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Instrumentation

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PORTABLE SCINTILLATION COUNTERS FOR GEOLOGIC USE*

By

E. E. Wilson, V. C. Rhoden, W. W. Vaughn, and Henry Faul

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PORTABLE SCINTILLATION COUNTERS FOR GEOLOGIC USE

By E.E. Wilson, V.C. Rhoden, W.W. Vaughn, Henry Faul

ABSTRACT

A small, light, portable scintillation counter, primarily intended for geologic field use, has been designed and is now commercially manufactured. The instrument embodies a very fast trigger-amplifier and a compact relaxation-oscillator power supply. The circuit takes full advantage of the high counting rate that can be obtained from a sodium iodide crystal. Another, still smaller and lighter, scintillation counter of the total intensity type is now being tested.

INTRODUCTION

From rather clumsy beginnings (Rajewsky, 1943; Ridland, 1945), the portable gamma-ray detector has rapidly developed into a popular geologic tool. It is probably true that there are more gamma-ray detectors in use today than all other geophysical instruments.

The Manhattan Engineer District expended considerable effort on the design of a portable Geiger-Müller survey meter for health physics work. The basic design adopted toward the end of the war utilized the Schmitt (1938) trigger circuit as an amplifier, with various high voltage supplies (dry batteries, oscillators, vibrators), and was produced commercially by a number of instrument manufacturers. The instrument was clearly successful and continues to be manufactured to this day without major modifications. In spite of the fact that this instrument was designed primarily for use in health physics work indoors, it has found wide acceptance in geologic field application (Faul, 1948, 1950).

With increasing experience in radiation measurement for geological applications, it became more and more apparent that the ordinary survey meter did not have sufficient sensitivity to be useful in studies where one was dealing with low activities, roughly of the order of background radiation. Large G-M tubes were connected to the survey meter, singly or in bundles, and it was found that with such arrangements it was possible to obtain data of great geologic significance (Nelson, 1953; Slack, 1949; Slack and Whitham, 1951; and many unpublished reports). However, the large counters (up to 40 inches long) had one great disadvantage: they were exceedingly clumsy to use in the field.

A portable scintillation counter would not be subject to this handicap. Such an instrument was announced by Brownell in Canada (1950), and became commercially available shortly thereafter. The Canadian instrument was relatively large and heavy (about 15 lbs.), had considerable drift with temperature and time, and was very costly (over $1,000 in the U.S.) so that it could not become widely used. Nevertheless, Brownell's work showed that the scintillation counter could be very useful in geologic studies.

About 1950, portable scintillation counters were developed independently at the Oak Ridge National Laboratory and Los Alamos Scientific Laboratory. Each of these instruments had definite advantages: the Oak Ridge circuit (Borkowsky and Dandl, private comm.) was very fast and had a good oscillator power supply; the Los Alamos circuit (Watts, private comm.) was built with subminiature tubes and could be made very small and light. Obviously, an instrument combining the advantages of both designs would be of great value to the geologic profession, and we decided to undertake this development.

The instrument that was developed (fig. 1) weighs about 7 pounds, stands about 12 inches high, and retails for about $500. It has now been produced in quantity by three manufacturers and extensively used during the 1953 field season by many private individuals and personnel of the U. S. Geological Survey, the U. S. Atomic Energy Commission and the U. S. Department of Agriculture. Much remains to be learned about the calibration and optimum energy response of scintillation counters for field use, but there is no doubt that, in spite of their serious limitations, they are of great value to the geologist.

PHYSICAL DESIGN

The outward design of the instrument was determined largely by a committee of field geologists in Denver, under the chairmanship of L. R. Page of the Geological Survey. It was decided that the instrument should be housed in two boxes, of which one would contain little more than the batteries, or roughly half the weight of the device. The battery box has suitable loops so that it can be worn on the belt, and is connected to the probe by a flexible coiled cord.

The probe contains most of the circuitry, the sensitive element, and the meter. It must be as light as possible, and waterproof for work in mines. For obvious reasons, the probe must be very rugged. The meter must be placed to be easily readable at arm's length, and the use of the instrument should require only one hand. The probe fastens to the battery case with a spring catch and must be firmly held, yet easily removed.

