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Author
Jenkins, Kenneth Durl.

Publication Date
1952-05-01
UNIVERSITY OF CALIFORNIA
Radiation Laboratory

Contract No. W-7405-eng-48

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SCINTILLATING CRYSTAL GAMMA COUNTER
Kenneth Durl Jenkins
(Thesis)
May, 1952

Berkeley, California
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Abstract of
"Scintillating Crystal Gamma Counter"
(Master's Thesis)
Kenneth D. Jenkins
B.S.(University of California) 1948

A description will be given of a simple counter which makes maximum use of existing commercial equipment and will count gamma rays down to ten kilovolts with no appreciable electrical or thermal noise being introduced. The counter has good stability and its gain can be made to stay constant indefinitely.
ACKNOWLEDGEMENTS

The writer wishes to express his gratitude to Dr. Kenneth Scott, Dr. Joseph G. Hamilton, and Dr. Thomas M. Putnam for making available the time and equipment necessary for the progress of the project, for their general assistance throughout the course of the project, and for their help in preparing this paper. The writer wishes especially to thank Jack Alley for his able assistance and indoctrination during the early part of this work.
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INTRODUCTION

The interest in crystal counters has grown considerably in the past few years, primarily because of the increased availability of a wider variety of scintillating crystals and the development of specific photomultiplier tubes for this type of counter. A few articles\(^1,2,3,4\) on various phases of work on scintillating crystal counters have appeared recently, but in none thus far has there been any attempt to set forth most of the parameters necessary for designing an efficient counter.

Two approaches will be put forward in this paper: one primarily for the nuclear research workers and radio-biologists who are not electronics engineers, in which a simple counter making maximum use of existing commercial equipment will be described; the second, delving into some of the more technical aspects of the subject, to assist the experimenter to build the most efficient counter for his specific purpose.

A simple counter should meet the following specifications:

1. Be a direct replacement for a G-M tube and its quenching amplifier on a scaler having a regulated high voltage supply.

2. Be able to measure efficiently all gamma energies above 50 kilovolt without the introduction of any thermal tube noise at room temperature.

3. Be small enough to be moved about with one hand while in operation, and to be placed within a radiation shield no larger than that necessary for a G-M tube.
4. Have a simple method for indefinitely maintaining a constant counting efficiency.

The crystal, photomultiplier tube, and pre-amplifier are mounted as a single unit about 2-1/2 inches in diameter and 10 inches long, as shown in Fig. 1. The unit is designed to be plugged into a scaler having an input voltage sensitivity between 0.1 and 1.0 volts and a regulated high voltage supply adjustable between 700 and 2,000 volts.

A thallium-activated sodium iodide crystal 1-1/2 inches in diameter and 1/2 inch thick is used because of its high efficiency for detection of gamma rays. As the crystal is hygroscopic, it must be protected from the atmosphere; this protection is accomplished by sealing the crystal in dry oil on the face of the photomultiplier tube, thus offering the best possible light geometry. The photomultiplier tube (5819) is especially selected for its low thermal tube noise. The circuit (Fig. 2) was designed for use on a Tracerlab "Autoscaler". The pre-amplifier has a gain of approximately 200, yet it is able to pass a pulse sufficiently sharp to operate a scaler without any coincident correction for counting rates up to 10,000 counts per second. The amplifier is not a linear amplifier, but it is designed to take a wide range of input voltages without blocking. The voltage applied to the photomultiplier is only half that supplied by the scaler, thus preventing the accidental application of an overrated voltage to the tube.

The counter may be put inside of a lead shield and radioactive samples placed under it, in a manner similar to that done with a G-M tube; or a
Fig. 1

Preamplifier-photomultiplier-crystal-assembly
Fig. 2

Preamplifier circuit
directional shielding cone may be screwed onto the end of the photomultiplier tube.

Several counters such as the one described above have been in use at the University of California for over a year and have given excellent results.

