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INTEGRATING CIRCUIT FOR VAPOR-TYPE GEIGER-MÜLLER COUNTERS

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ABSTRACT

A circuit is described for integrating the pulses from tube counters filled with alcohol vapor and argon and for measuring the output on a rugged milliammeter. These counter tubes require no external quenching device, therefore a simple resistance-capacity coupled amplifier is arranged to amplify and level the pulses. They are then rectified and fed into a condenser with resistance leak. A vacuum-tube voltmeter stage is incorporated in the circuit to measure the voltage of this condenser. This voltage is proportional to the counting rate under the conditions obtained in this circuit.

Two types of portable apparatus, operated from the 110 volt a-c supply, are described which use the circuit outlined above. One is a sensitive counter unit suitable for measuring low gamma-ray intensities, down to the equivalent of 0.1 microgram of radium. The output meter is a milliammeter with a full scale deflection of 1.5 milliamperes. A multirange switch permits operation at several sensitivities. On the most sensitive range the sensitivity is 0.03 milliampere per microgram of radium at 1 meter. The scale of the meter is linear with the counting rate so that comparisons between radioactive sources can be made when desired without reference to the calibration surve. A carefully prepared calibration curve can be used to determine gamma-ray intensities in this region of intensity to within a few percent. The calibration remains comparatively steady over periods of months.

The other apparatus based upon the same circuit is a dosage meter for gamma-rays which indicates on a milliammeter the gamma-ray dosage in terms of roentgens per day and in addition gives a visual and audible alarm when this dosage reaches the tolerance level of 0.1 roentgen per day. At the present time a general exposure of this amount is regarded as safe. This equipment is designed to give warning of excessive general exposures wherever large sources of gamma radiation are present, such as in the use of radium, high-voltage tubes, and cyclotrons.

CONTENTS

I. INTRODUCTION

The properties of alcohol vapor-argon counters [1] are such that considerable simplification of counter control circuits for use with them can be effected. The most important characteristic in this connection is their self-quenching property, which obviates the necessity of any external quenching device, such as a Neher-Harper stage. This self-quenching is operative with comparatively low resistances in the counter circuit, so that the counters are capable of

[1] A. Trost, Z. Physik **105**, 399 (1937).

very rapid counting. It is therefore possible to arrange a simple circuit to amplify and integrate the output from these counters even at the highest counting speeds of which they are capable. A resistance-capacity coupled vacuum-tube circuit has been developed in which the pulses are amplified and leveled and then rectified and used to charge a condenser provided with a resistance leak. A vacuum-tube voltmeter stage with linear scale is used to measure the voltage of this condenser, which is proportional to the counting rate. In developing this circuit, care has been taken to secure a linear scale on an output meter which is rugged and suitable for portable use. Attention has also been given to details of the circuit so that the cumbersome parts could be avoided with no sacrifice of reliability.

This paper describes two forms of portable apparatus which are based essentially upon the same circuit but are intended for quite different uses. One is a sensitive gamma-ray counter which is suitable for measuring intensities down to the equivalent of 0.1 microgram of radium. The output meter of this model is a milliammeter with a full scale deflection of 1.5 milliamperes and has a sensitivity on the highest range of approximately 0.03 milliampere per microgram of radium at 1 meter.

The other device is a relatively insensitive counter unit for indicating gamma-ray dosages near the tolerance level for human exposure. This equipment is provided with a milliammeter calibrated in terms of roentgens per day. It also gives an audible and visual alarm when the general intensity reaches the tolerance level of 0.1 roentgen per day.

II. TUBE COUNTERS FILLED WITH ALCOHOL VAPOR AND ARGON

Numerous suggestions have been offered for the preparation of counter tubes containing alcohol vapor. Particular attention has been given to the treatment of the metal tube in order to produce a satisfactory counter. The type of surface ordinarily formed by oxidation from prolonged exposure to air does not always give satisfactory results in these counters. Some investigators state that copper is quite unsuited for this purpose, unless given some special treatment as by strong oxidation or lacquering. Brass has been reported to be satisfactory after cleaning and oxidizing by exposure to air for several days. The experience of the writer indicates that good results are obtained only when the metal surface of the tube of the counter has been treated in some way. Trials of various methods of oxidation have not yielded uniform results with the same metal. Different metals appear to require various degrees of oxidation.