Figure 1. Three commercially available versions
of the portable scintillation counter

The sensitive element is a very fragile assembly and must be mounted in the probe with utmost care to prevent damage in normal (i.e., rather rough) use. The thallium-activated sodium iodide crystal, about one cubic inch or larger in volume, is housed in a thin spun-aluminum can (fig. 2) filled with clear silicone fluid of very high viscosity (as much as several hundred thousand centistokes). The can slips over the end of the photomultiplier and is attached with industrial adhesive tape. A phosphor bronze spring keeps the polished face of the crystal in contact with the photocathode. The other surfaces of the crystal are left rough. Commercially available potted crystals are preferred by one manufacturer, but the silicone mount originally developed at the Chalk River Laboratory (Carmichael, private comm.) is less costly and mechanically sturdier. We have not observed any detrimental reaction between the crystal, the tape, and the silicone oil. The photomultiplier is magnetically shielded by a thin sheet of highly permeable nickel-iron alloy such as is available commercially under various trade names. The entire assembly of the sensitive element is suspended in the probe in sponge rubber, to minimize damage when the probe is dropped accidentally.

ELECTRONIC DESIGN

The pulse amplifier (fig. 3) is a trigger pair of sub-miniature tubes (type CK-533 AX) with V-1 normally conducting. The input sensitivity is variable by means of the potentiometer marked "CALIBRATE", which directly affects the bias on V-2 and to some extent, the bias on V-1, and is adjustable down to a few millivolts, or a point just above the dark current of the photomultiplier tube. The amplifier has a gain of