In studies upon biological material the crystal gamma counter has made practicable the use of many new radioactive elements for which the counting efficiency of the G-M tube is too low to be satisfactory. In counting most gamma rays there is no problem with self-absorption, thus making unnecessary the reduction of the tissue to an ash, as in beta-counting thereby both eliminating one possible source of error and speeding up the process to reduce the time necessary for the counting of short half life isotopes.

In medical research the greater efficiency of the crystal counter makes it possible to use smaller doses of radioactive materials such as $^{131}$I in the evaluation of thyroid function without a reduction in counting rates or accuracy. Because of this the patient receives less undesirable radiation from the test dose than previously.

A typical set of curves (Fig. 3) of counting rate versus photomultiplier tube voltage is shown for four different radioactive elements. The gain is varied by varying the volts per stage on the photomultiplier tube; thus gain and voltage are synonymous. With a low voltage only the most energetic of the gamma rays are counted. As the voltage is increased the counting rate increases rapidly at first, but with a further increase in
Counting rate of several radioactive samples, as a function of the volts per stage of the photomultiplier tube. The threshold energy is the voltage required to make a given gamma ray energy give a count of half the count of its plateau.

The crystal used was of sodium iodide; it was 1-1/2 inches in diameter, 1/2 inch thick, and weighed 65 grams. It had been sealed for four months before curves were taken. The Co\textsuperscript{60} sample was spread evenly in a 1-1/2 inch porcelain dish and placed 3 inches from the crystal face. The same sample in the same position gave a beta-gamma count of 830 c/s on a G-M tube which had a 1.43 mg/cm\textsuperscript{2} mica window 6.4 cm. in diameter. Using a 110 mg/cm\textsuperscript{2} aluminum beta shield lowered the counting rate to 97 c/s. The I\textsuperscript{131} sample was prepared and counted in the same manner as the Co\textsuperscript{60}; the beta-gamma count on the G-M tube was 950 c/s, while the gamma count was only 14 c/s with a lead beta filter. The Am\textsuperscript{241} standard was a point source placed 1/2 inch from the crystal; the standard gave a count of 1300 c/s in an internal gas ionization counter which has a 40\% geometry. The Cd\textsuperscript{109} standard gave a count of 14 c/s on the above G-M tube.
voltage the counting rate flattens off into a plateau. Successively weaker gamma rays require correspondingly greater voltage before they are counted. If the threshold for any gamma ray energy is considered to be the gain required to count 1/2 the count of the plateau, a plot of threshold energy versus gain will be a straight line. By considering the thermal and electronic tube noise as having a threshold when the tube noise count is equal to the radiation background count, an equivalent energy can be established for the tube noise. If a long half life standard having a low-energy gamma ray is used, for example Am$^{241}$ or Cd$^{109}$, the voltage can be adjusted to the threshold of their energy, thus making the overall gain constant. The standard used to set the gain should have a gamma ray energy preferably less than 1/3 the energy of the sample, in order to operate on the plateau for that sample. In the event that the sample has a secondary threshold near the gain setting of the selected standard, another standard should be used, or the gain should be adjusted to a different point on the threshold curve. It is recommended that a curve of counting rate versus photomultiplier tube voltage be made for any new radioactive element in order to determine the proper point at which to set the standard so as to count the sample on the flattest part of its plateau. The setting at a constant gain is not to be confused with counting efficiency, as it will take care of the aging of the tubes and surface clouding of the crystals only; counting efficiency is governed by the physical size and shape of the crystal and the relative position of the radioactive sample to the crystal.
When counting samples that have both gamma and beta rays present, it is necessary to be sure that sufficient absorber is placed in front of the crystal to remove all of the beta radiation. In the case of $^{131}I$, 200 mg of aluminum per square centimeter is adequate.
CRYSTALS

The choice of the type of crystal to use in a scintillation counter is governed by several factors: physical qualities, cost, decay time, light yield, and efficiency.

The light decay time must be short enough to avert overlapping of the light pulses in fast counting. Whether a crystal with a very short or a relatively long time constant is used, the pulses from the photomultiplier tube are very short, similar to the noise pulses, when the crystal is made to scintillate by a weak gamma ray; a strong alpha or beta ray is required to give off enough photons for the photomultiplier tube to see the whole duration of the light pulse.