As a result of experiences of this kind, several types of lacquer have been tried. Coatings of varying thicknesses have been tested, applied in different ways. Best results have been obtained to date by dipping the tube in a dilute solution of commercial Bakelite lacquer and allowing it to dry in the air at room temperature. A dilution to about 10 percent of the original strength in amyl acetate has been found suitable. A coating which is too thick or which has been baked at temperatures above 50° C usually ruins the tube for satisfactory performance in a counter. The fact that the lacquer must be in a soft state suggests that the solvent, amyl acetate, may be responsible in part, at least, for the properties of the counter tube. Experiments are in progress to determine whether this is the case.

The proportions of alcohol vapor and argon used in filling these tube counters are not critical. It is apparently necessary to have a pressure of approximately 1 cm of Hg of alcohol vapor, regardless of the total pressure in the tube, to secure proper quenching. Counters have been made which operate satisfactorily with around 1,000 volts applied to the tube with total pressures varying from 2 to 8 cm of Hg. Counters of the same size prepared at the same time, as outlined above, usually have the same characteristics, operating within a few volts of the same voltage. Counters have been made as large as 10 cm and as small as 1 cm in diameter. They have shown sensitivities approximately proportional to the area of the longitudinal cross section. After a short aging period, usually a matter of a few days, during which they are permitted to operate continuously, the sensitivity of a given counter remains essentially constant over a period of months.

A study of the curve showing counting rate versus voltage has been made for a number of these counters. To date it has not been found possible to produce counters of this type with any portion of this curve parallel to the voltage axis. However, a "plateau" does exist in which the slope of the straight portion is very slight. For our best counters this is usually of the order of 0.15 percent of the average counting rate per volt applied to the tube. Therefore, a change of a few volts produces no appreciable error. Fortunately, it is possible to stabilize the voltage applied to the counter by means of neon lamps, so that fluctuations are reduced to 2 or 3 volts. The voltage thus obtained is practically independent of the supply voltage over any range usually encountered. A typical curve showing the voltage characteristics of these counters is shown in figure 1. The slope of the straight portion is 0.16 percent per volt over a range of about 100 volts. The data for this curve were taken with a carefully tested scaling circuit which recorded the total number of individual counts for each point. Similar data for different values of the capacity of the condenser used to couple the counter to the amplifier have been taken. Values between 0.00001 microfarad and 0.00005 microfarad have little effect upon the shape of this curve.

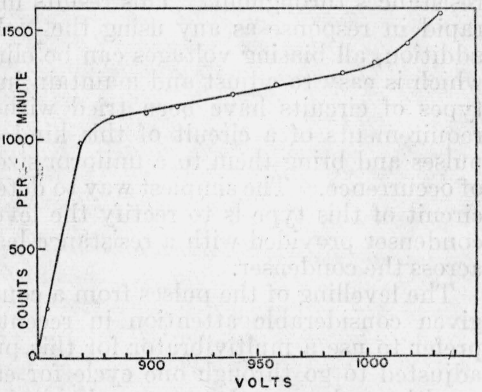

FIGURE 1.—*Characteristic curve voltage versus counting rate, for alcohol vapor-argon tube counter.*

Using the method of lacquering described above, the kind of metal used for the tube of counters filled with alcohol vapor and argon does not seem to be important. Counters have been made with brass, copper, and aluminum tubes and with copper-gauze cylinders as the tubular electrode. These have all shown similar characteristics.

III. THE CONTROL CIRCUIT

The writer has previously described [2] a circuit for integrating and measuring the rate of pulses from counters filled with argon and hydrogen. For this type of counter a Neher-Harper or similar stage is required in the control circuit for high rates of counting, since the argon-hydrogen counters are not self-quenching. The successful use of the Neher-Harper stage requires a bias voltage which must be carefully adjusted and maintained at a constant value. The experience of the writer has been that this adjustment is difficult to make. If the correct adjustment is not made either spurious pulses may easily be introduced, which do not originate in the tube counter, or the full number of pulses may not be measured. Either condition is unsatisfactory. The use of a battery to provide this bias voltage is undesirable in a circuit which otherwise is operated entirely from the a-c supply.

Fortunately the Neher-Harper stage is not required with counters filled with alcohol vapor and argon. The self-quenching properties of these counters are so effective that conventional resistance-capacity coupled stages may be used with comparatively low values of the resistances throughout. This results in circuits which are at least as rapid in response as any using the Neher-Harper arrangement. In addition, all biasing voltages can be eliminated, resulting in a circuit which is easy to adjust and maintain in proper adjustment. Several types of circuits have been tried with various modifications. The requirements of a circuit of this kind are that it shall amplify the pulses and bring them to a uniform size and then measure their rate of occurrence. The simplest way to determine the rate in a high-speed circuit of this type is to rectify the levelled pulses, feed them into a condenser provided with a resistance leak, and measure the potential across the condenser.