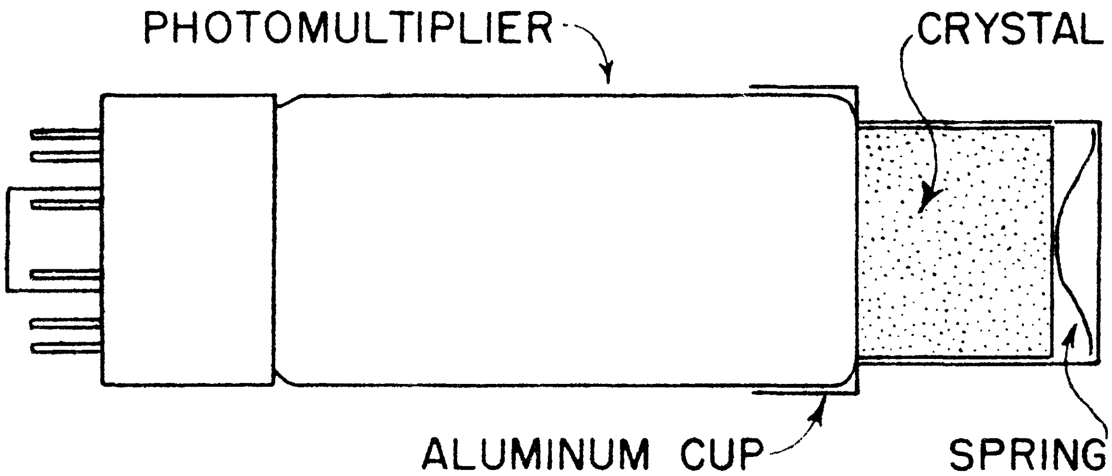

FIGURE 2, THE CRYSTAL-PHOTOMULTIPLIER ASSEMBLY

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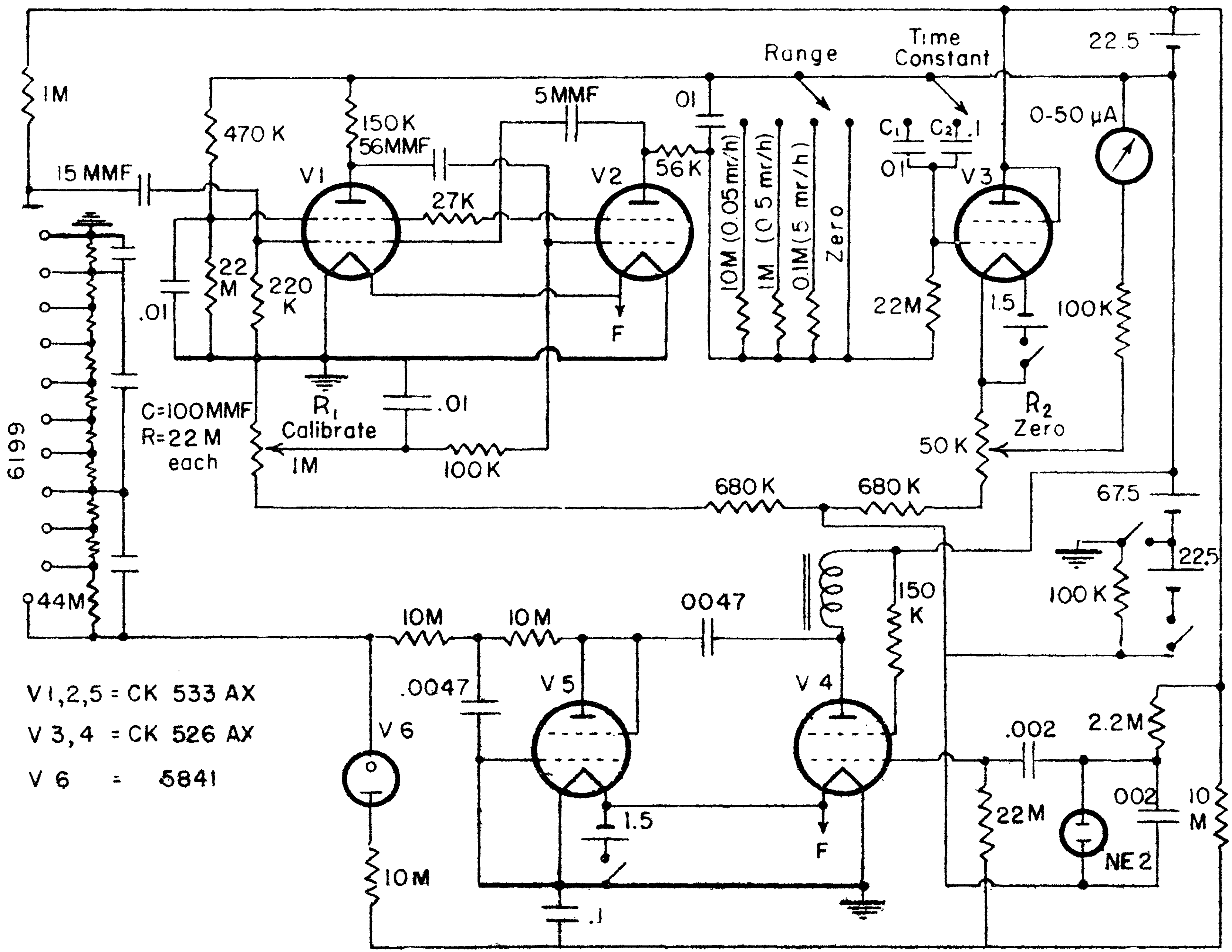

FIGURE 3, CIRCUIT DIAGRAM OF THE PORTABLE SCINTILLATION COUNTER

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20, a pulse length of 6 microseconds and a 14 microsecond resolution period. The pulse length and resolution period are independent of range setting, and less dependent on input pulse amplitude and counting rate than any other type amplifier tested for portable scintillation counters. Specifications call for a minimum rate of 150,000 counts per minute in a field of one milliroentgen per hour of radium gamma rays with a cylindrical crystal one inch thick and 1¼ inches in diameter. The ranges are selected by switching resistors in the plate circuit of V-2. A series network with pre-selected values for the range settings was tried and was very satisfactory, but procurement of resistors of the correct values for quantity production proved to be difficult. The present method was chosen as a compromise. Two time constants of 1 and 10 seconds are obtained by switching condensers C_1 and C_2 respectively. The necessary voltage to drive the metering circuit is obtained from the range resistors in the plate circuit of V-2. This circuit is essentially a vacuum tube voltmeter using a type CK-526-AX. A four-volt swing of the grid of V-3 will give full scale deflection on the 50 microampere ruggedized meter. The grid voltage versus plate current curve is linear over the operation range of grid voltages so that the meter deflection is linear with respect to the voltage developed across any range resistor. Other tubes may be used where higher meter currents are required, as in some applications discussed below. The potentiometer R_2 in the cathode circuit, which is controlled externally, serves as zero balance. Zero drift is extremely small, less than one microampere in 40 hours of operation.

The negative 900 volts for the photomultiplier is supplied by an oscillator high voltage supply with an approximate plate efficiency of 16 percent. The overall efficiency is about 3.5 percent. The relaxation oscillator (approximately 100 cps) triggers the grid of V-4. The reactive voltage developed by the choke in the plate of V-4 is rectified by V-5 and regulated by V-6. This voltage is sensitive to oscillator frequency which drifts as the battery supply fades. The frequency is set slightly above the optimum point which gives a peak to be reached and traversed during the useful life of the "B" batteries. This in turn gives constant voltage for a longer time per battery change. Additional compensation is afforded by feed-back of the change of voltage with load at the regulator tube through R_2 to the grid of V-4. The selection of chokes for the high voltage supply is also very important. Only two reactors of a group tested, the UTC had sufficient positive impedance. The resistive and hysteresis loss in other chokes tested was excessive.

The use of a ruggedized meter may be thought extravagant by economy-minded constructors, but we have found through experience that meter damage is a major item of service on instruments of this general size and shape. Tall, narrow instruments such as these (fig. 1) are easily knocked over, with obvious consequences for the meter.