The relative light yield of the crystal affects the equivalent energy of the photomultiplier tube noise.

The efficiency of a crystal is dependent upon its ability to stop gamma rays, which are stopped according to the probability of their striking an electron; thus the absorption is on a logarithmic basis:

\[ I = I_0 e^{-\mu x} \]

- \( I \) - gamma intensity out of absorber
- \( I_0 \) - original gamma intensity
- \( \mu \) - mass absorption coefficient
- \( x \) - thickness of absorber

There are three methods of gamma ray absorption which contribute to the mass absorption coefficient. First, the photoelectric absorption (\( \mu_p \)), which is most important at low energies:
\[ \mu_p = \frac{Z^5}{E^{7/2}} \]

Z = atomic number
E = Gamma ray energy

Second, Compton scattering (\(\mu_s\)), which is the most important method of absorption for most gamma rays used in tracer work, i.e. in a range from 100 KW to 1 Mev:

\[ \mu_s = \frac{Z}{E} \]

The third method, pair production, is of little concern in tracer work, because it is effective only for energies well above 1 Mev.

The curves shown in Fig. 4 were calculated for the relative absorptions of different types of crystals of 1 cm. thickness each. The actual amount of absorption is not a completely accurate basis for measuring the efficiency of the counter, for, as in the case of Compton scattering, the gamma ray will penetrate the crystal, but it will lose enough energy in the crystal to be counted. When an N.B.S.* Co\textsuperscript{60} standard was used, the measured efficiency was found to be 30 \%, as against a calculated value of 17\%. In the energy region of Compton scattering, the efficiency can be almost twice the calculated value. It is also evident from the same reasoning, and it is shown on Fig. 3, that there will be no flat plateau in this region. Aside from the counting efficiency of the gamma rays which actually penetrate the crystal, there is also an efficiency due to the geometry of the crystal. When an I\textsuperscript{131} sample, assayed at 1.1 uc \( \pm 10\% \), spread evenly over the bottom of a 1-1/2 inch diameter porcelain dish was

* National Bureau of Standards
Fig. 4

The absorption in different crystals each one centimeter thick vs. the energy of the incident gamma ray. (calculated)
placed directly on the window of the counter, it gave a count of 12,000 c/s plus a 3% coincident correction, thus giving an overall counting efficiency of 30 ± 3% of the total number of disintegrations present. Fig. 5 shows the deviation in counting over a thirty day period; this deviation is no greater than that which is found when making two successive counts on the same sample. In trying to position two similar samples under the counter one may expect a probable error of 2%.

A list of various crystals and their properties follows:

**Sodium iodide** (NaI) activated with thallium is the best all round crystal for use in gamma counting, as it is cheap, readily available in any size and shape, optically clear, machinable, easily cut by hand, has a short time constant (~25 ns), has the highest light yield, and gives excellent efficiencies for most gamma rays used. It does have one major disadvantage; it is deliquescent and must be protected from the air or from moisture in any form. These crystals keep best in a moisture-free oil. After the crystal has been cut and properly shaped any outer yellow coating or scratches can be polished off with a rag saturated with 200 proof alcohol. Once the crystal has been sealed in dry oil it will give satisfactory results for about a year, after which time it should be taken out and repolished by the method given above.

**Potassium iodide** (KI) activated with thallium is unsatisfactory for gamma counting because of the internal radiation of the K40.

**Calcium tungstate** (CaWO3) is the most efficient and reliable crystal which can be used. It is expensive and must be purchased pre-shaped, as
The counting stability using a Co 60 sample. The counter gain was reset each day with the Am 241 standard. The slope is presumably due to the 5.2 year half life.
it is a hard, jewel-like, clear crystal. For a given crystal the efficiency will remain constant, even when using different photomultiplier tubes. The time constant (3 us) is about the maximum usable length. The light yield is about half that of NaI.