The levelling of the pulses from a counter for this purpose has been given considerable attention in recent years. Many investigators prefer to use a multivibrator for this purpose. The multivibrator is adjusted to go through one cycle for each pulse applied to it. The resulting pulses are then assumed to be identical. Tests in this laboratory show that a multivibrator stage must be made up of carefully selected components to function properly and that the circuit constants are usually different for each one assembled from apparently identical parts. Furthermore, the pulse from a multivibrator stage is dependent on the plate voltage, so that uniform pulses are only secured when the plate voltage is carefully regulated. These experiences led to a careful comparison between the output from a multivibrator and a simple triode stage arranged so that each pulse from the counter carried the grid voltage to, or below, the cut-off for the plate current. Each arrangement was found to be equally satisfactory when a stabilized voltage was used for the B supply. However, the multivibrator required frequent adjustment to insure proper conditions for oscillation. Under these circumstances, the simple triode stage is preferable.

The wiring diagram of the complete circuit finally adopted is shown in figure 2. The control circuit proper employs three vacuum tubes,

[2] L. F. Curtiss, J. Research NBS 23, 137, (1939) RP1223.

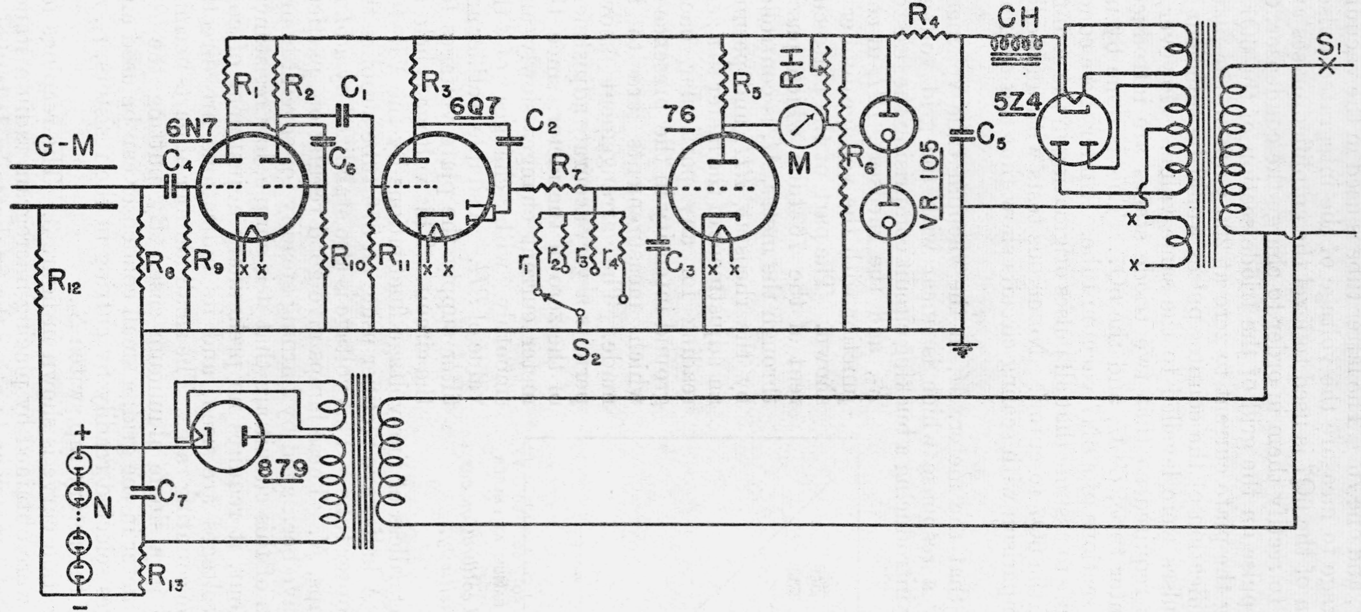

FIGURE 2.—*Wiring diagram for integrating circuit for alcohol-vapor counters with linear output meter.*