The heart of the portable scintillation counter is the sensitive element, a thallium-activated sodium iodide crystal and photomultiplier tube. The thallium content of the crystal is about 1 percent by weight. Approximately 25 percent of the gamma rays from Ra produce sufficient light in a 1 x 1¼ inch crystal to be detected by the circuit with a photomultiplier tube of minimum acceptable sensitivity. The type 6199, although far from ideal for this application, was used because it was the only small window (1.5 in. dia.) tube available when the instrument was designed. This tube is often microphonic, and sometimes exhibits two stable states of operation, apparently related to the physical position of the dynode structure in respect to the cathode at fixed dynode voltage. A slight jarring will cause the tube to "jump" from one stable state to another. With dynode voltage held constant, the sensitivity varies over a wide range. Selection of tubes from commercial runs is essential. On the average, about one out of four tubes can be used in this instrument. The tubes tested in our laboratory exhibit a trend in sensitivity that can be associated with physical dimensions. The more sensitive tubes are usually shorter in length. The new type 6291, is not microphonic in ordinary handling, has exceptional gain and is relatively uniform in sensitivity (factor of 4 in 7 tubes tested). Unfortunately, the necessary overall operating voltage of 1200 volts is somewhat high for portable instruments. Much of the difficulty with photomultipliers may be circumvented by operating each tube at its best voltage. When the regulator tube (V-6) is matched to the photomultiplier, the sensitivity will be much more uniform. However, commercially available regulator tubes cover only a narrow range of voltage. Regulators with a spread of voltages (900 to 1050 volts) can be obtained on special request and make possible the selection of the proper regulator for the individual phototube being used. The matching procedure makes it possible to use some photomultipliers otherwise discarded, but greatly complicates servicing.

Pulses of all amplitudes come from the photomultiplier. They are roughly linear with the energy dissipated in the crystal, up to a point of saturation. The lower limit for pulses that are detected by the amplifier is usually determined by the ultimate input sensitivity of the circuit rather than the background noise of the photomultiplier. Very fine pulse height discrimination is common practice in the laboratory, but is difficult to achieve in a simple portable instrument with any degree of reproducibility.

CALIBRATION

In principle, the absolute calibration of a scintillation counter is no different from the same procedure for a Geiger-Müller counter. The instrument is brought into a known flux of gamma radiation, usually from a radium needle, and the circuit is adjusted to give the correct reading in milliroentgens per hour. If all instruments are correctly calibrated, their independent readings can be compared directly, regardless of the spectrum of the source of the gamma rays measured, and the intensity will be in milliroentgens per hour if the source is radium.

In practice, however, various difficulties come up. Our instrument is calibrated by first flight quanta from an effective point source. Scattered radiation is measured separately and is subtracted from the gross intensity. In nature, the source is almost always extended, and much of the radiation reaching the detector has been scattered, so that the effective spectrum is greatly enriched on the soft end.

The G-M counter is not particularly sensitive to soft radiation, and a point-source calibration is reasonably adequate. The scintillation counter, however, has good sensitivity down to very low energies and most of the scattered radiation is detected. Consequently, the portable scintillation counters calibrated with a point-source will not show the right intensity (in milliroentgens per hour) when the measured radiation is scattered. The gross readings are still comparable from counter to counter, but the units are essentially meaningless in practice.

The second difficulty in wholesale calibration arises from the great variation in photomultipliers and the consequent wide variation in sensitivity of the scintillation counters. Given a group of instruments, one has the alternative of either tailoring each circuit to fit the particular photomultiplier or calibrating all instruments at the sensitivity level of the worst one in the group. The first alternative is prohibitive in cost, and the second tends to remove the greatest advantage of the scintillation counter, its high sensitivity. It has been our experience that geologists prefer to have their instruments adjusted for optimum sensitivity, at the expense of absolute calibration. It is too early to say whether future experience will modify this view.

The third problem is due to the nonlinearity of the circuit at very high counting rates. Even with a dead time of only about fifteen microseconds, coincidence loss is high at the rates that are observed in some phases of geophysical exploration, particularly underground. We see no simple way of greatly reducing the dead time of the circuit. G-M counters should be used where the intensity is too high for linear operation of the scintillation counter.

The stability of the pulse height acceptance level of this circuit is considerably better than one normally expects from portable equipment. This stability is achieved by suitably matching the various batteries and their loads so that bias on the grid of V-2 decreases as the plate voltage decreases with aging batteries. In addition, the oscillator may be adjusted to a frequency higher than the optimum. Thus, the voltage on the photomultiplier increases with aging batteries, with the net result of stable overall sensitivity. Specifications require that one calibration adjustment be sufficient to keep the sensitivity within 10 percent of the original value for a period of 25 eight-hour days (at constant temperature).