**Anthracene** \((\text{C}_6\text{H}_4 - \text{C}_2\text{H}_2 - \text{C}_6\text{H}_4)\). being a hydrocarbon, has very poor stopping power for gamma rays. Thick crystals sufficiently clear for counting purposes are not readily obtainable.

**Stilbene** \((\text{C}_6\text{H}_5\text{CH} \cdot \text{CHC}_6\text{H}_5)\) is also a hydrocarbon, but it can be obtained in thick, clear crystals. A crystal about 5 cm. thick will give an efficiency similar to that of a 1 cm. thick NaI crystal. It is brittle and must be protected from shock. It is difficult to cut, so it should be purchased pre-shaped. As the surface has a tendency to oxidize and become cloudy, it should be sealed from the air. It is relatively expensive, has a very short time constant (0.008 us), and its light yield is about 1/3 that of NaI.
PHOTOMULTIPLIER TUBE

Two principal types of photomultiplier tubes are used in scintillation counters: the 1P21 and the 5819. The photosensitive cathode of the 1P21 is 1/2 x 1 inch in area; it is inside the tube, where it is difficult to obtain good light geometry, but equivalent noise energies as low as 10 KV were obtained. The 5819 was especially designed for scintillation counters. It has a large (1-1/2 inch diameter) photosensitive cathode on the end of the tube, thus allowing the best possible light geometry. Because of this increased light geometry, the equivalent noise energy has been found to be as low as 500 volts, at room temperature.

Every photomultiplier tube should be checked to determine the equivalent energy of its noise. Of the twenty-four tubes checked by the writer, five were unsatisfactory because their noise energies were above 30 KV, and four tubes had noise energies below 2 KV. The two major sources of noise are thermal and positive-ion feedback currents. The thermal noise is dependent upon the temperature of the tube and varies slightly from tube to tube because of the variation in light sensitivity; it can be reduced by lowering the temperature of the tube. The positive-ion feedback noise is dependent upon the voltage applied to the tube, and it varies greatly from tube to tube. In some of the tubes checked, this type of noise was not detectable; in others, it was high enough to render the tube unsatisfactory. When using refrigerants on the tube to reduce the thermal noise, care must be taken to find a tube which is not subject to positive ion feedback noise.
Fig. 6 shows the noise counting rate versus the equivalent noise energy at different temperatures. For this test a tube having both thermal and positive ion feedback noise was chosen, in order to show the effect of temperature on both types of noise.

Because the noise and gain are each a function of the tube voltage, there is an optimum output pulse voltage which will give the lowest noise energy. Fig. 7 shows the equivalent energy of the noise as a function of the input threshold voltage to the preamplifier. This optimum output voltage varies from tube to tube, but in most instances it is in the vicinity of one millivolt.

Various voltage distributions between the dynodes of the photomultiplier tube were tried. It was found that when the variation in voltage between adjacent dynodes was small, the actual type of the total distribution—be it uniform, linear, or functional—had little recognizable effect upon the noise energy; therefore, a uniform distribution, with resistors being within 10% of each other, is recommended. One important exception, however, is the voltage between the cathode and the first dynode; because of the relatively large spacing this voltage can be between two and two and one half times the voltage between dynodes, without creating a large potential gradient. The effect of varying the cathode voltage is shown in Fig. 8.

The gain of the photomultiplier tube is affected by very slight magnetic fields. If the tube is to be moved about or placed near an induction field, e.g. a transformer, a magnetic shield is desirable, in order to stabilize the gain.
Photomultiplier tube noise as a function of temperature (no crystal). The equivalent noise energy was extrapolated from curves with the crystal present.
Fig. 7

Equivalent noise energy vs. threshold voltage of the preamplifier.
Fig. 8

Equivalent noise energy vs. the ratio of the voltage between the cathode and first dynode to the voltage between dynodes.
PRE-AMPLIFIER

The type of amplifier used in the operation of a scintillation counter is relatively unimportant, as long as its gain is sufficient and its rise time sharp enough to operate the scaler. On the other hand, there are many points to be considered in building a pre-amplifier, in order to have a more efficient unit.