C_1, C_4, C_6, =0.00005 microfarad
C_2=0.00001 to 0.0005 microfarad
C_3, C_5=8 microfarads
C_7=4 microfarads
RH=0.5 megohm
r_1=1 megohm
r_2=2 megohms
r_3=3 megohms
r_4=5 megohms
R_1, R_2=0.1 megohm
R_3=0.5 megohm
R_4=3,000 ohms
R_5=5,000 ohms
R_6=25,000 ohms
R_7=10 to 15 megohms
R_8, R_9, R_{10}=1 megohm
R_{11}=2 megohms
R_{12}=40 megohms
R_{13}=3 megohms

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one 6N7, one 6Q7, and one 76. The latter tube is used in the vacuum-tube voltmeter stage to measure the voltage of the integrated pulses. The triode section of the 6Q7 is used to level the amplified pulses and the diode section to rectify them in order to charge the condenser, C_3. Since a −4 volt pulse on the grid of the triode section of the 6Q7 is sufficient to bring the plate current to zero at 200 volts on the plate, a moderate amplification of the counter pulses would be sufficient to insure that all pulses were levelled to the same value. However, a negative pulse is required so that two triode stages are introduced between the counter tube, *G–M*, and the 6Q7. This is done by use of the two triode sections of a 6N7 vacuum tube. Under these conditions, it is quite safe to assume that all pulses originating in the counter throw the grid of the 6Q7 to cutoff. Numerous tests with an oscillograph and by comparison with scaling circuits show that this assumption is justified.

It is desirable that the meter, *M*, in the vacuum tube voltmeter stage, shall show a response which is linear with the grid voltage. This is secured by introducing a bucking circuit comprising the resistor, R_5, and the rheostat, *RH*, in conjunction with the voltage divider as shown. The part of the plate current of the 76 tube which passes through the meter, *M*, is controlled by the rheostat, *RH*, and permits an adjustment of the meter to a zero reading for any particular background intensity in the presence of which measurements are to be made. The arrangement shown permits a very accurate adjustment of the zero of the meter, since the meter current changes slowly and smoothly with changes of the value of *RH*. A simple rectifier and filter supply the plate voltages for the circuit. This voltage is held at a steady value regardless of line-voltage fluctuations by the VR–105 regulator tubes. A half-wave rectifier using an 879 tube supplies the voltage for the counter tube. This voltage is also stabilized by a bank of small neon lamps, *N*. These lamps give good regulation, particularly after they have been aged by burning steadily for several hours.

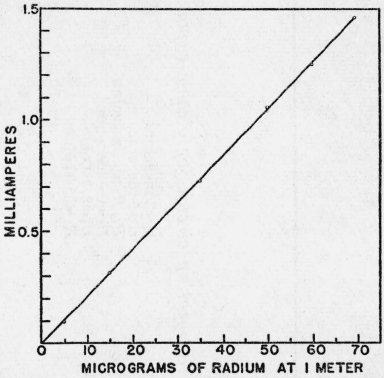

FIGURE 3.—*Typical calibration curve at high sensitivity.*

The advantages of this circuit are that it is simple, low resistances are used throughout, it requires no preliminary adjustment of constants, no bias voltages are used, and its indications are directly proportional to the counting rate. The small number of parts permits it to be mounted in a single aluminum case. By putting the RC circuit of the voltmeter in the grid, a small condenser can be used and a number of ranges selected readily by cutting in the resistors, r_1, r_2, r_3, r_4, by means of the rotary tap switch S_2.

A typical calibration curve is shown in figure 3. The readings for the points shown were obtained by placing microgram radium standards at a distance of 1 meter and noting the final steady deflection of the milliammeter. Approximately 5 minutes is required for the RC circuit to come to an equilibrium value. The sensitivity here shown is 0.021 milliampere per microgram of radium and was obtained with 3 megohms and 8 microfarads in the RC circuit of the voltmeter stage. The sensitivity is increased to 0.033 milliampere per microgram of radium at 1 meter when 4 megohms are used in this circuit. At this sensitivity 1 microgram of radium at 25 cm gives a deflection of about 0.5 milliampere, or about one-third of a full-scale deflection on the meter. Our experience indicates that this circuit retains its calibration over periods of months. Figure 4 shows a complete set of calibration curves for all four ranges of one of the instruments. The values of the resistances, r_1, r_2, r_3, and r_4, are 1, 2, 3, and 5 megohms. For $r_1=1$ megohm, 300 micrograms of radium are required for a full-scale reading of 1.5 milliamperes; and for $r_4=5$ megohms, 35 micrograms give the same reading. This is about as large a range as can be covered with a given size of counter tube.