SPECTROMETRY

It is frequently suggested that portable scintillation counters be used as spectrometers to identify the radiation source by the energy of its gamma rays (Pringle et al., 1950, and others). We have found that interest in this application is largely academic. It is true that a portable scintillation counter could distinguish between uranium, thorium, and potassium under specially favorable conditions. However, the required source concentration is so high that almost any geologist can identify the mineral long before he has assembled enough of it for a spectrometric examination. For some of the rarer thorium-uranium minerals, a visual estimate of the thorium-uranium ratio may not be possible. The physical determination of this quantity is difficult even with fairly complete equipment in the laboratory (Peirson, 1951; Eichholz, et al., 1953) and one should not expect too much from portable equipment.

SPECIAL APPLICATIONS

The scintillation counter described here can be used in automobiles and small aircraft without modification. The sensitivity is entirely adequate for these purposes. A more elaborate version constructed in our laboratory uses crystals two inches in diameter to increase the sensitivity. For use on automobiles, the detectors are shielded with 1/2 inch of lead to improve directional sensitivity toward the sides. A detector is mounted on each side of the roof of a car (fig. 4) and

Figure 4. Car-mounted twin scintillation heads, shielded with lead for directional search.

the output of both photomultipliers is fed into a circuit very similar to that shown in figure 3, except that the output tube is a type CK4506 AX which has sufficient power to drive a strip chart recording milliammeter. A switch permits the use of one or both of the detectors to facilitate directional searching.

The same basic circuit also has been modified for gamma-ray logging of holes as deep as 1,000 feet (fig. 5). Whenever it is necessary to transmit pulses over cables even just a few feet long, a matching circuit of the type shown in figure 6 is found useful. The logging probe contains a photomultiplier with a small crystal and the matching circuit. A similar circuit precedes the input in the surface instrument which is identical to the carborne or airborne unit discussed earlier.

When it is necessary to feed more than one photomultiplier into the circuit shown in figure 3 with matching circuits in between, special care must be taken to separate the input channels or amplify the signals prior to combining them. Transistor networks are very useful for this purpose. If the channels are not separated, some of the signal from one detector will be dissipated in the matching networks of the other(s) with the consequence of impaired overall efficiency.

FUTURE DEVELOPMENTS

It is not likely that the size and weight of the present instrument can be radically reduced by future design. It is hoped, however, to improve stability and reproducibility to a point where the instrument can be calibrated in absolute units and can be used for accurate surveys.

A new design has been "on the boards" for about a year and is now reaching the prototype stage (fig. 7). The new instrument uses the same high

