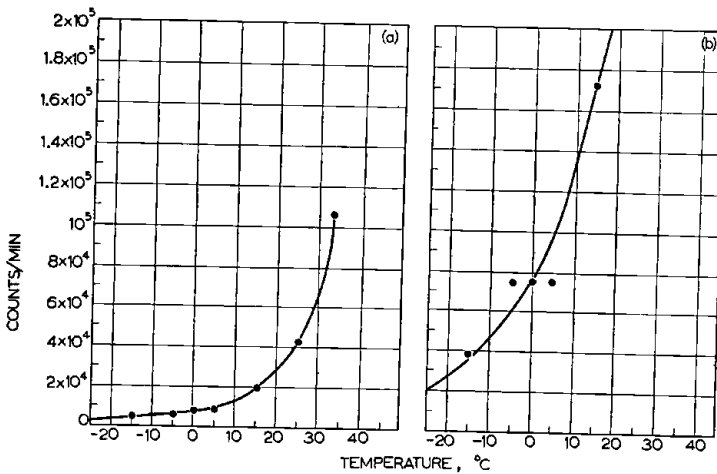


Fig. 4 'Dark Noise' shown as a function of temperature at a fixed high voltage setting of tap 6 or 1020 V for the same 'quiet' (a) and 'noisy' (b) tubes shown in Figs. 2 and 3.

interest to note the slopes of the curves at low temperature contrasted with those in the region of room temperature. For the acceptable tube at 0°, a variation of $\pm 5^\circ$ makes very little change in the dark noise. However, for the same quiet tube at 25°, a spread of $\pm 5^\circ$ gives a rather considerable change in dark noise. So to operate liquid scintillation equipment at room temperature, as we are operating the Tri-Carb spectrometer on display here

at Northwestern during this Conference, it is certainly desirable to know what room temperature is and how much it varies.

After looking in detail at the Du Mont 6292 photomultipliers, the question naturally arises as to whether the data would be similar for other types of photomultipliers. In an attempt to find the answer to this question, a group of Du Mont 6467's, which we found to be the second best tube type available for this kind of work, was examined in detail. (The rough work sheets on these tubes shown at the Conference are omitted from this publication.) The general shape of the noise plots is essentially the same as for the 6292's. The best tubes of this type were not as good as the average good tube in the 6292 group. Also, generally the efficiencies were not as high as with the 6292.

So with this background information on photomultipliers—the main problem in liquid scintillation counting—we go on to what is generally considered to be the best equipment for this type of counting, namely, the coincidence instrument with pulse height analysis.

TRI-CARB LIQUID SCINTILLATION SPECTROMETER

Figure 5 shows a simplified diagram of the Tri-Carb spectrometer. Here, instead of having one photomultiplier looking at a vessel containing the liquid scintillator and the internal sample of radioactivity, we have two

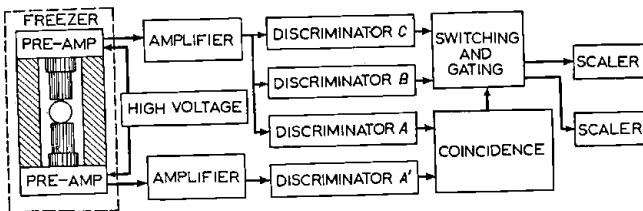


Fig. 5. Simplified block diagram of the Tri-Carb liquid scintillation spectrometer.

photomultipliers. Each has its own preamplifier and amplifier. The output pulses from the amplifiers go on to discriminators. In the simplest setup we would have only discriminator *A* and discriminator *A'* feeding into the coincidence circuit, which in turn would feed into one scaler. However, for a more sophisticated setup, we add discriminators *B* and *C*, and some switching and gating which then become necessary, and we use two scalers. In this arrangement we are able to get two channels of pulse height analysis. This is useful in counting samples with a single isotope for reasons such as control of background or quench and color effects. Obviously it is useful in the simultaneous counting of two isotopes in a single sample.