The sensitivity of this equipment can also be controlled by changing the size of the counter or the value of the coupling condenser, C_2. For large steps in sensitivity, a counter of different size must be used. This circuit will work well with counters as large as 10 by 40 cm and as small as 1 by 1 cm. Sizes outside this range have not been tried.

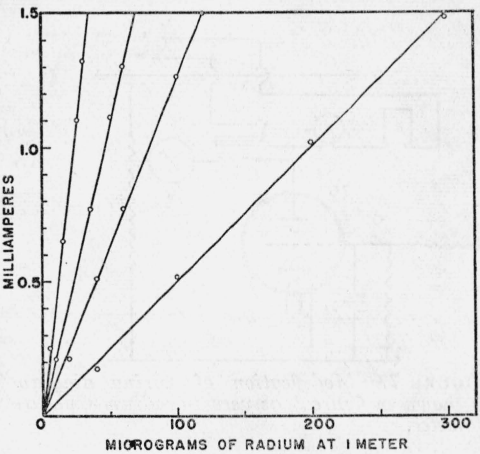

FIGURE 4.—*Group of calibration curves for a multirange instrument.*

The linear characteristic of the output meter makes it convenient to measure gamma-ray intensities by direct comparison with microgram standards of radium. For most accurate measurements, a direct comparison, selecting a standard somewhere near the value of the unknown, permits measurements to be made independently of the original calibration. Gamma-ray standards for this purpose consisting of ampoules containing 5 ml of solution and having radium contents of 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, 50.0, and 100.0 micrograms are now available at the National Bureau of Standards.

The compactness of the circuit permits it to be built into a single cast-aluminum case 7 by 6 by 18 in. The case is provided with short standards bored to hold the tube counter. Thorough ventilation is required as a result of the considerable heat developed by the rectifier tubes. This is secured by numerous perforations in the top and bottom of the case. The milliammeter, M, is mounted in the top of the case for ease of observation. The knobs of the range switch, S_2, and of the bucking circuit rheostat, RH, are brought out at the side. The total weight, most of which is in the transformers, is 24 lb. A view of the interior of this case, with parts in place, is shown in figure 5, and an exterior view in figure 6.

IV. RADIO EXPOSURE METER

The use of alcohol vapor-argon counters also permits considerable improvement in the radium exposure meter described by the author.[3] The same basic circuit as shown in figure 2 is used for this meter. The only changes are in the vacuum-tube voltmeter stage. The range switch, S_2, and the bucking circuit, including R_7 and RH, are eliminated. The modifications added are shown in figure 7. A relay, Z, is connected in series with the milliammeter, M. A buzzer, B, and lamp, L, are connected in the contact circuit of the relay which closes this circuit through a low voltage winding on the power transformer. The tension of the relay spring is adjusted to close the contact at the desired value of the current in the meter, M.

For this instrument a small counter, 1 by 1 cm, is required because of the relatively high intensity of gamma radiation to be measured. It is also important to use a counter with a length approximately equal to the diameter so that it may have the same sensitivity in all directions. These smaller counters have a voltage characteristic similar to that of the larger counters and will operate over about the same range of voltages, 700 to 1,000 volts.

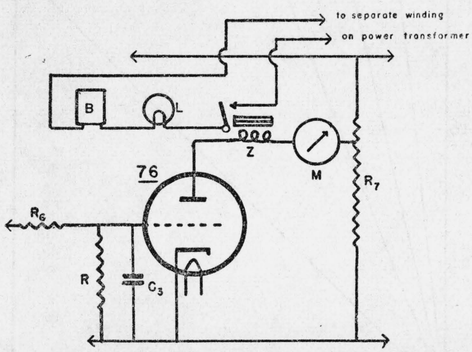

FIGURE 7.—*Modification of wiring diagram shown in figure 2, as used in radium exposure meter.*

As a result of the elimination of the bucking circuit, the meter scale is not linear in this instrument and the meter reads downward for increasing intensities. The scale is almost identical with that described for the argon-hydrogen counters.[4] The relay is adjusted to close when the intensity reaches the value of 0.1 roentgen[5] per day, providing a visual and audible warning of excessive general exposure.