First, and of prime importance, the amplifier must be noise-free—i.e., not introduce counts of its own. Shielding is effective against most noises caused by local electrical radiation, and adequate filtering and by-passing will eliminate most line disturbances. Tube microphonics must be considered if the amplifier is to be moved about during operation.

The photomultiplier tube socket should be of good quality, mica-filled bakelite, because the high voltages applied to the tube can cause the generation of noise in the socket. The value of the resistors used for the photomultiplier tube voltage divider is dependent upon the current available from the high voltage supply, and it has little effect upon the operation of the tube. If large value (1 M) resistors are used, the dynodes should be adequately by-passed—the final stages, especially. The lower the value of the bleeder resistors, the more stable and less susceptible to noise the tube will be; however, the greater heat dissipation has a tendency to raise the temperature of the photomultiplier tube.

The voltage applied to the tube must be well filtered if the cathode is grounded, as any noise pulses will be transmitted to the amplifier.
An excellent way to eliminate the necessity for high voltage capacitors is to place lower voltage capacitors in series across the bleeder resistor. When the plate is operated at ground potential, and a high negative voltage is applied to the cathode, the voltage need not be so well filtered, since any fluctuations of voltage will only vary the gain of the tube and, therefore, are not readily transmitted to the amplifier.

The load resistor on the photomultiplier tube does not determine the pulse gain: the pulse gain is proportional to the output capacitance of the tube. The output pulse has a steep wave front \((10^{-9})\) and decays with a time constant equal to the load resistance times the output capacitance. This time constant should be approximately two microseconds long in order to accommodate most amplifiers and yet be able to take counts of up to ten thousand per second without a coincident correction. The output capacitance is lowest if a cathode follower is placed directly on the output of the tube. A further reduction in the output capacitance of the tube can be made by coupling the last dynode to the output of the cathode follower, as shown in Fig. 9. This reduction is possible because most of the output capacity of the tube is between the plate and the last dynode. The extra gain obtained by the circuit is not made at the expense of the photomultiplier tube or the amplifier, thus enabling the voltage to be lowered on the photomultiplier tube, thereby reducing its noise; at the same time, the output pulses are greater than the input noise of the amplifier.

The pulse gain of an amplifier cannot be calculated in the ordinary manner, as an amplifier will have a different effect when the polarity of
Fig. 9

Cathode follower connected to reduce the output capacitance of the photomultiplier tube.
the pulse is reversed. In the case of a photomultiplier tube the polarity of the pulse is known; thus the amplifier can be designed accordingly. The method for determining the gain when a negative pulse is being used is to calculate the gain in the usual manner, and then treat the problem as a transient. Essentially, gain is reduced by approximately the ratio of the decay time of the input pulse to the rise time of the amplifier; the rise time is equal to the load resistance times the output capacitance of the amplifier. The calculation of the gain of an amplifier with a positive input pulse is similar to that of one with a negative input pulse, except that the rise time is controlled by the transconductance of the tube, not the load resistor, and the output capacitance; the decay time, however, is controlled by only the load resistance and the output capacitance. Thus, if a sharp positive pulse of short duration if applied to an amplifier, the rise and decay times of the output pulse will not be the same. If the output tube of the pre-amplifier has a positive input pulse, a cable with considerable shunting capacitance can be used without seriously affecting the rise time of the output pulse, due to the low resistance equivalent of the transconductance. To keep the apparent transconductance of the output stage high, the cathode must be adequately by-passed. The circuit shown in Fig. 2 has a calculated gain of 500, but it has a measured gain of only 200 for sharp pulses from the photomultiplier tube. Fig. 10 shows the relative effect of each time constant on the amplitude and duration of the pulse.

One further consideration must be taken into account when applying positive pulses to an amplifier: the stage must be protected from high
pulses which will drive the grid positive and cause the stage to block for a period of time approximately equal to the time constant of the coupling capacitor and the grid leak resistor. The blocking time can be reduced by placing a short time constant (3 to 5 us) in the grid circuit, so that any charge on the coupling capacitor can leak off before the next pulse arrives.