Photomultipliers are placed in a freezer and ordinarily operated in the neighborhood of 0°C . This reduces the number of thermal pulses originating in each photomultiplier. The coincidence circuit then practically eliminates

those that remain. (A couple of counts/min of 'accidentals' are considered acceptable at a tritium operating point.) When a pulse of light originates in the sample vessel, it is seen simultaneously by both photomultipliers—the pulses proceed through their respective preamplifiers, amplifiers, and discriminators and arrive at the coincidence circuit simultaneously—thus causing this circuit to produce an output pulse. On the other hand the thermal noise pulses occur randomly and independently in the two photomultipliers and do not arrive at the coincidence circuit at the same time (except rarely by accident), and thus they are not permitted to pass this point to be recorded.

Similarly the coincidence circuit eliminates effects of phosphorescence in the sample vial and photomultipliers. The reason for this is that this is a single photon phenomenon; the light is not emitted in large pulses or bursts of photons as is the case with radioactive disintegrations in the scintillator. The photons from the phosphorescence are emitted randomly one at a time, and they can go to one photomultiplier or the other—but not to both. Then, due to the quantum yield of the photocathode, only about 10 per cent of those photons that reach a photomultiplier will cause photoelectrons to be emitted. Thus it is apparent that the level of phosphorescence would have to be quite high to create a noticeable effect in a coincidence-type instrument. DAVIDSON and FEIGELSON¹ have reported that exposure of sample vials to ultraviolet radiation immediately prior to counting can create levels of phosphorescence that will give high counting rates.

For purposes of pulse height analysis in the Tri-Carb spectrometer, we try to approach what we would consider the ideal situation if there were no problems such as dark noise and phosphorescence, namely, that of having only a single photomultiplier. In other words, we perform pulse height analysis on the output from one photomultiplier only; this we call the analyzer. The other we call the monitor, and there no pulse height analysis beyond the base line or *A'* discriminator is used. A higher gain photomultiplier is selected for the monitor so that it can most efficiently perform its simple function of establishing coincidence. The gain of the analyzer is determined by the portion of the spectrum to be observed; excess gain cannot be utilized.

A more detailed block diagram of the Tri-Carb spectrometer is presented in Figs. 6, 7, 8 and 9. The lower right-hand part of each figure shows part of the front panel of the control console as it appears in the four different modes of operation indicated in these figures. The little array of lights associated with the selector switch and with the three discriminator helipot shows graphically these modes of operation.

Selector position one, shown in Fig. 6, gives single channel operation. This is not a normal operating position, but is rather a mode of operation used for servicing or for checking dark noise in the individual photomultipliers. There is no coincidence in this position. The output from the *A* or

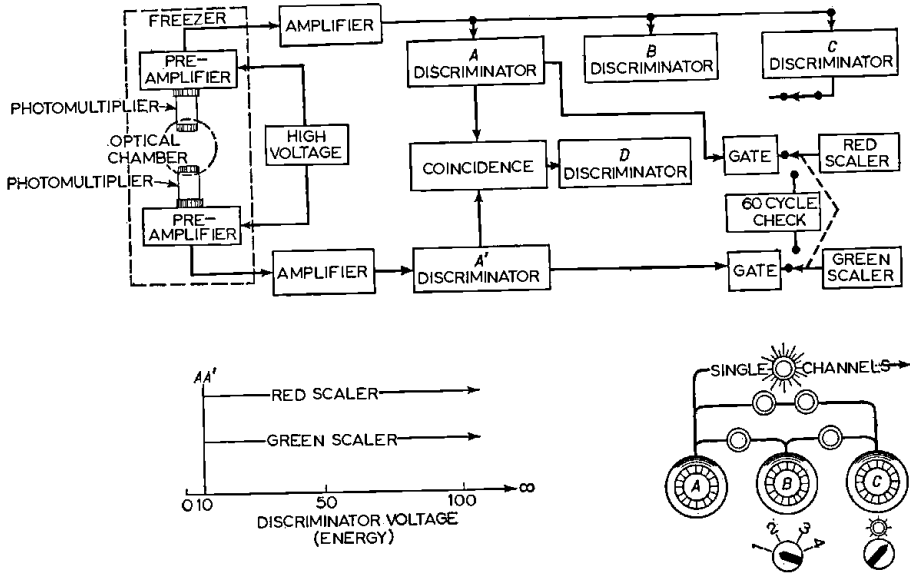


Fig. 6. Detailed block diagram—selector position 1.