Although this meter was originally designed for use in hospitals and laboratories where large quantities of radium are handled, it is obvious that it can be used equally well in connection with high-voltage installations or cyclotrons where artificial gamma radiation is generated. The most satisfactory method of use is undoubtedly as a monitor, placing the instrument at a position habitually occupied by operators. It can also be used to survey a laboratory under given conditions of operation to determine certain zones of safety under these conditions. Such a survey would, of course, need to be repeated when changes were made in the operation of the source. For complete protection in a large installation, several units properly located would be required. It would be desirable to have them switched on automatically with the source. Warning would then be given of any unsafe conditions which arise from an increase in the gamma-ray intensity as a result of unforeseen changes in the apparatus generating the artificial radio

[3] L. F. Curtiss, J. Research NBS 23, 479 (1939) RP1246.
[4] L. F. Curtiss, J. Research NBS 23, 479 (1939) RP1246.
[5] At the present time a general exposure of 0.1 roentgens per day of 8 hours is regarded as safe. See Handbook H23, NBS, on Radium Protection.

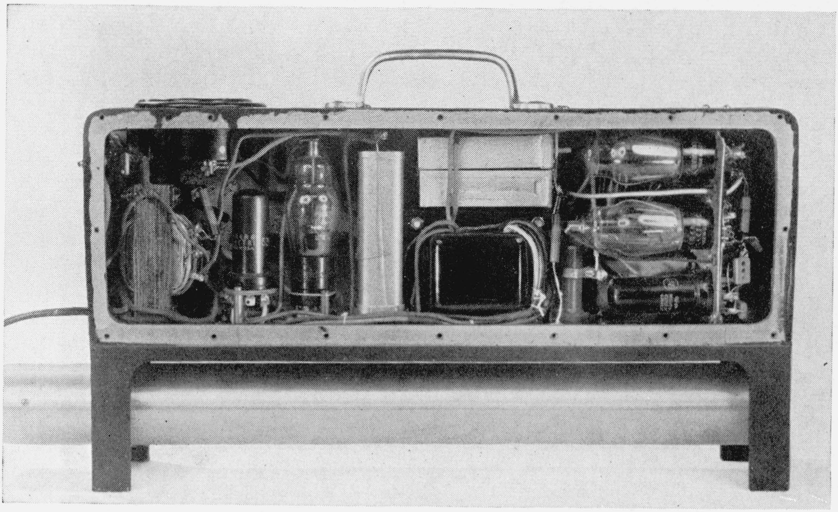

FIGURE 5.—*Interior view of assembled gamma-ray counting-rate meter.*

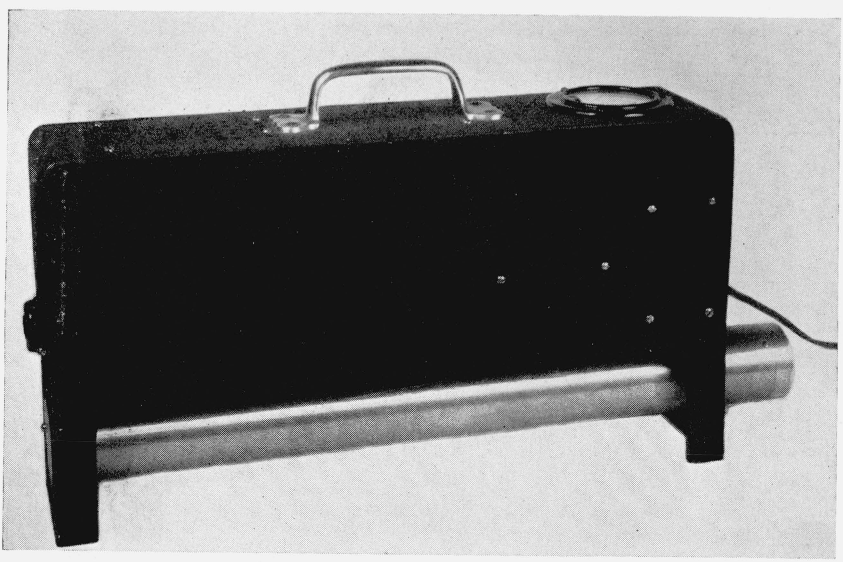

FIGURE 6.—*Exterior view of gamma-ray counter.*

activity. When equipped with a boron trifluoride tube counter, this device is also useful in warning of dangerous intensities of neutrons. The low efficiency of these counters makes this somewhat difficult. Experiments are in progress to determine the proper arrangements for a warning device of this type.

The writer acknowledges the aid of L. L. Stockmann and B. W. Brown in assembling and testing these units. He is also indebted to A. V. Astin for advice regarding various details of the amplifying and integrating circuit.

WASHINGTON, July 2, 1940.