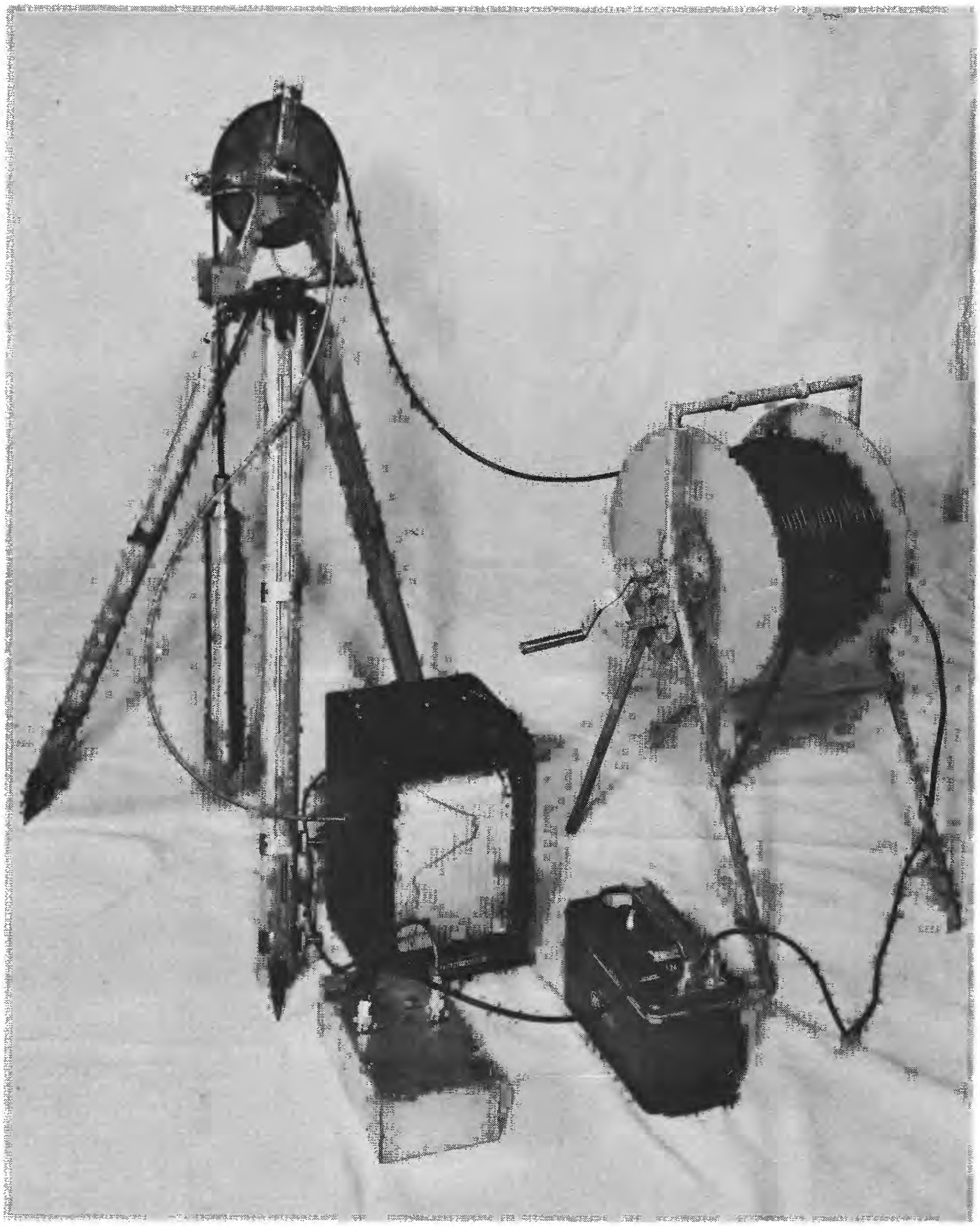

Figure 5. Scintillation logging equipment, showing probe, reel with 1000 feet of cable, ratemeter, vacuum-tube voltmeter, current amplifier, and strip-chart recorder. The voltmeter and recorder can be omitted for logging of holes in remote areas where transport is a problem.