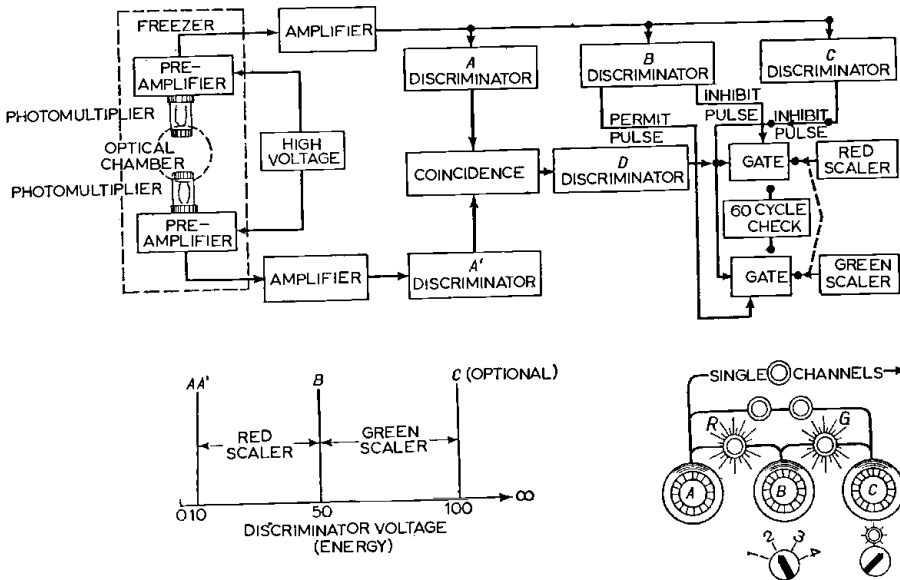


Fig. 7. Detailed block diagram—selector position 2.

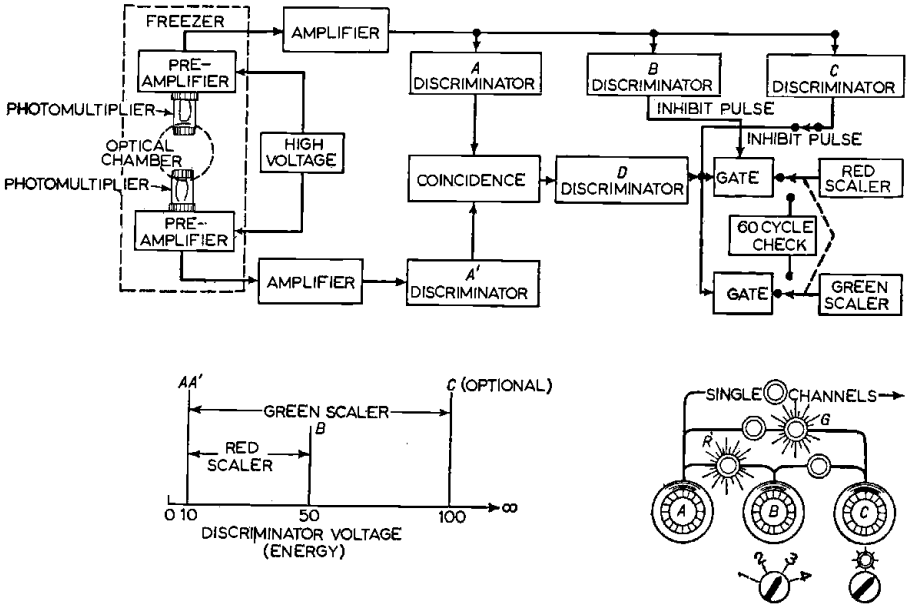


Fig. 8. Detailed block diagram—selector position 3.