As stated above, the design of the amplifier is not important to the operation of the counter. However, if the pre-amplifier is to be mounted with the photomultiplier, it should have the maximum possible efficiency in order to reduce the heat to a minimum, thereby allowing the temperature of the photomultiplier tube to remain as low as possible without special cooling. Nor should there be any large-surface metal-to-metal contact between the pre-amplifier chassis and the iron case about the photomultiplier, because of the high heat transfer, although some electrical contact should be made in order to reduce any electrical pickup noise.
Fig. 10

Pulse shape as affected by the preamplifier shown in Fig. 2

- **e1**: Pulse at plate of photomultiplier tube
- **e2**: Pulse at plate of first amplifier
- **e3**: Pulse at grid of second amplifier
- **e4**: Pulse at output
ASSOCIATED EQUIPMENT

There are, on the market today, many scaling circuits which can be readily adapted for a scintillation counter. The scalers most easily converted are those which have an external quenching amplifier near the G-M tube, in which case filament and plate power for a pre-amplifier are available.

Due to the relatively short dead time of a scintillation counter, the maximum counting rate is controlled by the scaler. When the triggering time required is longer than one microsecond, the output time constant of the photomultiplier must be lengthened accordingly, by increasing its plate load resistor. The input voltage sensitivity of the scaler is immaterial, but the preamplifier used should extend this range downward to between one and three millivolts.

The high voltage power supply can be either positive or negative, but it should be regulated for .01% variation in output voltage for a line voltage variation of 1%. The voltage should be adjustable for over two-thirds of its range. A dropping resistor must be placed in series with the photomultiplier voltage divider in such a manner, that for maximum voltage from the high voltage supply not more than 1,000 volts is placed across the photomultiplier tube.

If an available scaler does not have a properly regulated high voltage power supply, a circuit similar to the one shown in Fig. 11 can be used. This circuit will deliver an adequately regulated negative voltage adjustable from 300 to 800 volts. Two sources of power are required: a 350 volt AC voltage from the plate transformer, and the regular B+
Fig. 11

Circuit of regulated voltage supply for photomultiplier,
voltage. The circuit is a standard half-wave voltage doubling circuit, with a pentode replacing the parallel diode. The DC path is through the rectifier, the load, and back through the control tube (6 AG 5); thus the 6AG5 is a series regulator tube. The voltage is regulated by varying the DC voltage drop across C₁. C₁ cannot be a polarized condenser, because when the voltage output goes below half-voltage, the DC potential reverses across C₁. The circuit, as is, does not degenerate the AC on the output, but a high degree of filtering is not necessary when a high negative voltage is applied to the cathode of the photomultiplier.

If the scaler has no discriminator (pulse shaper), one must be added, as, unlike the G-M tube—which has equal amplitude pulses, the pulses out of a scintillation counter are proportional to the incident gamma energy. The discriminator should be some type of trigger circuit, such as the one depicted in Fig. 12, rather than a limiting type of pulse shaper which, in general, do not work well over wide ranges of signals. The total gain of the counter can be varied by adjusting the triggering voltage on the discriminator, but the amount of gain variation obtainable is small. Since a wide variation in gain is obtainable by varying the voltage on the photomultiplier tube, it is advisable to set the discriminator at some stable fixed voltage.

Because the pulses out of the photomultiplier tube are proportional to the gamma energy stopped by the crystal, it is relatively simple to make a differential discriminator which will count gamma rays over a short range of gamma energies only. Thus, given a single sample containing two or more radioactive elements having different gamma energies, each
Fig. 12

Pulse height discriminator to make all output pulses the same amplitude.
element can be counted in the presence of others which have either higher or lower gamma energies. If two discriminators are connected in parallel (Fig. 13), each set at a different input sensitivity, and their output connected in anti-coincidence, a low energy gamma ray will not trigger either discriminator, and a high energy gamma ray will trigger both discriminators and thus not be counted, but a gamma ray of the desired energy will trigger only the more sensitive discriminator and, therefore, be counted. The spread of energies to be counted is varied by adjusting the difference in the triggering voltages of the discriminators, and the median energy is adjusted by varying the voltage on the photomultiplier tube. Actually, the high-voltage control can be calibrated in gamma ray energy for quick identification of known radioactive elements.