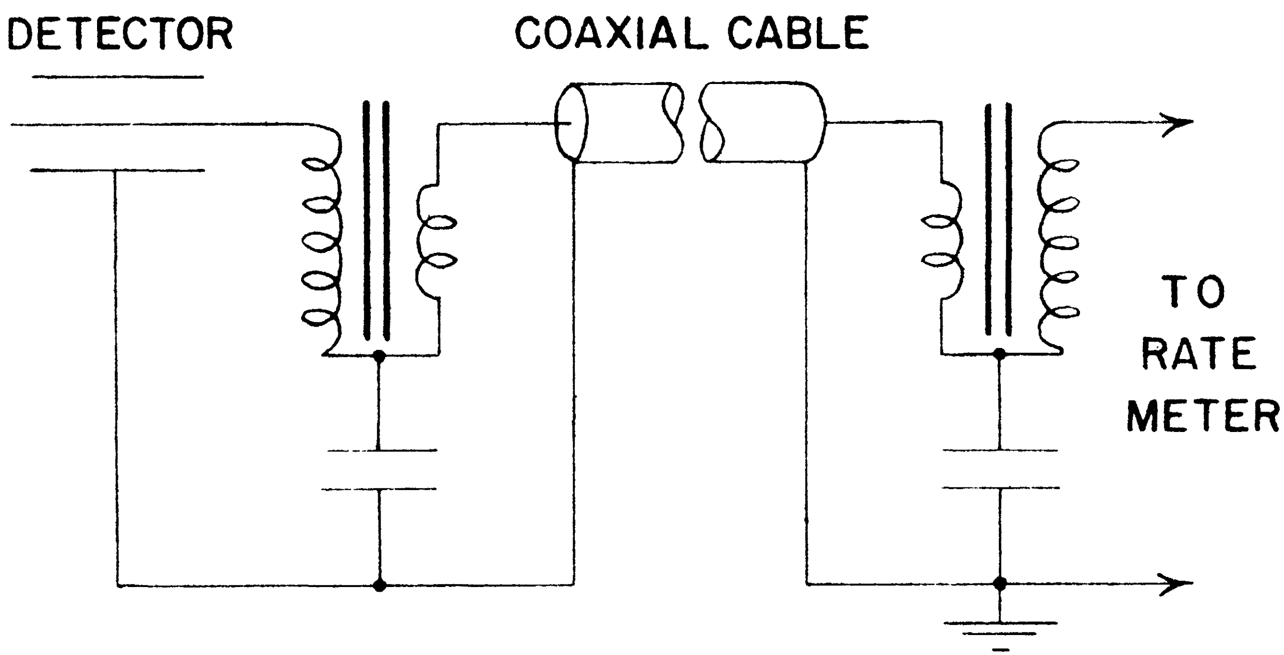

FIGURE 6, MATCHING CIRCUIT FOR TRANSMISSION OF PULSES OVER LONG COAXIAL CABLES

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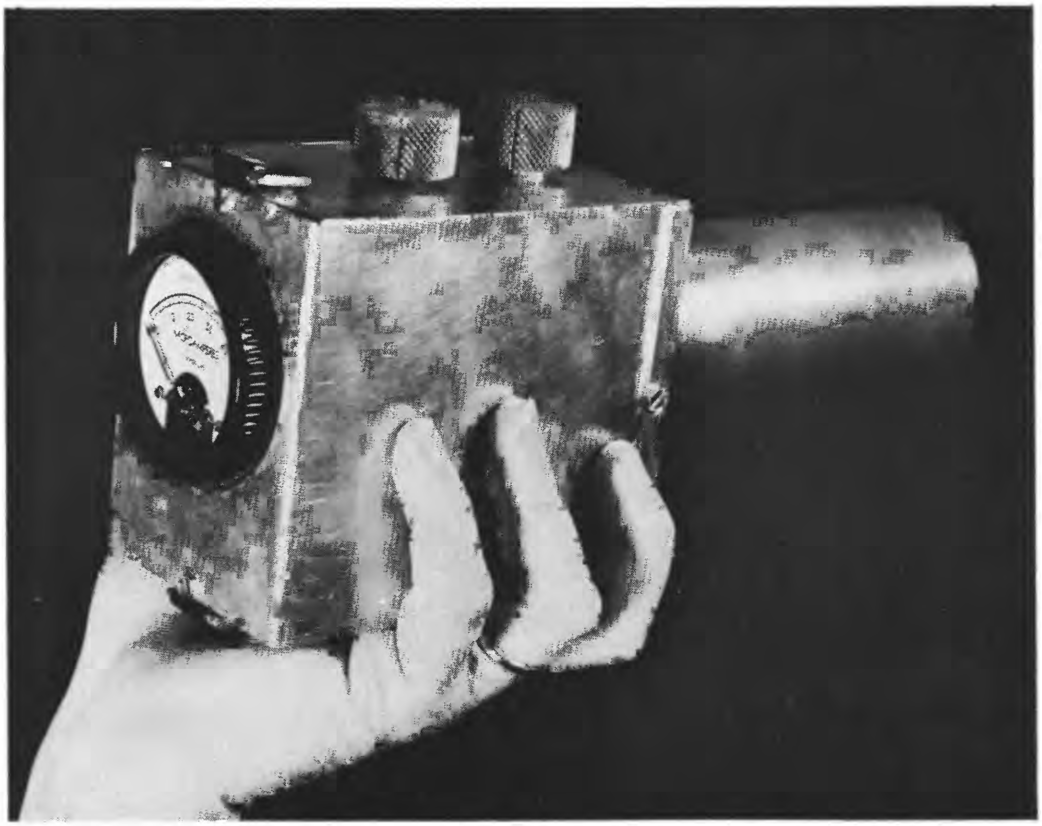

Figure 7. Experimental model of the integrating (total intensity) scintillation meter.

voltage supply, but the counting circuit is greatly simplified. This circuit does not "count" pulses, but, in effect, measures the total intensity of light emitted by the crystal. Since the amount of light is a function of both the number and the energy of the incident gamma rays, the meter reading of this instrument will indicate more nearly the "total dosage rate" rather than the number of disintegrations of a source of radiation.

The circuit (fig. 8) is essentially a D.C. amplifier, biased to projected cut-off. The meter is in series with the plate and is mechanically set to read zero when about three microamperes of plate current flow. Bias is applied to the cathode by means of a bleeder network. The screen is supplied by a separate 22.5-volt battery connected directly between screen and cathode. This arrangement prevents the falling off of screen voltage which would result in non-linear response of the meter if the screen were fed by means of a dropping resistor or bleeder from B +. The signal is applied directly to the grid from dynode No. 10, as a positive voltage is required, and the sensitivity is controlled by the amount of resistance in this circuit. Earlier experimental measurements with this type of circuit showed rather large and frequent upswings of the meter while measuring relatively low background radiation. These upswings are attributable to large pulses, from ten to thirty volts in amplitude caused by cosmic showers, whereas the average pulse from radium has a peak value of about two volts. The effect of these extremely large pulses is reduced in this circuit, because any pulse greater than about 2.5 volts in amplitude drives the grid positive in respect to the cathode and is clipped in the grid circuit. In addition, the flow of