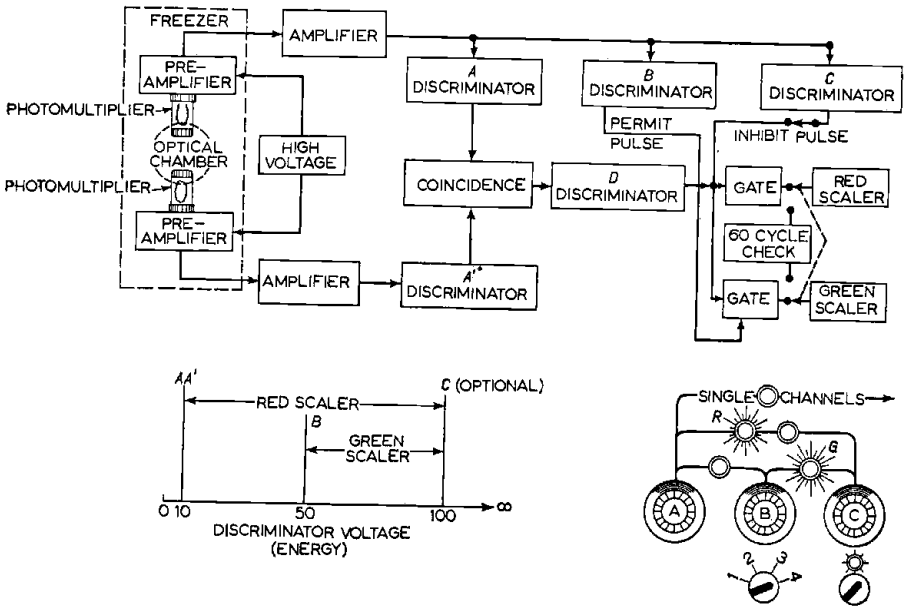


Fig. 9. Detailed block diagram—selector position 4.

analyzer photomultiplier goes through the complete *A* channel of electronics—preamplifier, amplifier, *A* discriminator—and on to the red scaler. The output from the *B* or monitor photomultiplier goes through the *B* channel—preamplifier, amplifier, *A'* discriminator—and on to the green scaler. It should be noted in passing that no upper level discrimination is used in this mode of operation—all pulses which exceed the setting of discriminators *A* and *A'* are counted.

Selector position two, shown in Fig. 7, is a normal coincidence mode of operation. All pulses that exceed the *AA'* discrimination level but which are smaller than the *B* discrimination level are recorded in the red scaler. All pulses above the *B* discriminator but which do not exceed the *C* discriminator (when it is turned on) are recorded in the green scaler. When the *C* discriminator is not turned on, all pulses which exceed the *B* discriminator level are recorded on the green scaler.

Selector position three, shown in Fig. 8, is probably the most commonly used mode of operation of the Tri-Carb spectrometer. Typical operating conditions might have the *AA'* discriminator set at 10 V, the *B* discriminator set at 50 V and the *C* discriminator turned off. Thus all pulses from 10 to 50 V would be recorded in the red scaler and all pulses which exceed 10 V ($10-\infty$) would be counted on the green scaler. From Fig. 8 it may be seen that a pulse which triggers both the *A* discriminator and the *A'* discriminator causes the coincidence circuit to fire through the *D* discriminator, thus establishing a permit pulse in both the red scaler gate and the green scaler gate. Then if the pulse is big enough to fire the *B* discriminator also, an inhibit pulse is fed to the red scaler gate so that the pulse does not record in that scaler (10–50 V window). If the *C* discriminator is off, no inhibit pulses can be fed to the green scaler gate and all pulses which are big enough to establish permit pulses will be recorded on the green scaler ($10-\infty$).

Selector position four, shown in Fig. 9, is simply one more mode of operation which can be used to present the data in a different form.