The particular anti-coincident connection shown in Fig. 13 puts out a pulse if either discriminator puts out a pulse, but not when both are triggered simultaneously. This setup permits counting of either high, low, or differential gamma energies by means of turning off the appropriate discriminator.

On experimental tests using mixtures of two different samples with different gamma ray energies the differential gamma counter counted each element with an accuracy consistent with the accuracy of mixing the different samples.

Due to the high counting rate and efficiency obtainable with a scintillation counter, it is sometimes desirable to use a counting rate meter instead of a scaler. When counting samples at rates above 500 counts per second, for example, there is a definite saving of time using
Fig. 13

Differential pulse height discriminator.
a counting rate meter. But for samples giving below 100 counts per second, greater speed and accuracy can be obtained with a scaler: because of the randomness of the counts a long time constant must be placed on a counting rate meter, making it difficult to note when the meter has come to equilibrium at low counting rate.

Two types of counting rate meters are in general use today. The most common and simplest is the kind used in survey work; it has an absolute accuracy of ±10%. The circuit usually consists of a start-stop multivibrator with a meter in the tube which is normally cut off. Calibration is accomplished by varying the grid time constant. Less common is the precision counting rate meter, with an accuracy of ±1%. Such a high degree of accuracy can be maintained only by eliminating the effect of the vacuum tubes on the circuit.

A circuit similar to the one shown in Fig. 1 is very stable and will count random counts up to 6,000 counts per second without necessity for any coincident correction. The constant current tube, V2, places a fixed voltage on either R1 or R2, depending upon which section of V1 is conducting. As the voltage on the grids of V1 is changed by a pulse which trips the Eccles-Jordan circuit, V3, the voltage switches back and forth from R1 to R2. Condensers C1 and C2 must then charge and discharge alternately by this amount of voltage. The full wave bridge rectifies this voltage and is read on meter M1. Calibration is made by switching the meter to read the current through V2 and adjusting its grid voltage to obtain full scale reading on the meter. The range of the counting
Fig. 14

Precision counting rate meter for random spaced pulses.
rate meter is obtained by switching in condensers with different values for $C_1$ and $C_2$, and a fine adjustment is made by adjusting different shunts on the meter. The time constant of the meter must be long enough to take care of the randomness of the counts; that is, it should be equivalent to at least the time necessary to get 1,000 counts.

An experimental counter was built, which consisted of a photomultiplier tube with a cathode follower, an amplifier, a differential discriminator, a precision counting rate meter, and a voltage regulator for the photomultiplier tube. Provision is made to connect the discriminator to a scaler when counting very slow samples. The complete counter, with the exception of the photomultiplier tube and cathode follower, is housed in an 8" x 8" x 16" cabinet.
CONCLUSION

A great quantity of material has been put forth for the purpose of facilitating the designing of efficient scintillating crystal gamma counters. Not all of the information available is of prime importance: much of it deals with matters which have only a relatively minor effect upon the operation of a counter. However, a few salient points do stand out:

1. The crystal should be of a very dense material in order to obtain high efficiency at high gamma ray energies.

2. The equivalent noise energy of the whole circuit should be sufficiently low to allow counting on the plateau of all desired gamma ray energies without any electronic or thermal noise counts being introduced.

3. The largest factor in reducing the equivalent noise energy is getting the best possible light efficiency between the crystal and the photomultiplier tube.

4. The method of using a low energy gamma standard to adjust and stabilize the gain to a constant level hour after hour and day after day makes the counter a reliable, absolute unit.

Satisfactory results can be obtained with little difficulty if the ordinary rules of good engineering are followed.
BIBLIOGRAPHY