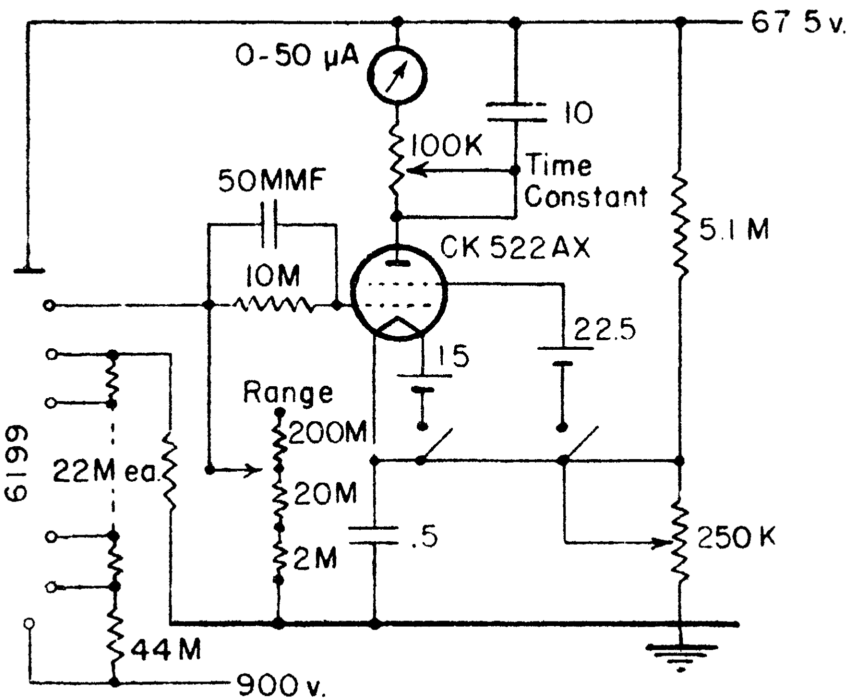

FIGURE 8, CIRCUIT DIAGRAM OF THE INTEGRATING SCINTILLATION COUNTER.
THE POWER SUPPLY IS IDENTICAL TO THAT SHOWN IN FIG. 3.

grid current thus caused develops a bias pulse across the 10 megohm grid leak - 50 micromicrofarad condenser combination to counteract the effect of the large pulse on plate current.

A potentially useful feature of this integrating instrument is the continuously variable time constant of the meter circuit. By adjusting the 100,000 ohms potentiometer in series with the meter, the response time (and therefore the flutter) of the meter can be made to have any value that the particular situation demands.

The complete unit, including batteries, is now contained in a case 4 x 4 1/2 x 3 inches, with a probe 2 inches in diameter projecting 5 1/2 inches from the front (fig. 7). The meter is mounted in the back of the case. The total weight of the preliminary model is less than 3 1/2 pounds, and it has a battery life of nearly 200 hours. Bench tests show negligible drift in zero and sensitivity throughout the life of the batteries.

There are definite drawbacks to this circuit in its present form. Only the best of photomultipliers will work satisfactorily; most have insufficient gain at 900 volts; some have too much dark current; some have internal leakage which affects the zero adjustment. The dark current sets a lower limit to the useful response of the instrument. A larger crystal will help solve this difficulty, but the weight and cost of the crystal becomes an item to be considered in the design of a small instrument. The high value of range resistors (200 megohms on the most sensitive range) may make the reading sensitive to humidity changes. It is not known how this instrument will compare in the field with those already in use and described in the earlier parts of this paper. Because the meter indication depends as much on energy as it does on the number of disintegrations, it is possible that this instrument will not show as good a response to weak anomalies in the field as the instruments now in use. The great advantages of small size and weight and slightly lower construction cost may overbalance the obvious shortcomings of the circuit. Extensive testing, now in progress, will be required before the usefulness of the design can be determined.

ACKNOWLEDGMENTS

We are greatly indebted to our colleagues at the Oak Ridge National Laboratory and Los Alamos Scientific Laboratory for their kind and helpful assistance during the early phases of this work. Particular thanks are due Messrs. C. J. Borkowsky, Ray Dandl, R. J. Watts, and F. J. Davis. Dr. Hugh Carmichael of the Chalk River laboratory and Mr. John Harshaw of Harshaw Chemical Company have been very helpful in discussions of the various techniques of crystal mounting. We are grateful to the many geologists and engineers who have helped us in the practical field evaluation of this instrument and whose patience and goodwill we so frequently strained. The work here reported is part of a program that the U. S. Geological Survey is conducting on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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