LIQUID SCINTILLATION COUNTING DATA

What is the basis for the data presentation used in liquid scintillation counting? It is extremely important that this be clearly understood in order to comprehend all of the data to be presented subsequently. Figure 10 shows the relationship between the actual pulse picture occurring in the instrument and the unique counts/min vs. high voltage plot used in liquid scintillation work.

When a low voltage is applied to the photomultiplier as in the left-hand side of Fig. 10, all of the pulses are small; very few of them exceed the 10 V discrimination level shown in the pulse picture. In the curve this is shown as a low count. When the voltage is increased, as in the center of the figure, the

pulses become larger; most of them fall somewhere between the 10 V and 50 V discrimination levels shown. Consequently in the curve, this is shown as a rather high counting rate. The upper curve is the integral count, or everything above 10 V in this case. It naturally begins to exceed the 10–50 V curve as soon as some of the pulses are amplified to levels greater than 50 V.

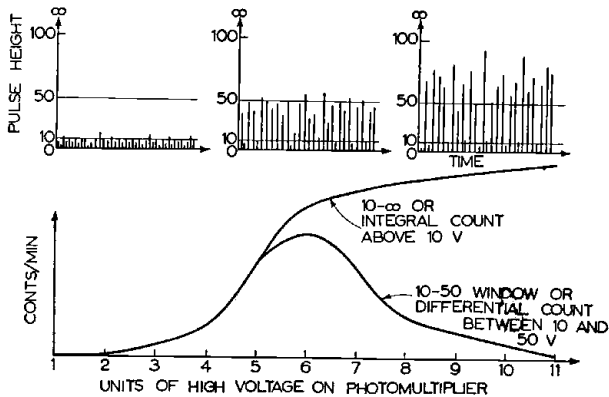


Fig. 10. Relationship between the actual pulse picture and the unique 'counts/min vs. H.V.' plot used in liquid scintillation counting.

As still higher voltage is applied to the photomultiplier, the pulses continue to grow and more and more of them exceed the 10 V level. Thus the integral curve continues to rise; it can never decrease. It can, however, level out as the condition is approached where 100% of the pulses exceed the 10 V level. On the other hand, when the voltage is increased and the pulses are all large, it is apparent that the count rate in the 10–50 V window will again be very low. This is the situation at the right-hand side of Fig. 10.

Figure 11 presents some actual data using the plot just described. It shows absolute counting efficiency of a pure sample of carbon-14 labeled benzoic acid when counted in several different discriminator windows as photomultiplier high voltage is varied.

Perhaps for someone who has not worked in this field at all, the question arises: 'Why not operate with no upper discriminator at the highest voltage and thus obtain the highest efficiency possible?' The reason is simply that the background count increases so that it isn't always desirable to maximize efficiency. In order to get a more favorable background, an upper discriminator is utilized and counts are taken in something like the 10–50 V window shown. This is not an arbitrary thing though, and fixed values cannot be assigned to be used in all situations. The actual choice of discriminator settings to be used depends upon the particular sample, sample vessel and instrument being used. The operator must decide on the basis of these factors just which levels of discrimination will give the best results.

One obvious reason for operating at the peak of a differential curve is that it gives the highest efficiency possible in the particular discriminator window selected. But another reason for operating right at the peak was first pointed

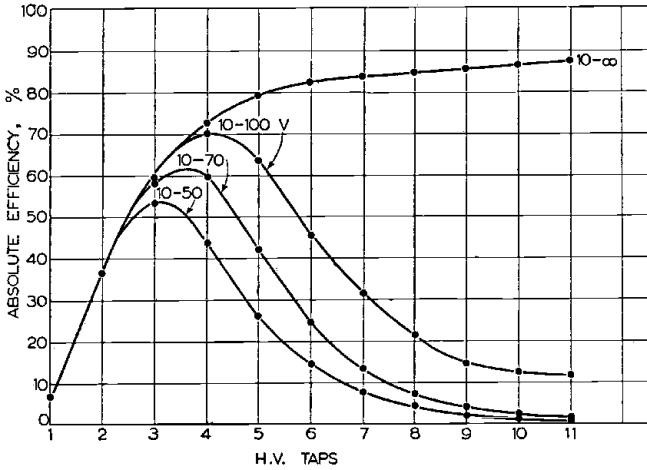


Fig. 11. Typical counting efficiencies with various discriminator window settings using a pure sample of benzoic- C^{14} acid in toluene, PPO and POPOP.

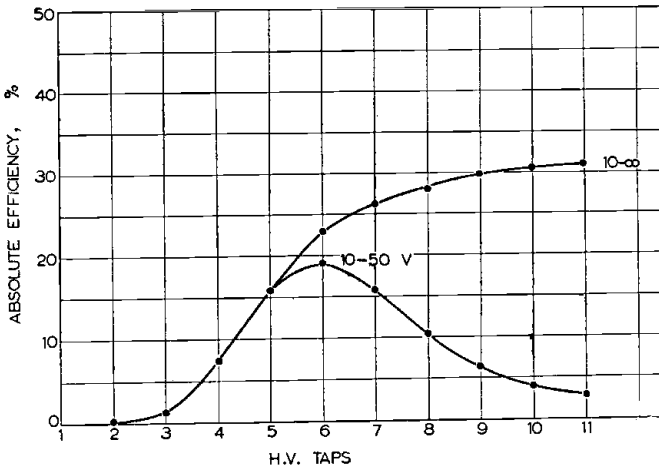


Fig. 12. Typical counting efficiencies using a pure sample of tritiated toluene in toluene, PPO and POPOP.

out by ARNOLD² and described as balance-point operation. Certain factors in the over-all counting setup are subject to variations which can result in slight changes in pulse amplitudes with time. These factors can be in the sample itself, in the optics of the sample chamber, or in the electronics. But regardless of where such variations may occur, the resultant changes in count

rate will be very much less if operation is originally established at the peak of a differential curve than they would be if integral operation were used or if differential operation were used on a steeply sloping part of the curve rather than at the peak.

Figure 12 presents some quantitative data on a pure sample of tritiated toluene in toluene, PPO and POPOP. The sample was counted in one of the ordinary 5 dram vials most commonly used in the Tri-Carb spectrometer. For integral operation, $10-\infty$, it shows an efficiency of a little over 30%. For differential operation in a $10-50$ V window, it shows approximately 20% efficiency. Using a special sample vessel, in the form of a right circular cylinder with the ends optically coupled to the two photomultipliers, it is possible to get integral operation up to around 50% efficiency on such a sample of tritium.

Figure 13 shows something that is of particular concern to people interested in the practical, everyday use of liquid scintillation counting techniques—

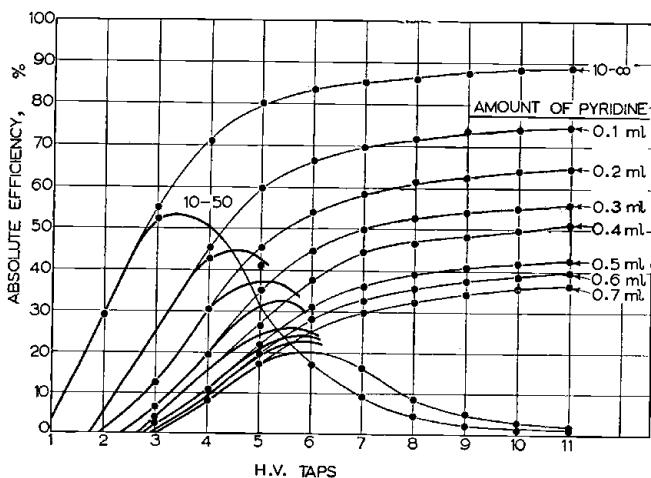


Fig. 13. Quench effects with the addition of pyridine to benzoic- C^{14} acid. Initial total volume was 16 ml and total activity was 115,200 disintegrations/min.

quench effects of a sample on the scintillation solution. The first or highest curves show integral and differential operation with a pure sample of benzoic- C^{14} acid. The total sample volume was 16 ml and the total carbon-14 activity was 115,200 disintegrations/min. The succeeding curves show the effects of adding 0.1 ml aliquots of pyridine, a severe quencher. It is important to note that the effect of quenching is not only to reduce the maximum efficiency, but also to shift the curves to the right. This indicates that the light pulses have been degraded and it is necessary to apply more high voltage in order to see the equivalent curves.

It is apparent from Fig. 13 that it would be undesirable to count a quenched sample of carbon-14 at the same high voltage ordinarily used for a pure sample of carbon-14; the efficiency would be greatly reduced and the advantages of balance-point operation would be completely lost. This means that if an instrument is to be used for practical carbon-14 counting where quenching may be encountered, it must be capable of counting, without excessive background from dark noise and phosphorescence, at the higher gain required—and this can be as high as required for tritium work.

An interesting difference between carbon-14 and tritium counting may be observed by studying quenching curves. When successive aliquots of quench material are added to a pure tritium sample, the resulting curves lie almost directly below the pure sample curve. There is practically no shift to the right as there is in the case of carbon-14. This indicates that the number of photons caused by each tritium disintegration is so small that most of the pulses resulting in the photomultipliers start from single photoelectrons off the photocathodes. In other words, it is not possible to get smaller size pulses through the photomultipliers. As the originating light pulses are degraded by a quench material, we simply find that fewer pulses happen to be detected at the photocathodes.

It has been estimated that an average tritium pulse of about 6 keV will cause the emission of some 30–40 photons in a scintillation solution such as the common toluene, PPO and POPOP. If the optics were perfect, the average number of photons going to each photocathode would be 15–20. Then, assuming a photocathode efficiency of about 10%, the average number of photoelectrons emitted from each photocathode for this average tritium pulse would be between 1 and 2. Since the optics are not perfect, and since tritium pulses smaller than the average will create fewer photons, it is obvious that not every tritium disintegration will result in a pulse getting through each photomultiplier to establish a coincidence count. This is the reason that maximum efficiencies approaching 100% cannot be obtained for tritium as they can be for carbon-14, which in a pure sample will cause nearly ten times as many photons as tritium. Scintillators capable of greater light output and photocathodes with higher quantum yields would both be very helpful in improving counting efficiencies for tritium samples.

AUTOMATIC TRI-CARB SPECTROMETER

Figures 14, 15 and 16 show the physical appearance of the commercial liquid scintillation counting instrument which we manufacture—the Tri-Carb liquid scintillation spectrometer.

Figure 14 shows the sample chamber for the manual Model 314. This is shielded by 2 in. of lead in all directions, including the ends where large lead slugs are incorporated into the preamplifier construction.

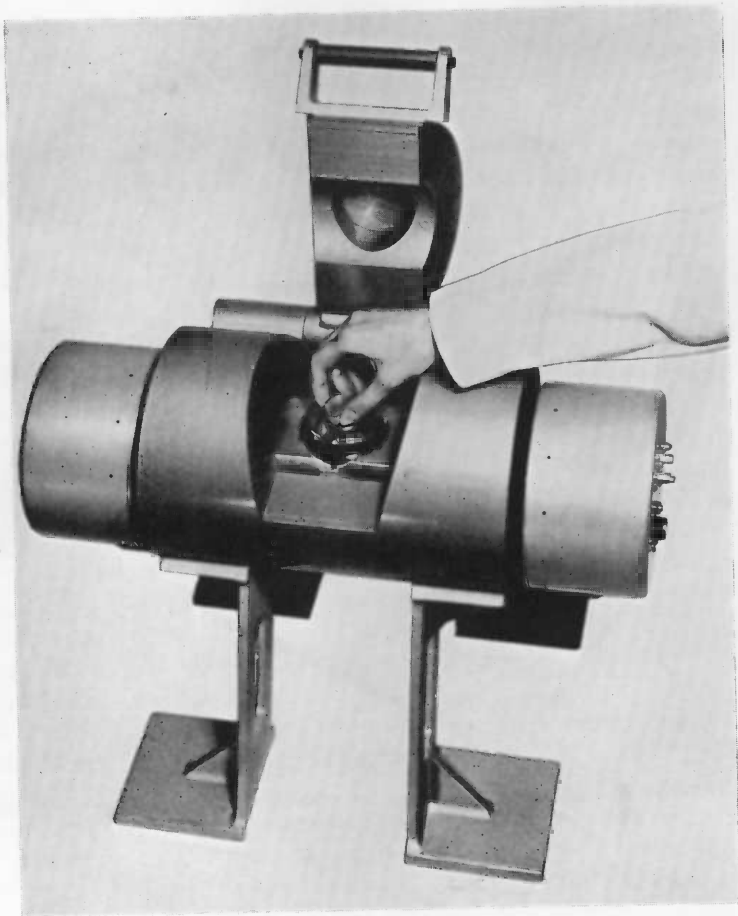


Fig. 14. Lead-shielded sample chamber used for manual counting of individual samples in the Tri-Carb spectrometer.



Fig. 15. Iron-shielded sample chamber used for automatic counting of up to 100 samples in the automatic Tri-Carb spectrometer.



Fig. 16. Overall view of the automatic Tri-Carb liquid scintillation spectrometer showing samples being loaded into the turntable inside the freezer prior to automatic counting.

Figure 15 shows the automatic sample changing device for the automatic Model 314X. It handles up to 100 standard 5 dram vials. A different turntable is available for handling larger vessels. Samples are loaded into the turntable which has both rotation and translation mechanisms. An elevator lowers the sample vial to be counted into a light-tight chamber where it is moved around in an arc 180° to the exact center of the large iron block. There a second elevator lowers the vial to the counting chamber between the two photo-multipliers. The actual counting chamber is shielded by 4 in. of iron.

Figure 16 shows an over-all view of the automatic Model 314X being loaded with samples. In addition to the standard Tri-Carb electronics which have been described earlier, this unit consists of switchgear necessary for the sample changing device, an electronic timer, and a completely transistorized readout, all located in the auxiliary cabinet on top, and a digital printer located on the side of the main control console. Operation is based on both preset time and preset count; whichever setting is reached first stops the count, and all the data is printed out as follows:

- Sample number
- Time to hundredths of a minute
- Red scaler count
- Green scaler count

Figure 17 shows a greatly simplified block diagram which breaks down the automatic operation into a programming cycle and a printout cycle. There

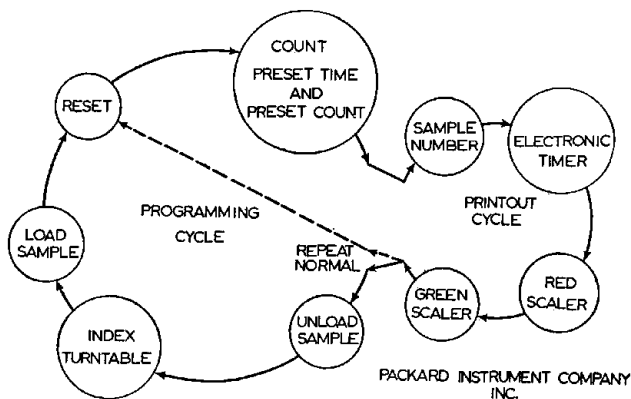


Fig. 17. Simplified functional diagram of the automatic section of the Model 314X automatic Tri-Carb liquid scintillation spectrometer.

are two basic modes of operation for this equipment—normal and repeat. In normal operation the sample is loaded, counted, the data printed out and the sample unloaded. The turntable then indexes the next sample into position and the cycle repeats. When all of the samples have been counted, the turntable resets to the number 1 position and they are all counted again; this

continues until the instrument is stopped by the operator. In the repeat position, a single sample is counted over and over, as for statistical studies.

The introduction of completely automatic equipment has added, to an already impressive list, one more important reason for the rapid increase in the use of internal sample liquid scintillation counting.

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